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Matrix based fertilizers reduce nitrogen and phosphorus leaching in three soils

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Abstract

We compared the efficacy of matrix based fertilizers (MBFs) formulated to reduce NO_3^-, NH_4^+, and total phosphorus (TP) leaching, with Osmocoate® 14-14-14, a conventional commercial slow release fertilizer (SRF) and an unamended control in three different soil textures in a greenhouse column study. The MBFs covered a range of inorganic N and P in compounds that are relatively loosely bound (MBF 1) to more moderately bound (MBF 2) and more tightly bound compounds (MBF 3) mixed with $Al(SO_4)_3H_2O$ and/or $Fe_2(SO_4)_3$ and with high ionic exchange compounds starch, chitosan and lignin. When N and P are released, the chemicals containing these nutrients in the MBF bind N and P to a $Al(SO_4)_3H_2O$ and/or $Fe_2(SO_4)_3$ starch–chitosan–lignin matrix. One milligram (8000 spores) of *Glomus intradices* was added to all formulations to enhance nutrient uptake. In all three soil textures the SRF leachate contained a higher amount of NH_4^+, NO_3^- and TP than leachate from all other fertilizers. In all three soils there were no consistent differences in the amount of NH_4^+, NO_3^- and TP in the MBF leachates compared to the control leachate. Plants growing in soils receiving SRF had greater shoot, root and total biomass than all MBFs regardless of $Al(SO_4)_3H_2O$ or $Fe_2(SO_4)_3$ additions. Arbuscular mycorrhizal infection in plant roots did not consistently differ among plants growing in soil receiving SRF, MBFs and control treatments. Although the MBFs resulted in less plant growth in this experiment they may be applied to soils growing plants in areas that are at high risk for nutrient leaching to surface waters.

Keywords: Starch; Chitosan; Lignin; Mycorrhizae; Aluminum sulfate; Iron sulfate

1. Introduction

Nitrogen (N) and phosphorus (P) are the two soil nutrients that most often limit plant growth. When N and P fertilizers are added to the soil overall N and P use efficiency is low because only the soluble fraction of these nutrients can be taken up by plants (Vassilev and Vassileva, 2003). Land managers and home owners commonly apply soluble forms of N and P as inorganic fertilizers in quantities greater than plants can assimilate, leading to leaching and often surface and ground water contamination (Vitousek et al., 1997; David and Gentry, 2000; Edwards et al., 2000; Sharpley et al., 2000).

Transport of P from agricultural soils to surface waters has been linked to eutrophication in fresh water and estuaries (Bush and Austin, 2001; Broesch et al., 2001; Daniel et al., 1998). Nitrogen and P accumulation in fresh or brackish water can overstimulate the growth of algae creating conditions that interfere with the health and diversity of indigenous plant and animal populations (Tveite, 1994; Pohle et al., 1991). Nonpoint N sources were responsible for more than 90% of N inputs to more than half of the 86 rivers studied in United States. Nonpoint P sources contributed over 90% of the P in a third of these rivers. Along the coastline of the North Atlantic Ocean nonpoint sources of N are some 9-fold greater than inputs from wastewater treatment plants (Bricker et al., 1999). Eutrophication is also widespread and rapidly expanding in most temperate lake, stream and coastal ecosystems. The incidence of harmful algal blooms has dramatically increased in recent years (Bricker et al.,

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1999). This increase is linked to eutrophication and other factors, such as changes in food webs that may increase decomposition and nutrient recycling or reduce populations of algae-grazing fish.

Fertilizer regimens could greatly benefit from more effective time release technologies that can better protect surface and ground water. We developed matrix based fertilizers (MBFs) that may reduce NH_4, NO_3 and total P (TP) leaching. The MBFs cover a range of inorganic N and P in compounds that are relatively loosely bound (MBF 1) to more moderately bound (MBF 2) and more tightly bound compounds (MBF 3) mixed with $Al(SO_4)_3H_2O$ and/or $Fe_2(SO_4)_3$ and with the high ionic exchange compounds starch, chitosan and lignin. We added *Glomus interadicies*, a species of arbuscular mycorrhizal fungal spores that will form mycorrhizae in high nutrient environments, in the MBF formulations to increase plant nutrient uptake. Our objective was to determine if MBFs combined with arbuscular mycorrhizae would reduce N and P leaching compared to a slow release fertilizer (SRF) in sand, sandy loam and loam textured soils in a greenhouse column study.

