Nitrogen Nutrition Budgets in Four Orchard Groundcover Management Systems

Amaya Atucha, Ian A. Merwin and Michael G. Brown
Department of Horticulture
Cornell University
134A Plant Science Building
Ithaca, NY 14853

> **"Excessive nitrogen applications can cause water contamination. Our research suggests that N in orchards is lost primarily through subsurface leaching rather than surface runoff, regardless of groundcover management system. In our high organic matter content soil, pre-emergent or post-emergent herbicide systems led to a small N deficit which could be met with foliar nitrogen sprays which result in less leaching potential."**

Intensive use of pesticides and fertilizers to increase crop yields can cause surface and groundwater contamination by agrochemicals. Estimating and budgeting nutrient fluxes and requirements under different orchard systems can help to sustain high yields of marketable fruit while minimizing fertilizer losses in leaching or runoff. Nutrient inputs, recycling pools, and outputs from the crop-soil system can be quantified, and retention or transfers of nutrients can be budgeted on a year-round basis (Palmer and Dryden, 2006). Nutrient budgeting is a useful tool for optimizing fertilizer programs in orchards, but there are very few published reports on this topic (Tagliavini et al., 1996). Aside from adverse environmental impacts, over-fertilization can cause nutrient imbalances within fruit trees that reduce productivity and fruit quality. High supplies of nitrogen (N) during the fruit ripening period may depress red color development (Wargo et al., 2004), delay ripening, and induce vegetative growth late in the growing season, making trees more susceptible to winter cold damage. Over-supply of N can also cause excessive vegetative growth and self-shading within the tree canopy, reducing flower bud development, fruit set, and fruit quality (Weinbaum et al., 1992).

Nitrogen fertilizer that is not taken up by plants or soil microorganisms is prone to leaching or runoff, and such losses are more likely when N fertilizer inputs are not adjusted for crop demand and N availability. Nutrient availability, recycling and losses reportedly vary among different orchard groundcover management systems (GMSs) (Merwin et al., 1994; Merwin and Stiles, 1994; Merwin et al., 1996). N-mineralization is greater in soil environments that promote the release of plant available N forms from soil organic matter, and soil organic matter (SOM) content is usually higher in GMSs that include mulches, year-round groundcovers or surface vegetation during some part of the year (Hogue and Neilsen, 1987). SOM promotes N mineralization by increasing soil microbial biomass and activity (Yao et al., 2005) that releases nutrients to the tree roots. The N recycling in soils under clean cultivation or residual herbicide treatments is less than that under surface groundcovers, because of decreased return and incorporation of plant residues to the soil in weed-free orchards compared with mulches and mowed grass covers or cover crops (Merwin, 2003).

Different nutrient budgets would be expected among various orchard GMSs because nutrient inputs and outputs differ among those systems. Despite the known relationships between soil nutrient availability and groundcover or soil management, there have been no previous long-term studies of GMS impacts on orchard nutrient budgets. This study was conducted to quantify inputs and outputs of N in an orchard under four different GMSs, with and without N fertilizers.

Material and Methods

The experimental site was a 0.8 ha, 17-year-old orchard located on the east side of Cayuga Lake near Ithaca, NY. The soil is an Ovid glacial till, silty clay loam that was prepared for planting in 1991 by removing a previous old orchard and installing a subsoil grid of 12 drainage lysimeters. After the site was limed, ploughed and disked, a red fescue (*Festuca rubra*) turfgrass was sown throughout the orchard. Interstem apple trees ('Empire' on M.9/MM.111 rootstocks) were planted in April 1992 at 3 x 6 m spacing. Four GMS treatments were established in 2-m-wide strips within the tree rows, and maintained since 1992. These GMS treatments were assigned randomly to 12 plots, with three replicates per treatment. Each test plot was 9-m wide across the slope and 25-m long down-slope, including four parallel tree rows containing 20 to 24 trees separated by 4-m wide grass drive lanes (Merwin et al., 1996).

