제 2 주 제

사과의 유기농 재배방법에 따른 질소이용효율과 잉여 및 분배 추정

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Estimated Nitrogen Efficiency of Use, Surplus, and Partitioning in Young Apple Trees Grown in the Varied Organic Production Systems

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개 요

멀칭과 유기질 비료에 따른 질소이용효율과 질소잉여를 추정하기 위해서 미국 알칸소지역의 주립대학 농장에 2006년도에 친환경 유기농 사과과원이 조성되었다. 3년째 되던 해에, 식물성퇴비 멀칭과 나무껍질 멀칭으로 처리된 나무들이 종이 멀칭이나 풀 베어서 불어넣기로 처리된 나무들에 비교해서 더욱 두꺼운 나무 직경율과 수체 내 질소축적 추정율, 엽 내 질소이용 효율을 나타냈다. 나무껍질멀칭으로 처리된 나무들은 식물성퇴비 멀칭처리구와 비교해서 재식 후 3년차에 상대적으로 낮은 질소 잉여 추정율을 나타냈고, 식물성퇴비 멀칭 처리구들은 9월에 토양이나 토양용액 내에 높은 농도의 질산태질소를 나타내서 지하수 내에 용탈과 오염 가능성을 시사하였다. 전반적으로, 나무 생장이나 질소이용도와 관련해서 멀칭처리가 유기질 비료보다 유의성 있게 높은 효과를 나타냈다.

Introduction

Currently, orchard ground cover management systems (GCS) are getting more attention due to environmental, ecological factors, and lack of herbicides for organic fruit production systems. These GCS may contribute to the tree nutrition and affect tree vigor. Also, the GCS can prevent water runoff as well as increase water infiltration and nutrient leaching under heavy rainfall or irrigation (Chalker-Scott, 2007). However, there is limited information available for fertilizer recommendations in organic systems with GCS. Correspondingly, farmers often apply more organic fertilizer and mulch than may be needed to increase fruit yield because of insufficient science-based information (Ju et al., 2005).

Although applied organic materials like manures may contain a substantial amount of nitrogen (N), the N in the soil can be inadequate or may be available in the wrong season to maximize the tree growth. Unused N can be leached outside the rooting zone and moved into the ground water following heavy irrigation or rainfall (Ju et al., 2005). Nutrient budgets have been a valuable tool to summarize and facilitate the understanding of nutrient cycling in agroecosystems (Oenema et al., 2003). Thus, N balance can be useful information to estimate N use, surplus, and N cost in a growing season (Barry et al., 1993; Puckett et al., 1999). N surplus, which is an extra amount of total N during a non growing season, can be strongly affected by management practices, such as nutrient source, fertilizer application quality, and GCS (Ju et al., 2005).

Applying any nutrient sources in accordance with the nutrient requirement of the apple trees is crucial to increase plant productivity and N use efficiency (NUE) (Aguirre et al., 2001; Neilsen et al., 2001; Toselli et al., 2000). Leaf NUE (LNUE) was measured in terms of the leaf dry weight produced per unit of N in the leaf, which can also indicate whether N is being used efficiently to produce dry matter in a tree. A large percentage of the N is invested in leaves, and thus different NUE among trees could be described at the leaf level N as a LNUE (Yasumura et al., 2002).

Estimations of annual N partitioning and dry matter production in the various tree organs could lead to information on how to adjust N in a soil and on the requirements in perennial parts necessary for annual growth. Estimates of N requirement and N surplus of the trees should be considered prior to applications of nutrient in order to minimize polluting losses from the soil-tree system. In this study, organic apple production systems were compared to investigate N partitioning, leaf NUE, and N surplus in order to understand how the production system affects tree growth and efficiency and the potential environmental impacts.

