Final Project Report to the NYS IPM Program,
Community IPM 2000 – 2001

Title:
The Impact of Pest Management Systems on Surface and Ground Water Quality

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Bluegrass Lane
Ithaca, NY

Abstract:
The impact of various turfgrass pest management strategies (PMS) on water quality has recently become a concern for many golf course superintendents, sports facilities managers and homeowners. With water quality standards becoming increasingly stringent, management practices have had to follow suit. Uses of alternative control strategies have become increasingly important. This includes the use of biological, cultural and preventative control practices to reduce pest pressure, as well as environmental impacts. Turfgrass is, no doubt, a beneficial addition to most ecosystems, yet when mismanaged could cause harm as well. Mismanagement of the turfgrass ecosystem could greatly influence the nitrogen, phosphate and pesticide levels in surface and ground water, causing problems for communities that depend on clean water for consumption as well as recreation. Aquatic ecosystems as well can be severely harmed by increased levels of nitrogen and phosphate, which can cause algal bloom, decreased dissolved oxygen levels, and eutrophication, which in turn has an impact on nearly all ecosystems. Pesticides that find their way into surface or ground water pose a problem to exposed species ranging from fish to humans. When pesticides are found in drinking water above set levels, the water is no longer potable, and is in many cases very dangerous to consume. When managed correctly, turfgrass provides

many positive attributes, including increased UV absorption, CO2 remediation, soil stabilization, habitat, ground and surface water filtration, and aesthetic and recreational benefits. We are studying the impact of three of the most commonly implemented turfgrass pest management systems, (preventative, IPM, and organic systems) on surface and ground water quality and turfgrass performance. The results will hopefully provide answers on how to produce acceptable turfgrass quality while protecting the environment.

Results of this study to date have been unable to select pest management strategy that is the best. Nutrient analysis indicates that all systems; Organic IPM and Preventative have the potential to negatively impact water quality. Establishment was the most dangerous time, with large concentrations of nutrients, especially nitrate, found in water. Pesticide movement via runoff was greatest for Preventative PMS. Overall the results to date indicate that the PMS selected may not be the most important factor impacting water quality.

What is clear is that environmental and site conditions dictate turfgrass effects on water quality. The soil type, organic matter content, infiltration rate, slope, and water content can and in many cases do influence nutrient and pesticide runoff and leachate. Rainfall rate, intensity and duration play an important role in both pesticide and nutrient retention. Adequate turfgrass density and organic carbon content will minimize and in some cases altogether prevent contaminant movement off site. Pesticide formulation and application timing are important, and should be evaluated as part of any pest management system. Across the board, none of the pest management systems produced consistently significantly lower impacts on water quality.

Background and Justification:
There is a considerable controversy over the use of synthetic pesticides on non-food crops like lawns, athletic fields and golf courses. The concerns range from human exposure to pesticides via air (volatilization), drinking water (surface waters or wells) or direct contact (spray drift or contact with pesticide residue from treated turf such as children on lawns and athletic fields) to the impacts of pesticides on plant and animal ecosystems.

Approaches to pest management vary greatly in different turfgrass settings. Some turf managers rely on preventative pesticide control programs where the desire for quality leaves little margin of error. Most managers rely on IPM practices including the use cultural, biological and pesticide control options. There is small but growing segment of turf managers that only use natural-organic pest management approaches (cultural and biological control coupled with natural organic fertilizers). The Cornell Turfgrass Program has been responsible to developing and evaluating the effectiveness of many of the cultural and biological pest options available.

Each of the three different pest management systems (preventative, IPM and natural-organic) may provide effective pest management under slight to moderate pest pressure. Under high to extreme pest pressure the natural-organic pest management system may not provide for total control resulting in turf death and stand density decline.

A decline in turf density has been shown to increase the runoff of nitrogen and phosphorus from turf (Kussow, 1996). Under certain condition pesticides can runoff or leach from turfgrass areas (Petrovic, et.al., 1994). Thus, each of the pest management systems could have a negative impact of surface or ground water quality. Even pesticides and nutrients, which are tightly bound to soil particles, can move, through erosive process. Turfgrass has been shown to reduce sediment erosion by up to 70% compared to bare soil (Carroll, et. al., 1998). However, there has not been a comprehensive study of the nature proposed here to evaluate the impact of pest management strategies on water quality. Results for the first year of this project, conducted during the establishment phase, strongly confirms that turfgrass density is very import in determining the extent of nutrient runoff and leaching. More runoff was observed on plots with lower turf density, which were being maintained under IPM and organic pest management systems.

Soil hydraulic, chemical and physical properties can also influence movement of pesticides and nutrients to ground or surface water bodies. We have shown that the infiltration rate of the soil can reduce the runoff volume leaving a site, and hence the total chemical or nutrient load in surface waters. Sandy soils generally have a higher infiltration rate, lowering runoff, and increasing leachate movement. In this case, ground water may be negatively effected, as sands have a reduced ability to bind nutrients and pesticides once the water has entered the profile. Clays which have much lower infiltration rates, allow more water to leave the site as runoff, but can immobilize great amounts of pollutants once the water enters the soil profile. As the infiltration rate approaches steady state, or the constant rate water will enter the soil, the saturated hydraulic conductivity of the soil is approximated (Wilkinson & Blevins, 1999). This is important in that we may predict subsurface movement of non adsorbed solutes, such as nitrate, as it will generally move with the water in the soil. Studies conducted by the USGS have found that soils with a high clay content will not ultimately retard movement of anions such as nitrate (Wilkinson & Blevins, 1999). Movement of adsorbed solutes such as phosphate, or certain pesticides may also be predicted knowing chemical parameters, such as the adsorption partitioning coefficient (K_{oc}), the solubility in water or the degradation rate of the chemical (Tuxen, et.al., 2000). Robertson (1995) found that attenuation of phosphate in the soil is accomplished mainly by adsorption to soil particles, which retards movement, by a factor of up to 20.

Cation exchange capacity (CEC), which is higher in clays, serves to adsorb many positively charged ions (such as phosphate), and pesticides (Fetter, 2001). Increased soil organic matter may also immobilize many compounds due to cation holding capacity. However, increase soil organic matter may increase the levels of nitrate leaching to ground water (Horst, et.al.,1999), as increased organic matter can increase the rate of N mineralization. Nitrate is not held well by either clays with high CEC, or by soil O.M., as it has a negative charge, and is too large to be effectively adsorbed. (Fetter, 2001)

The three pest management systems may have different impacts on water quality, based on stage of development of turf density. Traditional PMS produced denser turf more quickly and thus had less initial impact on water quality. However, the proposed research in this project will be necessary to provide turfgrass managers the ability to select a pest management system with the least impact on the environment on a long term bases. This project will be in the second year of a long-term effort (3 to 5 years) and will produce results to be available for demonstration after the first or second year.

Objectives:
The first objective of this study is to evaluate the impact of pest management systems (PMS) on pesticide loads is surface water runoff. In addition, our objective is to categorize and evaluate the extent to which pesticides are found in water that has moved past the root zone as leachate.