The four GMS treatments were: 1) PreHerb: A pre-emergence residual herbicide treatment consisting of three herbicides (glyphosate, norflurazon and diuron) tank-mixed at 2.0, 3.0 and 2.5 kg a.i.·ha^{-1}, respectively, applied in mid-May each year; 2) PostHerb: A post-emergence herbicide treatment consisting of glyphosate applied at a rate of 2 kg a.i. ha^{-1} in mid-May and July each year; 3) Mowed Sod: A red fescue (*Festuca rubra* L) turf grass originally seeded in 1991, that eventually comprised a mixture of various grass and broadleaf species, mowed monthly during the growing season each year; 4) Mulch: A 15-cm thick layer of composted hardwood bark mulch applied in 1992, 1995, 1998, 2000, 2002 and 2005 at a rate of 27 kg·m^{-2} and the N content (dry weight) of the bark mulch material averaged 0.47%. Glyphosate herbicide was spot-applied to the Mulch plots in mid-May annually from 1996 onward, to suppress emergent perennial weeds.

Soil and tree nutrient content were evaluated annually, and for the present study we monitored nutrient dynamics in a year with N and P fertilizer additions (2005), and another year without ground-applied fertilizers (2007). In May 2005, we applied ammonium nitrate (34N-0P-0K) at a rate of 318 $g \cdot tree^{-1}$ providing 0.108 kg $N \cdot tree^{-1}$ and 60 kg $N \cdot ha^{-1}$—a typical N amount for apple trees of this age and size in commercial NY orchards (Stiles and Reid, 1991). Routine fertilizer P applications for mature apple trees are not recommended in NY orchards, but to test for differential GMS effects on P leaching, we applied 22.7 kg of superphosphate (0N-45P-0K) as a side dress soil application beneath trees in May of 2005. In the following years no N or P fertilizers were applied beneath trees in this study.

The 12 independent subsurface drainage lines intercepted leachate from each GMS treatment area, draining to the lower edge of each GMS plot to belowground collection stations where subsurface leachate from individual plots was collected. Surface runoff was measured at the lower edge of a 6-m^2 area within each GMS. A micro-sprinkler irrigation system provided irrigation during prolonged dry periods. Calibrated tipping buckets measured outflows of water from each treatment in both subsurface drainage and surface runoff catchments. Nutrient concentrations in subsurface leachate and surface runoff were measured whenever the sample bottles were full during the study. Nutrient budgets were constructed using the entire runoff and leachate datasets for both 2005 and 2007.

Tree and fruit nutrient analyses. Fruit yield was recorded from 1994 onward, as harvested fruit (kg) per tree, fruit counts, fruit size (g), and total yield per tree (harvested + dropped fruit in $kg \cdot tree^{-1}$). Fruit yield data were collected separately for each tree and then averaged to provide a treatment mean for each GMS. During harvest in 2005 and 2007, a random sample of 10 apples per plot was selected for total N analysis. To calculate total N exported in fruit, the average yield for each study year was multiplied by the percentage of N and total amount of fruit harvested that year.

To determine the amount of N recycling from tree leaf drop, one tree in each plot was wrapped with nylon netting in early autumn to catch its leaves as they abscised. When leaf drop was complete, leaves were collected and analyzed for N content. Dormant tree prunings were also weighed and analyzed for nutrients. Samples of the groundcover vegetation were collected both years, and the N recycling from groundcover biomass decomposition was determined.

Soil N mineralization rates under different GMS treatments were estimated based on potentially mineralizable nitrogen (PMN), corrected for observed soil temperature and moisture. After precipitation or irrigation events, water samples were collected from the subsurface drainage and surface runoff sampling stations, and their N and P content were determined using established methods. Soil sample cores were analyzed for nutrient content, pH and organic matter at the Cornell Nutrient Analysis Lab.

