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Impacts of nutritional status of bio-solids on corn (*Zea mays* L.) used in agriculture

Khaliq Dad, Abdul Wahid*

Bahauddin Zakaryia University, Multan, Pakistan

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Abstract

The main objective of the present study was to investigate the fertilizer field value of seven different types of biosolids including lime stabilized, composted, liquid mesophilic anaerobically digested (MAD), thermally dried mesophilic anaerobically dried, thermally hydrolyzed mesophilic anaerobically digested, dewatered mesophilic anaerobically digested and thermally dried raw biosolids. They were analyzed for their nutrient contents and were tested for their fertilizer value for corn (*Zea mays*) in field trials. The type and amount of different biosolids had significant impact on the fresh and dry weight yields of corn. Growth parameters including plant height, stem diameter and leaf area were also significantly different among different types of biosolids. Highest amount of total Nitrogen (N) was found in dewatered cake. Most of it was ammonium-N. In contrast, thermally treated biosolids had the lowest total N content. The amount of Phosphorus (P) was also analyzed in different biosolids and it was highest in liquid Mesophilic Anaerobic Digestion (MAD) and dewatered biosolids at the rate of 2.35% and 2.32% respectively. The results indicated that the yield of the crop was positively related with the increasing amounts of biosolids.

* **Corresponding Author:** Abdul Wahid ✉ wahid_64us@yahoo.com

Introduction

Sewage sludge or biosolids refer to the solid or semisolid substances produced from the treated wastewater and sewage. They are produced in large quantities by rapidly growing population. The management and utilization of these materials have been a topic of great debate among academicians and practitioners (Parameswaran and Anderson 2007). The biosolids have been reported to contain pathogens and pollutants, mostly heavy metals, that have adverse effects on human beings, flora and fauna of agricultural crops and physical as well as chemical properties of the soils (Sidhu and Toze 2009). Managing large quantities of biosolids and sewage sludge is a global concern (Pritchard 2012). Historically, the biosolids have been dumped in oceans but the awareness about water pollution and knowledge about the harmful effects on aquatic life since 1980s resulted in prohibition of ocean dumping in many countries such as Sweden and other European nations (Swanson *et al*., 2004).

The application of biosolids to agricultural lands has come forward as a significant and well – established sewage management technique for last two decades. A significant portion of the sewage sludge produced by human beings is being spread onto the soils used for agricultural purposes. Biosolids have significant advantages for agricultural application such as they can provide macronutrients especially N and P to crops (Brisolara and Qi 2015, Rigby *et al*., 2015).

Moreover, they can also provide other essential elements including sulphur (S), and Magnesium (Mg). Due to the presence of a significant amount of organic matter, they can also enhance soil fertility by improving soil structure, water holding capacity and water infiltration (Sanchez-Monedero *et al*., 2004). The use of biosolids in agriculture is encouraged as it helps in conservation of organic matter and completion of nutrient cycles (Daigger 2009). For instance, Sims and Sharpley (2005) reported the exhaustion of phosphorus reserves till the end of 21st century if extraction continued at its present rate and emphasized that its recycling was mandatory.

Keeping in view the importance of biosolids as organic fertilizers, it is essential to understand the degree and rate of N and P availability, uptake of the nutrients by plants and the amount of N and P contained in different types of biosolids if we are to optimize the efficiency of biosolids application for agricultural purposes. It is fundamental to quantify the availability of nutrients in the biosolids and their release rate in order to provide effective recommendations on the use of these new types of biosolids for agricultural purposes. This quantification would also enable farmers to maximize the utilization of macro nutrients supplied by different biosolids (Thangarajan *et al.*, 2013). At present, fertilizer recommendations for inorganic fertilizers have been well documented. However, not many studies have focused on agricultural benefits of the new types of biosolids for fodder crops. The current study is a valuable addition to the current knowledge regarding the agricultural use of expanding range of biosolids and other sewage sludge products being recycled for agricultural land application. The aim of the current study is to investigate the nutritional status of different types of biosolids materials and the impact of these materials on the growth and yield of maize (*Zea mays* L.).

Materials and methods

The field trials to achieve the objectives of this research were conducted at a village named Shah Sadar Din, district D.G. Khan, Punjab, Pakistan. As the main objective of the study was to explore nutritional value of the biosolids, nutrient competition trials were conducted to evaluate the impact of N and P fertilizer on the corn (*Zea mays* L.) for two years. The nutrients competition trials investigated the effect of biosolids and synthetic fertilizers on the nutritional value maize (*Zea mays* L.) as forages over a two year period.