The study will also evaluate impact of the 3 PMS on nutrient runoff, more specifically, the extent to which nitrate, phosphate, and ammonium are found in surface water and leachate (impact on groundwater quality)leaving a turfgrass site

Procedures:
The site for the runoff study is the Cornell University Turfgrass Field Research Laboratory, Ithaca, NY. The site was characterized as to extent and direction of slope and soil. A grid system was developed with 20 x 20-ft areas which had soil samples removed. Selected samples were tested at the Cornell Nutrient Analysis Laboratory for nutrient capacity. All samples were the subjected to Particle Size Analysis via the Hydrometer Method to determine soil classification. Nine 20 by 20 foot plots were established in July 2000 on Arkport sandy loam, which has medium risk of surface and ground water determination, USDA-NRCS rating. Three plots (reps) of each PMS will be treated as follows to simulate a lawn or athletic field:

1. Preventative PMS: Kentucky bluegrass and perennial ryegrass plots were seeded in mid July 2000. These plots have a high nutrient and quality expectation and a low pest tolerance. Pest damage will not be tolerated, so all plots will be treated (entire plot) in advance of any anticipated pest or at first observance. Nutrient program will consist of high rates of water-soluble sources. Fertilizer is applied 4 times per year at 1-lb. N/ $1000ft^2$ rates. Pesticides selection will be based on efficacy of control, not on the basis of environmental, or ground and surface water risk.

2. IPM-PMS: Plots were seeded with Kentucky bluegrass, endophytic perennial ryegrass cultivars in mid July 2000. All current state of the art IPM practices will be used including pest resistant grasses, biological, cultural and physical controls. Scouting and monitoring will be done routinely. If a pesticide is needed one will be selected to have a low risk to surface and ground water determination, and will be spot treated if possible. Fertilizer program will integrated water quality BMP (soil test, low rates, care on timing and the use slow release sources and/or natural organic disease suppressive sources). Pesticide (having a low potential for both surface and groundwater contamination) and fertilizer applications will be made only during periods of low risk of heavy rainfall creating runoff or excess leachate.

3. Natural-organic PMS: This PMS was seeded in July 2000 with Kentucky bluegrass and endophytic perennial ryegrass cultivars. Procedures will be similar to the IPM except no pesticides (other than natural organic-biocontrol materials) will be used.

Fertilizers used will only be from natural-organic materials (composted bio-solids and animal wastes).

All runoff events (natural or from irrigation) are collected, volume determined and a sub-sample collected and frozen until analyzed for pesticides or nutrients (NO_3-N, NH_4-N and PO_4). Simulated rainfall events to produce runoff will also be done on small plots (2 m x 2 m) several time during the year if natural events do not occur (this was not needed since there were numerous natural events in 2001).

The site for the leaching section of the project will also be at the Cornell University Turfgrass Field Research Laboratory, Ithaca, in the Modified Soils Facility designed to collect leachate leaving the root zone (18 " deep). Plots are 7.5' diameter plastic lined small swimming pools that contain a drain to capture all leachate. Each plot (pool) has a separate irrigation and leachate collection system. All of the above PMS are repeated to 3 plots (reps) with of the same soil in the runoff study. Every (rainfall or irrigation) event that produces leachate, is collected, the volume of leachate recorded, and frozen until analysis. Daily samples will be collected and combined into a weekly composite sample.

The concentration of nutrients is determined at the Cornell University Nutrient Analysis Laboratory, Ithaca, and pesticides at the Food Science Dept., Cornell University, Geneva.

Monthly turf quality ratings were performed using a rating system similar to that used by the National Turfgrass Evaluation Program (NTEP). Whereby quality is rated on a scale of 0-9, with unacceptable, dead, necrotic turf receiving a 0 and perfect turf a 9. A score of 6 is generally considered acceptable turfgrass. Statistical analysis of ratings is performed to determine which PMS produces adequate quality.

Turfgrass shoot density counts were conducted on a bi-monthly basis throughout the growing season. A grid is laid on the turf and shoots were counted on a 9 in^2 area, three reps for each plot. The counts are the averaged for each plot, returning the number in shoots/in^2. The density data is then used in various analyses to explain runoff volumes, and contaminant concentrations.

Infiltration rates were determined for the site in October 2001. A grid was devised on the hillside on 25-m intervals, where tests were performed. Constant head infiltration test was performed by inserting a 650 cm^2 ring 15-cm deep into the soil profile, with ~ 10 cm. left above the soil surface. 4000 ml of water was then added to the ring to begin the test. As the water enters the soil, more is added to keep the level constant. Every 5-min. the volume added is recorded. The tests were run for 2.5 hr each. This allowed the infiltration rate to approach steady state. Actual steady state rates were determined using the Green/Ampt equation.

Organic carbon samples are taken on a periodic basis (bi-monthly). Past research has shown that the % organic carbon content of the above soil surface plant matter (shoots, thatch, stolons) is an important factor in pesticide retention. Multiple samples were taken from each plot and submitted for analysis to Cornell CALS Nutrient Analysis Laboratory, Bradfield Hall, Ithaca, NY.

Results and discussion:
To date there have been 34 runoff events, where water was collected from at least 1 of the 9 plots. In most cases, there was water collected as runoff from most of the plots. Leachate has been collected 29 times, (composite samples). There was adequate leachate to collect from all of the plots, every event.

Nutrients:
Analysis of the nutrient concentrations and fluxes (volume*concentration) in runoff and leachate water was performed using the General Linear Model (SAS Institute), followed by a Tukeys pairwise comparison of means to determine significant differences between treatments. A natural logarithmic transformation was performed on all data sets to remedy non-linearity of residuals, and increasing error variance.

Levels of nutrients found in runoff water were initially very high following establishment. This was due to the lack of turfgrass shoot density. See Fig 1.
While concentrations of nutrients in runoff was generally stable across varying levels of turfgrass shoot density, the fluxes generally declined as density increased. Increased shoot density presents a physical barrier to sheetflow, slowing the runoff, and allowing water to enter the soil. Runoff volumes collected were 2-3 times higher during establishment (after correction for rainfall rates and intensity). Less intense storms (< 1 cm/hr rainfall) caused runoff at establishment.

In runoff, Phosphate was found at levels <2 mg/l, and ammonium <5 mg/l. Both phosphate (PO_4^+) and ammonium (NH_4^+) are cations (positively charged), and as such will generally be tightly bound to soil particles and soil organic matter. Once bound, movement is via erosion, where soil particles are detached and transported to water bodies. There was generally an insignificant amount of erosion at the site.

Nitrate levels were very high at establishment, mean concentration >50 mg/l, mean flux > 150 mg, or 5-15 times The EPA MCL for nitrate (10 mg/l). Nitrate (NO_3^-), an anion (negatively charged) does not adhere, or bind in significant quantities to soil particles, or organic matter, and generally moves with water. Since there was very little turfgrass at establishment to utilize the nitrate, it was very mobile, and easily transported via water. This can explain the high quantities of nitrate leaving the site in both runoff and leachate.

