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EVALUATION OF PERFORMANCE AND PLANT AVAILABLE NITROGEN IN COMPOSTED AND UNCOMPOSTED METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO BIOSOLIDS

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LIST OF ACRONYMS

Abbreviation/Acronym	Definition
C	carbon
District	Metropolitan Water Reclamation District of Greater Chicago
DM	dry matter
EC	electrical conductivity
Exp.	experiment
KCl	potassium chloride
N	nitrogen
NH_4-N	ammonium nitrogen
NO_3-N	nitrate nitrogen
PAN	plant available nitrogen
TKN	total Kjeldahl nitrogen

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DISCLAIMER

Mention of proprietary equipment and chemicals in this report does not constitute endorsement by the Metropolitan Water Reclamation District of Greater Chicago.

SUMMARY

Composting the Metropolitan Water Reclamation District of Greater Chicago's (District) biosolids with bulking agents (leaves, wood chips, landscaping waste) helps to stabilize biosolids to produce a value-added product with a low potential for residual odors. This greenhouse study was conducted to evaluate and demonstrate the agronomic value of the District's composted biosolids generated by co-composting biosolids with wood chips and landscape waste. Corn (*Zea mays*), ryegrass (*Lolium perenne*), and miscanthus (*Miscanthus giganteus*) were grown in 2013 (Experiment [Exp.] I) and 2014 (Exp. II) (three times each year) in a silty clay loam soil amended with the District's composted and uncomposted biosolids and at a rate of 400 mg total nitrogen (N) kg^{-1} soil (equivalent to 870 kg total N ha^{-1}). Four additional treatments that received only chemical fertilizers (ammonium nitrate) at 0, 35, 69, and 138 mg N/kg (equivalent to 0, 75, 150, and 300 kg N/ ha, respectively) were included in both Exp. I and Exp. II as a reference for assessing and characterizing the relative plant available N (PAN) of the biosolids products. Plant growth and dry matter (DM) yield in composted and uncomposted biosolids were similar for the three test plants. It was also observed that 100 percent composted biosolids could be used as a growing media without impacting plant growth or DM yield. In addition, the dry-matter yields of plants grown in 100 percent composted biosolids were greater than what was observed in a commercial compost and chemical fertilizer applied at an agronomic rate. Uptake of N in composted biosolids was similar for ryegrass and miscanthus. However, uptake of N by corn was lower from composted biosolids than from the uncomposted biosolids and commercial fertilizers, which could be due to relatively lower initial PAN in composted biosolids. The PAN in composted biosolids was <10 percent of the total N, and was 10 - 20 percent of total N in the uncomposted biosolids. The results of the study show that the District's composted biosolids are a valuable source of N to support the growth of turfgrass, bio-energy crops, and row crops. However, higher loading rates of composted biosolids will be required to supply the comparable amount of N supplied by air-dried and centrifuge cake biosolids typically used in the District's land application program.

INTRODUCTION

Composting biosolids with bulking agents, such as wood chips and landscaping wastes, increases the stability of the organic matter in biosolids, resulting in a product that is less odorous and has greater public acceptance for land application.

The N mineralization rate of soil amendments, including compost and biosolids, and the amount of N released from these amendments are largely controlled by properties such as the carbon (C):N ratio, the structure of organic C, and the form of N (Wilkinson et al. 1998; He et al., 2000; Eghball et al., 2002; Cabrera et al., 2005). The C:N ratio in typical composted biosolids is low compared to most other types of compost, and land application of composted biosolids is generally not expected to increase the soil C:N ratio above the critical (20:1) level expected to immobilize plant available N in the soil (Douglas et al 2003; Nishio and Oka, 2003; Flavel et al. 2005).

The lower C:N ratio of composted biosolids compared to uncomposted biosolids may result in differences between these products with respect to PAN and agronomic benefits. This information is required for advising users of composted biosolids to determine the application rates to optimize agronomic benefits. Thus, the main objective of this study was to evaluate the agronomic performance and characterize relative PAN in composted biosolids.