Nitrogen budget. A balance sheet of nutrient inputs and outputs for each GMS treatment was prepared, following conceptual models used by other researchers. Fertilizer applications and N inputs from irrigation, precipitation and mulch were tabulated as external N inputs to the orchard. The N releases from aboveground biomass decomposition, litter fall and pruned wood, and soil mineralization were tabulated as internal fluxes; and N losses through harvested fruits, surface runoff and subsurface leaching were tabulated as external outputs from the orchard.

Table 1. Total groundcover biomass production under four GMS treatments in a 15 year-old Empire/M.9/MM.11 apple orchard in Lansing, NY.

	Total groundcover biomass production ($kg \cdot ha^{-1}$)	
GMS Treatment	**Year 2005**	**Year 2007**
PreHerb	855.7 b[z]	526.7 b
PostHerb	1035.7 b	793.4 b
Sod	1754 a	2100.2 a
Mulch	966.3 b	653.3b

[z]Different letters within columns denote significant differences in means among GMS treatments at P ≤ 0.05.

The N budgets assumed that our GMS treatments covered 1/3 of a hectare (only tree rows) and the other 2/3 of the hectare were covered by identical turf-grass drive lanes in all treatments.

Results

Groundcover biomass was greater in the Mowed Sod treatment than other treatments during both years (Table 1). The N release from groundcover residue decomposition was highest for the Mulch treatment in both years, and higher in all GMSs during 2005 following fertilizer applications, compared with 2007 (data not shown). There were no significant differences among the GMSs for N release from groundcover residues in 2005, but in 2007 the Mulch plot groundcover litter released more N than the other treatments.

Soil N mineralization rates under different GMSs differed greatly among the four treatments, but followed similar trends in both years (Figure 1). The treatment rankings for N mineralization rates were Mulch > Sod > PostHerb > PreHerb; the N mineralization rate of PreHerb soil was only 10% that of Mulch soil.

The outflows from leaching and runoff differed between the two years, from month to month within years, and among the four GMSs (Table 2). Water outflows from subsurface leaching were greater than those from surface runoff during 2005. During 2007, the surface water runoff volumes were higher than those in 2005 for the PreHerb, PostHerb and Sod treatments (Table 2). As in the previous year, Mulch plots had lower surface runoff volumes than the PostHerb plots. Water outflows through subsurface

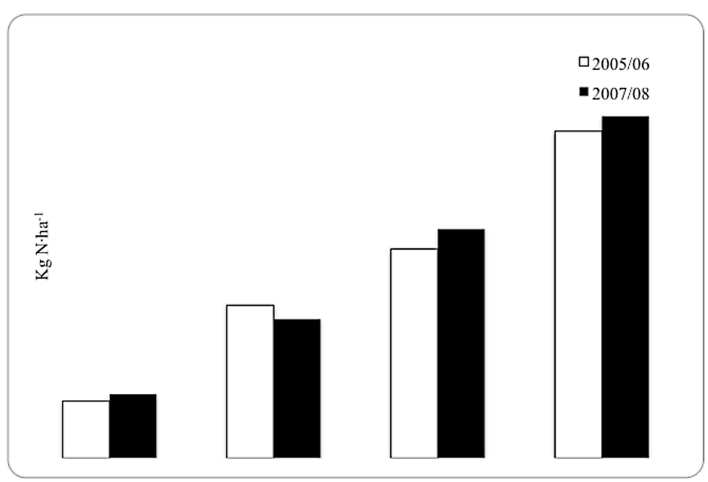

Figure1. Soil N mineralization (kg $N \cdot ha^{-1}$) under four GMSs treatments in 2005 and 2007.

drainage differed greatly over time in both years, and outflows were correlated with precipitation and soil freezing/thawing events. The greatest leachate outflows were observed during Oct. and Nov. in 2005, and in Nov. and Dec. in 2007. The lowest amounts of subsurface outflow occurred during May in both years (Table 2).

