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Research Article

The effects of biogas slurry on the production and quality of maize fodder

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Abstract: The present study examined the effectiveness of biogas slurry (liquor from anaerobic digestion process) as a nitrogen source for the production of maize fodder (*Zea mays*). Maize fodder was cultivated as a control (T_0: 0 kg of slurry N ha^{-1}) and with 3 different levels of biogas slurry—T_1 (60 kg of slurry N ha^{-1}), T_2 (70 kg of slurry N ha^{-1}), and T_3 (82 kg of slurry N ha^{-1})—in a randomized block design. The parameters studied were plant height, stem circumference, number of leaves, leaf area, dry matter yield, and nutrient contents in maize fodder. Maize plant height and stem circumference were significantly ($P < 0.01$) influenced by increasing the rate of biogas slurry 14, 28, 42, and 56 days after sowing. The number of leaves in fodder plants did not differ significantly, but leaf area significantly ($P < 0.01$) differed between the treatment groups. The highest maize fodder biomass yield was observed in T_2 (54.12 t ha^{-1}). In the case of crude protein, a significant difference ($P < 0.01$) was observed between the treatment groups and the highest value was also observed in T_2 (11.91%). A significant difference was also observed in dry matter ($P < 0.05$) and ash ($P < 0.01$) content between the treatment groups, but not in acid detergent fiber (ADF) or neutral detergent fiber (NDF). Based on these results, it may be concluded that the application of approximately 70 kg of biogas slurry N ha^{-1} will improve the production of biomass and nutrient content in maize fodder.

Key words: Biogas slurry, biomass, plant height, leaf area, maize fodder

Introduction

Bangladesh is primarily an agricultural country and its agriculture is closely related to livestock. Livestock is a major component of agriculture in Bangladesh, and the present livestock population is estimated to be 23.5 million cattle and buffaloes, 14.61 million goats and sheep, and 120.67 million poultry (BBS 2004). About 84% of the total cultivable land is used for rice production and only 0.05% for forage production; the remainder of the land is used for other crops (BBS 2005). As farmers are interested in producing food grains for human consumption, the country is faced with an acute shortage of fodder for livestock. Maize, or corn (*Zea mays*), is widely used as an excellent livestock feed as grain, green fodder, or silage (Haque 2003), and recently has been used for human consumption.

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Maize is considered an ideal forage crop because it grows quickly, produces high yields, is palatable, is rich in nutrients, and helps to increase body weight and milk quality in cattle (Sattar et al. 1994). As fodder for livestock, maize is excellent, highly nutritive, and sustainable, in green or dry condition, and is very responsive to nitrogen fertilization (Hukkeri et al. 1977). Nitrogen fertilization directly contributes to the quantity and quality of forage production. Excessive and imbalanced use of chemical fertilizers has adversely affected the soil, causing a decrease in organic carbon by reducing the microbial flora in the soil, and increased use of nitrogen fertilizer is contaminating water bodies, thus affecting fish fauna and posing a health hazard for humans and animals (Rahman et al. 2008).

Bangladesh has a good opportunity to use biogas slurry as a nitrogen fertilizer, because 2000 biogas plants are already established in the country. The government of Bangladesh has been implementing the National Domestic Biogas and Manure Programme (NDBMP) since 2006, with the objective of developing and disseminating biogas technology in rural areas, and the ultimate goal of establishing a sustainable and commercial biogas sector in the country. The Infrastructure Development Company, Limited (IDCOL), with financial assistance from SNV, Netherlands and KFW, Germany, set a target of installing 60,000 biogas plants at an estimated cost of US $37 million by the year 2010 (Daily Star 2008). From these existing biogas plants at least 60 t of biogas slurry are produced daily in Bangladesh, and this production will increase to 180 t per day in 2010. Bangladesh can make an eco-friendly environment by using this large quantity of biogas slurry in crop cultivation.