Materials and Methods

'Enterprise' apple trees on M.26 rootstocks were planted in an organically managed orchard at the University of Arkansas, Main Agricultural Experiment and Extension Center, Fayetteville (Latitude: 36.1 N; Longitude: 94.1 W; Altitude: 427 m) in March, 2006. Before planting, the site had not been used for several years. There were extensive soil moving, grading, and tillage in late summer and fall in 2005. Incorporation of lime at a rate of 900 kg per hectare was applied to adjust soil pH. Horse manure was applied about 900 kg per hectare to increase soil fertility. The row middles seeded with K-31 tall fescue and winter wheat nursery crop in 2005. Trees were planted 2 m between trees and 4 m between rows for an approximate density of 1495 trees per hectare. Trees were trained as a 3.5 m tall vertical axis with a 2-wire trellis system for tree support and training. The soil series on the site was a mixture of a Captina and Pickwick silt loams with 5.5 pH, and moderately drained. The experiment was a 4 × 3 factorial of four GCS by three fertilizer treatments. The GCS were as follows: 1) urban green compost from leaves, grass, and small brush (GC), 2) raw wood chips (WC), 3) shredded paper mulch (SP), and 4) mow-and-blow green mulch (MB). The GCS were split-plot for nutrient source treatments applied. The nutrient source treatments were: A) formulated, certified organic pelletized fertilizers (10N-2P-8K, Nature Safe®) (CF), B) composted poultry litter (PL), and C) control (NF) where nutrition would be derived from the GCS.

On the mulched treated plots (GC, WC, and SP), an approximately 8 to 12 cm thick layer of mulch was initially applied in April in 2006 and annually reapplied for maintaining the mulch depth by adding the GCS in years 2 and 3. The purpose of the GCS was for control of undertree competitive vegetation. For the MB plot, the grass was mown and tilled as needed during a season, and the mown grass from between rows was blown under the tree as an on-site produced mulch. Annual nutrient applications (PL and CF) were made at rates equivalent to approximately 50 g per tree of actual N per tree per year tree age in April.

Random samples of GC, WC, CF, and PL were collected, dried, and ground in a blade mill grinder. Paper was snipped into small pieces with scissors, and grass clippings were ground in a Wiley Mill (Thomas Co., U.S.A) through 20 mesh screen. The samples were analyzed as a combined bulk sample for nitrogen (N) and carbon (C) analyses at the UA Soil Analysis Laboratory. Total N and C were analyzed using micro-Kjeldahl technique and dry combustion with LECO FP 428 and with LECO CN 2000, respectively (Table 1). GCS biomass per square meter was sampled and dried at 70°C for three days for measuring the dry weight in year 1. GCS additional input in years 2 and 3 were estimated by measuring additional amounts of applied each GCS. Total N input from the GCS was then calculated by multiplying the mulch dry weight with the mineral concentrations (Table 2).

Soil was sampled with a 2 cm diameter soil probe following locally recommended protocols (Chapman and Daniels, 2001) at 10 to 30 cm depth in mid-September of year 3 for nitrate (NO_3) analyses. The soil NO_3 was analyzed using the colorimetric method on autoanalyzer (SKALAR) at the UA Soil Analysis Laboratory. Three suction lysimeters per each treatment were installed in March in year 3 at 30 cm depth on the tree drip line approximately 50 cm from the trunk for sampling soil solution. The solution was collected in the date corresponding to the soil sampling, and the [NO_3] in the solution was analyzed by a colorimetric method on autoanalyzer (SKALAR) at the UA Soil Analysis Laboratory. Estimated wet deposited N was obtained from the national atmospheric deposition program (NADP, 2009). The amount of irrigation, supplied by city water, was recorded during a season, and the total N input from irrigation was estimated by requesting the total N data in the ground water in Northwest Arkansas (Beaver water district, 2008).

Leaves from a mid position of the current year's shoots were sampled approximately 100 days after bloom from years 1 to 3, measured with leaf area meter (LI-3000 A Area Meter, U.S.A), and dried at 70°C for three days. The samples were then weighed and ground for total N analysis as described above. Undertree vegetation of each treatment was sampled on each GCS per square meter in summer, dried, and weighed. N removal from undertree vegetation was estimated from the amount of vegetative dry weight and N concentration in the vegetation. Trunk cross-sectional area was measured at 30 cm above graft union annually in November. Leaf nitrogen use efficiency (cm^2TCSA g^{-1}N kg^{-1} leaf dw) was then calculated from the value of trunk cross sectional area divided by leaf nitrogen concentration taken in August.

In year 3, total leaf area in October was estimated from counting all the leaves on the tree, removing each 25th leaf, a 4% sampling (Wünsche and Palmer, 1997), and measuring the leaf area of this sample using a LI-3000 A Area Meter. Total leaf area of the whole canopy was calculated from the area of removed leaf samples multiplied by 25, and then total leaf N content was estimated.