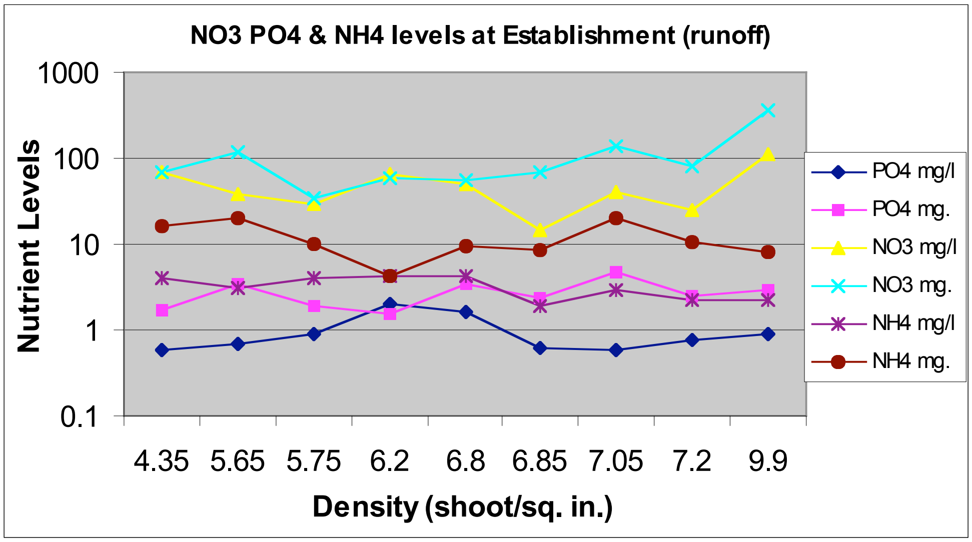


Fig 1 Nutrient Runoff Conc. And Flux vs. Density yr. 1 (7/00-11/00) Note: log scale

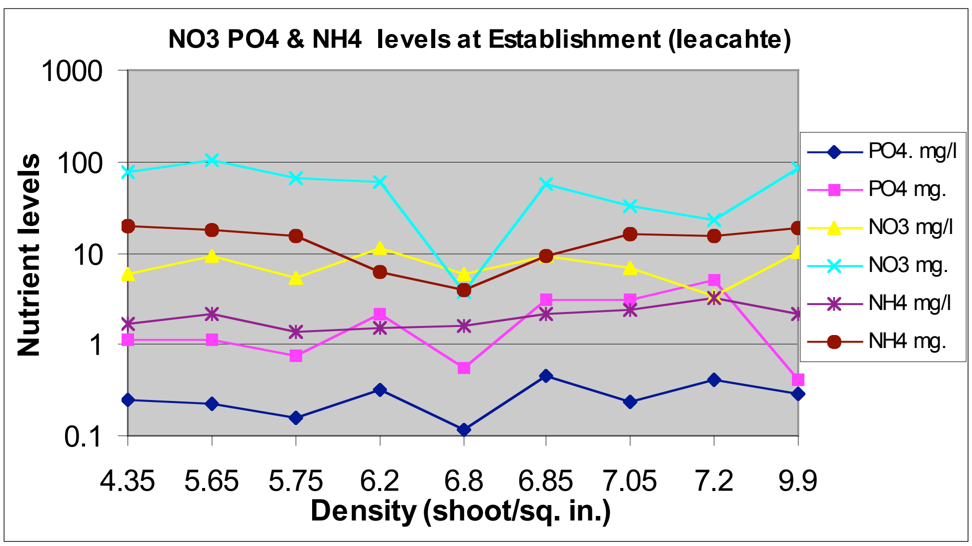


Fig. 2 Nutrient leachate Conc. And Flux vs. Density yr. 1 (7/00-11/00) Note: log scale

During the establishment phase there was not a strong relationship ($p = 0.84$) between density, and runoff volume or concentration collected from the plots. All plots had what can be considered low turfgrass shoot density, all < 9 shoots / sq. in. , most <6 shoots/sq in. There was, however, a significant relationship between the runoff volume and the infiltration rate. ($p = 0.05$, $r^2 = 0.421$) That is, as the infiltration rate measured in cm/hr increased, the runoff volumes decreased. Increased infiltration rates allow more water to enter the soil leaving less to move from the site as runoff.

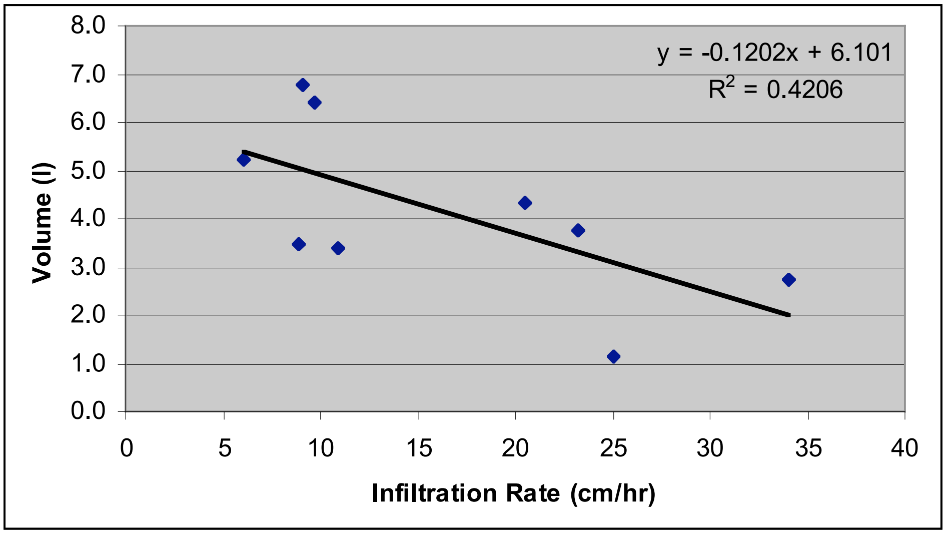


Fig 3. Infiltration rate vs. Runoff Volume yr. 1 (7/00-11/00)

Concentrations of nutrients in runoff generally were not significantly different between treatments, (IPM, Preventative, Organic) during the establishment phase. The following are exceptions. Leachate volumes were higher for IPM treated plots. ($p = 0.0128$) The leachate NH_4 concentration was higher for the Organic PMS ($p = 0.0048$). The NH_4 flux was significantly lower for the Preventative PMS ($p = 0.0017$). This was an artifact of the significant difference in the volumes of leachate.

Runoff Vol. (l) Mean	Leachate Vol. (l) Mean	N	Treatment
4.301 A	9.968 A	24	IPM
4.731 A	5.981 B	24	Preventative
3.365 A	5.913 B	24	Organic

Means with the same letter are not significantly different at $\alpha = 0.05$
July 2000-November 2000

Runoff Conc. mg/l Mean	Runoff Flux mg. Mean	Leachate Conc. mg/l Mean	Leachate Flux mg. Mean	N	Treatment
PO_4					
0.7378 A	2.9019 A	0.31114 A	2.2310 A	24	Preventative
1.0448 A	3.3776 A	0.33116 A	2.7552 A	24	IPM
1.0991 A	1.8989 A	0.17317 A	0.8209 A	24	Organic
NO_3					
55.43 A	180.76 A	7.600 A	48.75 A	24	Preventative
40.10 A	75.56 A	8.381 A	83.90 A	24	IPM
53.67 A	59.89 A	6.577 A	37.43 A	24	Organic

NH_4

2.3745 A	12.228 A	1.6180 A	9.963 A	24	Preventative
3.6865 A	13.172 A	1.9021 A	17.200 B	24	IPM
3.5119 A	10.347 A	2.5892 B	13.544 B	24	Organic

Means with the same letter are not significantly different at α= 0.05
July 2000-November 2000

Once adequate density was established in the second year, levels and fluxes of nutrients stabilized, and have remained at low levels, generally below maximum contaminant levels established by the EPA.