The PO_4-P concentrations in surface runoff and subsurface leachate water were generally very low (ranging from 0.03 to 1.1 mg L^{-1} in leachate, and from 0.1 to 1.3 mg L^{-1} in runoff) , and did not differ consistently among GMSs during either year of this study (data not presented).

There were big differences for NO_3-N concentrations in runoff water among the four GMSs during 2005, but not 2007 (Table 3). For Mulch and Sod plots, NO_3-N runoff concentrations were lower in 2005 than in 2007, and during 2005 the NO_3-N concentrations in runoff were greater in herbicide plots than in Sod and Mulch plots. However, during 2007 when N fertilizer was not applied, no differences were observed in NO_3-N runoff concentrations among the GMSs. During 2005, the lowest NO_3-N runoff concentrations were observed in Oct. and Nov., and the highest concentration was in June. The N concentrations in runoff water were significantly lower during Aug., and higher during June, July, and Oct. of 2007.

Leachate water NO_3-N concentrations were much higher during 2005 than 2007 (Table 3). PreHerb plots had the least observed leachate NO_3-N concentrations both years. During 2007, NO_3-N concentrations in leachate water were 90% lower than those observed in 2005. Mulch plots had the highest concentration of NO_3-N in subsurface leachate (Table 3). The time effect was significant for NO_3-N concentrations in subsurface leachate water during both years, but these trends were complex and weather driven. During both 2005 and 2007, Nov. was the month with the lowest concentrations of NO_3-N in leachate.

Table 2. Water flow from run-off and sub-surface leachate plots collected during May-Dec. 2005 and 2007 in a 15 year-old Empire/M.9/MM.11 apple orchard in Lansing, NY.

Treatment	Surface Runoff water volumes ($L \cdot m^{-2}$) May-Dec[z] 2005		2007		Sub-surface Leachate water volume ($L \cdot m^{-2}$) May-Dec[z] 2005		2007	
PreHerb	11.6 ± 3.8	b[y]	32.9 ± 9.7	ab	34.2 ± 11.9	a	44.7 ± 18.4	b
PostHerb	30.7 ± 9.9	a	87.9 ± 24.8	a	47.7 ± 13.7	a	41.5 ± 14.6	ab
Mulch	6.7 ± 1.1	b	6.6 ± 1.0	b	53.5 ± 16.1	a	61.7 ± 21.3	a
Sod	21.0 ± 6.4	ab	36.6 ± 11.4	ab	42.3 ± 11.5	a	51.4 ± 16.2	ab
Month								
May	1.8 ± 0.4	b	3.4 ± 2.9	e	1.3 ± 0.7	d	1.1 ± 1.0	e
June	9.1 ± 1.4	a	40.5 ± 22.8	abc	6.6 ± 2.2	c	17.2 ± 4.9	c
July	30.9 ± 16.2	a	27.6 ± 14.8	bcd	40.7 ± 11.1	bc	13.5 ± 4.5	cd
August	10.0 ± 1.2	a	76.9 ± 28.1	ab	8.6 ± 2.4	c	46.4 ± 7.8	b
September	16.6 ± 5.9	a	7.6 ± 1.9	cde	6.8 ± 2.0	cd	3.4 ± 0.9	de
October	18.5 ± 5.9	a	3.4 ± 1.6	de	116.0 ± 22.5	ab	3.3 ± 1.1	de
November	50.4 ± 14.3	a	41.5 ± 13.9	abc	129.4 ± 19.8	a	71.8 ± 10.8	b
December	3.2 ± 1.5	b	130.5 ± 36.0	a	45.9 ± 18.8	bc	241.8 ± 30.2	a

[z]Water flow was determined as total water flowing out from each GMS treatment. Data were log-transformed, and means were tested for significance level, but mean values presented in the table are from untransformed data.
[y]Means followed by a different letter in a column for treatments and months were significantly different at P ≤ 0.05.

Table 3. Average Nitrate-N (NO_3-N) concentration in runoff and leachate samples collected from June to Nov. 2005 and 2007 in the four GMSs in a 15 year-old Empire/M.9/MM.11 apple orchard in Lansing, NY.