Fruit was harvested on GC and WC treated trees in September of year 3, sliced, and dried at 60°C for 7 days. The fruit samples were ground for total N analysis as described above. Root growth was estimated with root capture tubes. The 17 cm long and 4 cm diameter PVC tube with several holes on the walls was fully covered with synthetic nets for root production measurement, but one end of the tube was not covered for filling soils. Soil auger was used for drilling soil holes, and two tubes per treatment tree were inserted in the rooting zone and backfilled with the soils in March in year 3, according to the ingrowth core method (Steingrobe et al., 2001). The cores were extracted in November, and then the root dry weight per tree was roughly estimated from the volume of 30 cm soil depth. All current year's shoot length was measured in November of year 3, and shoot dry weight was adjusted by the regression graph between shoot length and shoot dry weight. Three replicate ground samples of fruit, root, and shoot were then measured for total N analysis as described above on the GCS N analysis.

Soil N budget was estimated by following formula (Ju et al., 2005 Oenema et al., 2003):

Total N surplus = input components (total N from nutrient source+ GCS + wet deposition + irrigation) - output components (total N removed by aboveground plant parts (vegetation+fruit)).

Fallen leaf and pruning wood were not included for output components as they were recycling into the orchard.

Trees were planted in 9-tree plots of each ground cover. The split-plots were the three nutrient source treatments. Each treatment unit subplot was comprised of 3 trees where the experimental unit (data unit) was a single tree in the center of the triad and the other trees were guard trees to prevent cross-treatment contamination. The experimental orchard rows were guarded along the ends and with outside guard rows. The data analysis was performed using Proc GLM procedure in SAS statistical analysis system (SAS version 8.2, NC, U.S.), and mean seperation was calculated by least significant difference (LSD, α = 0.05).

Results and Discussion

Nutrient analysis in raw materials. The mulches and nutrient sources varied in [N] and C:N (Table 1). For nutrient source treatments, PL and CF, were applied to rates to equalize the amount of N content applied per tree per year. Roughly, PL was applied at a volume rate of 5.8-times the CF to equalize the [N] applied. The GC and MB mulches had similar total [N] to the PL. The SP mulch had very low [N] but high [C] resulting in very high C:N ratio. Gale et al. (2006) stated that high C:N ratio typically reduced the residue's ability to decompose, and the C:N ratio was a good indicator of plant available N released for fresh crop residues or manures. Under WC and SP treated mulches with a high C:N ratio combined with CF or PL would facilitate the decomposition of the surface mulches. The low C:N ratio of mulch biomass, such as compost (Table 1), would have significantly affected nutrient availability in the soil. However, GC plot with additional nutrient supplement, CF or PL, could have increased more microbial populations and reduced N mineralization rates because the compost would be a substrate for the microbes in those trees (Choi et al., 2001).

Estimated total N surplus. Estimated total N input ranged from 91 to 3074 g per tree during the three years (Table 2). GCS was the main source for the total N input on the soil regardless of the nutrient sources because large amounts of the GCS had been applied for three years. N of irrigation and wet deposit also contributed little to the total N input. GC+CF had the greatest total N input, but MB+NF had the least. The GC treated tree had the greatest N input due to the greater [N] and amount applied, and SP and MB trees had the least. Annual N inputs from GC and WC trees with any type of the nutrient sources averaged approximately 1005 and 436 g per tree, respectively, compared to the N fertilizer application amount recommended by young apple trees (50 g N per tree per year tree age per year). There were no differences among the management systems for the estimated N output (Table 2). However, GC and WC treated trees had insignificantly more plant removal N because those trees were allowed to fruit in the third year. MB+NF tree used more N (6.7%) from the total N input because the tree received smaller amounts of N input from mown grass with no fertilizer but had more N output from undertree vegetation compared to other treatments. Estimated N surplus ranged from 85 to 3064 g per tree during three years, which had a similar level to the total N input by the treatments. The GC treated tree with the nutrient sources had the greatest N surplus, which averaged 3004 g N per tree during the three years in the orchard system. The N surplus could mostly be lost by ammonia volatilization, denitrification, nitrate leaching, or trapped in various soil fractions or stored in the permanent parts of the tree (Ju et al., 2005).