Design of the Field Trials

The design of the field trails was based on a split plot arrangement after Cleaver *et al.* (1970). The design consisted of three blocks where every treatment was applied to each plot. The treatments were randomly assigned to each plot as every plot was divided into sub-plots. The size of each sub plot was 130cm x

170cm. One of the plots was used as control and no biosolids were applied. The rates of biosolids as well as fertilizers were randomly assigned to all the sub plots in ascending order. The sub – plots were treated with biosolids at dry weight amounts of 0 tons, 3.33 tons, 6.66 tons and 10.00 tons/ha.

The field trials were conducted with 7 treatments in the first year (i.e. 2012) with 105 plots and these trials were repeated with 7 treatments during the next year with 105 plots. The treatments included mineral control that consisted of mineral N (i.e. ammonium nitrate in prilled form) at the rates of 0kg, 30Kg, 60Kg, 90Kg and 120Kg per hectare; mineral nitrogen along with single P (Phosphorous) dressing in the form of granulated STP (Super triple phosphate) of 50 kg/ha; mineral phosphorus was applied at the rates of 0Kg, 25Kg, 50Kg, 75Kg and 100Kg per hectare; and mineral phosphorus with solitary N dressing at 60 Kg/ha. All the biosolids were applied for the first year's trials on maize and were also used for the second year. All chemical analysis of biosolids and soil was carried out as per slandered procedures.

Results

Nutritional Status of Biosolids

The biosolids were chemically analysed to find the N contents of biosolids applied in trial 1 and 2. Each biosolid was sampled thrice and the samples were pooled together. It was observed that nutrient contents of biosolids had little variation within batches. The total nitrogen and its quantities in chemical form varied insignificantly between two years of the trials. The dewatered cake contained highest amount of total nitrogen (i.e. 5.70%) with most proportion as ammonium-N (NH_4^+) ions (Table 1).

Table 1. Nitrogen and phosphorus contents of different biosolids applied to fields during 2012 in Trial 1.

Biosolids	DS%	TN (%DS)	NH_4^+-N (mg/Kg DS)	NO_3-N (mg/Kg DS)	Org-N (%DS)	Mineral N (%TN)	Total P (% DS)	(Extracted P (mg/Kg DS)
Dewatered MAD	26.7	5.70	8734	<0.01	4.73	14.95	2.32	1135
Thermally Dried MAD	87.5	4.15	967	<0.01	4.31	2.31	2.07	523
Thermally dried raw biosolids	85.6	4.10	254	7.49	4.48	0.53	1.61	183
Liquid MAD	1.98	1.47	0.77	-	0.87	39	2.35	8171
Lime Stabilized	39.7	1.03	506	<0.01	1.05	4.45	0.38	1527
Composted Biosolids	55.3	1.32	113	1073	1.26	7.9	0.61	394
Thermally Hydrolyzed MAD	2.24	1.65	0.67	-	0.97	31	1.92	1053

Where DS= Dry Solids, TN= Total Nitrogen, MAD= Mesophilic Anaerobically Digested.

In contrast, thermally dried biosolids contained slightly lower nitrogen content as compared to the biosolids that were mechanically dewatered. Thermally treated biosolids showed lower total N because they lost their mineral nitrogen due to thermal oxidation. Total nitrogen content of Thermophilic Anaerobic Digestion (TAD), Mesophilic Anaerobic Digestion (MAD) and thermally hydrolyzed sludge was quite similar to thermally treated sludge but they contained higher amounts of mineral N (i.e. approximately 14.95%).

Liquid biosolids contained 1.98% of total nitrogen most of which was in mineral form. The lime stabilized and composted biosolids contained low total N contents of 1.03% and 1.32% respectively (Table 1). Lime stabilized biosolids contained 1.03% and 1.32% of total N in 1st and 2nd trial respectively. The lower amount of total N in limed sludge is accounted for the higher amounts of lime added for treatment. Composted biosolids contained 1.32% and 1.41% of total N with maximum portion in the form of nitrates indicating the aerobic stabilization of biosolids.