Treatment	Runoff NO^3-N concentration ($mg \cdot L^{-1}$) June-November[z] 2005		2007		Leachate NO^3-N concentration ($mg \cdot L^{-1}$) June-November[z] 2005		2007	
PreHerb	5.83 ± 2.40	ay	4.55 ± 3.11	ns	4.14 ± 2.82	b	0.55 ± 0.41	b
PostHerb	3.07 ± 1.02	ab	2.64 ± 0.90		13.02 ± 4.30	ab	0.77 ± 0.26	b
Mulch	1.58 ± 0.67	b	5.51 ± 1.39		10.07 ± 3.71	ab	1.60 ± 0.51	a
Sod	1.86 ± 0.85	b	3.82 ± 1.08		12.79 ± 7.81	a	0.99 ± 0.16	b
Month								
June	5.26 ± 2.25	a	4.56 ± 1.10	a	32.74 ± 17.58	a	0.93 ± 0.19	ab
July	3.35 ± 1.04	ab	4.33 ± 1.26	a	14.73 ± 6.09	ab	1.10 ± 0.52	ab
August	2.76 ± 1.13	ab	1.50 ± 0.68	b	5.37 ± 2.32	bc	0.79 ± 0.27	b
September	3.66 ± 1.45	ab	3.52 ± 1.30	ab	4.30 ± 1.14	cd	1.37 ± 0.41	a
October	1.99 ± 1.02	b	7.30 ± 3.01	a	1.57 ± 0.56	de	1.16 ± 0.38	ab
November	1.49 ± 0.54	b	3.57 ± 2.38	ab	1.31 ± 0.27	e	0.51 ± 0.25	c

[z]Data were transformed using log transformation. Transformed means were tested for significance level. Values presented in the table are from untransformed data.
[y]Means followed by a different letter in a column for treatments and months were significantly different at P≤0.05, ns- not significantly different at P≤0.05

Overall, the total N losses (kg $N \cdot ha^{-1}$) in runoff from this orchard during 2005 were greater in the PreHerb and PostHerb than in the Sod and Mulch treatments (Figure 2A). During 2007, N runoff losses were again higher in the PostHerb treatment compared with the other GMSs (Figure 2C). For the calculated N losses (kg $N \cdot ha^{-1}$) from subsurface leaching, the Mulch plots generally had the greatest N leaching losses during both years of observations, despite substantial variation from month to month each year.

Nitrogen budgets. We compiled annual N budgets for each GMS during 2005 when N fertilizer was applied, and for 2007 when no N fertilizer was applied, normalizing calculations for an area of one hectare (Table 4). The N mineralization inputs from Mulch were two-fold greater in 2005 than in 2007, due to the recent mulch application and cumulative decomposition from previous applications in 2005. The exogenous inputs (fertilizers, irrigation and precipitation) were equivalent for all GMS treatments except Mulch, and there were substantial differences between 2005 and 2007 due to the N fertilizer applications in 2005. External N inputs from the Mulch ranged from 3 to 69 times greater than in other GMSs during 2005 and 2007, respectively, reflecting the N inputs from mulch biomass and decomposition.

Nutrient recycling through groundcover biomass decomposition, soil mineralization, litter fall and pruned wood constituted internal fluxes that differed among the GMSs annually and between the two years (Table 4). The combined soil N mineralization and recycling surface biomass accounted for about 60% of the total internal N cycling in all treatments during both years. Total internal fluxes were lower in the two herbicide GMSs than in Mulch and Sod treatments, and in both 2005 and 2007, harvested fruit represented more than 70% of N outputs from the orchard. Nitrogen losses through surface runoff were approximately 1 to 4% of N losses, and subsurface leaching represented 18 to 22% of N losses during 2005. In contrast, during the 2007 observations surface runoff N losses were two times greater than subsurface leaching N losses, across all treatments. The overall balance for N among GMS treatments in 2005 was positive (inputs exceeded outputs), and it was greater in the Mulch and Sod than in other GMSs. In 2007, the overall balance for N in this orchard was negative for PreHerb and PostHerb, and positive for the Mulch and Sod treatments.