Trunk cross-sectional area. Interaction effect of GCS*NS in year 3 was observed for the trunk cross-sectional area (TCSA) ($P < 0.05$) (Table 3), an indication of the total vegetative growth of a tree. GC and WC with any nutrient sources had the largest TCSA in year 3. The SP+NF treated tree had the smallest TCSA (791 mm^2) in year 3 and was observed to be approximately 30% of the TCSA in GC and WC trees. TCSA was significantly different among the GCS during the years, but no significant differences were observed for nutrient source. TCSA increase (%) was affected by interaction treatments ($P < 0.05$), which was similar result to the TCSA in year 3. GC and WC treated trees had almost two times TCSA increase (%) from initial to year 3 compared to the SP and MB trees. Except for GC treated tree, the TCSA increase (%) was insignificantly greater on the CF and PL trees with WC, SP, and MB compared to the NF tree with the GCS.

Tree fraction N content. Estimate of total N content in annual growth per tree was significantly different within interaction treatments ($P < 0.05$) (Table 4). WC+PL tree had the greatest total N content (50 g) per tree, while SP+NF had the smallest (16 g). All GC and WC treated trees had greater estimated total N content in leaf, current season shoot, and fruit, resulting in greater total N content per tree compared to the SP and MB trees in year 3. The total N content of GC and WC trees averaged about 42.5 g per tree, which was similar to the common range of estimated apple crop N requirements (Levin et al., 1980; Nesme et al., 2006). Leaf N partitioned almost 50% of the total N content per tree due to greater [N] in the leaves. The MB tree that received lower N input (250 g) than the SP treatment (203 g) (Table 2) had a similar total N content to the SP tree.

Figure 1 shows the effects of N input from GCS and nutrient source on the TCSA increase, which may also affect N surplus during the three years, in order to observe which production system could be more efficient for tree growth and reducing N loss. The WC tree with any nutrient sources had larger TCSA but much less N surplus than that of the GC tree with the nutrient sources (Fig. 1-A). High N surplus creates a risk for N leaching or immobilization during the non growing season when the trees were not actively assimilating N (Sanchez et al., 1995). The SP+NF treated tree had the least TCSA increase (%) but a similar N surplus to the MB or SP tree with the nutrient sources (Fig. 1-B). The amount of N surplus also proportionally affected TCSA increase (%) (r^2 = 0.886).

Leaf N use efficiency. There were no interaction effects for leaf Nuse efficiency (LNUE) (Table 5), defined as TCSA increment per N produced in a leaf. LNUE was greater on the GC or WC treated trees during the three years, followed by SP and MB treated trees, regardless of a type of nutrient sources. However, trees treated with SP or MB had rather increased LNUE (%) from years 2 to 3 compared to the trees applied with WC and GC trees although no significant difference was observed by the GCS (P = 0.054). In year 3, the trees mulched by GC and WC with the nutrient sources were allowed to bear fruit, which might have resulted no differences in LNUE increase from years 2 to 3 compared the SP or MB trees that were not allowed to bear fruit. Average leaf area was not affected by interaction between GCS*nutrient source or by nutrient source during the years (Table 5). WC treated tree had larger leaf area during the years possibly due to high leaf [N] (data not presented).

N surplus and [NO_3] in soil and soil solution. Nitrate is a mobile element in soil or soil solution, which can be leached out of tree root zones after high rainfall or irrigation occurs. Accumulated soil solution and soil [NO_3] were related to the estimated N surplus (r^2 = 0.872 and = 0.917, respectively) at 30 cm depth in mid-September (Fig. 2-A and -B) this implies that more N surplus could induce nitrate leaching during winter. Especially, the GC+PL treated tree showed approximately 70 mg/L of [NO_3] in 30 cm soil depth (Fig. 2-A), which exceeded 45 mg/L of nitrate established for safe drinking water by U.S. Environmental Protection Agency (1993). Schleef and Kleihanss (1994) mentioned that more than 100 $kg·ha^{-1}$of annual N surplus could be regarded as a baseline for nitrate leaching into the ground or run off on the surface area. Our GC treated plot averaged 2504 $kg·ha^{-1}$ of N surplus per year (conversion from 1001 N g per tree per year) (Table 2) while SP and MB plots averaged approximately 40 $kg·ha^{-1}$ of N surplus.

