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Use of dolomite phosphate rock (DPR) fertilizers to reduce phosphorus leaching from sandy soil

G.C. Chen[a], Z.L. He[a,b,*], P.J. Stoffella[b], X.E. Yang[a], S. Yu[b], D. Calvert[b]

[a] *Department of Natural Resource Science, College of Environmental and Resource Sciences, Huajiachi Campus, Zhejiang University, Hangzhou 310029, China*
[b] *IFAS, Indian River Research and Education Center, University of Florida, 2199 South Rock Road, Fort Pierce, FL 34945, USA*

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Fertilizers developed from dolomite phosphate rock (DPR) reduce phosphorus leaching from sandy soil

Abstract

There is increasing concern over P leaching from sandy soils applied with water-soluble P fertilizers. Laboratory column leaching experiments were conducted to evaluate P leaching from a typical acidic sandy soil in Florida amended with DPR fertilizers developed from dolomite phosphate rock (DPR) and N-Viro soil. Ten leaching events were carried out at an interval of 7 days, with a total leaching volume of 1183 mm equivalent to the mean annual rainfall of this region during the period of 2001–2003. Leachates were collected and analyzed for total P and inorganic P. Phosphorus in the leachate was dominantly reactive, accounting for 67.7–99.9% of total P leached. Phosphorus leaching loss mainly occurred in the first three leaching events, accounting for 62.0–98.8% of the total P leached over the whole period. The percentage of P leached (in the total P added) from the soil amended with water-soluble P fertilizer was higher than those receiving the DPR fertilizers. The former was up to 96.6%, whereas the latter ranged from 0.3% to 3.8%. These results indicate that the use of N-Viro-based DPR fertilizers can reduce P leaching from sandy soils.

Keywords: Phosphorus leaching; DPR fertilizers; Water-soluble P fertilizer; Sandy soils

1. Introduction

Nutrients from applied fertilizers are positive assets if retained in the soil for uptake by plants, but become environmental pollutants if leached into watercourses or groundwater (Lewis and McGechan, 1998; McGechan and Wu, 1998; McGechan and Lewis, 2000). In the past, much attention was paid to nitrogen as a nutrient and pollutant, due to its high solubility and leachability into groundwater (Wu et al., 1998). However, more attention has been recently paid to the potential contamination of phosphorus to surface water (He et al., 2003; Zhang et al., 2002, 2003, 2004) because phosphorus is a limiting nutrient in most freshwaters (Sharpley and Beegle, 1999).

Application of P fertilizers can enhance agricultural production in soils with low P availability, especially in the tropical and subtropical region. However, P application in excess of plant requirements often results in contamination of aquatic systems. It has been reported that leaching of P contributes to eutrophication of fresh water bodies due to the availability of

* Corresponding author. Institute of Food and Agricultural Sciences, Indian River Research and Education Center, University of Florida, 2199 South Rock Road, Fort Pierce, FL 34945-3138, USA. Tel.: +1 772 468 3922x109; fax: +1 772 468 5668.
E-mail address: zhe@mail.ifas.ufl.edu (Z.L. He).

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soluble P to algae (Sonzogni et al., 1982; Izuno et al., 1991; Sharpley et al., 1994; Grobbelaar and House, 1995; Correll, 1998; Daniel et al., 1998; Parry, 1998; Sims et al., 1998). There has been an increasing interest in developing slow release P fertilizer to reduce P leaching losses from agricultural soils.

Water-soluble P fertilizers applied to sandy soils, which are widespread in Florida, are readily subjected to leaching, especially during the rainy season. Phosphorus leakage from agricultural soils has been suspected to be one of the major nonpoint sources for pollution of surface waters (Calvert, 1975; Calvert et al., 1981). Therefore, there is an urgent need for new types of P fertilizers that are agronomically effective and environmentally friendly. Phosphate rock (PR) has been directly applied to P-deficient acidic soils because it is nearly as effective as water-soluble P fertilizer but more cost-effective for correcting P deficiencies (Rajan et al., 1991; Wright et al., 1991; Chien and Menon, 1995). Phosphorus fertilizers developed from phosphate rock may also be superior to water-soluble P fertilizer for acidic sandy soils due to their slow release characteristics of P in terms of pollution of surface water.