Runoff volumes, although higher in actual amounts, are actually less once correction for rainfall depths and intensity have been considered. Below are the actual volumes collected from the runoff plots. Volume corrections were by comparison of rainfall depths, and intensities compared with the volume of runoff collected. Intensities and depths tended to be much higher since March 2001, (no rainfall intensities below 2 cm/hr), where as July 2000 – March 2001 saw 12 of 19 runoff events with intensities < 2 cm/hr (establishment period). Below is a table showing mean runoff and leachate volumes since inception, includes establishment.

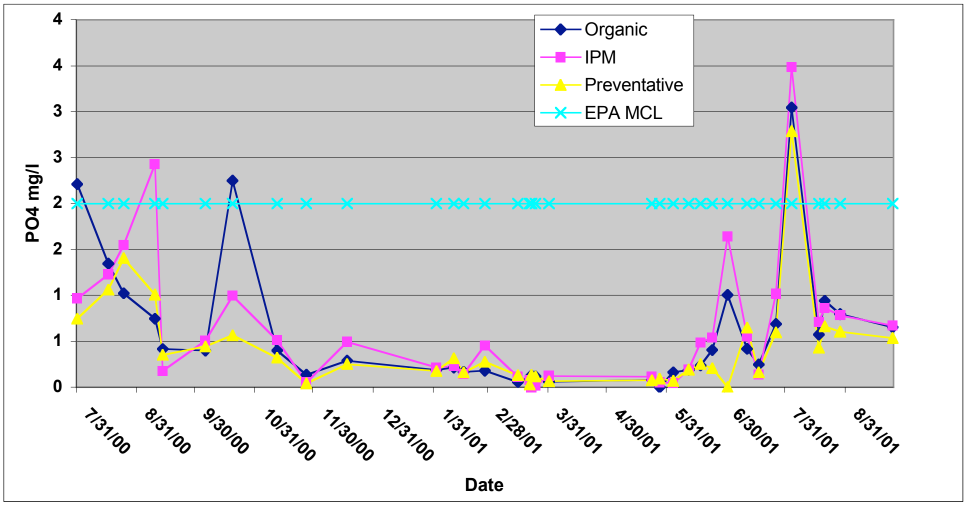
Leachate volumes between establishment and post establishment are not significantly different. Once correction for rainfall is made, they are almost equal. Comparisons for treatments shows that the volumes of leachate for the preventative PMS are significantly lower than the IPM and Organic PMS. Densities were higher on the Preventative PMS plots, and as such, the plots were able to utilize a greater amount of the applied water. Denser turf is associated with greater root mass, and increased levels of uptake, respiration and transpiration.

Runoff Vol. (l) Mean	Leachate Vol. (l) Mean	N	Treatment
13.388 A	11.767 A	24	Organic
12.500 A	9.328 A	24	IPM
14.081 A	7.118 B	24	Preventative

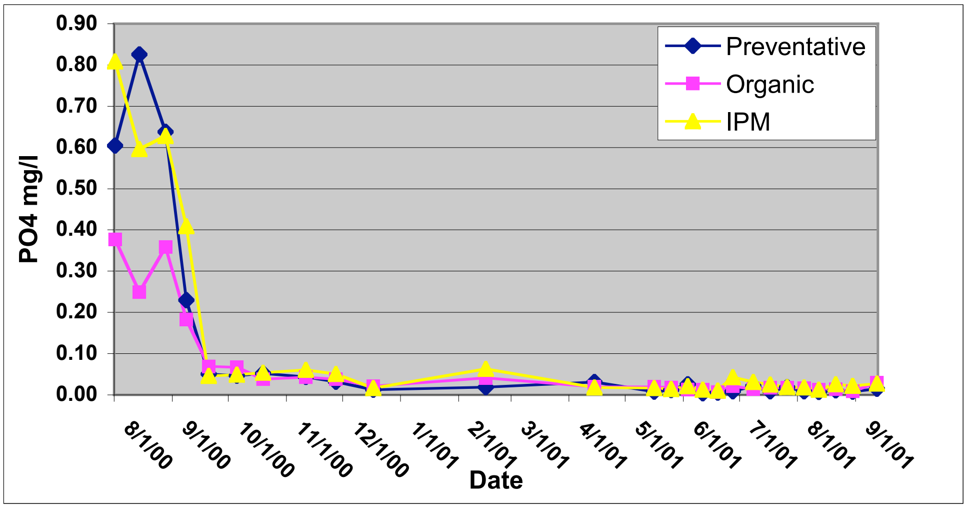
Means with the same letter are not significantly different at α= 0.05
July 2000-October 2001

Initial comparison since inception of the study has indicated that phosphate concentrations measured in mg/l are not significantly different between treatments. Levels are well below EPA MCL for drinking water (<2 mg/l). See table below. Fluxes were also lower following establishment. The Flux from the IPM PMS was significantly

Time series plot of PO_4 concentration in runoff



higher (p = <0.0001) than the others, again due to lowered density in the spring. Current concentrations and fluxes are no lower than at establishment, although the overall mean is lower now then at establishment, due to very low levels (< 1 mg/l) leaving the site during the winter. Levels are above the EPA MCL for phosphate in drinking water in a number of cases. Phosphate is tightly bound to soil particles, but is mobile if exchange or binding sites is filled. An established turf stand neither requires nor utilizes phosphate at significant levels, and as such, uptake is generally not responsible for remediation. Phosphate will also bind to organic matter in the soil, and turfgrass is a prolific producer of organic matter, through thatch and clipping decomposition, although there is no thatch currently. This is one possible way that more phosphate can be attenuated in the soil.