MATERIALS AND METHODS

Composted Biosolids

The composted biosolids used in this study were produced by co-composting lagoon-aged and un-aged biosolids with landscape wastes and wood chips. Aged (biosolids that had been lagoon-aged for ≥18 months) and cake (< 1 year lagooning) biosolids were each composted with bulking materials at a 1:1 (biosolids-to-bulking materials) ratio. Two types of dewatered biosolids, low solids lagoon-aged (aged biosolids) and centrifuge cake (un-aged biosolids), were each composted with woodchips at a 1:1 (weight-by-weight) ratio. The biosolids and bulking materials were mixed with a mechanical auger and placed on a paved bed for ten days followed by additional mixing to increase the solids content to 40 percent. The mixtures were then piled as windrows. During the first 15 days (composting period), the windrows were turned every three days. After the composting period, the windrows were allowed to "cure" for 3.5 months and were turned every three weeks during that period. Samples of the composted biosolids were collected at the end of the curing period for chemical analyses and odor evaluation. More details of the composting procedure are documented elsewhere (Monitoring and Research Report No. 13-38, 2013).

Experimental Set-Up

The study involved growing corn (*Zea mays*), ryegrass (*Lolium perenne*) and miscanthus (*Miscanthus giganteus*) for six months each in a silty clay loam soil amended with the composted and uncomposted biosolids mixes in a greenhouse. Selected properties of the composted and the uncomposted biosolids used in the study are summarized in Table 1.

The study commenced in 2013 (Exp. I) and repeated in 2014 (Exp. II) and consisted of four replicates of eight treatments in Exp. I and II arranged in randomized, complete block design. Four of the treatments included uncomposted centrifuge cake, lagoon-aged biosolids and the compost products of these biosolids, all applied at 400 mg total N kg^{-1}soil (equivalent to 870 kg total N ha^{-1}). The other four treatments were control, which received no compost or biosolids amendment but ammonium nitrate fertilizer at 0, 35, 69, and 138 mg N kg^{-1} (equivalent to 0, 75, 150, and 300 kg N ha^{-1}, respectively). The chemical fertilizer treatments were included in the study as a standard to compare the response of the composted and uncomposted biosolids.

The study was designed to evaluate composted and uncomposted biosolids applied at a total N rate that was four to five times the typical N rate for turf (~180 kg N/ha) and corn (~200 kg N ha^{-1}) in Illinois. This takes into account that less than 25 percent of the total N in the organic materials is plant available as established in the Illinois Administrative Code Title 35 Part 391 Rule "Design Criteria for Sludge Management."

In both experiments, composts, biosolids, and fertilizers needed for each treatment were weighed and blended with 3 kg topsoil collected from Matteson, Illinois. The biosolids were re-dried before mixing with the soil. The soil is drummer silt clay loam classified as fine, mixed, super-active, mesic typic endoaquolls soil. In Exp. II, the composted and uncomposted biosolids

TABLE 1: SELECTED PROPERTIES OF COMPOSTED AND UNCOMPOSTED BIOSOLIDS USED FOR THE STUDY

Biosolids/Compost	EC mS cm^{-1}	NH_3N mg kg^{-1}	Nitrate mg kg^{-1}	TKN mg kg^{-1}	C %	C:N
AB[1]	4.55	2,711	552	28,134	20.9	7.45
AB Compost[2]	4.14	1,102	411	24,855	22.1	8.87
CB[3]	3.31	1,445	327	26,499	20.2	7.64
CB Compost[2]	2.36	1,069	226	20,107	19.6	9.31

[1]Aged biosolids.
[2]All composts are generated from 1:1ratio of biosolids:landscape waste.
[3]Centrifuge cake biosolids.

were blended with soil and water added to field capacity, and the amended soils incubated for four months (January 17 – May 16) prior to planting. Chemical fertilizer treatments were not incubated, but treatments were applied at planting. All pots treated with chemical fertilizer also received Sul-Po-Mag to provide sufficient sulfur, potassium, and magnesium. The amended soils were placed in 8-inch depth pots, and water was added as needed to the soil (in the pots) to field capacity. Grab soil samples were taken at planting and the initial weight of the pots at field capacity was measured and water added (depending on the weight loss of the pots) to maintain the soil moisture near field capacity during the study. Drainage was collected in saucers placed underneath each pot and was poured back into the respective pots.