In addition to biogas from manure, slurry would be a secondary product that is also an inexpensive way to reduce environmental pollution by recycling animal waste. Biogas slurry is a digested by-product of livestock manure that contains a lot of nitrogen, phosphorus, and other macro- and micronutrients. As such, it helps maintain soil fertility and pH, improving fodder production. The application of slurry to cropland is an attractive option for its disposal, because the physical properties of the soil are improved and nutrients are supplied (Mosquera et al. 2000). Biogas slurry is a typical organic fertilizer that ensures the proper use of livestock waste for sustainable crop production and maintenance of an eco-friendly, pollution-free environment.

Factors that influence nitrogen availability from slurry are its inorganic N content, digestion process (aerobic or anaerobic), C:N ratio, pH, the method and timing of application, and soil type and properties (Warman and Termeer 2005). Due to the decomposition and breakdown of its organic content, digested slurry provides fast-acting nutrients that easily enter the soil solution, thus becoming immediately available to plants. They simultaneously serve as primary nutrients for the development of soil organisms, e.g. the replenishment of microorganisms lost through exposure to air in the course of spreading the slurry over the fields. They also nourish actinomycetes that act as organic digesting specialists in the digested sludge (Kossmann and Ponitz 1996). The addition of organic matter to slurry is useful for maintaining or increasing the organic substances or nitrogenous compounds in soil that decompose slowing but steadily. Animal waste causes environmental pollution when applied to land without appropriate controls and management (Balsari et al. 2005), whereas agronomic utilization of biogas slurry represents the best solution for its re-use.

The demand for organic food production is increasing because of its ability to maintain health without the risk of synthetic enzymes and hormones, or other chemical effects on food. Producing maize fodder with biogas slurry and feeding this fodder to animals is an effective way to produce organic meat and milk for human consumption. There are limited data available on the growth, biomass yield, nutrient content, chemical composition, and energy content of maize fodder treated with different doses of biogas slurry. Therefore, the present study aimed to assess the suitability of biogas slurry as a nitrogen fertilizer in maize fodder cultivation by measuring yield and chemical quality.

Materials and methods

Experimental materials and procedures

This study was conducted through the production of maize fodder treated with different levels of biogas slurry and the laboratory analysis of samples. Fodder production was performed with biogas slurry between January and April 2007. During the experimental period the maximum and minimum temperatures were 30 and 18 °C. The relative humidity during the period ranged from 75.4% to 84.5% and average rainfall was 180 mm. The experimental soil condition was silt loam texture. The land was prepared well by local tillage implements to obtain the desirable tilts for maize cultivation. Weeds and stables of the previous crop were carefully removed and then the land was divided into 12 plots, according to the layout of the experiment (Table 1). Each plot was 10 m^2 (4 × 2.5 m). The experiment was conducted in a randomized block design (RBD) comprising 4 levels of biogas slurry N: 0, 60, 70, and 82 kg ha^{-1}, referred to as treatments T_0, T_1, T_2, and T_3, respectively. Just before the final stage of land preparation, biogas slurry was applied as organic fertilizer to the designed experimental plot. Then, the experimental plots were prepared and leveled. The quantity of N applied to each plot was calculated from the availability of N in the biogas slurry. In addition to nitrogen, biogas slurry supplies a good amount of phosphorus and potassium. The physicochemical properties of the soil and biogas slurry are given in Table 2.

Table 1. Layout of the experiment.

Replication	Treatment			
	T_0	T_1	T_2	T_3
R1	T_0R_1	T_1R_1	T_2R_1	T_3R_1
R2	T_0R_2	T_1R_2	T_2R_2	T_3R_2
R3	T_0R_3	T_1R_3	T_2R_3	T_3R_3

T_0: No slurry N; T_1: 60 kg of slurry N ha^{-1};
T_2: 70 kg of slurry N ha^{-1}; T_3: 82 kg of slurry N ha^{-1}

Table 2. Characteristics of the experimental soil and biogas slurry.