Phosphorus Content of Bio-solids used in Trials

From the analysis of biosolids, it was found that the level of P was considerably lower than the N level in biosolids. The highest total P content was observed in dewatered (2.32%) and liquid biosolids (2.35%) respectively. Lime stabilized and composted biosolids had the lowest total P content at the values of 0.38% and 0.61% respectively (Table 1). The same was the case with the biosolids analyzed for the second trial as illustrated by Table 2. Thermally hydrolyzed MAD also showed higher P content.

Table 2. Nitrogen and phosphorus content of different biosolids applied to fields during 2013 in Trial 2.

Biosolids	DS%	TN (%DS)	NH_4^+-N (mg/Kg DS)	NO_3-N (mg/Kg DS)	Org-N (%DS)	Mineral N (%TN)	Total P (% DS)	(Extracted P (mg/Kg DS)
Dewatered MAD	23	5.8	8756	<0.01	4.81	14.83	2.13	1152
Thermally Dried MAD	82.3	4.23	972	<0.01	4.23	2.27	2.11	538
Thermally dried raw biosolids	77.8	4.09	256	7.45	4.32	0.57	1.58	192
Liquid MAD	1.92	1.63	0.81	-	0.77	45	2.37	8271
Lime Stabilized	38	1.32	524	<0.01	1.13	4.53	0.47	1543
Composted Biosolids	56	1.41	125	1133	1.36	7.81	0.67	408
Thermally Hydrolyzed MAD	2.25	1.72	0.61	-	1.08	35	1.87	1107

Where DS= Dry Solids, TN= Total Nitrogen, MAD= Mesophilic Anaerobically Digested.

Soil Analysis

For setting up the trial, soil samples were taken from the trial site just before the onset of cropping system. Three different soil samples were taken from the trial area at depths of 30, 60 and 90cm. The samples from all the depths were pooled together and were analyzed by Soil and Water Testing Laboratory, D.G. Khan, Punjab Pakistan. The results of the soil analyses are illustrated in the following tables (Tables 3 and 4). The soil was alkaline as its pH ranged from 7.4 to 8.9.

The total N content of the soils in 2013 trial ranged between 0.051% (w/w) and 0.213% (w/w) (Table 4) and it was higher than the nitrogen content of the first trial. Initially, the value of ammonical-N ions was measured to be 8.7% (Table 3) and it was between 3.9% and 19.1% for the second trial.

The nitrate level on the surface of the soil ranged from 18.1% to 29.3% in the first trial but they were between 3.6% and 25.2% in the second trial.

Table 3. Data of Soil Analysis for Trial 1.

Organic Matter %	pH meq 100 /g	CEC	Nitrates-N	Ammonium-N	Extractable concentrations mg/Kg-DS			SO_4^{2-}
					P	K	Mg	
2.6	7.4	8.5	18.1	8.7	34	92.1	52.6	24.3
4.2	8.1	8.9	29.3	13.2	32.8	115	96	-

Note: CEC = Cation exchange capacity.

Table 4. Results of Soil Analysis for Trial 2.

	Depth Cm	Total N % (w/w)	Nitrate mg/kg	Ammonium N mg/kg	CEC meq 100/g	pH	P mg/kg - DS	K mg/kg - DS	Mg mg/kg - DS	Sulphate mg/kg - DS	Organic Matter % DS
B1	0-30	0.213	23.8	17.3	4.2	7.9	86.3	8.7	31.7	53.4	2.1
	30-60	0.124	15.2	12.1	3.9	8.3	78.1	10.1	50.3	43.5	1.9
	60-90	0.078	8.1	5.7	3.8	8.9	51.8	12.7	58.1	37.1	1.5
B2	0-30	0.232	25.2	19.1	4.1	8.1	77.3	9.5	34.2	57.1	2.3
	30-60	0.131	16.1	11.3	3.6	7.4	61.9	12.4	43.6	51.9	1.7
	60-90	0.081	7.0	3.9	3.1	7.8	44.3	14.2	57.3	46.3	1.3
B3	0-30	0.191	18.7	15.4	4.6	8.7	85.7	10.1	35.1	48.2	2.5
	30-60	0.098	11.3	9.6	3.8	8.1	59.1	13.1	49.9	40.1	1.9
	60-90	0.051	3.6	5.1	3.2	7.7	41.6	15.7	57.3	38.5	1.4

The data suggests that the nitrogen content in nitrate form was higher during the first trial but the value was a bit low during the second trial where data has been taken from different depths and blocks. However, the data for the first trial represents the pooled soil taken from the trial site. The amount of organic matter was between 2.6% and 4.2% for the first trial while it varied between 1.3% and 2.5% for the soil in the second trial.

