Nutrient Content, Value, and Management of Biosolids

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Nutrients are essential elements required for plant growth and function. These elements include carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), and zinc (Zn). Biosolids contain all essential plant macro- and micro-nutrients and can serve as a substitute for or reduce the use of commercial fertilizers. An advantage of using biosolids is their ability to slowly release N as soil bacteria decompose and release N from organic matter. Typical macronutrient concentration ranges in biosolids are listed below (Cogger et al. 2006).

- Nitrogen: 2.0 – 8.0%
- Phosphorus: 1.5 – 3.0%
- Potassium*: 0.10 – 0.60%
- Sulfur: 0.60 – 1.3%
- Calcium: 1.0 – 4.0%
- Magnesium: 0.40 – 0.80%

*Potassium often does not occur in high enough concentration to meet plant needs (according to soil testing recommendations) when biosolids are applied at agronomic N rates.

Biosolids applications are regulated by the United State Environmental Protection Agency (USEPA) Part 503 Rule to protect surface and ground water bodies from nutrient contamination (USEPA, 1995). Nitrogen is typically the nutrient that controls application rates through an agronomic rate approach (i.e., application of plant available biosolids-borne N to meet crop N need). Unfortunately, biosolids are “unbalanced” fertilizers that typically result in over-application of P when supplied to provide plant N need. Increasing concerns of P loss to surface waters has resulted in state level biosolids P applications regulations. Despite research demonstrating that the source of P has significant impact on the potential risk, most state P regulations assume that all sources of P have the same availability and mobility. Continuous application of biosolids can result in accumulation of P, but the fraction of mobile P in biosolids is lower than most other organic amendments (e.g., manure), making it less likely to be environmentally available (Ajiboye et al., 2004). Regulations should, therefore, be based on potential transport risk rather than total P in biosolids.

Nitrogen

Biosolids, as well as other organic amendments, can be a challenge when applied to meet a crop’s N need. Most (50-90%; Rigby et al., 2016) biosolids’ N is in organic form, which must be mineralized to inorganic plant available N (PAN) before it can be assimilated by crops. Microbes decompose organic matter, releasing into the soil inorganic ammonium (NH4) N not used by the microorganisms. Other microbes further transform NH4 into nitrate (NO3).

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Both of these forms of inorganic N are available for plant uptake. Estimating the mineralization rate of organic N into inorganic N is key in N management. Inadequate amount of inorganic N formation results in crop N insufficiency and yield reduction, while excessive inorganic N formation can lead to crop nutrient imbalance, increased disease prevalence, and risk of nitrate leaching into groundwater. Considerable research has been conducted to determine the rate of formation of PAN for various biosolids' products, in different environments, and under various climatic conditions (Cogger et al. 1999; Cogger et al., 2004; Barbarick and Ippolito, 2000; Gilmour et al., 2003; Muchovej and Rechcigl, 1998; Parker and Sommers, 1983; Sullivan et al., 1997).

Biosolids stabilization methods, soil type, and local climate affect both biosolids N mineralization rate and leaching risk of nitrate through a soil (Antille et al., 2013; Correa et al., 2006, 2012; Paula et al., 2011; Yoshida et al., 2015). The USEPA (1995) estimated first year mineralizable N coefficients of 30% for aerobically digested, 20% for anaerobically digested, and 10% for composted biosolids. The guidelines also suggested that, following the year of application, the amount of N mineralized decreases by 50% each year until 3% mineralizable N is reached. About a decade later, Gilmour et al. (2003) concluded that there was little difference in N mineralization rate among aerobically or anaerobically digested and lime-stabilized biosolids. Climate (i.e., temperature and moisture) appears to be more important than biosolids processing method on N mineralization rate (Gilmour et al., 2000). This work resulted in a recommended organic N mineralization rate for digested and lime-stabilized biosolids for N fertilization of summer annual crops of 35% for Virginia soils east of the Blue Ridge Mountains and 30% for Virginia soils west of the Blue Ridge Mountains. Rigby et al. (2016) proposed mean mineralizable N rates, as a proportion of the organic N content, of 47% for aerobic digestion, 40% for thermal drying, 34% for lime treated, 30% for mesophilic anaerobic digestion, and 7% for composting over a wide geographic distribution.