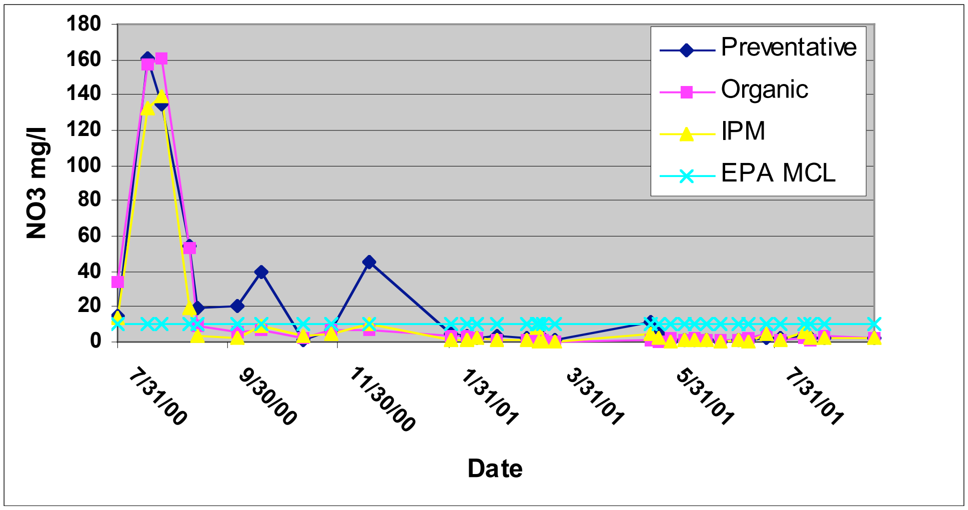


Time series plot of PO_4^{3} concentrations in leachate

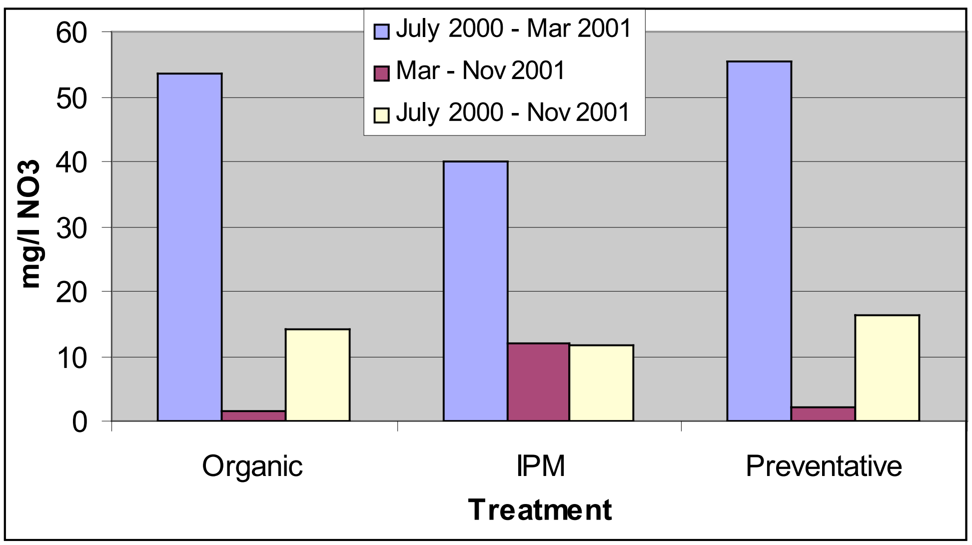
Runoff Conc. mg/l Mean	Runoff Flux mg. Mean	Leachate Conc. mg/l Mean	Leachate Flux mg. Mean	N	Treatment
PO_4					
0.6343 A	6.650 A	0.11895 A	0.9967A	102	IPM
0.5843 A	5.076 A	0.06631 A	0.4272 B	102	Organic
0.4383 A	6.650 A	0.10556 A	0.7618 B	102	Preventative
NO_3					
14.223 A	31.36 A	2.2458 A	15.599 A	102	Organic
11.567 A	31.80 A	3.3006 B	33.361 A	102	IPM
16.201 A	61.06 A	3.0986 B	19.736 A	102	Preventative
NH_4					
1.1171 A	11.033 A	0.9631 A	4.9805 A	102	Organic
1.5793 A	8.027 A	0.6917 A	6.0691 A	102	IPM
1.5176 A	9.352 A	0.5865 A	3.2015 B	102	Preventative

Means with the same letter are not significantly different at α= 0.05
July 2000-October 2001

Nitrate concentrations and fluxes have decreased substantially for the Organic and Preventative PMS since establishment. Overall levels are lowest for the IPM PMS, but concentrations in runoff water from the IPM plots have increased significantly ($p = 0.0011$) since March of 2001, despite adequate density. Density was somewhat lower for the IPM plots coming out of winter, although the difference in density does not explain the increased concentrations of NO_3 in runoff. It is possible that the use of the more soluble commercial fertilizers (Lesco 24-5-11 48% slow release) caused more NO_3 to leave the site. This more soluble form coupled with the decreased density may be responsible. Below is a table comparing nitrate levels at establishment, following establishment, and the total concentrations since the start of the study. The graph below shows very high levels initially, well above MCl for drinking water. Following establishment the levels declined to well below the MCL (10 mg/l) for all but the IPM PMS. Overall averages are still above levels generally considered safe. NO_3 fluxes have followed a similar trend, high at establishment, declining steadily once turf was established, with the total somewhere in between.

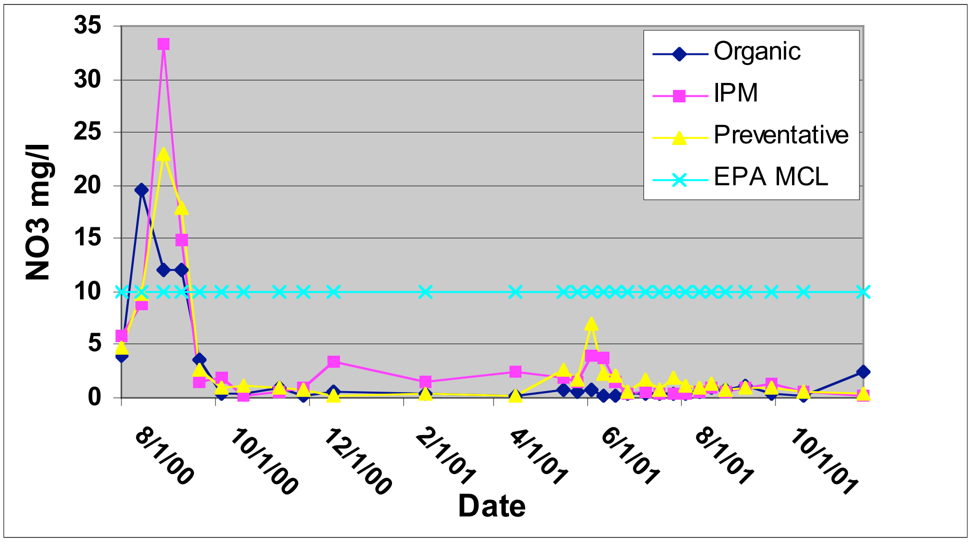


Time series plot of NO_3 concentration in runoff



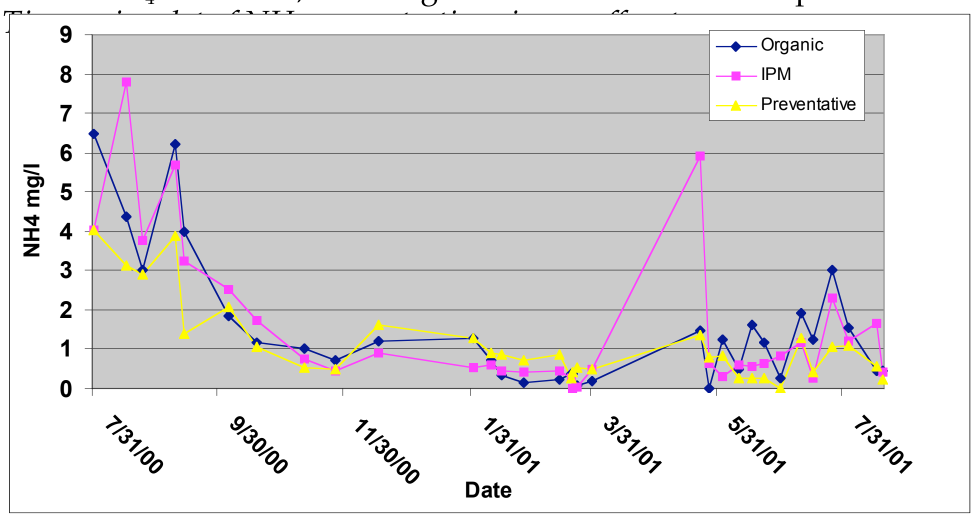
Comparison of NO_3 levels in runoff at establishment, post establishment and since inception