Large amounts of dolomite phosphate rock (DPR) materials are produced as by-products during processing of PR to phosphoric acid in Florida. They contain substantial amounts of P, Ca, and Mg, and can be used for developing slow-release P fertilizers. Organic materials that may be used with the DPR material to produce slow release P fertilizers are wastewater residuals, i.e. biosolids, which are generated during the treatment of domestic sewage and contain high organic matter content and moderate amounts of nutrients needed by plants (USEPA, 1994). Greenhouse studies demonstrated that application of the DPR fertilizers made from the DPR materials and N-Viro soil consisting of biosolids and fly ash (50:50) significantly improved the growth of millet (*Setaria italica*), used as an indicator crop (He et al., 2002). DPR fertilizers also have other desired properties such as provision of Ca, Mg, and other nutrients. DPR fertilizers were observed to enhance growth of citrus and vegetable crops (He et al., 2004). However, environmental impacts of the DPR fertilizers need to be evaluated for field application, especially P leaching from sandy soils, which is a public concern in Florida.

The major objective of this study was to evaluate P leaching from sandy soil amended with DPR fertilizers, as compared with water-soluble P fertilizer. This information is needed to develop best management practices for citrus and vegetable crop production.

2. Materials and methods

2.1. Soil and N-Viro-based DPR fertilizers

A typical acidic sandy soil (Wabasso, sand 96.1%, silt 2.3%, and clay 1.6%) classified as hyperthermic Alfic Haplaquods, was collected at the 0–30 cm depths in Fort Pierce, Florida. Wabasso sand is a representative agricultural soil of commercial citrus and vegetable production systems in the Indian River area. Selected properties of the soil were 5.0 g kg^{-1} organic C, 0.23 g kg^{-1} total N, pH 4.1 (1:1 H_2O), pH 3.2 (1:1 KCl), 5.1 mg NaOH extractable P kg^{-1} soil, 0.6 mg Olsen-P kg^{-1} soil.

The DPR source selected for this study was from an IMC facility in Central Florida because of its relatively higher concentrations and availability of P and other nutrients such as Ca and Mg than other DPR sources. The N-Viro soil was provided by the Florida N-Viro, L.P. Company. It was made of biosolids and fly ash (1:1) and has been increasingly used in citrus groves, gardens, and vegetable fields in Florida and other states in the USA. The DPR was ground to <100 mesh and then mixed with N-Viro soil at the proportions of 0, 10, 20, 30, 40, 50, and 100% DPR. The DPR fertilizers were incubated at room temperature for 10 days prior to use. Some chemical properties and nutritional values of these DPR fertilizers are presented in Table 1.

Total C and N in the DPR fertilizers were determined by dry combustion using a CN analyzer (Vario Max CN, Macro Elemental Analyzer System GmbH, Hanau, Germany). The pH was measured in water at the solid/water ratio of 1:2 (w/w) using a pH/ion/conductivity meter (Accumet Model 50, Fisher Scientific Inc., Atlanta, GA). Electrical conductivity (EC) was measured in solution at a solid:water ratio of 1:2 using a pH/ion/conductivity meter (Accumet Model 50, Fisher Scientific). Available P was extracted using either 0.5 M

Table 1
Relevant properties of tested DPR fertilizers

DPR fertilizers with DPR%	pH (H_2O)	Total C (g kg^{-1})	Total N (g kg^{-1})	Total P (g kg^{-1})	Total Mg (g kg^{-1})	$CaCO_3$ (%)	Olsen-P (mg kg^{-1})	Mehlich-1P (g kg^{-1})
0	11.7	88.2	7.24	4.93	1.96	25.3	326	0.21
10	11.5	79.4	6.52	15.7	2.56	29.7	546	1.38
20	11	70.6	5.79	26.4	3.16	34.1	608	3.60
30	10.7	61.8	5.07	37.2	3.77	38.6	583	4.64
40	10.5	52.9	4.34	47.9	4.37	43.0	528	5.21
50	10.4	44.1	3.62	58.7	4.97	47.4	527	6.31
100	7.2	0.00	0.00	112.4	7.98	69.5	307	21.20

$NaHCO_3$ or Mehlich I reagent and P concentration in the extract was determined by the molybdenum-blue method (Olsen and Sommers, 1982). Total concentrations of P, Ca, and Mg in the DPR fertilizers were determined using an inductively coupled plasma atomic emission spectrometer (ICPAES, Ultima, J.Y. Horiba Inc., Edison, NJ, USA) following digestion with aqua regia and hydrofluoric acid (Hossner, 1996).