Characteristics	Soil	Biogas slurry
Organic matter (%)	1.1	-
Clay (%)	20	-
Silt (%)	66	-
Sand (%)	14	-
Soil type	Silt loam	-
Electrical conductivity (dS m^{-1})	1.48	-
Moisture content (%)	-	79
Total nitrogen (mg kg^{-1})	1.32	5.88
Total phosphorus (mg kg^{-1})	1.38	2.72
Total potassium (mg kg^{-1})	3.94	1.33
Extractable sulfur (mg kg^{-1})	1.02	0.79
pH	6.7	7.8

T_0: No slurry N; T_1: 60 kg of slurry N ha^{-1};
T_2: 70 kg of slurry N ha^{-1}; T_3: 82 kg of slurry N ha^{-1}

Barnali maize was sown for this experiment, which is normally used for grain production. There is no specific variety of maize for fodder production, and so Barnali was selected for fodder production and for observing the efficiency of slurry nitrogen. The cultivation procedure and harvesting time for maize are different than for grain and fodder production. Barnali seeds were sown using a line sowing method, maintaining row-to-row spacing of 30 cm, seed-to-seed spacing of 15 cm, and a depth of 5 cm. In the case of grain production, the line-to-line distance is 75 cm, plant-to-plant distance is 25 cm, and harvesting time is 90-120 days (Haque 2003), whereas the distance is 30 cm (line-to-line) and 15 cm (plant-to-plant), and harvesting time is 55-60 days for fodder production (Motalib 2003). The seed rate was 55 kg ha^{-1} (Rahman et al. 1993) and the germination rate was 90%.

Necessary gap filling was performed 1 week after germination. Intercultural operations, i.e. weeding and mulching were also performed, but no insecticide was applied. No irrigation was applied due to natural rainfall during the experimental period. Plant height and stem circumference were measured (cm) every 14 days. Leaf area was calculated (cm^2) from the average length and width of the leaf (base, middle, and tip of the leaf). Before cutting the fodder plant, the average number of leaves in each plant was counted randomly in each plot.

Motalib (2003) reported that the optimum time for harvesting green maize plants as fodder is when 50% of the plants are in the flowering state and contain 60%-70% moisture. At this stage maize plants contain sufficient nutrients and are sufficiently succulent. Finally, maize fodder from each plot was harvested 56 days after sowing, when 50% of the plants were in the flowering state. Harvesting was performed manually and samples were kept for further analysis. Immediately after harvesting, biomass yield of the maize fodder from each plot was recorded using a weighing balance.

Analysis

Total nitrogen in soil, biogas slurry, and maize fodder was determined according to the Kjeldahl method. Soil and slurry sample pH levels were measured using a pH meter by diluting the samples with distilled water at a ratio of 1:5 after 2 h of continuous shaking. Total phosphorus and total potassium in soil, slurry, and maize fodder samples were determined by the Bray method (Bray and Kurtz, 1945). Extractable S in soil, slurry, and maize fodder samples was determined according to Jones (2001). Electrical conductivity (EC) was measured by extracting the soil sample with water (soil:water and weight:volume ratios were 1:1) using the method described by Whitney (1998). Representative samples of fresh fodder were oven dried at 100 °C for 24 h (Cherney 2000) to determine dry matter (DM) content. Oven-dried samples were ground (Cyclotec 1993 sample mill tecator, Sweden) to 1.0 mm for chemical analysis. The ground samples were bottled, covered with aluminum foil, and kept in desiccators. Ash content was determined by burning the OM in a muffle furnace at 550 °C for 5 h. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) content were estimated using the methods of Faichney and White (1983).

Statistical analysis

The data were analyzed using the MSTAT statistical package program and differences between the treatment mean results were determined using Duncan's multiple range test (DMRT), based on the principles of Steel and Torrie (1980).