Conclusions

Trees treated with SP and MB did not achieve growth goals and fill their allocated space within the third season of this study, but they had similar increased TCSA and LNUE from years 2 to 3 compared to the GC and WC trees. The WC treated tree that had similar N content to the GC tree reduced N surplus and [NO_3] in soil or soil solution in fall. All GC treated plots that applied large amounts of green compost could have been high risk of potential surplus N. When all growth, N surplus, and N partitioning effects were evaluated, it appeared that GCS had a greater overall effect on the variables than did nutrient source because large amounts of GCS affected for N content in annual growth, total N input, and N surplus compared to the nutrient source. In some cases, the NF treatment in combination with the GC treatment tended to increase TCSA more than that of CF or PL with GC treatments. However, the opposite results were observed on the WC, SP, and MB plots the GCS treated tree with PL or CF had insignificantly greater TCSA than those with NF. The low C:N ratio of compost addition to nutrient source would have immobilized N in the soil because the amendment served as a substrate and induced increasing microbial activity. Relatively high C:N ratio of wood chips and paper or low amount of grass mulch input would have facilitated N mineralization in a soil by applying supplemental nutrient sources with low C:N, which would have affected satisfactory tree growth by the treatments.

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Table 1. Carbon (C) and nitrogen (N) concentrations of ground cover mulches and nutrient source in average of 3 years in an organic apple orchard, Fayetteville, AR.

Content	Ground cover mulch (%, dry wt)				Nutrient source (%, dry wt)	
	Green compost (GC)	Wood chips (WC)	Shredded paper (SP)	Mow-and -blow (MB)	Commercial fertilizer (CF)	Poultry Litter (PL)
C	17.0[z]	28.7	35.5	34.5	33.4	27.8
N	1.2	0.7	0.2	1.7	5.0	1.2
C:N	15.0	42.2	215.1	15.5	7.1	23.2

Ground cover mulches and nutrient sources were not statistically analyzed, but results were from a bulk analysis derived from random samples of the mulches or nutrient sources, and were representative of the treatments.

[z]Presented values were yearly averaged from the nutrient analyses during three years.

Table 2. Estimation of nitrogen (N) surplus of an 'Enterprise'/M.26 apple tree in an organic orchard as affected by ground cover management system (GCS) and nutrient source (NS) during the three years (total of 3 seasons).

Treatment	Input N(g)/tree				Output N(g)/tree	Used N(%)	Surplus N(g)/tree
	GCS+NS	Irrigation	Wet Deposition	Total input	Plant remove[z]	Plant remove	
GC+CF	3053 a[y]	2.46	19.3	3074 a	10.0	0.3 d	3064 a
GC+PL	3046 b	2.46	19.3	3067 b	10.7	0.3 d	3057 b
GC+NF	2882 c	2.46	19.3	2904 c	11.8	0.4 d	2892 c
WC+CF	1346 d	2.46	19.3	1368 d	7.4	0.5 d	1361 d
WC+PL	1339 e	2.46	19.3	1361 e	8.1	0.6 d	1353 e
WC+NF	1175 f	2.46	19.3	1197 f	5.5	0.5 d	1192 f
SP+CF	287 g	2.46	19.3	309 g	1.1	0.4 d	308 g
SP+PL	280 h	2.46	19.3	302 h	1.0	0.3 d	301 h
SP+NF	116 k	2.46	19.3	138 k	1.1	0.8 d	137 k
MB+CF	240 i	2.46	19.3	262 i	5.4	2.1 c	256 i
MB+PL	233 j	2.46	19.3	255 j	6.0	2.3 b	249 j
MB+NF	69 l	2.46	19.3	91 l	6.1	6.7 a	85 l
		ns	ns		ns		

[z]Plant remove was estimated by fruit and vegetation productions on the GC and WC plots, and the remove of SP and MB plots was from vegetation density.
[y]Means comparisons among treatments within a column by LSD; means followed by different letters are significantly different, 5% level. ns = not significantly different.
GC = green compost, WC = wood chips, SP = shredded paper, and MB = mow-and-blow.
CF = commercial fertilizer, PL = poultry litter, and NF = no fertilizer.

Table 3. Trunk cross sectional area (TCSA) and TCSA increase (%) of an 'Enterprise'/M.26 apple tree in an organic orchard as affected by ground cover management system (GCS) and nutrient source (NS) from initial to year 3 (2008).