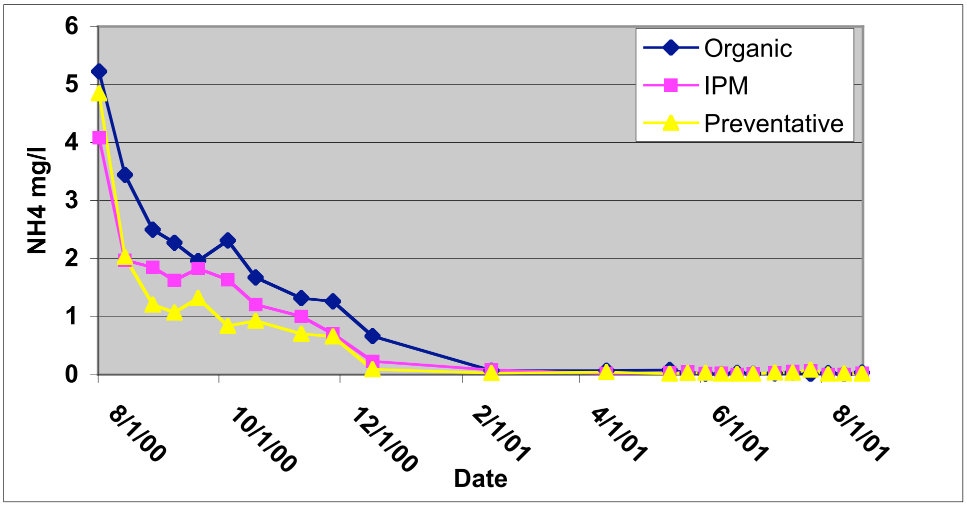
NO_3 levels in leachate were well below levels of concern for human consumption, (~ 3 mg/l) since July 2000. Levels are < 1 mg/l since March 2001. Overall, Organic PMS, had the lowest levels of NO_3 in leachate water, see table above. This may be due to the less soluble form of nitrate found in composts and organic fertilizers. The nitrogen needs to be converted to nitrate by microorganisms, as opposed to time or controlled release sources such as the Lesco products used on the IPM and Preventative plots. Nitrogen release dependent on microbial activity in the soil is more variable, and less predictable than release dependent upon water content or temperature.



Time series plot of NO_3 concentration in leachate

Ammonium, NH_4, when found at levels above 2 mg/l can cause problems for fish, especially trout, but is generally not considered a problem in drinking water until much higher levels are reached. As such it is not regulated by the EPA as a drinking water contaminant. Overall levels of NH_4 in runoff water were below what can be considered dangerous levels since establishment. Concentrations in runoff or leachate were never > 10 mg/l in any sample. Likewise, fluxes from the plots did not reach high levels. In leachate water the preventative PMS treatments produced the lowest fluxes of NH_4. ($p = 0.0285$) This may have occurred for a number of reasons. The fertilizer used on the preventative plots (Lesco 35-3-5) has a low NH_4 content; most of the nitrogen is in the nitrate form. Higher density may also be responsible for increased uptake of water and hence NH_4 in the soil, allowing a smaller amount to escape.

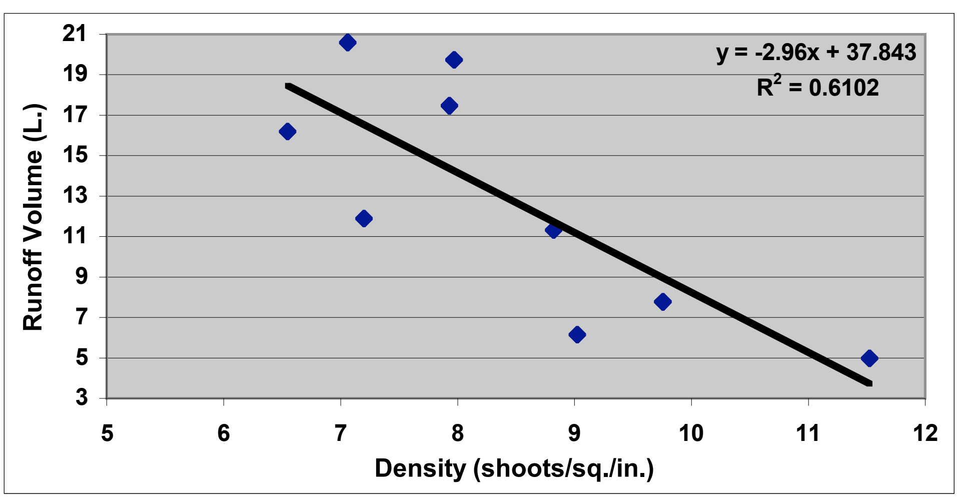




Time series plot of NH_4 concentration in leachate

It was mentioned previously in the result that density measured in shoots/sq. in. has a significant impact on the volume and quality of water leaving a site. It is well know that density and runoff have an inverse relationship, increased density decreases runoff. This is accomplished through a number of processes. More shoots will first intercept, and break up rain droplets. By breaking the droplets, soil sealing can be prevented. Sealed soil greatly reduces infiltration rates, and hence increases runoff. Denser shoots generally require more root mass to take up adequate water for use. Therefore, a denser canopy uses more water. A larger water requirement will pull more water from the soil, reducing saturation, which will allow more water to enter the soil profile, reducing runoff losses. More shoots are also associated with greater transpiration (water use) rates, converting water in the liquid phase to gaseous. Perhaps the most important way in which shoot density limits runoff is physically. Shoots present a physical barrier to runoff, slowing it down and allowing it to infiltrate the soil. Below is the regression plot of turfgrass density against runoff volume. This represents a significant relationship ($p = 0.003$).

Density Volume Regression July 2000- Nov 2001



The rate at which water enters the soil is another important parameter when predicting nutrient runoff. Infiltration of runoff water will reduce first the volume coming off a site, and increase the likelihood that nutrients will be attenuated in the vadose zone. In some cases, increased infiltration may present as much of a problem as runoff. Sands, which generally have a higher infiltration rate, owing to larger pore diameters, do not, in most cases binds or remediates as high a quantities of nutrients, especially NO_3. Clays and loams, which have much lower intrinsic infiltration rate, tend to bind, and hold more nutrients allowing for uptake by plants, or mineralization. These differences are due to charges, and exchange sites found in the soils. Clays have a strong negative charge, which will attract positive cations, and bind them in the profile. Sands do not have a strong charge, and most of the binding is accomplished via organic matter.

