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# Maize (*Zea Mays L*) production in a semiarid area of South Africa from co-application of biogas slurry with chemical fertilizer and effects on soil quality.

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## Abstract

Most smallscale farmers still use the traditional way of agricultural crop farming, and relay mostly use of chemical fertilizers (CF). Recently CF have become expensive and could in some way have a negative impact on soil quality after long term application. However, co-application of biogas slurry (BGS) with CF could help reduce farming costs while improving dry matter yields, grain yields, primary macronutrient uptake of (Nitrogen) N, (Phosphorus) P, (Potasium) K, (Calcium) Ca and (Magnesium) Mg and soil concentration of pH, (organic carbon) OC, N, P, K, Ca and Mg after crop harvest. The study was a field experiment conducted in 2016-2017 and 2017-2018 growing seasons. The field experiment was arranged in a randomized complete block design with four replicates. The treatments were based on percentages of recommended N rates of 120 kg N ha$^{-1}$ for maize production. The BGS/CF treatments were (i) 0/0, (ii) 0/120, (iii) 24/96, (iv) 48/72, (v) 72/48, (vi) 96/24, (vii) 120/0 kg N ha$^{-1}$. The spreading of the combination of BGS/CF treatments was performed by hand and incorporated into the top soil (0-10 cm) in each experimental plots. BGS/CF (48/72) treatment resulted into higher dry matter yield in 2016-2017, which was higher than all other treatment combinations, while in the 2017-2018 season, treatment of (0/120) resulted into higher dry matter than all other treatment combinations. The 48/72 and 0/120 treatments resulted into similar grain yield in 2016-2017 season which were higher than all other treatments. Treatments of 48/72, 72/48 and 120/0 had higher N, P, K, Ca and Mg uptake than 0/0, 0/120, 24/96 and 96/24 treatments in both seasons. Soil pH, total N, K, and Mg were high from the treatment of (120/0) than all other treatments in 2016-2017 while in the 2017-2018 season, treatment of (48/72) had higher OC, P and K after maize harvest. The findings of his study show that co-application of BGS/CF at 48/72 and 72/48 have maize yield benefits compared to the two resources, BGS/CF (120/0) and BGS/CF (0/120), applied separately in soil especially in the arid and semi-arid regions.

**Keywords**:

Dry matter yield; nutrient uptake; soil nutrient reserves; co-application; grain yield, dryland

## Introduction

Global pressure on agriculture for higher food production [1] has increased agricultural intensification, to maximize crop yields per unit area [2]. Intensification of agricultural production without replenishment of soil nutrients reserves causes soil fertility declines and poor soil quality [3], a major constraint for crop productivity [4-6]. Chemical fertilizers (CF) have been used to supply essential soil nutrients and increase crop yields for many decades [7]. However, long-term excessive use of CF decrease organic soil carbon (C), microflora and fauna and overall soil quality, increase greenhouse gas emissions [8;9] and could contaminate water bodies [10;7]. In addition, each CF provides only particular essential nutrients to the crop [11].

Smallholder farmers, including those in South Africa use CF for crop production, however they do not apply sufficient quantities due to high cost of CF [11] and that could reduce potential yields targets. However, co-application of CF with organic fertilizers could add extra nutrients especially from the organic sources which would otherwise have to be disposed of, presenting risks on the environment (e.g eutrophication of waters). [12] suggested that organic fertilizers are believed to be beneficial in improving soil quality and while on the other side reducing fertilizer costs for marginal farmers that can not afford expensive CF.

Research has shown a huge demand for eco-friendly practices to achieve sustainable food production [12;13]. The use of locally available organic fertilizers could reduce dependence on commercial fertilizers [14;10;15]. Some of the locally available organic fertilizers include animal manures and biogas slurry (BGS) produced from biogas technology. The biogas technology produces energy (methane) through anaerobic digestion of organic wastes, like animal manures, thereby reducing environmental pollution [15]. Biogas slurry, a by-product after anaerobic digestion of organic waste, contains large amounts of micro and macronutrients, necessary for plant growth [16;2;11]. The slurry can act as a soil conditioner, while its decomposition mineralises essential nutrients, increasing their availability in soil and crop biomass accumulation and yield [17]. While the use of CF alone decreases soil quality, desired crop yields are difficult to achieve by only supplying organic fertilizers [18]. High crop yields, improved soil fertility levels and overall quality can be achievable through supplementing CF with organic fertilizers, especially on smallholder farms [19;11]. Co-application of BGS with CF has the potential to supply soil nutrients needed for crop growth. The combined application of BGS with CF improves carbon-to-nitrogen (C:N) ratio and nutrient transformations and could increase crop yields [11]. However, there are contradictory findings in the literature on the effects of co-application of BGS with CF on soil quality, nutrient availability and crop yields.