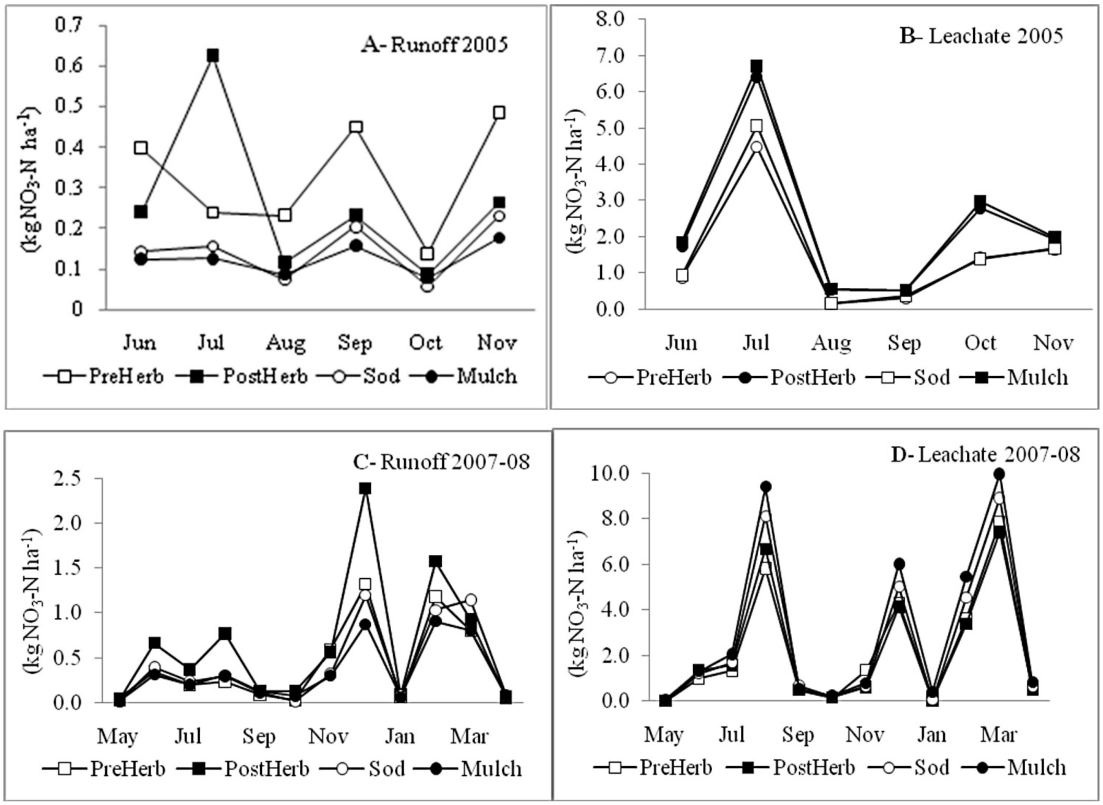

Figure 2. Estimated N losses (kg NO_3-N·ha^{-1}) in runoff and leachate from Jun. to Nov. 2005, May to Dec. 2007, and Jan. to Apr. 2008. The N loss was calculated as total outflow N considering that GMS treatment areas (tree rows) comprised 1/3 of the orchard floor, and the other 2/3 consisted of sod drive lanes throughout the orchard.

Discussion

During 2005 and 2007, the Mulch treatment usually had the least surface runoff and the greatest amounts of subsurface leaching, confirming mulches' widely reported capacity to reduce surface runoff, and to absorb and infiltrate greater amounts of precipitation compared with the bare soils typical of herbicide or cultivation GMSs (Hogue and Neilsen, 1987). A previous study of soil conditions at our site by Oliveira and Merwin (2001) showed lower bulk density, greater porosity, and higher infiltration capacities and saturated hydraulic conductivity in soil under Mulch in comparison with other GMSs, which was consistent with the increased infiltration and subsurface leaching of water observed in Mulch plots during the present study.