In Exp. I, three sets of 32 pots (eight treatments and four replicates) were prepared to grow ryegrass (*Lolium perenne)*, corn (*Zea mays*), and miscanthus (*Miscanthus giganteus*) for six months (June - November 2013). The three test plant species were selected to represent typical crops being fertilized under the District's biosolids land application programs (turf for local landscape use was represented by ryegrass, corn and miscanthus to represent farmland application). Miscanthus was included because of the growing interest as a bio-energy crop in Illinois. Corn was grown three times in succession (June 1 – July 13, July 13 – August 29, and September 4 – November 26). The third corn was grown for longer period because of depleted nutrients that reduced the growth rate.

In Exp. II, two sets of 36 pots (nine treatments and four replicates) were used to grow corn and ryegrass between May and October 2014. Corn was grown four times (each for six weeks) between May and October. At the end of each corn cropping, the aboveground biomass was harvested and dried. Corn roots were removed, thoroughly washed with deionized water, and dried. The dry weights of shoot, root, and total dry-matter yield were determined for each crop.

The ryegrass was clipped monthly, dried, weighed, and analyzed for N. Miscanthus, grown only in Exp. I, was harvested twice (August and November 2013) for the aboveground biomass yield and N analysis. The dried plant tissue samples were ground in a Willey mill using a 2-mm screen and stored in capped glass jars until analyzed. Soil samples were taken from each pot at the beginning of the study and after the final crop clippings in 2013 and 2014 and analyzed for pH, electrical conductivity (EC), total Kjeldahl N (TKN), nitrate N (NO_3-N), and ammonium N (NH_4-N).

For demonstration study, four plants (ryegrass, cowpea, lettuce, and spinach), were grown separately using composted biosolids (at 25, 50, and 100 percent dry-weight basis), a certified commercial compost obtained from Home Depot (applied at 25 percent and 100 percent dry-weight basis), and soil amended with the agronomic rate of chemical fertilizer (150 kg N ha^{-1}) to compare the performance of these products as an ideal growing medium.

Analysis

Composted and uncomposted biosolids used in this study and the amended soils from each pot were sampled and analyzed for pH, EC, TKN, NO_3-N, NH_4-N, and other relevant chemical properties. The pH and EC of the samples were measured in 1:10 (sample: water ratio) extracts using a pH/EC meter (Soil and Plant Analysis Council, 1999). For TKN analysis, samples were digested in concentrated sulfuric acid at 350°C for one hour, cooled, and diluted with 20 mL water. The TKN was then analyzed colorimetrically using the Salicylate – Nitroprusside procedure (Plank, 2002). The NO_3-N, and NH_4-N were extracted with 1M potassium chloride (KCl) and extracts analyzed by colorimetry (Mulvaney, 1996) using the Lachat Quickchem flow injector autoanalyzer (Zellweger Analytics, Milwaukee, WI).

Plant tissue samples were all analyzed for total N following acid digestion using the TKN method. Standard Quality Assurance/Quality Control protocols were observed during soil, compost, and plant sample collection, handling, and chemical analyses.

Calculations

1. **Plant N uptake:** Plant N uptake was calculated as a product of dry-matter yield and plant tissue N concentration.

2. **Relative Plant Available N:** Relative PAN in composted and uncomposted biosolids was determined as a point estimate using an equation proposed by Tian et al (2000) as follows:

   Mean N uptake per unit fertilizer N applied = [(Plant Total N uptake at 75 kg N/ha - Plant Total N uptake at 0 kg N/ha)/75 + (Plant Total N uptake at 150 kg N/ha - Plant Total N uptake at 0 kg N/ha)/150 + Plant Total N uptake at 300 kg N/ha - Plant Total N uptake at 0 kg N/ha)/300]/3. .... Equation (1)

   N uptake per unit compost N applied (PCi) = (Plant Total N uptake of treatment - Plant Total N uptake of control) / Total N applied .... Equation (2)

   Relative PAN was determined by combining both equation (1) and (2) as: [N uptake per unit N applied (PCi)]/(Mean N uptake per unit fertilizer N applied) .... Equation (3)

STATISTICAL ANALYSIS

The soil and plant data were analyzed by the one-way analysis of variance approach using SAS software (Littell, 1996). The treatment means were compared by Tukey's test using SAS software (SAS Institute, 1999). Statistical differences were declared at a significance (α) level of 0.05. The assumption of normality was verified by the Kolmogorov and Smirnov method for all datasets.