Results

Maize fodder height

Table 3 shows the height of maize fodder at different time intervals and in response to different levels of slurry treatment. It can be seen from the table that application of different levels of biogas slurry resulted in significantly ($P < 0.01$) different plant heights, up to 28 days after sowing. Maximum maize height occurred with T_2 (97.56 cm) at this stage, whereas T_3 (highest slurry group) resulted in the minimum plant height (88.78 cm). The growth rate of maize increased after 28 days of sowing, until the flowering stage. At the final stage (harvesting at 56 days), maximum plant height was in T_2 (258.63 cm), followed by T_3 (247 cm), T_1 (243.83 cm), and T_0 (226.67 cm); differences between the treatment groups were significant ($P < 0.01$).

Table 3. The effect of biogas slurry on plant height in maize fodder (*Zea mays*).

Days after sowing	Plant height (cm)				SEM	Level of significance
	T_0	T_1	T_2	T_3		
14	25.11^c	27.57^b	31.00^a	27.55^b	0.75	**
28	94.84^b	93.78^b	97.56^a	88.78^c	1.93	**
42	189.20^d	196.55^c	203.98^a	200.00^b	2.14	**
56	226.67^d	243.83^c	258.63^a	247.00^b	3.50	**

T_0: No slurry N; T_1: 60 kg of slurry N ha^{-1}; T_2: 70 kg of slurry N ha^{-1}; T_3: 82 kg of slurry N ha^{-1}
Mean values with different superscript letters in the same row differ significantly
**$P < 0.01$

Stem circumference

The development of stem circumference in maize fodder according to treatment group is shown in Table 4. We observed significant differences ($P < 0.01$) in maize fodder stem circumference between the treatment groups at every developmental stage of growth. Initially (14th day) higher slurry nitrogen was associated with larger stem circumference ($T_3 > T_2 > T_0 > T_1$). With time, T_2 resulted in significantly larger stem circumference, as compared to the control and other treatment groups at 28, 42, and 56 days; however, the chronology of the other 3 treatments differed slightly at the different growing stages, as follows: $T_2 > T_1 > T_3 > T_0$, $T_2 > T_3 > T_0 > T_1$, and $T_2 > T_1 > T_3 > T_0$ at 28, 42, and 56 days, respectively. According to the stem circumference results, biogas slurry N clearly influenced the growth and production of maize fodder, but an excessive level (82 kg of slurry N ha^{-1}) of biogas slurry negatively affected stem circumference.

Leaf number and area

The number of leaves and leaf area are shown in Table 5. The number of leaves per maize plant ranged from 12.33 to 13 in the different treatment groups. There was no significant difference in the number of leaves per plant between the treatment groups. In the case of average leaf area, we observed significant differences ($P < 0.01$) between the treatment groups. The highest and lowest leaf area was for T_2 (533.77 cm^2) and T_0 (391.13 cm^2), respectively. Application of biogas slurry gradually increased the average leaf area as the level of N increased to 70 kg of slurry N ha^{-1}, but average leaf area was decreased at higher application of slurry N. Average leaf area for T_3 was lower than for T_2 and T_1, indicating that T_3 might have had an inhibiting effect due to the high N level of biogas slurry.

Table 4. The effect of biogas slurry on stem circumference in maize fodder (*Zea mays*).

Days after sowing	circumference (cm)				SEM	Level of significance
	T_0	T_1	T_2	T_3		
14	2.85^b	2.54^b	2.91^a	2.92^a	0.74	**
28	4.40^b	5.18^a	5.37^a	4.79^b	0.13	**
42	6.67^b	6.42^b	7.29^a	6.80^b	0.11	**
56	7.78^c	8.77^b	9.14^a	8.38^b	0.19	**

T_0: No slurry N; T_1: 60 kg of slurry N ha^{-1}; T_2: 70 kg of slurry N ha^{-1}; T_3: 82 kg of slurry N ha^{-1}
Mean values with different superscript letters in the same row differ significantly
**P < 0.01

Table 5. The effect of biogas slurry on the number of leaves, leaf area, and biomass yield in maize fodder (*Zea mays*).