It is clear from the results of the soil analysis that the values of P and trace elements like S, K and Mg were higher during the second trial as compared to the first trial values (Tables 3 and 4).

Plant Height

At control i.e. 0.00 tons of biosolids applied to the maize, the mean value was approximately 95.05±3.14cm. The descriptive analysis revealed that the mean plant height was highest for liquid MAD at 120.35±3.23, 133.2±3.67 and 147.25±3.11 for 3.33 tons/ha, 6.66 tons/ha and 9.99 (approximately 10 tons/ha) of the liquid MAD application. The least plant height was observed at different levels of thermally dried raw biosolids with mean plant heights of 102.75, 104.95 and 110.75cm at 3.33, 6.66 and 9.99 tons/ha of biosolids respectively. The mean, standard deviation and standard error of mean values of plant height for different treatments at different levels show that their means were less than the means for liquid MAD. However, there was a little difference between the mean plant heights for liquid MAD and mineral N treatment. It was found that the mean plant height increased with increased amount of biosolids (Fig. 1).

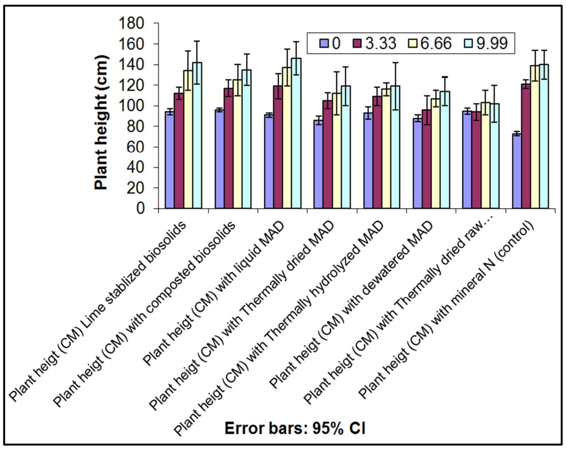

Fig. 1. Plant heights (cm) when different amounts of different biosolids were applied.

Stem Diameter

In order to explore the impact of different amounts of treatments on stem diameter, four plants were sampled from each level of each treatment and the diameters of their stems were measured. The results (Fig. 2) showed that the mean stem diameter for control was 1.08cm for control. The mean stem diameter values for mineral N were 1.21±0.08, 1.315±0.0125 and 1.25±0.032cm for three applications of the mineral N. For lime stabilized biosolids, the mean stem diameter was the lowest of all treatments at 1.14, 1.18 and 1.21 cm with 3.33, 6.66 and 9.99 tons of biosolids applied respectively. The descriptive values for the stem diameter of maize plants treated with different biosolids at different levels are given below. The analysis of variance was conducted to know if the means for stem diameters differed significantly at 95% confidence interval. The results showed that mean of stem diameters differed significantly between groups. The results revealed that the stem diameters for maize plants treated with lime stabilized biosolids, composted biosolids, liquid MAD, thermally dried MAD, thermally hydrolyzed MAD, dewatered MAD and thermally dried raw biosolids at different levels different significantly at $p < 0.01$ between groups.

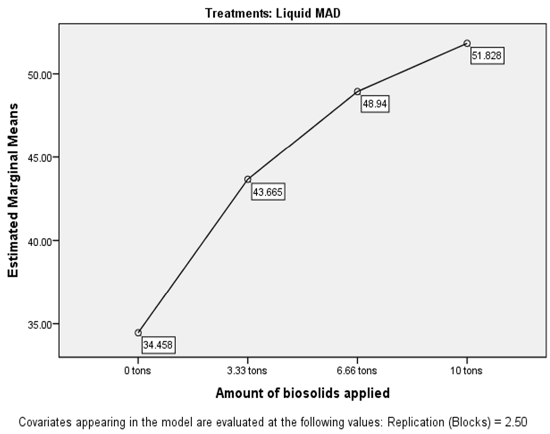

Fig. 2. Liquid MAD: Estimated marginal means of fresh weight yield of maize (tons/ha).

