EFFECT OF BIOSOLIDS APPLICATION ON PLANT AVAILABLE NUTRIENTS

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Introduction

Biosolids are a by-product of municipal wastewater treatment process which is extensively treated to meet all applicable federal and state regulations so that they can it can be safely applied to land. Approximately, 7.9 million dry metric tons of biosolids are produced annually in the United States (U.S.) and over 55% of this amount is beneficially utilized through land application (NEBRA, 2007). Farmland application of biosolids is considered to be one of the most economical and environmentally sensible options to manage biosolids because:

- biosolids are an excellent source of organic matter and all essential plant nutrients
- the practice is environmentally benign when done in compliance with regulations
- nutrients from biosolids have lower leaching potential than the commercial fertilizers
- biosolids application improves crop yield and grain quality
- biosolids application improves soil tilth and long-term fertility

The focus of this presentation is to provide a summary of federal and state regulations governing land application of biosolids produced by the Metropolitan Water Reclamation District of Greater Chicago (MWRD) and dynamics of nitrogen and phosphorus availability when biosolids are used in production of row crops in Illinois.

Regulations Governing Land Application of Biosolids

Land application of biosolids in the U.S. is governed by the U.S. Environmental Protection Agency (USEPA) under Title 40 of the Code of Federal Regulations (CFR), Part 503, which was promulgated in 1993 (USEPA, 1993). The Part 503 rule was developed after conducting a comprehensive risk assessment with the goal of protecting human and environmental health from contaminants that might be present in biosolids. The methodology employed in risk assessment was approved by a Science Advisory Board. The risk assessment evaluated 25 potential pollutants including trace elements and legacy pollutants through 14 exposure pathways and regulated nine trace elements (arsenic, cadmium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc). The most limiting pathway for each of the nine regulated trace elements was used to establish pollutant concentration limits and lifetime loading rate standards for land application of biosolids. The Part 503 Rule established two pollutant concentration limits in biosolids: ceiling concentration limits for all biosolids that could be land applied, and lower pollutant concentration limits that could be land applied without lifetime trace element loading restrictions.

Trace elements, especially heavy metals such as cadmium (Cd), lead (Pb), and copper (Cu) were a concern when land application of biosolids began in the U. S. in the 1970s. Since then, source control programs that were implemented due to promulgation of Clean Water Act in 1972 have been very effective in decreasing inputs of heavy metals and other trace elements to wastewater treatment facilities across the country. Table 1 shows mean concentrations of nine regulated trace metals in biosolids produced in the U.S. and at the MWRD. The data shows that the concentrations of all trace elements in biosolids produced nowadays are much lower than the Part 503 EQ limits and are no longer a concern for land application of biosolids.

In addition to trace elements, the Part 503 rule includes requirements for controlling pathogens, and stabilization of biosolids to minimize odors and attraction of vectors (such as flies, mosquitoes, rodents, etc.). The pathogen and vector attraction reduction (VAR) standards are met either by direct measurements or by using various well-defined processes approved under the Part 503 rule. The VAR standards are achieved through one of 12 options defined in the Rule that either reduce the attractiveness of the biosolids to vectors (e. g., achieving >38% reduction in volatile solids during biosolids processing), or prevent vectors from coming in contact with biosolids (e.g., incorporation of biosolids immediately after land application). Biosolids are classified as Class A or B under the Part 503 Rule depending on the pathogen criteria. The Class A criteria define the highest quality biosolids, which have undetectable levels of pathogens, and can be land applied without restrictions. The Class B criteria define biosolids in which pathogens are significantly reduced but are still at detectable levels. In Class B biosolids, about 99% of the bacteria, 90% of the viruses, and a lower percentage of the more resistant parasites are killed. The Class A pathogen criteria can be met by one of six treatment methods called processes to further reduce pathogens (PFRP), and Class B pathogen criteria can be met by treatment methods called processes to significantly reduce pathogens (PSRP) described in the Part 503 Rule. Biosolids meeting lower pollutant concentration limits and the Class A pathogen status are termed exceptional quality (EQ). In most circumstances, EQ biosolids can be land applied with no restrictions.

In the state of Illinois, land application of biosolids is governed by the Illinois Environmental Protection Agency (IEPA) regulation, 35 Illinois Administrative Code 391 “Design Criteria for Sludge Application on Land”. These regulations impose more stringent and more site-specific management practices on the land application of biosolids than the Part 503 rule. The regulations also require that both biosolids generators and appliers obtain a separate IEPA permit.

Nutrient Replacement Value of Biosolids

Application rate of biosolids to farmland across the U.S. is conventionally based on agronomic nitrogen (N) requirement. However, biosolids contain several macro and micronutrients and reduce fertilizer requirement for many other essential plant nutrients when applied at the rates to meet crop N needs. Mean, minimum, and maximum concentrations of macronutrients and micronutrients in fresh centrifuge biosolids generated by MWRD and applied during 2009 are shown in Table 2. First year nutrient replacement value of biosolids when applied at typical agronomic application rate of 10 dry ton per acre to meet corn N requirement is shown in Table 3. Typical application of biosolids to meet N needs of corn eliminates the need for application of all nutrients except K, which should be supplemented depending on soil test.