2.2. Column leaching experiment

Column leaching study was conducted using 27 plastic columns (6.6 cm inner diameter and 30.5 cm long) with leaching solution delivered by a peristaltic pump (Pump-Pro MPL, Watson-Marlow Inc., Wilmington MA). Each column was fitted with a fine netting at its bottom for leachate to pass through and to prevent soil loss.

Soil (1 kg oven-dried basis) was amended with different DPR fertilizers, pure DPR or N-Viro soil, or water-soluble P fertilizer, and then packed into the column. The treatments included: (1) control without any fertilizer, (2) the DPR fertilizers with proportion of DPR at 0, 10, 20, 30, 40, 50, and 100%, respectively, and (3) water-soluble P fertilizer with P from NaH_2PO_4. The DPR fertilizers were added to soil at 1% (w/w) and water-soluble P fertilizer was added with an amount of P equivalent to available P in the 25% DPR fertilizer. Each treatment was replicated three times. Soil columns were leached with deionized water. Leaching was carried out once per week for ten times. For each leaching, 118.3 mm of deionized water was used with the total leaching volume equivalent to the average annual rainfall (1183 mm) in the last three years (2001–2003). Leachate samples from each leaching event were collected and filtered through a Whatman 42 filter paper prior to analysis for reactive P and total P. Reactive P was determined using the molybdenum-blue colorimetry (Kuo, 1996) and the leachate was digested with acidified ammonium persulfate for total P analysis (Greenberg, 1992).

3. Results and discussion

3.1. Characteristics of the DPR fertilizers

Incorporation of DPR materials up to 50% did not affect good aggregation structure of the N-Viro products. What is more important is that addition of DPR above 20% significantly reduced odors of the N-Viro products. The nutrient composition and relevant properties of the newly developed DPR fertilizers are presented in Table 1. The N-Viro by itself had a high pH (11.7). Incorporation of the DPR materials decreased pH from 11.7 to 10.4, which is more favorable to crop growth. Addition of the DPR materials also significantly increased total and available contents of P and Mg and $CaCO_3$ equivalent, and thus increased liming capacity and nutrient supplying ability of the products, which makes the products more effective in eliminating soil acidity and increasing P and Mg availability. There were some positive interactions between the N-Viro soil and the DPR materials, as evidenced by the increased available P determined by Olsen method (Table 1). This effect is probably related to an enhanced dissolution of P from the DPR materials by organic matter from the N-Viro soil.

3.2. Environmental impact of P leaching in sandy soil

Sandy soils, commonly characterized by their low content of P-retaining soil constituents (clay, organic matter, and oxides of Fe and Al), are readily subjected to P leaching loss, especially when applied with water-soluble P fertilizers (Neller, 1946; Fox and Kamprath, 1971; Summers et al., 2000; Elliott et al., 2002). In our study, a typical sandy soil of Florida amended with water-soluble P fertilizer resulted in 96.6% of total added P leached after ten leaching events (Table 3). Moreover, 98.8% of leached P occurred in the first three leaching events. This result indicates that P leaching in sandy soils is extremely severe and may have a great impact on the environment.

Phosphorus leached from soils consists of reactive P and non-reactive P. Reactive P readily causes eutrophication of aquatic system due to its availability to algae. In our study, reactive P accounted for 67.7–99.9% of the total leachate P for each leaching event (Table 2), indicating that leached P was dominantly reactive. These results were consistent with those reported by Elliott et al. (2002) from two acidic sandy soils amended with eight biosolids. The dominant reactive P in the leachate is probably related to very low content of organic matter in the soil used in our study, for the DPR fertilizers applied to the soil only accounted for a very small proportion of the soil although they contain relatively high organic matter, with the exception of 100% DPR treatment that contained no organic matter. Higher percentages of reactive P in leachate P imply that it is especially important to control P leaching loss in the sandy soils.