Parameter	Treatment				SEM	Level of significance
	T_0	T_1	T_2	T_3		
No. of leaves	12.33	12.67	12.67	13.00	0.225	NS
Leaf area (cm^2)	391.13^d	485.90^b	533.77^a	447.23^c	0.05	**
Biomass yield (MT ha^{-1})	34.67^c	45.23^b	54.12^a	43.67^{bc}	2.20	**

T_0: No slurry N; T_1: 60 kg of slurry N ha^{-1}; T_2: 70 kg of slurry N ha^{-1}; T_3: 82 kg of slurry N ha^{-1}
Mean values with different superscript letters in the same row differ significantly
NS: Not significant; **P < 0.01

Biomass yield

There were significant differences ($P < 0.01$) in biomass yield between the treatment groups. T_0 had the lowest biomass yield (34.67 MT ha^{-1}), and yield gradually increased in T_1 (45.23 MT ha^{-1}) and T_2 (54.12 MT ha^{-1}) as the slurry N rate increased; however, the biomass yield for T_3 (43.67 MT ha^{-1}) was low, which might indicate that biomass yield was inhibited by the high slurry N level.

Nutritional state

The nutritional status of maize fodder in the different slurry treatment groups is presented in Table 6. Dry matter (DM) content of T_2 (21.31%) was significantly higher ($P < 0.05$) than T_0 (19.28%), T_1 (19.78%), and T_3 (19.74%). In the case of crude protein (CP) content, significant differences ($P < 0.01$) were observed between the treatment groups. CP gradually increased in T_1 and T_2, but decreased in T_3. Ash content was significantly higher ($P < 0.01$) for T_2 (10.23% on a DM basis) than for the other treatment groups. The lowest ash content was in T_0 (7.5%), indicating that biogas slurry had a positive influence on total ash content in maize fodder. In the case of fiber content, acid detergent fiber (ADF) and neutral detergent fiber (NDF) levels were high in this experiment, but there were no statistically significant differences between the treatment groups.

Table 7 shows that the nutrient (N, P, K, and S) content in maize fodder significantly differed between the treatment groups. The highest and lowest nitrogen content occurred in response to T_2 and T_3,

Table 6. The effect of biogas slurry on maize fodder (*Zea mays*) nutritional status.

Nutrients	Treatment				SEM	Level of significance
	T_0	T_1	T_2	T_3		
DM (%)	19.28^b	19.78^b	21.31^a	19.74^b	0.27	*
CP (% DM)	10.14^b	10.86^b	11.91^a	9.91^c	0.25	**
Ash (% DM)	7.50^d	8.49^c	10.23^a	9.36^b	0.32	**
ADF (% DM)	35.31	34.97	34.87	33.30	0.38	NS
NDF (% DM)	55.87	56.34	57.66	55.69	0.32	NS

T_0: No slurry N; T_1: 60 kg of slurry N ha^{-1}; T_2: 70 kg of slurry N ha^{-1}; T_3: 82 kg of slurry N ha^{-1}
Mean values with different superscript letters in the same row differ significantly
NS: Not significant; **$P < 0.01$; *$P < 0.05$

Table 7. The effect of biogas slurry on the nutrient content in maize fodder (*Zea mays*).