The infiltration rates for the soil on the runoff plots varies greatly. There is a strong gradient running up the slope. Rates at the toe of the slope infiltration rates are 5 – 10 cm/hr, while those at the crest are 20 – 40 cm/hr. Although the soil types are similar, Arkport Fine Sandy Loam at the toe, and Arkport Sandy Loam at the crest, huge differences in rates exist. Explanation of the differences in infiltration rates can not wholly be explained by the slight differences in soil classification. It is possible that there is an impermeable layer closer to the surface near the toe of the slope, which cause the profile to saturate more quickly, reducing the steady state infiltration rate. (We hope to explore this issue soon) Steady state infiltration was determined using the Green Ampt equation:

$$i = ic + B/I$$

Where

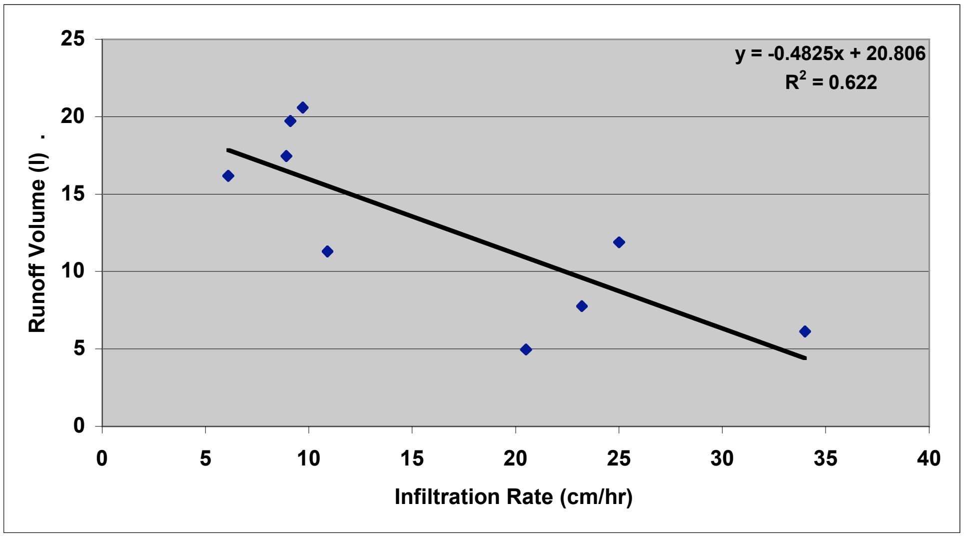
i = infiltration rate at any time t (cm/h)

ic = steady state infiltration rate (cm/h)

B = empirical fitting constant for soil. to be determined solving equation

I = cumulative infiltration (cm)

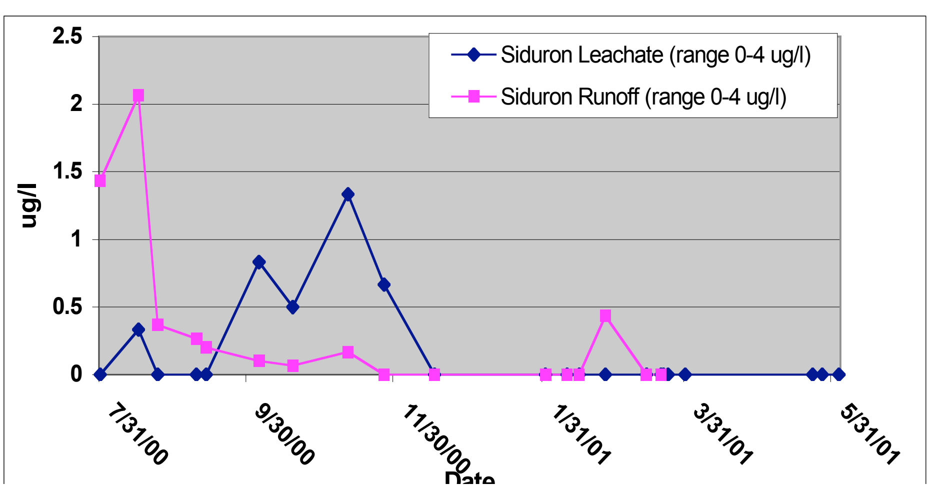
Regardless, the infiltration rate explains a significant ammount of the variation in runoff volumes collected($r^2 = 0.622$). Even more interesting is the relationship between turfgrass shoot density, infiltration rate, and runoff volume. A multiple regression with infiltration rate and density as the predictors has a $r^2 = 0.756$, indicating that there is an interaction between density and infiltration. As discussed earlier, increased density may allow more water to enter the soil, because it slows the speed of the runoff.



Infiltration rates vs. runoff volume

Pesticides:
Another objective of this study is to categorize and evaluate the extent to which pesticides are transported from a site. Pesticides, when found in surface or ground water are of a concern for human consumption, as such; the EPA has set MCL for many of the more widely used dangerous compounds. For instance, 2,4-D acid, a widely used herbicide, found in many different chemical formulations, has a MCL 0f 70 μg/l (70 ppb). Two important predictors of pesticide movement through a soil profile are the K_{oc}, and the soil half-life. The K_{oc} is the soil adsorption-partitioning coefficient, and is a measure of how easily a compound binds to organic matter and will move through the soil. Compounds with a K_{oc} higher then 200 generally do not move through the soil easily. Transport is thorough erosive process, where sediment is detached and moved to a water body (surface), where the compound can then diffuse into the water.

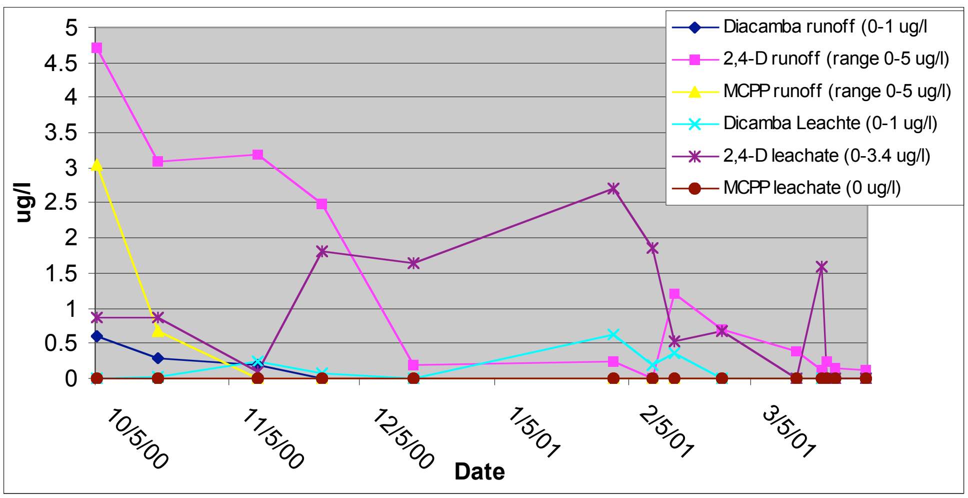
Siduron, or *Tupersan*, applied prior to planting last July. It is a preemergent grass control, and is considered non-mobile. Siduron has a K_{oc} value of 420 cm^3/g and a half-life of approximately 120 days in the soil. The compound is tightly bound to negatively charged clay particles, and soil organic matter. Sidurons general immobility in both runoff and leachate can be confirmed by looking at the concentrations that we saw moving form the site. Concentration were highest in runoff directly following application in July 2000, ad declined steadily to <0.5 μg/l with in 45 days after treatment. There was a bit of a lag before we saw the highest concentrations of Siduron



in the leachate. The compound took almost 100 days to move through the 18-in. profile. Lower concentrations were detected in the leachate with in 30 days of application. This may be explained by macropore or finger flow transport, where the compound moves with the water through large pores in the soil. Macropore flow likely only constitutes a small portion of the total flow, with the bulk transported by connective dispersive process. Siduron has a relatively long half-life in the soil, which may explain why it was detected at low levels in ground water well into the spring. Levels found in both runoff and leachate were entirely acceptable (below the MCL), even without substantial turfgrass cover for the season. Attenuation was accomplished almost entirely by binding to soil particles, and organic matter, where microbes can metabolized and degrade it.