The N inputs from Mulch were substantially greater than those in other GMS treatments (Table 4), due to organic matter mineralization from mulch residues that increased N availability over the years and elevated the potential for N leaching from Mulch plots. However, the observed N losses through runoff and leaching from Mulch plots were not proportional to the much greater N inputs in that GMS. Yao et al. (2005) attributed this prolonged retention of N in Mulch plots—even after 14 years of repeated applications that doubled soil organic matter content—to the high C-to-N ratio in bark mulch, and increased soil microbial activity in that GMS, which incorporated most of the N mineralized from mulch residues into microbial biomass and other stable forms of soil organic matter.

In the Sod plots, uptake and recycling of soil nutrients through surface vegetation retained much of the N that might otherwise have runoff, decreasing N losses through surface runoff compared to the PreHerb treatment. Although considerable amounts of N were mineralized from Sod residues, and there was a substantial amount of white clover (*Trifolium repens* L.) in the Sod plots that presumably released N during frequent mowing in this treatment, there were minimal runoff losses of N from the Sod plots. Contrary to the trends observed in Sod, Mulch and PostHerb treatments, during 2005 the PreHerb plots had more N loss through surface runoff than subsurface leachate. Because of negligible groundcover residue inputs over the course of this study in the bare soil of PreHerb plots, the soil pore volume, infiltration capacities, hydraulic conductivity, and aggregate stability all decreased compared with the other GMSs (Oliveira and Merwin, 2001). These conditions increased N loss from PreHerb plots through surface runoff, instead of subsurface leachate, when N fertilizer was applied in 2005.

Considering water quality, the average NO_3-N concentrations in surface runoff water during both years of this study ranged from 0.67 to 5.83 mg·L^{-1} (ppm) for all GMSs. These values are below the US-EPA recommended water quality standards for protecting human health, set at 10 ppm for NO_3-N (US-EPA, 2006). However, during 2005 the NO_3-N concentrations in leachate water from Mulch and Sod plots occasionally exceeded this potable groundwater standard. The PO_4-P runoff and leachate concentration values we observed in this orchard remained well below the US-EPA reference condition values for streams of upstate NY. Compared with NO_3-N—where the concentrations in leachate samples spiked during June and July 2005 after N fertilization—there was a much smaller peak for PO_4-P concentrations

Table 4. Annual nitrogen balance sheet for four GMS treatments in a 15 year-old Empire/M.9/MM.11 apple orchard in Lansing, NY during 2005, when N and P fertilizers were applied, and in 2007 without N or P fertilizers applications.

	Groundcover Management Systems (GMSs)							
	PreHerb ($kg\ N \cdot ha^{-1} \cdot yr^{-1}$)		PostHerb ($kg\ N \cdot ha^{-1} \cdot yr^{-1}$)		Sod ($kg\ N \cdot ha^{-1} \cdot yr^{-1}$)		Mulch ($kg\ N \cdot ha^{-1} \cdot yr^{-1}$)	
	2005	2007	2005	2007	2005	2007	2005	2007
External Inputs								
Fertilizer application	60.0	0	60.0	0	60.0	0	60.0	0
Mulch Biomass N	0	0	0	0	0	0	169.2	84.6
Rain water	0.9	1.2	0.9	1.2	0.9	1.2	0.9	1.2
Irrigation Water	1.8	0.03	1.8	0.03	1.8	0.03	1.8	0.03
Total Inputs	62.7	1.23	62.7	1.23	62.7	1.23	62.7 or 231.9^z	1.23 or 85.3^z
Internal Fluxes								
Recycling surface vegetation	15.1	19.5	20.9	21.5	23.6	29.9	25.1	24.4
Soil Mineralization	11.2	12.3	13.5	14.1	14.8	17.2	17.8	18.9
Leaf litter Fall	16.4	10.7	11.6	14.2	10.3	17.9	10.3	15.9
Pruned wood	4.1	11.5	5.6	13.2	4.8	14.5	5.2	14.9
Total internal fluxes	46.8	54.0	51.6	63.0	53.5	79.5	58.4	74.1
Outputs								
Harvested fruit*	69.3	57.3	82.2	70.3	54.9	61.0	80.9	78.0
Surface runoff	4.0	13.5	3.1	20.8	1.4	12.8	1.2	11.1
Subsurface leaching	16.1	5.2	18.9	5.2	16.1	5.9	20.9	7.4
Total outputs	89.4	76.0	104.2	96.3	72.4	79.7	103.0	96.5
Balance= (A+B)-C	20.1	-20.8	10.1	-32.1	43.8	1.1	18.1 or 187.3^z	-21.2 or 62.9^z

