ORGANIC WASTE NITROGEN AND PHOSPHORUS DYNAMICS UNDER DRYLAND AGROECOSYSTEMS

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ABSTRACT

Organic waste beneficial-use programs effectively recycle plant nutrients when applied at agronomic rates. Plant-nutrient availability, transport, and fate questions have arisen when organic wastes such as biosolids have been applied to dryland agroecosystems. What is the N-fertilizer equivalency of biosolids? What is the N mineralization rate of biosolids over periods of excess moisture or drought, and over long periods of time? Would biosolids, applied at an agronomic N rate for dryland winter wheat (*Triticum aestivum* L.), oversupply P? If over-application occurred, what would the repercussions be in terms of excess soil P? Our objectives were to determine: biosolids N fertilizer equivalency; biosolids N mineralization during years of above and below average precipitation, and long-term N mineralization; which soil P phases dominate following years of biosolids application; and the potential increased environment risk of P when applying an agronomic N rate or excessive rate of biosolids. To address questions related to N dynamics, we utilized research results collected between 1993 and 2004 from a site in Eastern Colorado which received 0, 1, 2, 3, 4, and 5 dry tons biosolids A^{-1}. To address questions related to P dynamics, results collected between 1982 and 2003 from a second Eastern Colorado site which received 0, 3, 6, 12, and 18 dry tons biosolids A^{-1} were used. During years of above-average and below-average precipitation, first-year biosolids N mineralization rates were estimated at 25-32% and 21-27%, respectively; long-term first-year mineralization rate ranged between 27-33%. Based on wheat-grain N uptake, we found that an application rate of 1 dry ton biosolids A^{-1} supplied about 20 lbs N A^{-1}. Based on the Colorado P index risk assessment, biosolids applied at agronomic N rates would not force producers to alter application strategies. However, based on this risk assessment, biosolids over-application would force land application to be based on crop P requirements. Previous results showed a minimum of 3 cropping cycles were necessary to reduce soil P concentrations to levels considered less apt in causing environmental degradation. A future reduction in water availability may force some Idaho agricultural land to shift from irrigated to dryland conditions. And, coupled with the increased production of dairy waste, land applicators will need to find new means to protect natural resources under dryland conditions. Results from our studies can help improve nutrient use efficiency and minimize environmental risk associated with dryland organic waste land application.

INTRODUCTION

Between 2001 and 2005 the number of dairies in Idaho decreased by 15%; however, the number of dairy cows increased by nearly 24% (Holley and Church, 2006). Results imply that larger confined animal feeding operations (CAFOs) are in service. Concurrently, the demand for water in the Western US has increased due to a number of factors such as drought, industrial demand, and population growth. Thus, in the future Idaho producers will most likely be asked to provide high-yielding, high-quality crops to support the dairy industry while being faced with a reduction in available water. Many reduced-water use or dryland crops will be grown on soils in close proximity to CAFOs. These soils will most likely receive greater quantities of animal waste as compared to soils located at greater distances from the CAFO, forcing producers to follow strict nutrient management plans. Best management practices will be coupled with waste applications based on agronomic requirements of crops to be grown.

Organic waste beneficial-use programs have been shown to effectively recycle plant nutrients when applied at agronomic rates. The USEPA (1993) 40 CFR Part 503 regulations for beneficial use of biosolids (sewage sludge) promotes recycling of this material on some crop lands since it is an excellent source of several plant nutrients such as N and P. However, mismanagement of N and P can lead to environmental issues such as ground/surface water contamination and waterway eutrophication. Thus, nutrient availability, transport, and fate concerns have arisen when organic wastes such as biosolids have been applied to dryland agroecosystems. For continuous land application programs under dryland conditions an important environmental quality and protection question is: How much N will be supplied by biosolids? Short and long-term answers to this question are important because most states require biosolids, as with other organic wastes, to be applied at the agronomic rate for N. And, because biosolids organic N concentrations are much greater than inorganic N forms, one may ask the following questions: What is the apparent first-year N mineralization rate in dryland agroecosystems? What is the first-year N mineralization rate during years of increased precipitation as compared to that during years of drought?