Time series of Siduron runoff and leachate

Applied September 2000, as *Trimec Classic* (2,4-D acid, Diacmba, & MCPP), concentrations of 2,4-D in runoff and leachate were never above 6 μg/l, (mean = 1.23 μg/l, range = 0-5.82 μg/l) for the first season. The graph below shows concentrations in runoff and leachate. Again, the highest levels were directly following application for



runoff, and 150 days later for leachate. The MCL of 70 μg/l for 2,4-D.
Time Series of Trimec Classic (2,4-D Diacamba, MCPP) in runoff and leachate

All of the three compounds in Trimec are categorized as mobile compounds, with K_{oc} values <200 cm^3/g. The K_{oc} for 2,4-D acid is 48 cm^3/g, which makes it relatively mobile. It has a short half-life, 7 days in the soil, which may explain why such low levels were detected. There was a 10-day period between application of Trimec, and the first runoff event, so already more than half of the 2,4-D was degraded. Organic carbon (O.C.) in the turf tissue may have also played a role in the low levels detected. Pesticide chemistry dictates that most compounds are bound to the tissue, where they can either confer protection on the desired plant, or kill undesired plants. This is where organic carbon plays a role in retention. Higher % O.C. will be able to bind more of a pesticide in the desired region.

Dicamba which has a lower K_{oc}, (13 cm^3/g considered highly mobile) was found in even lower levels than 2,4-D acid (less mobile). Concentration in runoff and leachate were < 1 μg/l, following the same general trend as 2,4-D acid. Higher levels in runoff directly after application, with a delay of 150 day before the highest concentration in leachate. With a half life of 14 days for Dicamba is degraded relatively quickly, and should not be seen at very high levels for an extended period.

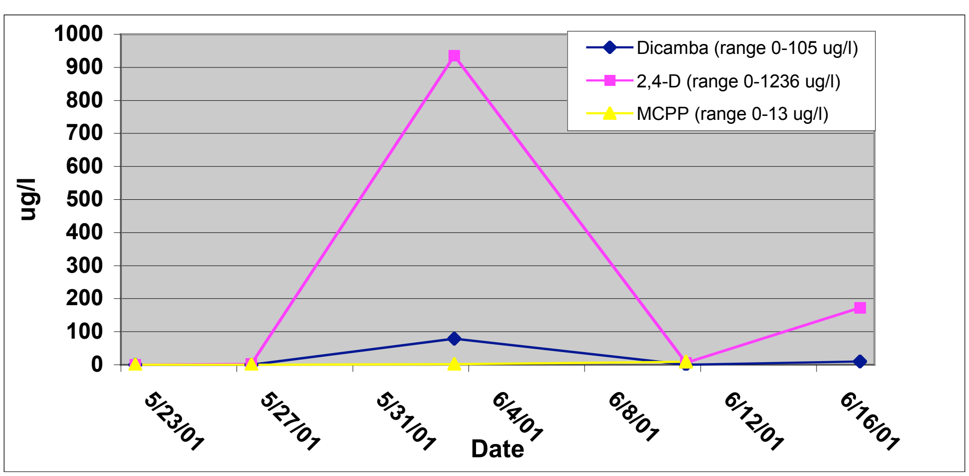
MCPP is the most mobile for the herbicides applied, yet was detected only in runoff, and only for a very short period of time. Maximum levels reached 5 μg/l 10 days after application. MCPP has a longer half-life, 120 days in the soil.

Trimec Classic does not contain equal portions of each compound (24.93 % 2,4-D acid, 2.76% Dicamba, & 13.85% MCPP). This may explain why we saw more less mobile 2,4D than the more mobile Dicamba and MCPP. Intuitively, this is what we could expect. 2,4-D applied at 2x (MCPP) or 10x (Dicamba) is going to be found at higher concentrations, even with varying degrees of soil binding and half lives.

A 2,4-D isoocytlester herbicide was applied at the same time Sept 27 2000, and was never detected above 1 μg/l in runoff or leachate. The isoocytlester formulation is just as effective a herbicide as the acid formulation, but poses a lower risk to ground and surface water contamination, according to risk assessment due to a much lower water solubility. This was verified through application. Weed control was more than adequate, and water was not contaminated.

In June of 2001 (6/3/01), Trimec Classic was applied again to control broadleaf weeds. Application was directly prior to a heavy thunderstorm (2 hr.) in which 0.69" of rain fell in 20 min, creating runoff. The herbicide did not have adequate time to dry (generally 36-48 hrs is desirable), and as such, large concentrations of 2,4-D and Dicamba were observed in runoff water. (We have not received the leachate analysis from the laboratory yet). Concentration in excess of 1200 μg/l for 2,4-D is almost 20 times the MCL in drinking water. Dicamba was observed at levels above 100 μg/l. Without adequate drying time, the pesticides will not be bound to the tissue, or in the soil, and are thus in a very easily transported condition. Again, 2,4-D, the least mobile was detected in the highest concentrations due to the application rate. Reapplication of Trimec Classic was required 14 days latter due to lack of weed control.

Time series of Trimec Classic (2,4-D, Dicamba, MCPP) in runoff May-June 2001



It is interesting to note that 2,4-D isoocytlestyer applied at the same time to the IPM plots was not detected above 1 μg/l in any sample, and was below detection limits in some. The isoocytlester formulation breaks through the cuticle of the weed much more effectively, and quickly then the acid formulation. The ester is also much less soluble in water, and has a K_{oc} of >500 cm^3/g, which would classify it as immobile. The half-life is 7-10 days.

This event shows that one of the most important considerations in pesticide application is timing. The herbicide needs time bind to the tissue to control undesired species, and to prevent contamination of surface and ground water. Formulation is also very important in pesticide selection. Select a pesticide, which provides adequate control while presenting minimal risk to water.

Runoff and leachate water from application of Fenoxaprop (Acclaim Extra, grass control) and Proxyl (grub control) are being analyzed, and should be available soon. Analysis of water for Trimec Classic, and 2,4-D isoocytlester continues.

Conclusion:
Results of this study to date have been unable to select pest management strategy that is the best. Nutrient analysis indicates that all systems; Organic IPM and Preventative have the potential to negatively impact water quality. Establishment was the most dangerous time, with some large concentrations of nutrients, especially nitrate, found in water. Pesticides runoff was greatest for the Preventative PMS. The overall results to date indicate that the PMS selected may not be the most important factor influencing water quality.

What is clear is that environmental and site conditions dictate turfgrass effects on water quality. The soil type, organic matter content, infiltration rate, slope, and water content can and in many cases do influence nutrient and pesticide runoff and leachate. Rainfall rate, intensity and duration play an important role in both pesticide and nutrient retention. Adequate turfgrass density and organic carbon content will minimize and in some cases altogether prevent contaminant movement off site. Pesticide formulation and application timing are important, and should be evaluated as part of any pest management system. Across the board, none of the pest management systems produced consistent significantly lower impacts on water quality.

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