2. Materials and methods

2.1. Fertilizer treatments

The MBF formulations in our study cover a range of common inorganic nutrient compounds combined with $Al(SO_4)_3H_2O$ and/or $Fe_2(SO_4)_3$. Starch, chitosan and lignin were chosen because of their high concentration of ionic exchange sites and their decomposition characteristics. Nutrients bound to the $Al(SO_4)_3H_2O$ and/or $Fe_2(SO_4)_3$ starch–chitosan–lignin matrix become increasingly available to plants as the organic components in the matrix degrade. The organic components in the matrix should degrade starch > chitosan > lignin in the order of more to less rapid. The matrix based formulations can be made to bind inorganic nutrients relatively loosely (MBF 1) to more tightly (MBF 3) by increasing the concentration of $Al(SO_4)_3H_2O$ and/or $Fe_2(SO_4)_3$ and by varying the amounts of starch, chitosan and lignin in the matrix. When the matrix is applied to soil the soil microorganisms will degrade the starch in the matrix comparatively rapidly while chitosan will degrade less rapidly. Lignin is expected degrade the slowest and should retain most of its ionic exchange sites for a longer time in most soil environments.

The MBF formulations are comprised of inorganic chemicals combined with starch, chitosan and lignin (Sigma, St. Louis, MO). Treatment 1 was a control; no fertilizer was applied to the columns (Table 1). Treatment 2 was 5.0 g of the Osmocote® (14-14-14) SRF which was equal to 345 μg N and 344 μg P per column and 167.7 kg N ha^{-1} and 166.9 kg N ha^{-1} (Table 1). Osmocote® (14-14-14) has a 3–4 month nutrient release pattern at 70 °C. Treatment 3 was MBF 1 which received 313.0 μg N and 164.0 μg P per column and was equal to 152 kg N ha^{-1} and 80 kg P ha^{-1}. Treatment 4 was MBF 2 which received 249 μg N and 181 μg P per column and was equal to 121 kg N ha^{-1} and 88 kg P ha^{-1}. Treatment 5 was MBF 3 which received 60 μg N and 294 μg P per column and was equal to 29 kg N ha^{-1} and 143 kg P ha^{-1}. We added treatments 6–8 to determine the effect of $Al(SO_4)_3H_2O$ and $Fe_2(SO_4)_3$ on N and P leaching in the columns. Treatment 6 was MBF 3 + Al − Fe which MBF 3 was placed over 0.488 g $Al(SO_4)_3H_2O$ without $Fe_2(SO_4)_3$. MBF 3 + Al − Fe received 60.0 μg N and 294.0 μg P per column and was equal to 29 kg N ha^{-1} and 143 kg P ha^{-1}. Treatment 7 was MBF 3 − Al + Fe placed over 1.600 g $Fe_2(SO_4)_3$ without $Al(SO_4)_3H_2O$. MBF 3 − Al + Fe

Table 1
Chemical compounds used to comprise three different matrix based fertilizers in mg N and P in each column[a]

Treatment Compound	1 CONT	2 SRF	3 MBF 1	4 MBF 2	5 MBF 3	6 MBF 3 +Al − Fe	7 MBF 3 −Al + Fe	8 MBF 3 −Al + Fe
NH_4NO_3	0.000	0.210	0.000	0.000	0.000	0.000	0.000	0.000
P_2O_5	0.000	0.200	0.000	0.000	0.000	0.000	0.000	0.000
K_2O	0.000	0.180	0.180	0.180	0.180	0.180	0.180	0.180
$Ca(NO_3)_24H_2O$	0.000	0.000	0.472	0.472	0.236	0.236	0.236	0.236
$Al(NO_3)_39H_2O$	0.000	0.000	0.750	0.750	0.000	0.000	0.000	0.000
$NH_4(H_2PO_4)$	0.000	0.000	0.230	0.230	0.115	0.115	0.115	0.115
$Ca(H_2PO_4)_2$	0.000	0.000	0.468	0.468	0.234	0.234	0.234	0.234
$Fe(P_2O_7)$	0.000	0.000	0.334	0.334	1.490	1.490	1.490	1.490
$Al(PO_4)_3$	0.000	0.000	0.360	0.360	0.000	0.000	0.000	0.000
$Al(SO_4)_3\ H_2O$	0.000	0.000	0.488	0.366	0.000	0.488	0.000	0.000
$Fe_2(SO_4)_3$	0.000	0.000	0.400	0.800	1.600	0.000	1.600	0.000
Starch	0.000	0.000	1.000	1.000	1.000	1.000	1.000	1.000
Chitosan	0.000	0.000	1.000	1.000	1.000	1.000	1.000	1.000
Lignin	0.000	0.000	1.000	1.000	1.000	1.000	1.000	1.000

[a](mg compound in each column) MBF 1 is matrix based fertilizer formulation 1 = 152 kg N ha^{-1} and 80 kg P ha^{-1}; MBF 2 is matrix based fertilizer formulation 2 = 121 kg N ha^{-1} and 88 kg P ha^{-1}; MBF 3 is matrix based fertilizer formulation 3 = 29 kg N ha^{-1} and 143 kg P ha^{-1}. SRF = slow release fertilizer 5.0 g of Osmocote® (14-14-14) which includes NH_4NO_3, P_2O_5 and K_2O.