RESULTS AND DISCUSSION

Amendments and Soil

The TKN in composted and uncomposted biosolids was above 2 percent. The C:N ratio in the composted biosolids was greater than in the uncomposted biosolids but less than 12:1. Previous studies indicated that organic materials with a C:N ratio less than 12:1 could result in net N mineralization when land applied and therefore enhance the release of N needed by plants (Iglesias-Jimenez and Alvarez, 1993). Thus, both biosolids and composted biosolids produced by the District have C:N ratios below the critical level documented to limit N availability to plants (Gutser et al., 2005).

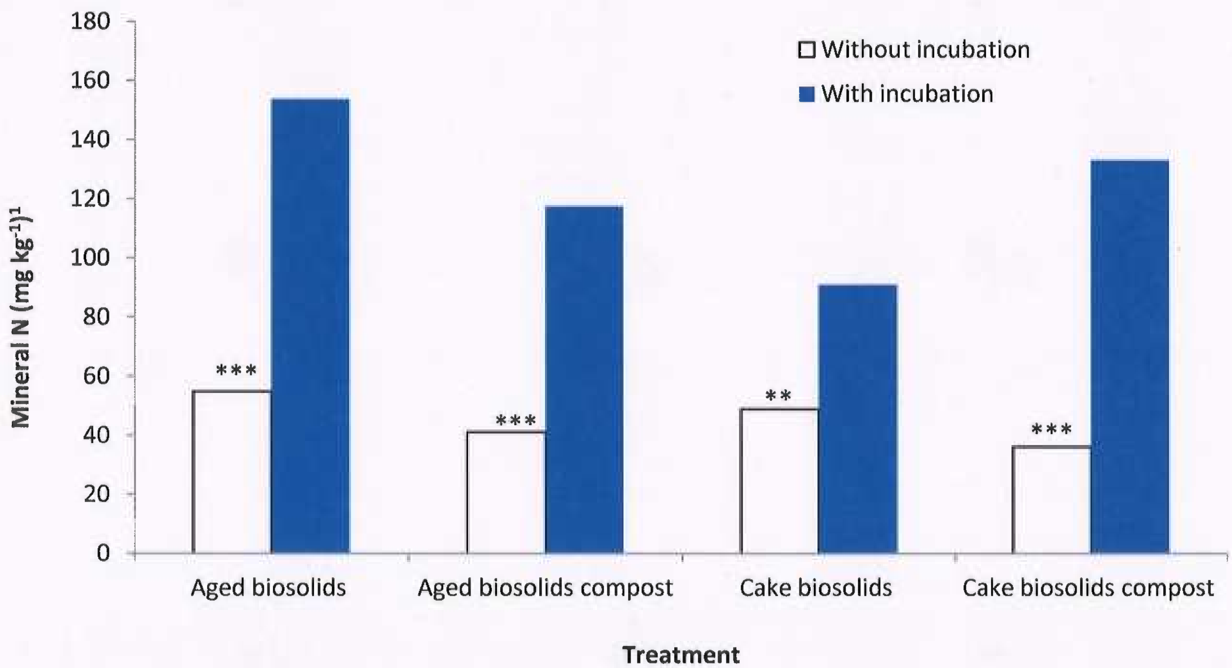
Samples taken from the treated soils in both Exp. I and II show a similar pH for all treatments. However, the EC in the fertilizer treatments was higher and increased with an increasing rate of fertilizer application. The EC values among the biosolids and composted biosolids treatments were similar and lower than the pots, which received 300 kg N ha^{-1} chemical fertilizer (Table 2). Thus, composted biosolids are expected to have minimal impacts on soil pH and EC. The levels of mineral N (NH_4-N + NO_3-N) in soil amended with composted and uncomposted biosolids were higher in Exp. II after four months of incubation than the soil in Exp. II, which was not incubated (Figure 1). Plants utilize soil N as NH_4-N and NO_3-N through the transport of water soluble N and absorption on root surface (Wild, 1988; Benbi and Richter, 2003).