Treatment	TCSA (mm^2)				TCSA increase (%)
	Initial	Year 1	Year 2	Year 3	Initial-year 3
GCS					
Green compost (GC)	219	611 a[z]	1623 a	2638 a	1134 a
Wood chips (WC)	241	624 a	1703 a	2594 a	981 a
Shredded paper (SP)	231	481 ab	868 b	1424 b	514 b
Mow-and-blow (MB)	232	386 b	764 b	1460 b	566 b
	ns				
NS					
Commercial fert (CF)	231	589	1413	2199	857
Poultry litter (PL)	233	513	1256	2098	812
No fertilizer(NF)	232	503	1160	1913	756
	ns	ns	ns	ns	ns
GCS × NS					
GC+CF	225	652	1641	2666 a	1092 a
GC+PL	213	494	1483	2387 a	1020 a
GC+NF	219	649	1683	2750 a	1212 a
WC+CF	225	726	2007	2710 a	1088 a
WC+PL	246	602	1630	2654 a	992 a
WC+NF	251	560	1523	2439 a	882 a
SP+CF	232	494	1047	1783 ab	667 ab
SP+PL	234	575	1099	1769 ab	661 ab
SP+NF	230	392	504	791 b	242 b
MB+CF	242	489	959	1730 ab	631 ab
MB+PL	229	330	683	1376 ab	540 ab
MB+NF	225	340	650	1274 ab	527 ab
	ns	ns	ns		
P value					
GCS	0.405	<0.01	<0.001	<0.001	<0.001
NS	0.579	0.447	0.072	0.275	0.234
GCS × NS	0.640	0.332	0.254	<0.05	<0.05

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

Table 4. Estimation of nitrogen (N) content in annual growth for each organ production per ‘Enterprise’/M.26 apple tree in an organic orchard as affected by ground cover management system (GCS) and nutrient source (NS) in the third year (2008).

Treatment	Tree fraction N content (g)				
	Root	Leaf	Shoot[z]	Fruit	Total
GCS					
Green compost (GC)	1.2 ab[y]	19 a	15 ab	7.0 a	42 a
Wood chips (WC)	1.0 ab	19 a	18 a	4.2 b	43 a
Shredded paper (SP)	2.2 a	9 b	9 b	0.0 c	20 b
Mow-and-blow (MB)	0.4 b	11 b	10 b	0.0 c	21 b
NS					
Commercial fert (CF)	1.0	15	14	2.8	33
Poultry litter (PL)	1.5	15	14	3.2	34
No fertilizer (NF)	1.2	13	13	2.9	30
	ns	ns	ns	ns	ns
GCS × NS					
GC+CF	0.9	19	12	6.3	38 bcd
GC+PL	1.1	17	14	6.9	39 bcd
GC+NF	1.6	20	18	7.5	47 ab
WC+CF	1.0	18	18	4.7	42 bc
WC+PL	1.5	22	22	4.6	50 a
WC+NF	0.7	17	15	3.1	36 cde
SP+CF	1.8	11	12	0.0	25 de
SP+PL	3.0	8	8	0.0	19 ef
SP+NF	1.9	7	8	0.0	16 f
MB+CF	0.4	13	11	0.0	24 de
MB+PL	0.6	10	9	0.0	20 ef
MB+NF	0.3	9	11	0.0	20 ef
	ns	ns	ns	ns	
P value					
GCS	<0.05	<0.001	<0.05	<0.001	<0.001
NS	0.555	0.461	0.949	0.765	0.896
GCS × NS	0.763	0.140	0.087	0.864	<0.05

[z]N content in a shoot was only estimated in a current season shoot.

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

Table 5. Leaf nitrogen use efficiency (LNUE) and average leaf area of an 'Enterprise'/M.26 apple tree in an organic orchard as affected by ground cover management system (GCS) and nutrient source (NS) from years 1 (2006) to 3 (2008).