In some situations, application of biosolids at an agronomic-rate must be based on P rather than N availability. For example, concerns about agricultural-P pollution of surface water prompted the state of Maryland to require P-based agronomic rates (Shober and Sims, 2003). Applying agronomic rates of biosolids, and many other organic materials, based on N equivalency leads to soil P accumulation since the P amounts applied exceed crop removal (Shober and Sims, 2003). Consequently, tracking labile P levels is crucial in any organic waste beneficial-use program. Because organic waste application based on N equivalency tends to oversupply P, one may ask the following questions: Is the excess soil P an environmental concern? If errors were made in agronomic rate calculations and over-application occurred, what would the repercussions be in terms of excess soil P?

The objectives of this research were to assess the 12-year or 20-year impact of repeated, increasing biosolids applications on the: 1) biosolids N equivalency; 2) N mineralization rate of biosolids applied to a dryland winter wheat fallow agroecosystem over 6 years of above average precipitation, 6 years of below average precipitation, and over the 12 year study period; 3) total recovery of biosolids applied P; 4) dominant inorganic soil P phases; and 5) potential of increased environment risk of P when applying an agronomic N rate or excessive rate of biosolids.

MATERIALS AND METHODS

Nitrogen Field Study

The N field study began in the summer of 1993 on plots approximately 20 miles east of Brighton, CO. From 1993 to 2004, anaerobically digested biosolids were collected prior to land application and analyzed for organic N, NH_4-N, and NO_3-N (Table 1). Every year biosolids were hand-applied to 6 ft by 56 ft plots at rates equal to 0, 1, 2, 3, 4, and 5 dry tons A^{-1}, hand raked to improve uniformity, and incorporated to a depth of ~ 8". Every year urea fertilizer (46-0-0) was hand applied to non-biosolids plots at rates of 0, 20, 40, 60, 80, and 100 lbs A^{-1}. These rates bracket those commonly used on dryland wheat in Colorado (typically 2-3 dry tons biosolids A^{-1}; 40 lbs N fertilizer A^{-1}). Four replications of all treatments were used in a randomized complete block arrangement. Grain samples were collected from all cropping years, and grain N concentration was determined by dividing protein content found with a Dickey John GAC III® near infra-red analyzer by 5.7. Grain N uptake (N_u) was determined by $N_u = N_c*Y*1000$, where N_c = grain N concentration and Y = grain yield. Linear regression analyses was then completed for the effects of biosolids and N fertilizer rates on N_u for each harvest and for the total grain yield and cumulative N_u for the first and second 6-year period, and over the 12 yrs of study. The first 6-year period (1993-1998) were years of above average precipitation; the second 6-year period (1999-2004) experienced drought conditions. We took the average intercept for each material's linear regression model and completed a second set of regression analyses where the intercept for the biosolids and the N fertilizer models were set to the average intercept of both. This approach allowed us to equate the N fertilizer to the biosolids regression equation. Nitrogen fertilizer equivalency (N_E) was then found by calculating the ratio of the slope of the biosolids curve to the slope of the N curve as: $N_E = B_{slope}/N_{slope.}$ Plant available N (N_p) from the USEPA (1983) calculation was next determined, assuming an application rate of 1 dry ton biosolids A^{-1} and a first-yr mineralization rate of 20%: $N_p = [N_{NO3} + K_v(N_{NH4}) + 0.20(N_o)]$ + residual, where N_{NO3} = biosolids NO_3-N content, K_v = NH_4-N volatilization factor (assumed to be a range of 0 for complete loss to 1.0 for complete recovery of NH_4-N), N_{NH4} = biosolids NH_4-N content, N_o = biosolids organic N content, and residual = residual N_o from previous two biosolids applications. Using N_E, $N_{p,}$ and assuming a 20% first-yr mineralization rate (USEPA, 1983), the effective N mineralization rates (M_r) for the first and second 6-year periods, and over the entire 12-year period was determined using $M_r = (N_E*0.20)/N_{p.}$