TABLE 2: INITIAL SOIL pH, ELECTRICAL CONDUCTIVITY, AND CONCENTRATIONS OF VARYING FORMS OF NITROGEN IN POTS USED TO GROW CORN IN EXPERIMENTS I AND II

Treatment	pH	EC	NH_4-N	NO_3-N	TKN
Experiment I (without pre-incubation)		mS cm^{-1}	----------------mg kg^{-1}	------------------	
AB[1]	7.4ns	0.79bc[4]	2.4c	52.4bc	2,795a
AB composts[2]	7.3	0.73bc	2.0c	39.0cd	2,764a
CB[3]	7.3	0.75bc	2.6c	46.4c	2,583ab
CB composts[2]	7.4	0.72c	2.5c	33.8d	2,415ab
Fertilizer @ 0 kg N ha^{-1}	7.3	0.70c	6.3b	35.0d	2,245b
Fertilizer @ 75 kg N ha^{-1}	7.4	0.76bc	4.4bc	53.7bc	2,318b
Fertilizer @ 150 kg N ha^{-1}	7.4	0.84b	5.8b	65.8b	2,411ab
Fertilizer @ 300 kg N ha^{-1}	7.3	1.02a	14.1a	113.9a	2,398ab
Experiment II (with pre-incubation)					
AB[1]	7.7 ns	0.92 ns	4.3b	113.3a	2,879 ab
AB composts[2]	7.8	0.80	4.4b	86.6b	2,307 b
CB[3]	7.7	1.01	6.8a	126.6a	3,008 a
CB composts[2]	7.8	0.69	5.0b	91.3b	3,233 a
Fertilizer @ 0 kg N ha^{-1}	8.0	0.66	5.3b	63.8c	2,542 b

[1]Aged biosolids.
[2]All composts are generated from 1:1 ratio of biosolids:landscape waste.
[3]Centrifuge cake biosolids.
[4]In each experiment, means followed by the same letter are not significantly different at 0.05 probability; ns = not significant).

FIGURE 1: MINERAL NITROGEN CONCENTRATIONS BEFORE PLANTING IN SOIL WITH AND WITHOUT PRE-INCUBATION IN EXPERIMENTS I AND II



[1]Mineral nitrogen = sum of NH_4-N and NO_3-N.

**Indicates significant difference in mineral N of soil samples from treatments with and without pre-incubation at $p = 0.01$.

***Indicates significant difference in mineral N of soil samples from treatments with and without pre-incubation at $p<0.001$.

Plant Dry-Matter Yields

Dry-matter yields of corn, ryegrass, and miscanthus from pots amended with both composted and uncomposted biosolids were identical (Table 3). The DM yields of corn and ryegrass were, in most cases, greater in the biosolids treatment than in the control treatment that received 0 kg N ha^{-1}. Other studies have also documented increased DM yield with compost application (Iglesias-Jimenez and Alvarez, 1993; Clark et al., 2000; Montemurro et al., 2005). In general, DM yields of corn, ryegrass, and miscanthus increased with the increasing rate of chemical fertilizer, and the highest DM yields were observed at 150 kg N ha^{-1} and 300 kg N ha^{-1} fertilizer treatment. The yield at 150 kg N ha^{-1} fertilizer treatment was similar to that at 300 kg N ha^{-1}. This observation suggests that the 150 kg N ha^{-1} fertilizer application rate supplied an optimum amount of nutrients to meet corn needs, and there was no additional response to N at the 300 kg N ha^{-1} rate. The DM yields of most crops planted in the uncomposted and composted biosolids treatments (aged and cake) were not significantly different from the optimum yield observed in the 150 kg N ha^{-1} chemical fertilizer treatment (Table 3). Thus, our results show that at the application rates used in this study, composted biosolids supplied sufficient N to meet the requirements of corn, miscanthus, and rye grass. The DM yields were also similar for all treatments with and without pre-incubation (Table 3).

In the demonstration study, biomass of plants at the lowest rate of composts tested (25 percent dry-weight basis) were greater than in soil amended with chemical fertilizer at the agronomic rate. The biomass of the tested plants increased with the application rate of composted biosolids (Figures 2 - 4) and the highest biomass was observed in the 100 percent composted biosolids treatment.