Treatment	LNUE[z] (cm^2TCSA g^{-1}N kg^{-1} leaf dw)			LNUE increase (%)		Average leaf area (cm^2)		
	Year 1	Year 2	Year 3	Yr 1 to 2	Yr2 to 3	Year 1	Year 2	Year 3
GCS								
Green compost (GC)	30 a[y]	81 a	119 a	177 a	50	27 ab	29 a	25 ab
Wood chips (WC)	31 a	83 a	122 a	178 a	53	31 a	29 a	26 a
Shredded paper (SP)	25 ab	45 b	73 b	79 b	61	26 b	20 b	23 ab
Mow-and-blow (MB)	20 b	39 b	68 b	107 b	74	25 b	23 b	23 b
					ns			
NS								
Commercial fert (CF)	28	68	102	140	55	28	26	24
Poultry litter (PL)	26	63	100	148	69	29	27	24
No fertilizer (NF)	26	59	90	125	54	26	24	25
	ns	ns	ns	ns	ns	ns	ns	ns
P value								
GCS	<0.05	<0.001	<0.001	<0.001	0.054	<0.001	<0.001	<0.05
NS	0.766	0.165	0.395	0.174	0.256	0.651	0.086	0.807
GCS × NS	0.341	0.208	0.100	0.515	0.065	0.096	0.119	0.925

[z]Leaf nitrogen use efficiency (cm^2TCSA g^{-1}N kg^{-1} leaf dw) = TCSA (cm^2)/August leaf N concentration ($g \cdot kg^{-1}$ dw).

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

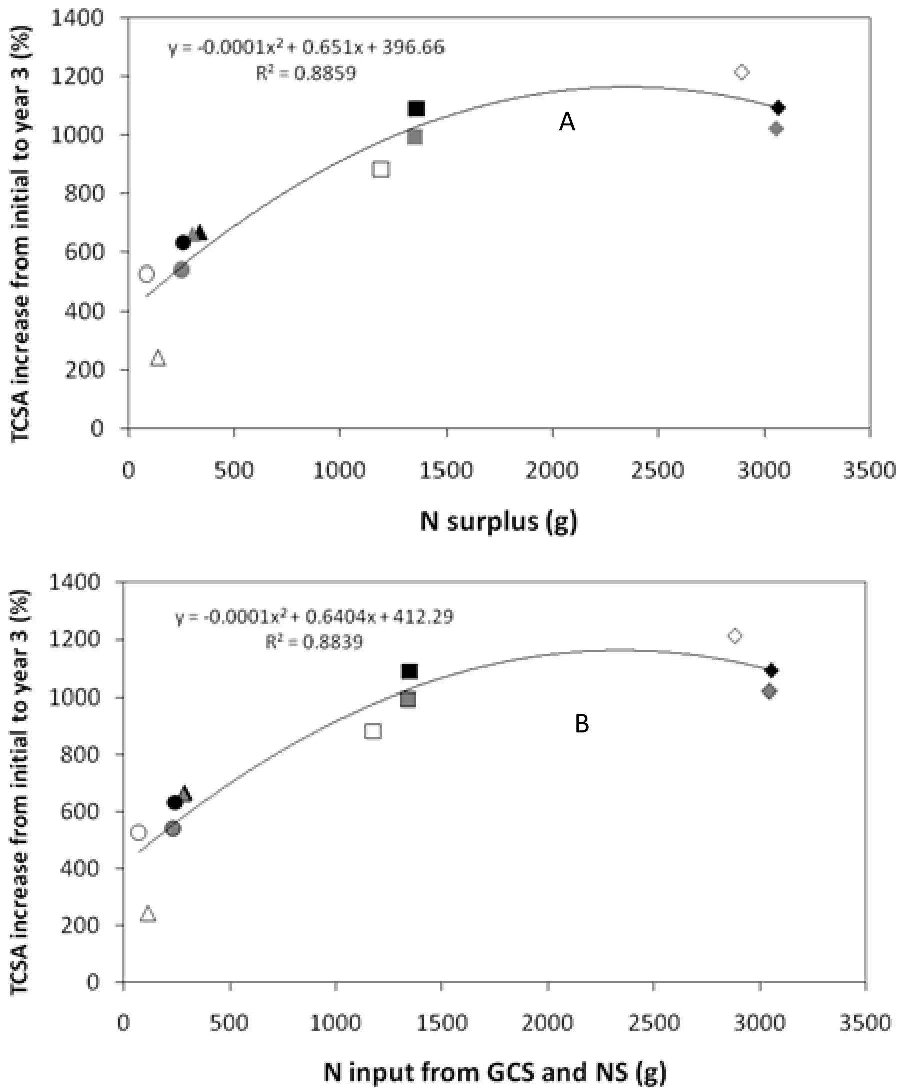

Fig. 1. Relationship between a three year N input (A) or N surplus (B) and TCSA increase of an ‘Enterprise’/M.26 apple tree in an organic orchard as affected by ground cover management system (GCS) and nutrient source (NS). Black, gray, and white color represent for commercial fertilizer (CF), poultry litter (PL), and no fertilizer (NF), respectively.