Phosphorus Field Study

The P field study began in the summer of 1982 on plots approximately 15 miles east of Brighton, CO. Every other year from 1982 to 2002, anaerobically digested biosolids were hand-applied to 12 ft by 56 ft plots at rates equal to 0, 3, 6, 12, and 18 dry tons A^{-1}, hand raked to improve uniformity, and incorporated to a depth of ~ 8". Biosolids were not applied in 1998 due to a potential land sale. Biosolids were collected every year prior to land application and analyzed for total P (Table 1). The 18 dry tons A^{-1} application rate was discontinued in 1992 because it was deemed excessive in terms of many soil parameters (N, P, micronutrients). In a previous study we utilized the 18 dry tons A^{-1} plots to determine the time necessary for P to be reduced to concentrations which would lower environmental risk (Barbarick and Ippolito, 2003). Four replications of all treatments were used in a randomized complete block arrangement. Yearly and cumulative masses of biosolids-borne P applied for each application rate were determined (i.e. P inputs). Yearly wheat grain samples were collected, digested with concentrated HNO_3, and analyzed for P. Yearly and cumulative masses of grain-P removed were determined based on P content and yield of grain. Phosphorus contained within wheat straw was assumed to be returned to the soil during conventional tillage practices. The potential soil P accumulation was estimated as the difference between the amount of biosolids P added and the amount of P removed in grain. Soil samples were collected from the 0-8 and 8-24" depths from each plot following the 2003 wheat harvest. Soils were air-dried, crushed to pass a 0.08" sieve, and total P determined using a 4 *M* HNO_3 digest. The actual increase in soil P (0- to 24-in depth) was calculated from the difference between the background (i.e. 1982) and 2003 4 *M* HNO_3 soil P concentrations. Dominant inorganic soil P mineral phases (soluble, Al-bound, Fe-bound, occluded, Ca-bound) were determined in the soil surface and subsurface. Finally, a P risk index assessment was used to determine P risk associated with agronomic or excessive biosolids application rates.

RESULTS AND DISCUSSION

Nitrogen Field Study

Twelve years of biosolids applications produced N equivalencies, based on winter wheat-grain N uptake, of about 20 lbs N A^{-1}. A dryland winter wheat crop typically requires about 40 lbs N A^{-1}; thus, approximately 2 dry tons biosolids A^{-1} would meet the crop N needs. Estimated biosolids first-year N mineralization rates over 6 years of above average precipitation were 25 to 32%, while over 6 years of below average precipitation were 21-27%. Over the 12 year study period, estimated first year N mineralization rates ranged from 27-33%. In Washington, Cogger et al. (1998) found that dryland winter wheat recovered 11to 44% of biosolids-borne N. Using 12-week laboratory incubations, Lerch et al. (1992) found a 55% mineralization for the L/E biosolids. He et al. (2000) reported 48% N mineralization from pelletized biosolids. Results from our research can aid land applicators in determining first-year N release from this organic waste under dryland conditions. Erring on the side of conservatism (i.e. greater first-year N mineralization), organic waste applicators could calculate and supply the crop N needs while protecting the environment against off-site N transport.

Phosphorus Field Study

Based on the difference between cumulative biosolids P added and cumulative grain P removed, predicted accumulated soil P in the 0, 3, 6, 12, and 18 tons biosolids A^{-1} treatments were -1, 18, 36, 76, and 36 lbs P, respectively (Table 2). The 1982 background soil P content (0-24-inch depth) was 60 lbs (Utschig et al, 1983). Increases in soil P within the 0-24-inch depth were evident for the control and all treatments in 2003, and actual and predicted increases for each treatment compared poorly. However, the control (0 tons A^{-1}) rate showed an increase of 11 lbs P over the site life, while the predicted P accumulation showed a decrease of 1 lb P. The control P increase could have been due to soil tillage redistribution (Yingming and Corey, 1993) since the research site is managed using conventional tillage practices. If actual increases for all biosolids rates were adjusted based on the difference between the control actual increase and the control predicted increase, 11 - (-1) or 12 lbs P, predicted and adjusted actual increases were more comparable (Table 2). Based on the adjustment, percent recovery in this study ranged from 92 to 128%. Essentially most of the added P can still be accounted for in the plots. We regressed cumulative mass of P applied versus cumulative biosolids applied, and showed that at agronomic rates about 0.13 lbs P A^{-1} should be redistributed per year due to conventional tillage.