TABLE 3: TOTAL DRY MATTER YIELD OF CORN, RYEGRASS, AND MISCANTHUS HARVESTED DURING THE STUDY

Treatments	Corn		Ryegrass		Miscanthus
	Exp. I	Exp. II	Exp. I	Exp. II	(Exp. I)
AB[1]	27.0ab[4]	27.0a	5.9ab	12.5a	9.7ab
AB composts[2]	24.6b	25.8ab	4.1b	9.1b	10.5a
CB[3]	26.4ab	24.5b	6.0a	9.7b	10.3a
CB composts[2]	22.1bc	22.1bc	5.4ab	7.7bc	8.7b
Fertilizer @ 0 kg N ha^{-1}	21.0c	21.3c	3.6c	6.5c	8.6b
Fertilizer @ 75 kg N ha^{-1}	21.9c	22.7bc	5.2ab	8.1bc	9.0ab
Fertilizer @ 150 kg N ha^{-1}	26.2ab	24.4b	6.1a	6.5c	12.0a
Fertilizer @ 300 kg N ha^{-1}	30.0a	25.7ab	6.8a	9.2b	11.4a

[1]Aged biosolids.
[2]All composts are generated from 1:1ratio of biosolids:landscape waste.
[3]Centrifuge cake biosolids.
[4]In each experiment, means followed by the same letter are not significantly different at 0.05 probability; ns = not significant).

FIGURE 2: DRY MATTER YIELD OF LETTUCE, SPINACH, COWPEA, AND RYEGRASS HARVESTED DURING A GREENHOUSE DEMONSTRATION COMPARING THE METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO'S COMPOSTED BIOSOLIDS AT THREE APPLICATION RATES AND A COMMERCIAL COMPOST AT 100 PERCENT RATE WITH CHEMICAL FERTILIZER IN 2014

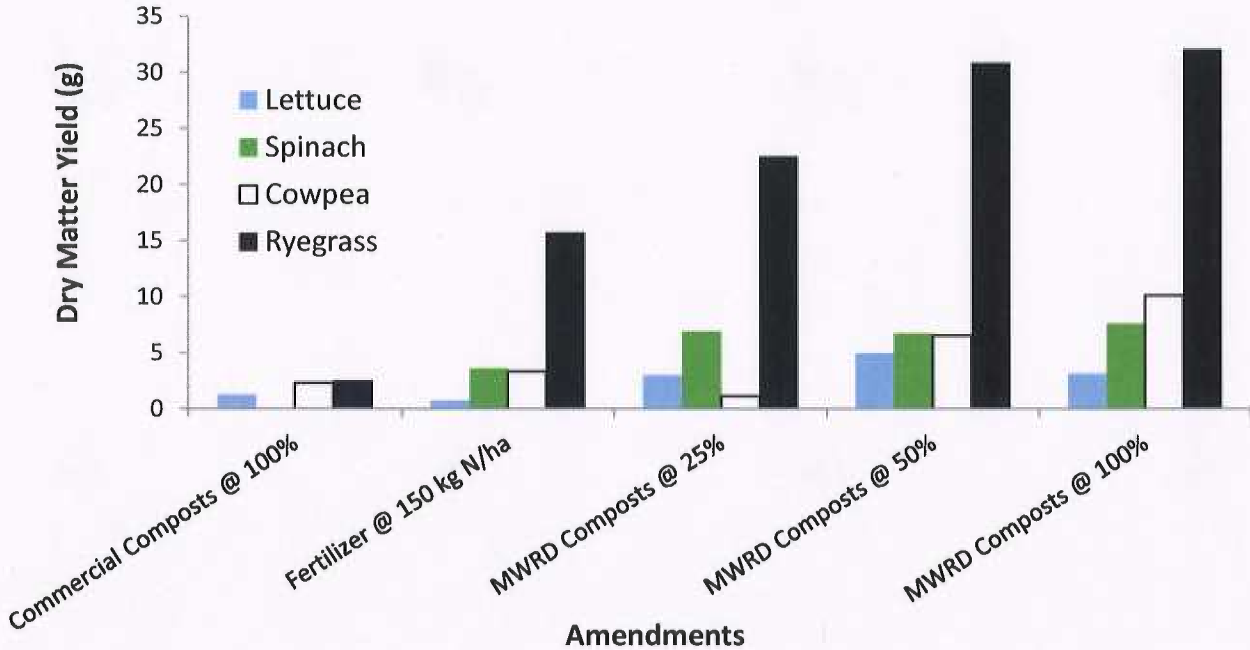


FIGURE 3: PICTURES OF RYEGRASS AND SPINACH TAKEN IN 2014 DURING A GREENHOUSE DEMONSTATION COMPARING THE METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO'S COMPOSTED BIOSOLIDS WITH A COMMERCIAL COMPOST AND CHEMICAL FERTILIZER