Biosolids may provide a more cost-effective approach to supplying crop N needs than commercial fertilizers. The slow-release of N is beneficial to long season crops as it becomes available as the crop needs it and may be less environmentally deleterious as excessive amounts of leachable soil inorganic N is generated slowly. Commercial fertilizers are mostly water-soluble and become immediately available and if not taken up by the crops, lost to leaching or volatilization. For example, Binder et al. (2002) reported that approximately 40, 20, 10, and 5% of the total biosolids-N were recovered by the crops in the 1st, 2nd, 3rd, and 4th year, respectively, after a single biosolids application. The relative yield increase was 33%, 21%, 14%, and 9% in the 1st, 2nd, 3rd, and 4th year, respectively, after application. However, short-season, fast-maturing, spring-planted crops may not have as much PAN available for their assimilation as needed if the biosolids-borne organic N does not mineralize as quickly as needed.

The potential for N mineralization and nitrogen loss via nitrate leaching, ammonia volatilization, and denitrification in biosolids-amended soils depends on climate, soil texture, soil pH, topography, cation exchange capacity (CEC), redox conditions, organic matter content, cropping systems, and time and methods of biosolids application (Nkoa, 2014; Rigby et al., 2016; Zinati et al., 2004). See Rigby et al. (2016) for an extensive review on the fate of N in biosolids-amended soil.

Phosphorus

Phosphorus is subject to different behavior under varying environmental conditions. Biosolids-borne P will occur in different soil fractions, each having different solubility, plant-availability, and mobility (Zinati et al., 2004). Biosolids typically have a low PAN:P ratio, resulting in the overapplication of P when applied at the crop's N needs (Cogger et al., 2006). Best management practices (BMPs) that limit the transport of soluble-P to water bodies is essential for biosolids-amended soil.

Biosolids P is largely present as inorganic phosphates of Fe, Al, and Ca. Labile (weakly bound, plant available) soil P fractions from application of P fertilizers and amendments are often smaller from biosolids than commercial fertilizers, manure, and yard waste (Ajiboye et al., 2004; He et al., 2000, Withers et al., 2001). Wastewater treatment processes also influence P solubility. The fraction of labile P is higher in biosolids produced via biological P removal than in digested or composted biosolids (O'Connor et al., 2004). Metal (i.e., Al, Fe) salt-treated biosolids have lower water-soluble P and lower concentrations of dissolved reactive P in runoff and leachate than soils receiving biosolids treated to biologically remove P and lime-stabilized biosolids (Elliot et al., 2002, 2005; Penn and Sims, 2002. Iron-associated P is less susceptible to loss than Al-associated P, which is less susceptible than Ca-associated P. However, Fe- and Al-bound P can shift to Ca-P and soluble P if treated with lime (Penn and Sims, 2002). Elliot et al. (2002) found that P leaching was small when biosolids treated with Fe and Al salts were applied in excess of crop P needs that.

Phosphorus loss from soil also depends on the degree of soil P saturation or the soil P storage capacity (Lu et al., 2012). Soil with increased P or that which has a low storage capacity (coarse-textured soils) will be more susceptible to P loss in runoff or leachate (Hooda, 2000; Nair and Harris, 2004; Nair et al., 2004; Pautler and Sims, 2000). Application of Fe- or Al-biosolids can increase the soil P storage capacity by providing additional sites for P adsorption or binding (Penn and Sims, 2002; Lu and O'Connor, 2001). To minimize P loss, best management practices (BMPs) such as cultivation against slopes, maintaining sufficient time between biosolids applications, consideration of climatic conditions before applying biosolids to the land, and systematic soil testing should be performed.

The Water Environment Federation fact sheet referenced below provides additional information on P and BMPs to reduce P losses from biosolids production, storage, and amended-soils.

Micronutrients

Biosolids contain all essential micronutrients for plants, most of which are rarely provided by conventional fertilizers (Logsdon, 1993; Lu et al., 2012; Warman and Termeer, 2005). Biosolids are excellent fertilizer sources for micronutrient-deficient soils, e.g., alkaline soils (Moral et al., 2002), dryland wheat (Barbarick and Ippolito, 2007), and coarse-textured (sandy) soil (Ozores-Hampton et al., 2011). Awad and Fawzy (2004) observed higher yields and concentrations of elements (N, P, K, Fe, Zn, Mn, Cu, Co, Cd, and Pb) in wheat where biosolids were used. Lombard et al. (2011) found that biosolids were effective sources of Fe for hybrid poplars and may be a sustainable alternative to costlier chelated Fe fertilizers.

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