Increasing biosolids rate did not affect soluble and Ca-bound P fractions in the 0-8-inch soil depth (data not shown). As compared to other soil fractions, the soluble fraction was relatively low because this fraction forms strong complexes with other soil mineral phases (i.e. Al-, Fe-, Ca-bound phases). No difference in the Ca-bound P phase was due to excess free Ca present in the system because this soil was derived from calcareous parent material. However, increasing biosolids rate increased P associated with the Al-bound, Fe-bound, and occluded phases. Maguire et al. (2000) utilized the same P fractionation technique and found that biosolids additions led to increases in both Al and Fe-bound P fractions when compared to untreated control soils. We observed the Fe-P fraction dominating all biosolids amended soil fractions, likely due to the addition of amorphous Fe-oxide phases since Fe is routinely added during wastewater treatment. Iron phases appeared to be transported downward, precipitating in the subsoil as occluded species. This P phase should not move deeper under dryland conditions.

Based on the Colorado P index risk assessment, the biosolids agronomic rate (2 dry tons A^{-1}) placed offsite P movement risk in the medium category. Accordingly, biosolids application could continue to be based on the crop N needs; best management practices should be considered to further lessen the potential offsite P movement. A tripling of the dryland wheat agronomic rate (6 tons A^{-1}) increased the offsite risk movement to a level considered very high, based solely on increased soil test P. Biosolids application would have to be based on crop P requirements, not N. This would limit the biosolids amount land-applied, and a supplemental N source would be needed to supply crop N requirements. Based on previous research (Barbarick and Ippolito, 2003), biosolids land application would need to cease for about 6 years (3 cropping cycles) to allow a reduction in soil test P levels comparable to agronomic rates. These results emphasize the need to strictly follow sound environmental practices when land-applying organic wastes.

Reductions in future water availability in Idaho will more than likely shift agricultural practices towards the use of reduced or dryland agroecosystems. And, with the increased Idaho dairy herd population, an understanding of organic waste utilization under reduced water conditions will be needed. Dryland production can be improved, input costs reduced, and environmental quality enhanced with scientifically sound knowledge of crop growth coupled with nutrient management and dynamics. Results from our research emphasize the need to strictly follow sound environmental practices when land-applying organic wastes.

Table 1. Organic N, NH_4-N, and NO_3-N in biosolids applied from 1993 to 2004 on the N field study plots. Biosolids-borne P applied from 1982 to 2003 on the P field study plots.

N Field Study Yr applied	Organic N	NH_4-N	NO_3-N	P Field Study Yr Applied	P
	---------------------- lbs ton^{-1}		--------------------		lbs ton^{-1}
1993	61.8	10	<0.2	1982	56
1994	53.4	11	<0.2	1984	22
1995	50.8	10	<0.2	1986	16
1996	24.8	17.2	<0.2	1988	31
1997	68.8	1.2	<0.2	1990	70
1998	22.4	8.6	<0.2	1992	74
1999	14	6.8	0.28	1994	33
2000	36	11.8	<0.2	1996	46
2001	42	8	<0.2	2000	72
2002	106	20.8	<0.2	2002	38
2003	38	5.2	0.22		
2004	60	7.2	<0.2		
1994	61.8	10	<0.2		

Table 2. The 1982 background soil P content, 2002-2003 harvest soil P content, actual increase in soil P content, predicted soil P content increase (based on background P, biosolids-applied P, and crop removal of P), adjusted actual soil P content (based on subtraction of control actual increase from predicted increase, or -12 lbs), and adjusted percent P recovery.

Biosolids rate	1982 background	2002-2003 harvest	Actual increase	Predicted increase	Adjusted actual increase	Adjusted percent recovery
tons A^{-1}	-------------------- lbs P in the 0-24-inch soil depth ---------------------					%
0	60	71	11	-1	-1	100
3	60	95	35	18	23	128
6	60	105	45	36	33	92
12	60	149	89	76	76	100
18[†]	60	109	49	36	37	103

[†] The 18 tons biosolids A^{-1} application rate was discontinued in 1992.

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