FIGURE 4: PICTURES OF RYEGRASS TAKEN IN 2014 DURING A GREENHOUSE DEMONSTRATION WITH THE METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO'S COMPOSTED BIOSOLIDS AT THREE APPLICATION RATES

Nitrogen Concentrations and Uptake in Plant Tissues

Composting had a minimal impact on plant tissue concentrations of N in ryegrass and miscanthus, as the levels were identical in composted and uncomposted treatments (data not shown). However, plant tissue N concentrations increased with an increasing rate of fertilizer application and were higher than the N concentrations observed in plants grown in pots amended with both composted and uncomposted biosolids. Higher plant tissue N concentrations were observed in corn grown in pots amended with uncomposted biosolids than amended in composted biosolids (data not shown). The N requirements of both ryegrass and miscanthus are low, which could explain the lower response to N compared to corn. Similarly, Sullivan et al. (2002) reported no response to compost N application by turf in the first year.

In both Exp. I and II, N uptake by corn was lower in composted biosolids than was observed in uncomposted biosolids (Figure 5). However, N uptake in composted and uncomposted biosolids was similar for both ryegrass and miscanthus (Table 4). The N uptake by corn and ryegrass increased with increasing rate of chemical fertilizer.

The estimated portions of the applied N taken up by the plants were greater in fertilizer (40 – 75 percent) than in uncomposted biosolids (10 – 20 percent) and the composted biosolids (<10 percent) (Figure 5). These findings are similar to other studies that reported lower compost N recovery in plants (Amlinger et al, 2003; Wolkowski, 2003; Hartl and Erhart, 2005).

The estimated relative PAN in uncomposted biosolids was greater than the composted biosolids (Table 5), and the lowest PAN was observed in composted cake biosolids. Thus, a higher rate of composted biosolids will be required to supply similar PAN as in uncomposted biosolids.