3.3. Comparison of P leaching from the soil amended with the DPR fertilizers and water-soluble P fertilizer

The concentrations of leachate P from the first leaching event were significantly higher than those from any subsequent leaching event for all the treatments. The greatest P loss occurred in the first leaching event and accounted for 30.6–89.42% of total P leached over

Table 2
Percentages of reactive P in total P leached for each leaching event during the whole study period

Treatment	Leaching event (%)									
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
100% DPR + 0% N-Viro	98.2	83.9	87.5	96.6	95.7	97.7	89.5	89.8	78.4	82.7
50% DPR + 50% N-Viro	94.4	81.1	87.2	94.3	87.7	88.1	80.6	73.2	70.5	73.7
40% DPR + 60% N-Viro	93.8	80.0	83.5	92.9	84.9	87.6	82.1	78.2	77.5	81.4
30% DPR + 70% N-Viro	90.1	81.8	83.3	95.7	85.2	87.0	81.3	77.1	77.0	79.5
20% DPR + 80% N-Viro	89.3	84.0	82.3	90.6	87.3	88.5	83.8	77.6	76.3	81.9
10% DPR + 90% N-Viro	90.0	84.0	85.3	91.2	86.7	90.0	79.4	74.6	73.5	75.7
0% DPR + 100% N-Viro	88.0	82.0	83.8	88.2	82.3	84.6	78.2	78.0	77.2	76.2
NaH_2PO_4	99.9	91.1	90.0	97.4	80.7	83.7	73.9	71.6	67.7	79.9
Control	91.4	81.0	78.8	83.6	78.3	81.9	71.2	80.2	68.1	80.8

the whole study period (Fig. 1). Leachate P concentration decreased with increasing leaching events and reached a relatively stable level after four leaching events (Fig. 1). (The concentrations of leachate P for the soil amended with water-soluble P were so substantially higher than those for other treatments in the first three leaching events that we had to present them separately (Fig. 1a,b) in order to show the differences in leachate P among the different DPR fertilizer treatments. There is a similar reason for the presentation of Fig. 2a,b.).

The concentrations of P leached from the soil amended with water-soluble P fertilizer were significantly higher than those amended with the DPR fertilizers in the first two leaching events (ranging from 118.7 to 11.5 mg/L for water-soluble P fertilizer and from 4.0 to 0.5