Diamond, square, triangle, and circle represent for green compost (GC), wood chips (WC), shredded paper (SP), and mow-and-blow (MB), respectively.

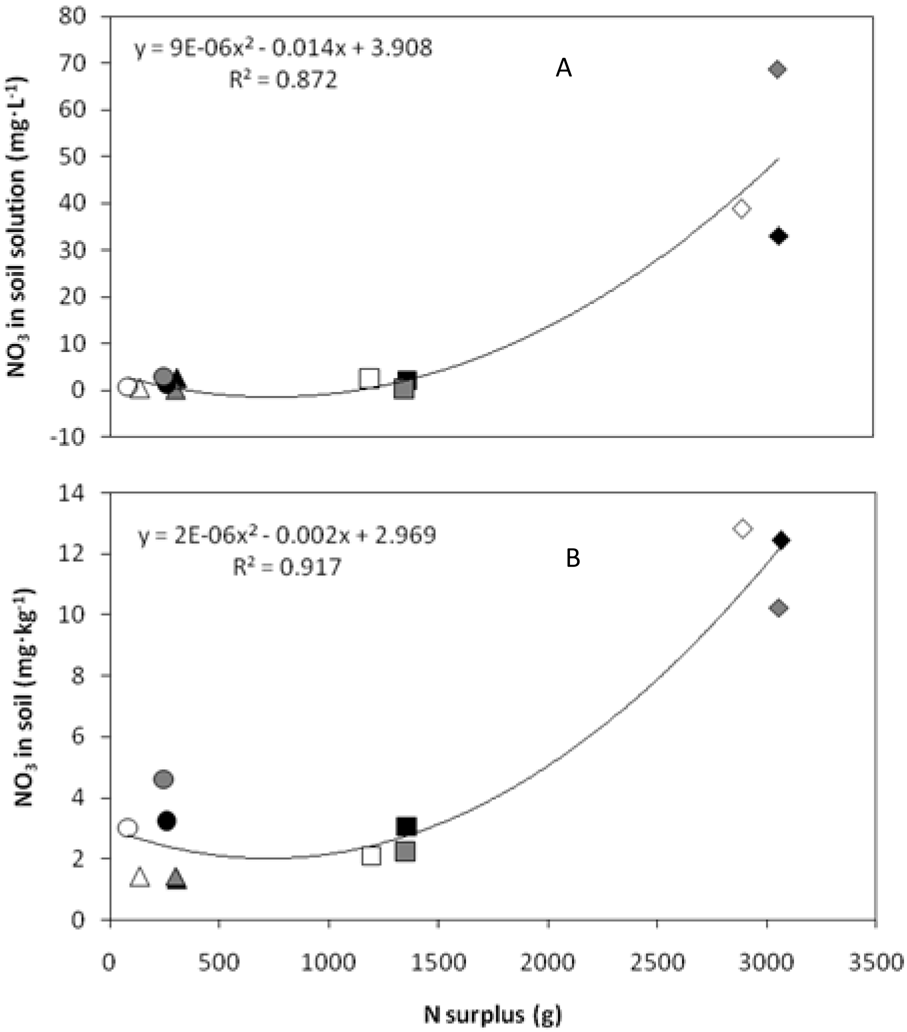

Fig. 2. Effect of a three year N surplus on [NO_3] in soil solution (A) at 30 cm and in soil (B) at 10 to 30 cm depths in the third year of an 'Enterprise'/M.26 apple tree in an organic orchard as affected by ground cover management system (GCS) and nutrient source (NS).

Black, gray, and white color represent for commercial fertilizer (CF), poultry litter (PL), and no fertilizer (NF), respectively.

Diamond, square, triangle, and circle represent for green compost (GC), wood chips (WC), shredded paper (SP), and mow-and-blow (MB), respectively.