Agronomic application rate of biosolids is based on crop N requirement and plant available N (PAN) content in biosolids. An example of PAN and corn N requirement calculations used to determine biosolids land application rate in Illinois is as follows:

PAN (lb/dry ton biosolids) = [0.2 x Organic N (mg N/kg) + 0.8 x Ammonia N (mg N/kg)] x 0.002

Organic N (mg N/kg) = Total Kjeldahl N (mg N/kg) - Ammonia N (mg N/kg)

Corn N requirement (lb/ac) = Grain yield (bu/ac) x 1.3 lb N/bu

Biosolids application rate (dry ton/ac) = Crop N requirement (lb/ac)/PAN (lb/dry ton biosolids)

This assumes that for anaerobically digested biosolids only 20% of organic N is mineralized during the first growing season and it decreases to 10%, 5%, and 2. 5% for the 2nd, 3rd, 4th, and 5th years, respectively, after biosolids application. The fraction of ammonia N retained after application of biosolids followed by immediate incorporation is 50% and 80% for sandy soils and for other soils, respectively. For surface applied biosolids without incorporation, the fraction of ammonia N retained is 25% and 50% for sandy soils and other soils, respectively. Residual organic N mineralization is accounted for calculating application rate for biosolids during each subsequent year. However, the fraction of biosolids organic N mineralized during the first growing season and the subsequent years could vary significantly depending on biosolids stabilization process, soil type, moisture content, and soil temperature. Freshly digested biosolids such as fresh centrifuge cake contain greater amount of mineralizable N than lagoon-aged or composted biosolids. Corn N requirement calculations are based on Illinois Agronomy Handbook recommendation.

Biosolids application at agronomic rate to meet crop N needs supply an excess of some nutrients (e.g., P) but not enough of others (e.g., K) because the ratio of nutrients in biosolids are different than the nutrients required by plants. Over application of nutrients may result in build-up in soil and potentially cause pollution of water bodies due to surface runoff, whereas under application of nutrients could result in economic loss due to lower crop yield. Therefore, land application of biosolids is carefully managed to maximize crop yield without any negative impact on the environment. Research shows that most of the P in biosolids is inorganic and is often associated with reactive aluminum (Al) and iron (Fe) making less water soluble and phytoavailable than fertilizer P reducing the potential for runoff losses of P in biosolids-amended soils (Maguire et al., 2000; He et al., 2010). Figure 1 compares effect of biosolids P with triple superphosphate fertilizer (TSP) on Bray 1 soil test P (soil test P) and water soluble P (WSP). Clearly, rate of P application from both sources resulted in linear increase in soil test P but the slope for biosolids was significantly lower (S = 0.60) than for TSP (S = 0.75). The effect of P rate on WSP was less than the effect on soil test P and varied among the P sources. Water-extractable P increased linearly and the slope was much greater for TSP (S = 0.69) than for biosolids P (S = 0.10 for aged and 0.05 for fresh cake, respectively). Our data show that the relative effectiveness of biosolids in increasing soil test P was about 80 percent relative to TSP, and the effectiveness in increasing WSP was 15% for aged and 10% for fresh cake biosolids. Furthermore, our research shows that phytoavailability of biosolids P was approximately 40 percent of TSP. In the United States Environmental Protection Agency (USEPA) guidelines on managing the land application of biosolids P, it is assumed that biosolids P is 50 percent as effective as fertilizer P (USEPA, 1995).

Soil Quality

In addition to providing savings of approximately $300/ac in input costs to the farmers, biosolids application also improves soil quality by supplying on average 4 – 5 dry ton/ac organic matter which improves physical, chemical, and biological properties of soil. Increased soil organic matter improves enzymatic activities and microbial function in soil. Overall, biosolids application improves nutrients cycling in soil and crop's ability to utilize soil nutrients. Biosolids application at the typical agronomic rate results in approximately 30 – 50 bu/ac higher corn yield in Illinois.

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Table 1. United States Environmental Agency limits for nine regulated trace elements in biosolids to be land applied and mean values for biosolids generated across the country and at MWRD.

Trace Element	Part 503 Limits		National	
	Allowable	EQ	Average[1]	MWRD
	----------	mg kg^{-1}	----------	
Arsenic	75	41	7	5
Cadmium	85	39	3	3
Copper	4,300	1,500	570	380
Mercury	57	17	1.3	1.0
Molybdenum	75	---	17	10
Nickel	420	420	53	40
Lead	840	300	80	100
Selenium	100	100	7	5
Zinc	7,500	2,800	1,015	725

[1]Based on USEPA's 2006 Targeted National Sewage Sludge Survey.
--- USEPA is re-examining these limits.
EQ = Exceptional quality biosolids.
MWRD = Metropolitan Water Reclamation District of Greater Chicago.

Table 2: Chemical composition[1] of fresh centrifuge cake biosolids generated by MWRD and applied to farmland during 2009.