Nutrients contents	Treatment				SEM	Level of significance
	T_0	T_1	T_2	T_3		
N (% DM)	1.622^c	1.737^b	1.905^a	1.585^d	.038	**
P (% DM)	0.151^b	0.195^a	0.201^a	0.192^a	.007	**
K (% DM)	2.005^b	2.211^{ab}	2.415^a	2.354^b	.056	*
S (% DM)	0.082^b	0.128^a	0.130^a	0.120^a	.007	*

T_0: No slurry N; T_1: 60 kg of slurry N ha^{-1}; T_2: 70 kg of slurry N ha^{-1}; T_3: 82 kg of slurry N ha^{-1}
Mean values with different superscript letters in the same row differ significantly
**$P < 0.01$ and *$P < 0.05$

respectively. The highest phosphorus content occurred in plants treated with T_2, followed by T_1, T_3, and T_0. In the case of potassium, T_2-treated maize had the highest value, followed by maize treated with T_3, T_1, and T_0. The highest S content was observed in T_2-treated maize and gradually decreased in maize treated with T_3, T_1, and T_0. Higher mineral content of the slurry might have been a factor that contributed to the high ash content in the slurry-treated maize fodder.

Discussion

Results from the present study show that the application of biogas slurry as a nitrogen fertilizer stimulated the growth of maize fodder; however, to obtain maximum growth, the application rate should be optimized, as excessive use could result in adverse effects on plant growth. Based on these results, approximately 70 kg of slurry N ha^{-1} is the optimum level for maize fodder growth. Reddy et al. (1987) reported the positive effect of nitrogen fertilizer on maize plant height; plant height increased significantly in response to applying as much as 80 kg of nitrogen ha^{-1}. Other factors might also affect fodder plant height, such as the genetic makeup of fodder, soil fertility, climatic conditions, quantity of daylight, light intensity, and season. Among these, genetic factors and soil fertility are more important. Nitrogen fertilizer, either organic or inorganic, always affects vegetative growth of the fodder plant (Rahman et al. 2008).

Biomass yield in fodder depends on the number of leaves, leaf area, fodder height, stem circumference, etc. As stem circumference increases, fodder production increases. We think that approximately 70 kg of slurry N ha^{-1} is an appropriate level for maize fodder growth. Reiad et al. (1997) reported that nitrogen affects vegetative growth and increases stem circumference. Maize stalk diameter was reported to be strongly influenced by environmental conditions (Duncan 1975). Rahman et al. (2008) observed that approximately 67 kg of slurry N ha^{-1} is an optimum level for maize fodder production.

The number of leaves per plant is controlled primarily by genetic factors and is also affected by some other environmental factors, such as seed rate and temperature. Ibrahim et al. (2006) reported that the number of leaves per plant in maize and cowpea is also affected significantly by different seed ratios and crop combinations. They observed that the average number of leaves per maize plant was 12.18 when maize was sown alone, but 11.82 when grown in combination with cowpea. Tollenar et al. (1979) reported that the number of leaves slowly and gradually declined as plants aged. Temperature and soil moisture are 2 important parameters that affect the number of leaves and an increase in temperature from 15 to 24 °C almost doubled the number of leaves. An increase in mean leaf area is an important factor in biomass yield, which is greatly influenced by optimum nitrogen application. Leaf area was unaffected by the level of N in an experiment conducted with 2 varieties of oat (Singh et al. 1996), which is in contrast to the results of the present experiment.

Increasing the level of slurry nitrogen presumably increased the availability of soil nitrogen, and that of other macro- and micronutrients, which might have enhanced meristematic growth and resulted in higher fodder yield. Nitrogen is a vitally important plant nutrient involved in protein and enzyme synthesis. All metabolic plant processes are controlled by enzymes. Moreover, nitrogen is an integral component of chlorophyll, the primary molecule that absorbs the light energy needed for photosynthesis. The observed increase in green forage yield in response to slurry nitrogen might have been due to its positive effect on cell elongation, cell division, formation of nucleotide and coenzyme in meristematic activity, and increasing photosynthetic surface, resulting in more production and accumulation of photosynthetic compounds. High P content of the slurry might also have positively contributed to the biomass yield of maize. Phosphate compounds act as an energy currency in plants, and play an important role in photosynthesis and the metabolism of carbohydrates; they are also stored for subsequent growth and reproductive processes.