FIGURE 5: TOTAL NITROGEN UPTAKE AND PERCENTAGE OF NITROGEN APPLIED TAKEN UP BY CORN DURING THE STUDY

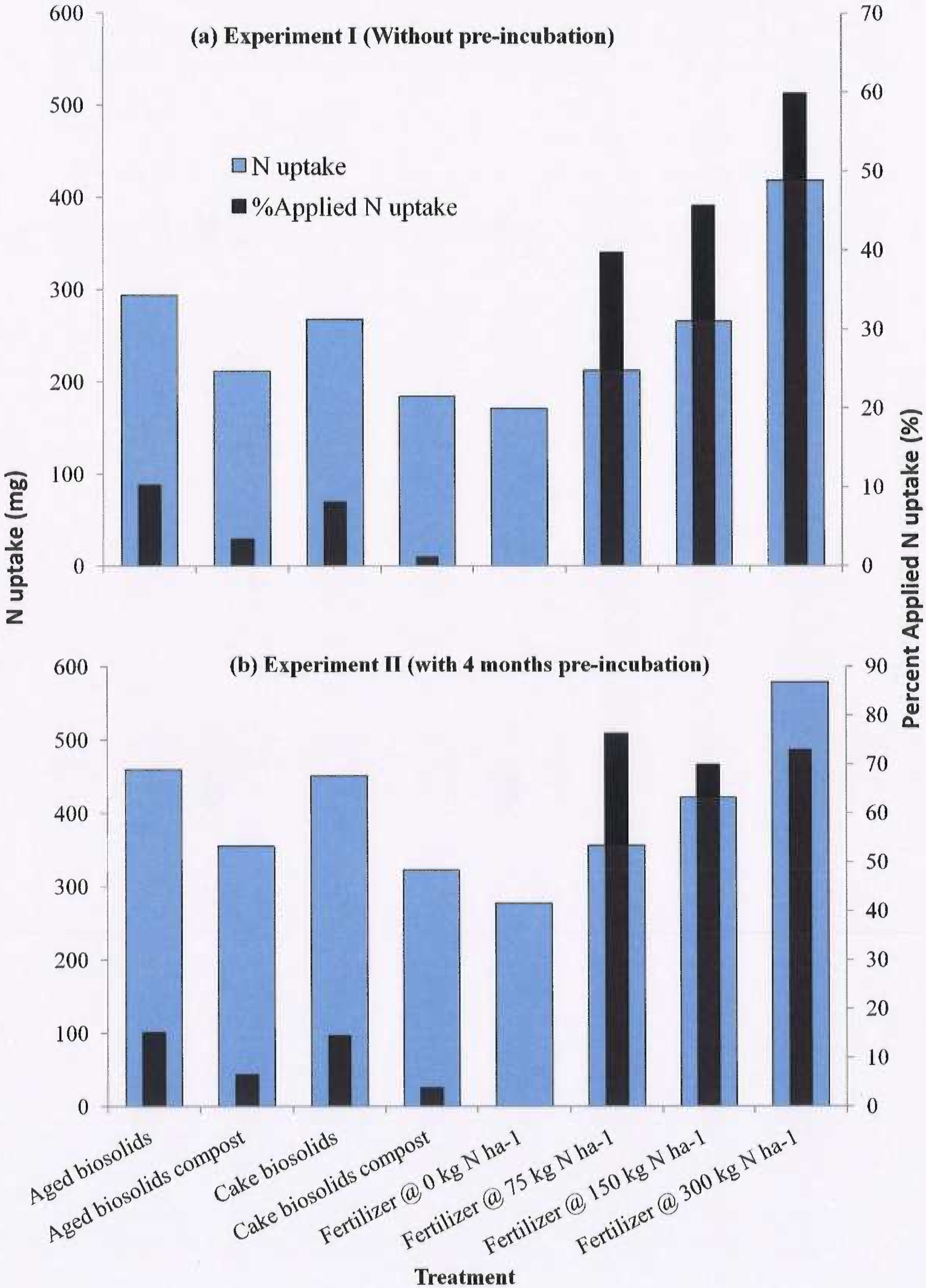


TABLE 4: TOTAL NITROGEN UPTAKE OF RYEGRASS AND MISCANTHUS HARVESTED DURING THE STUDY

Treatments	Ryegrass		Miscanthus
	Exp. I	Exp. II	Exp. I
	---------------------------mg pot^{-1}	---------------------------	
AB[1]	162ab[4]	588a	112ab
AB composts[2]	113b	400b	96b
CB[3]	157ab	477ab	110ab
CB composts[2]	128b	358bc	92b
Fertilizer @ 0 kg N ha^{-1}	81c	346bc	79c
Fertilizer @ 75 kg N ha^{-1}	106b	435b	90b
Fertilizer @ 150 kg N ha^{-1}	154ab	295c	115ab
Fertilizer @ 300 kg N ha^{-1}	220a	421b	135a

[1]Aged biosolids.

[2]All composts are generated from 1:1ratio of biosolids:landscape waste.

[3]Centrifuge cake biosolids.

[4]In each experiment, means followed by the same letter are not significantly different at 0.05 probability; ns = not significant).

TABLE 5: RELATIVE PLANT AVAILABLE NITROGEN[1] TO CORN, RYEGRASS, AND MISCANTHUS FROM BIOSOLIDS AND COMPOST BLENDS DURING THE STUDY

Treatment	Corn	Ryegrass	Miscanthus	Average ± SE
Experiment I	percent			
AB[2]	21.2	21.8	19.8	20.9 ± 1.0
AB composts[3]	7.0	8.7	10.3	8.7 ± 1.7
CB[4]	16.7	20.5	18.7	18.6 ± 1.9
CB composts[3]	2.3	12.6	7.6	7.5 ± 5.2
Experiment II				
AB[1]	21	77	ND[5]	-
AB composts[2]	9	17	ND	-
CB[3]	20	41	ND	-
CB composts[2]	5	4	ND	-

[1]Relative PAN = uptake/uptake from fertilizer x 100.
[2]Aged biosolids.
[3]All composts are generated from 1:1 ratio of biosolids:landscape waste.
[4]Centrifuge cake biosolids.
[5]Not determined.

CONCLUSIONS

Our results show that composted biosolids can be utilized as a fertilizer substitute for turf grass and row crops. Dry matter yields of corn, ryegrass, and miscanthus were identical for composted and uncomposted biosolids. However, the PAN in composted biosolids was lower (<10 percent of total applied N) than in uncomposted (10 - 20 percent of total applied N). It should be noted that PAN from organic materials, such as composted biosolids, can be affected by several parameters, and not all of them were evaluated in this study. The impact of other factors (such as soil type, temperature, variable moisture content) on PAN should be evaluated to validate the findings of this study. We also recommended further studies to evaluate the mineralization rate of composted biosolids application for growing row crops such as wheat and soybean.

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