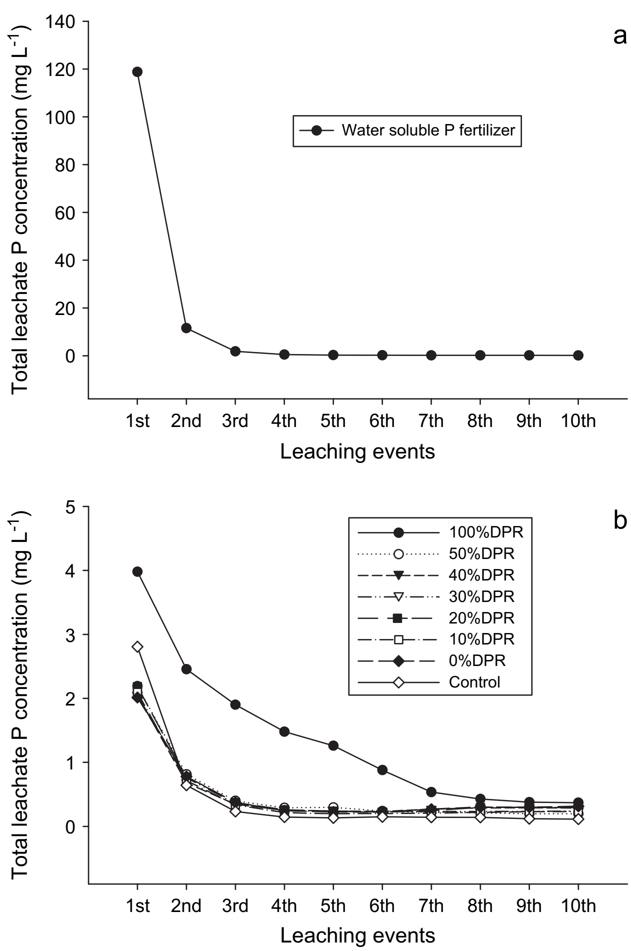

Fig. 1. Dynamic change of total P concentration in leachate from sandy soil amended with water-soluble P fertilizer or DPR fertilizers.

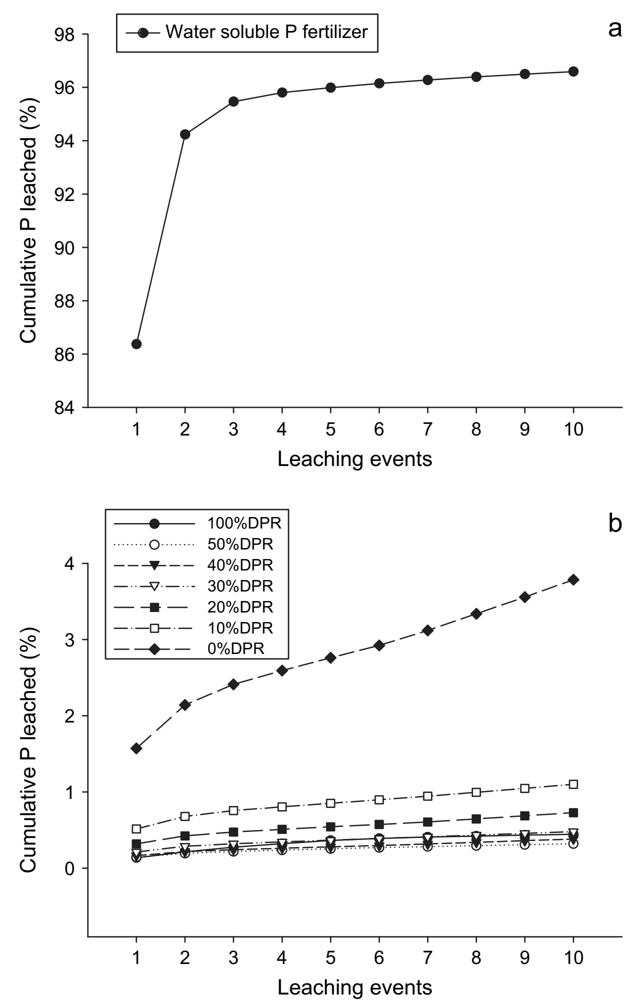

Fig. 2. Cumulative P leached (percentage of P added) from sandy soil amended with water-soluble P fertilizer or DPR fertilizers.

mg/L for different DPR fertilizers and control). Moreover, P concentrations in the leachate from the water-soluble fertilizer treatment were still higher than those from other treatments except for the 100% DPR treatment until the fourth leaching event, whereas those DPR treatments already resulted in leachate P concentrations close to the surface water standard of 0.1 mg/L established by USEPA (1987). These results indicate that DPR fertilizers were more environmentally friendly than the water-soluble P fertilizer as they resulted in much less P leaching from the sandy soil. In the fifth leaching event, leachate P from the treatment of water-soluble P fertilizer was lower than those from the treatments of 50% DPR and 100% DPR fertilizers, but still higher than those from other treatments. After six leaching events, leachate P from the soil amended with water-soluble P fertilizer was lower than those from all the DPR treatments but was close to that from the control (Figs. 1 and 2) because P amended to soil in water-soluble P fertilizer was quickly leached out, whereas the soils amended with different DPR fertilizers or N-Viro soil retained most applied P that is slowly released and not subjected to intensive leaching.