The results of the present experiment are similar to those reported by Khan et al. (1996) and Shahjalal et al. (1996). Kumar et al. (2001) reported that green fodder yield increased in response to increased levels of nitrogen fertilizer. Dauden and Quilez (2004) conducted a maize yield experiment using different levels of pig slurry, and observed no significant differences in plant height or biomass yield between the different treatments, but did observe that grain yield decreased as the rate of slurry N increased. The type of previous crop is also an important factor in dry matter yield in maize silage, and a significantly higher silage yield was observed after legume production with minimal N fertilizer (Gul et al. 2008). Rahman et al. (2008) observed that maize fodder biomass yield decreased in response to excessively high levels of slurry nitrogen.

DM content may vary according to variety, stage of fodder maturity, soil topography, season, temperature, climatic conditions, etc. Fodder DM content is also an indicator of its quality. The range of DM in maize fodder in response to different treatments is similar to that reported by Shahjalal et al. (1996). Beckwith et al. (2002) reported that crude protein content in cut grass increased as the level of cattle slurry increased. Sarker (2000) also observed an increase in CP in response to increasing the level of nitrogen fertilizer. The lowest CP value in T_3 would indicate that excessive slurry nitrogen might have inhibited protein synthesis in maize fodder. The CP content of fodder is the most important indicator of its quality. It has a direct effect on milk production in dairy animals and body growth in cattle.

Rahman et al. (2008) conducted an experiment with cattle slurry and observed that 67 kg of slurry N ha^{-1} resulted in higher OM, CP, and ash content in maize fodder, which is similar to the results obtained in the present experiment. Ash content in maize may also vary due to individual mineral contents in soil and slurry. The rate of biogas slurry application clearly affected N, P, K, and S content in maize. The highest N, P, K, and S content was obtained with T_2, indicating that it is the most suitable level (70 kg of slurry N ha^{-1}) for maize fodder growth. The lowest P, K, and S content was obtained in the control group, which might indicate that biogas slurry had a clear effect on those nutrients and on total ash content in maize fodder. It was observed that physical growth characteristics, yield, and nutritional quality gradually increased up to 70 kg of slurry N ha^{-1}, but higher levels of biogas slurry reduced the yield and other fodder qualities. Based on these results, it could be assumed that there might be an accumulation of some heavy metals in the slurry that reduced the yield and quality at the higher levels.

Jamali et al. (2008) examined the effect of sewage sludge on the growth and production of maize, and also determined the heavy metal content in the product. They observed that a significant amount of Zn, Cu, Cd, Pb, and other trace and toxic metals were present in the sewage sludge. They treated the sewage sludge with lime before application to the maize field, which had a positive effect on heavy metals. The experiment showed that heavy metals were transmitted from the sewage sludge to the maize and reduced the quality of the maize. Heavy metal content was significantly reduced (30%) in the lime-treated maize, as compared to the untreated sewage sludge. It is possible that some heavy metals were in the biogas slurry used in the present experiment, even though the biogas slurry contained a good amount of N, P, K, and S. Additional research should be conducted to identify which heavy metals are in biogas slurry and how to eliminate them.

Conclusion

The results of the present study show that:

Physical growth characteristics in maize fodder, i.e. plant height, stem circumference, and leaf area, as well as biomass yield, increased as the level of biogas slurry N increased up to 70 kg ha^{-1}. It might be concluded that approximately 70 kg of biogas slurry N ha^{-1} is an optimum level for maize fodder production.

In addition to nitrogen, biogas slurry contains a significant amount of P, K, and S, which might have affected the maize protein and ash content.

Excessively high biogas slurry N (82 kg of slurry N ha^{-1}) decreased maize biomass yield and nutritional quality, perhaps due to the presence of some inhibiting agents in the slurry. Further research is necessary to identify the cause of the observed decrease in yield and quality at that higher slurry N level.

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