Constituent	Unit	Mean	Minimum	Maximum
pH		8.0	6.0	8.4
Total Kjeldahl N	mg kg^{-1}	48,000	29,000	69,400
NH_3-N	"	11,500	3,325	19,300
NO_2+NO_3-N	"	140	35	695
Total P	"	21,435	15,850	25,225
Al	"	16,630	5,550	22,425
B	"	27	10	75
Ca	"	36,170	30,100	43,980
Co	"	<20	<20	<20
Cr	"	160	120	190
Fe	"	16,060	13,310	18,860
K	"	2,710	990	4,965
Mg	"	14,780	6,440	17,000
Mn	"	585	400	1,000
Na	"	1,140	800	1,975
V	"	20	20	25

Table 3. Fertilizer replacement value for fresh centrifuge cake biosolids.

	Nutrient Input[1]		Nutrient Cost	
Nutrient	Total, lb/ac	Available, % of total	$/lb[2]	$/ac
Nitrogen (N)	800	35	0.52	125
Phosphorus (P)	365	40	0.68	85
Potassium (K)	65	100	0.34	60
Calcium (Ca)	700	100	NA	NA
Sulfur (S)	20	40	NA	10
Copper (Cu)	7.6	---[3]	NA	NA
Zinc (Zn)	14.5	---	NA	10
Boron (B)	0.85	---	NA	10
Iron (Fe)	340	---	NA	NA
Magnesium (Mg)	350	---	NA	NA
Manganese (Mn)	8.8	---	NA	NA

[1]Based on biosolids application for corn @10 dry ton/ac.
[2]Based on 2012 prices in Illinois
[3]Enough to meet crop needs.
NA = Not known.

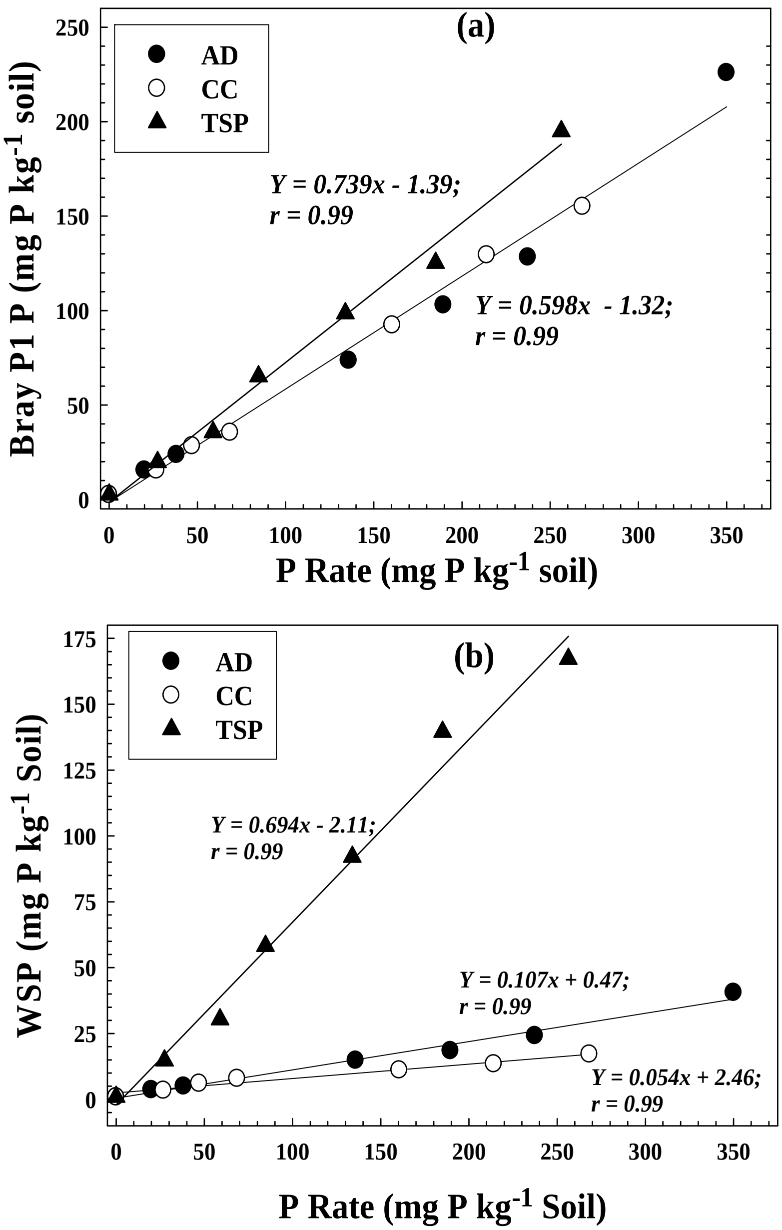

Fig. 1. Bray 1 P (a) and water soluble P (WSP) (b) in surface soil treated with varying rates of aged (AD) and fresh centrifuge cake biosolids (CC) and fertilizer (TSP) P before cropping in the greenhouse.

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