^{z}Values including calculated N inputs from mineralization of the mulch residue. Fruit yield results are presented in Atucha et al. 2011.

in leachate and runoff samples in June 2005, following P fertilizer applications.

The N budgets for two different growing seasons and fertilizer regimes in the 13th (2005) and 15th (2007) years of this study illustrate some important underlying trends among the four GMSs. These are the first published estimates for N cycles and allocations under different orchard GMSs, based upon long-term monitoring of nutrient dynamics in a commercial orchard, and they will be useful for improving the optimization of orchard fertilizer programs.

In summary, our research suggests that N in orchards is lost primarily through subsurface leaching rather than surface runoff, regardless of specific GMS effects. The N leaching losses in our test site were somewhat lower than those reported by others for fertilized apple orchards, where the observed N losses were about equally distributed between fruit crop removal and leaching. The generally positive balance for N supply in our site indicates that trees in Sod and Mulch plots were not N-limited; but the reasons underlying that positive N balance differed between Sod and Mulch treatments. For Sod trees, the positive N balance was driven by lower yields and greater N cycling from groundcover residues and soil mineralization; in Mulch trees the N surplus was driven primarily by mulch residue humus formation that increased soil organic matter N mineralization. Considering the cumulative increase in soil organic matter and N mineralization in Mulch plots over 15 years, and the substantial surplus of N in this GMS, there could be problems with N leaching in orchards that receive high annual inputs of compost, biomass mulch, or other nutrient sources used for organic production.

The N deficit for trees in our two herbicide GMSs indicates a need for N fertilization to meet fruit crop requirements in orchards where herbicides are used for weed control. However, the N deficit in these two herbicide treatments was relatively small—presumably because of the relatively high soil organic matter content at this orchard—and could have been compensated with foliar applications of urea or calcium nitrate during summer cover sprays, where the potential for leaching and runoff N loss is relatively low compared to the losses from ground-applied N fertilizer applications.

Summary

For the year with N fertilizer (2005) the overall N-balance was positive (inputs exceeded outputs) in all GMSs, but greater in the PostHerb and Mulch treatments. In the year without N fertilizer (2007), the overall N-balance was negative for PreHerb and PostHerb, and positive for Mulch and Sod treatments. Soil mineralization and recycling groundcover biomass accounted for > 60% of internal N fluxes, and harvested fruit represented > 70% of N outputs from the orchard during both years. During the year with N fertilizer, N losses were 1 to 4% in surface runoff, and 18 to 22% from subsurface leaching. In the year without N fertilizer, surface runoff N losses were two times higher than subsurface leaching losses in all GMSs.

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Amaya Atucha is a former graduated student at Cornell University who worked with Ian Merwin. **Dr. Merwin** is a research and teaching professor in the Dept. of Horticulture at Cornell's Ithaca campus who specializes in ground cover management of orchards. **Michael Brown** is a research technician who works with Dr. Merwin.