Among the DPR fertilizer treatments, 100% DPR treatment caused significantly higher leachate P concentration due to a larger amount of total P added to the soil. Leachate P concentration from this treatment remained relatively high up to the tenth leaching event and was approximately 1.2–1.9 times higher than those from other DPR fertilizer treatments. Leachate P concentration among the treatments of 0, 10, 20, 30, 40 and 50% DPR was not significantly different. Lower P concentrations were caused by the treatments containing N-Viro soil than by the control in the first leaching event, suggesting that N-Viro Soil has a high P-retention capacity and can hold more P in the soil against leaching.

When cumulative P leached (percentage in total P added) was presented against leaching events, it was clear that most P leaching loss occurred in the first three leaching events, accounting for 62.0–98.8% of the total P leached during the whole leaching period, with 30.6–89.4% from the first leaching event (Fig. 2). Over the whole leaching period, the treatment with water-soluble P fertilizer resulted in the most P loss (96.6% of total P added), of which 98.8% occurred in the first three leaching events (Fig. 2a). In contrast, P losses from the treatments with the DPR fertilizer were much less, only 0.3–3.8%, of which 62.0–68.7% occurred in the first three leaching events (Table 3, Fig. 2b). Among the treatments of DPR fertilizers, the 0% DPR fertilizer treatment caused the greatest P loss (3.8%), followed by the 10% DPR fertilizer treatment (1.1%). Phosphorus losses from all the other treatments were less than 1% (0.73, 0.48, 0.45, 0.38, 0.32%, respectively, for the 20, 30, 100, 40 and 50% DPR fertilizer treatments). These results indicate that the combination of N-Viro soil with DPR was more effective than N-Viro soil alone in reducing P leaching loss. Elliott et al. (2002) found that leachate P from two acid soils amended with eight biosolids was mostly below 0.3% of applied P. In our study, slightly higher percentages of P added with N-Viro-based DPR fertilizers were leached. This could be mainly attributed to greater leaching volume and more leaching events in our study while P leaching was also related to some soil properties including clay content, organic matter, Al and Fe oxides, $CaCO_3$, and soil pH (Cogger and Duxbury, 1984; Turtola and Jaakkola, 1995; James et al., 1996; Lookman et al., 1996).

Table 3
Amounts of P leached from the soil amended with various P sources after ten leaching events

Treatment	Total P leached (mg)	P leached (% of total P added)	Reactive P leached (% of total P leached)
100% DPR + 0% N-Viro	5.01 ± 0.59	0.45 ± 0.05	95.3 ± 2.8
50% DPR + 50% N-Viro	1.87 ± 0.24	0.32 ± 0.04	87.7 ± 4.6
40% DPR + 60% N-Viro	1.83 ± 0.13	0.38 ± 0.03	87.4 ± 2.5
30% DPR + 70% N-Viro	1.78 ± 0.07	0.48 ± 0.02	86.1 ± 1.4
20% DPR + 80% N-Viro	1.92 ± 0.15	0.73 ± 0.06	85.5 ± 2.2
10% DPR + 90% N-Viro	1.72 ± 0.09	1.10 ± 0.06	85.3 ± 4.0
0% DPR + 100% N-Viro	1.87 ± 0.17	3.79 ± 0.35	84.5 ± 5.9
NaH_2PO_4	51.13 ± 4.12	96.59 ± 7.78	92.6 ± 3.2
Control	1.74 ± 0.15	NA	92.8 ± 13.9

NA, not applicable.

4. Conclusions

There is a substantial impact of P leaching in sandy soils on the environment, especially on aquatic system because P leached from sandy soils with low organic matter was dominantly in reactive form (67.7–99.9%), which is readily available to algae. It is critical to control P leaching from the sandy soils where fresh water systems are sensitive to P input. The N-Viro-based DPR fertilizers seem superior to water-soluble P fertilizer in reducing P leaching from sandy soil due to their slow release nature. On average, < 1% of the total applied P was leached from the soils amended with the DPR fertilizers, whereas 96.6% was leached from the water-soluble fertilizer.

Based on the results from this study and our previous agronomic evaluation study (the results will be presented in another paper), use of the DPR fertilizers appears to be better than water-soluble P fertilizer for the acidic sandy soils because they can provide adequate P for crop growth with minimal loss of P by leaching.

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