The graphical presentation of these results is given below (Fig. 3). It is evident that the stem diameter at different concentrations of mineral N was highest along with the liquid MAD and thermally dried raw biosolids.

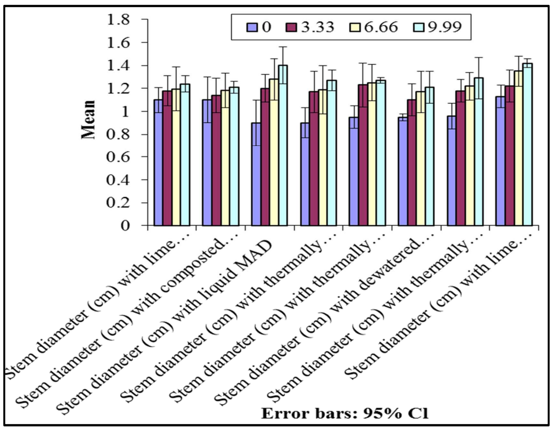

Fig. 3. Stem Diameter of Maize plants with application of all treatments at different quantities.

Leaf Area per plant

Leaf area per plant was another growth attribute that was measured during this study to evaluate the impact of different biosolids applied at different quantities on the growth of maize crop. The results (Fig. 4) showed that leaf area per plant with mineral N and liquid treatments was highest and it was statistically different from the leaf area values of plants treated with other biosolids including lime stabilized, composted, thermally dried, thermally hydrolyzed and thermally dried raw biosolids. The descriptive revealed that mean value for mineral was 2074.3±27.3cm² while it was 2064±24.9cm² for liquid MAD and with thermally dried MAD it was 2018.86±13.15cm².

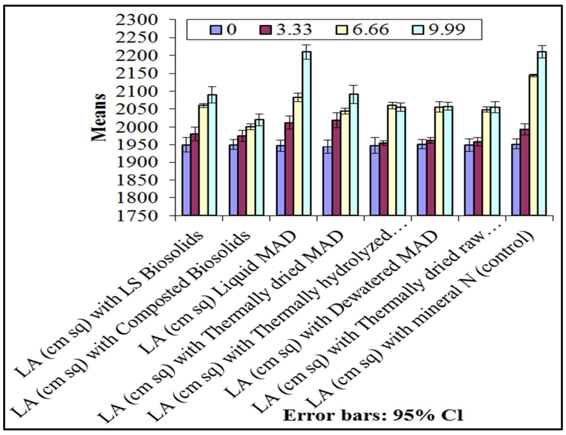

Fig. 4. Leaf Area/plant (Cm²) with different treatments applied at different levels.

It is very much clear that land application of biosolids and sewage sludge has been one of the cheapest and useful methods for management and disposal of these materials. Rigby *et al.* (2016) and Kleber *et al.* (2000) also reported the use of sewage sludge as soil fertilizer because it contained nutrient contents, particularly N and P. The current studies also focused on the availability of these two macro-nutrients to corn. The nutritional value of biosolids with respect to minerals including N and P were tested. Highest amount of total N was found in dewatered cake. Most of it was found the ammonium-N ions. In contrast, thermally treated biosolids had the lowest total N content. The low amount of total N can be explained on the basis of the method of treatment. These results are in line with those reported by Fernandez *et al.* (2006) who found higher amounts of biodegradable organic compounds in the sewage sludge that was thermally dried. The total N content of the dewatered cake was the highest because dewatering ensures the reduction in microbial activity in the biosolids and reduces leaching and evaporation losses.

It is the ammonium-N ions that are found in abundant form in the dewatered biosolids and it is produced as a result of mineralization. These results are endorsed by those found and reported by Paramashivam *et al.* (2016). Tarrason *et al.* (2008) also reported that composting and thermal drying of sewage sludge played significant role in modifying the stability and pool of N in the soil amended with processed sewage sludge.

Conclusion

From the above discussion, it is evident that the results obtained from this study are in line with the earlier studies on biosolids, their nutritional or fertilizer value and their impact on different growth factors of the fodder crops. The findings of this study revealed that the corn yields could be enhanced by amending the soils with different types of biosolids and treated sewage sludge. In this way, not only the fertilizers costs can be reduced but the problem of managing sewage sludge and other biological waste can be solved. However, a caution is required in the use of biosolids in order to avoid the toxicity and heavy metal accumulation in the soil.

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