In a study done in southern China by [20] on an Ultisol, co-application of BGS (feedstock pig manure and urine) with CF resulted in higher peanut grain yield than CF only, while the BGS only treatment resulted into higher peanut yields than co-applicaton of BGS with CF and CF only treatment. [7] reported in a study done in Pakistan an increased N content in plant parts and total N uptake of okra (*Hibiscus esculentus L.)* plant after co-application of sun-dried BGS (feedstock cattle dung) with CF. In contrast to the two studies, [11] reported in a study done in India no significant increase in the number of leaves of fodder maize crop after co-application of dry-BGS (feedstock cattle dung) with CF. [19] suggested that rice and wheat growth and yield attributes differed significantly because of the different N sources and their combinations and or ratios. In a study by [12] in India on inceptisols, addition of BGS (feedstock cattle dung) with CF at 50/50 ratio gives 20% greater number of leaves, leaf area, plant biomass, and cob yield of maize, compared to CF alone. Soil types, climatic and environmental conditions where the studies of [7;11;12] and [20] were conducted differ from the common soils found in Southern Africa and the nature of the feedstock used for production of biogas found in Southern Africa. The effectiveness of organic fertilizers is dependent on conditions that affect decomposition and mineralisation (i.e temperature, moisture, and composition of the organic material). The effect of these factors on rate of decomposition and mineralisation of N will determine the complementory effects when co-applied with CF. As such complementary effects in Southern Africa could be different to other regions if all these factors are accounted for. The contradictions in the literature could be a result of differences in the quality of the BGS, which depends on feedstock, combinations of BGS-to-CF, and soils and crop types used in the different studies. It is essential to find the optimal combination for co-applying BGS with inorganic fertilizers to produce higher yields of crops commonly grown on smallholder farms in Southern Africa.

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There are indications of declines in crop productivity in the sub-Saharan Africa region [4], particularly cereal and legume crops, which are commonly grown on smallholder farms. The decline in soil fertility, including low organic matter and nutrients, and climate change and high cost of CF explain the low productivity of cereal and legume crops on marginal farms. Most biogas plants in Southern Africa use cattle manure as a feedstock, and the BGS produced could be a useful organic fertilizer. There is a paucity of literature on work done on co-application of BGS with CF for increasing soil nutrient reserves and overall quality, of cereal crop yields in South Africa. It was hypothesized that BGS produced from cattle manure when co-applied with CF at equal ratios based on N, will result in the same maize dry matter, grain yield and nutrient uptake as the compound CF only, with additional benefits of increasing soil pH and organic C and available P, K, Ca and Mg under field conditions. The objective of this study was to determine the effects of co-application ratio of BGS with CF on nutrient uptake, dry matter and grain yields of maize and soil nutrient concentrations after harvest.

## Materials and methods

### Site description

The study site and details where the experiments were conducted is as described by [21].

### Sampling of soils and biogas slurry and initial characterisation

Soil samples and biogas slurry sampled for the purpose of the experiments are as described by [21]. Initial soil characterization also included analysis of extractable P (mg $kg^{-1}$), 6.35 ± 0.17; exchangeable K ($cmol_c$/kg), 0.20 ± 0.03; exchangeable Ca ($cmol_c$/kg), 3.32 ± 0.04 and exchangeable Mg ($cmol_c$/kg) 2.21 ± 0.03.

### Experimental set up and agronomic practices

The field experiment set up is as described by [21]. The treatments were combinations of BGS and CF, with CF being a compound fertiliser N:P:K, 3:2:1 (28). The 3:2:1 represents the ratio of N:P:K in the fertiliser while the 28 means that 28 % of fertiliser is made up of N, P and K. The BGS/CF treatments were based on percentages of recommended N rate (120 kg $Nha^{-1}$) were T1 = (0/0), T2 = (0/120), T3 = (24/96), T4 = (48/72), T5 = (72/48), T6 = (96/24) and T7 = (120/0), kg $Nha^{-1}$. These amounts corresponded to the recommended rate for maize gain yield potential of 5 t $ha^{-1}$. The application of treatments was performed by hand and incorporated by tillage. The P and K were corrected using single superphosphate and potassium chloride so that N becomes the only limiting factor.

### Trial monitoring

The water used for irrigation and irrigation schedules for the experiment conducted are as described by [21]. Weeding was done mechanically every third week, methamidofos 585 SL insecticide (AVIMA) was applied to control fall armyworm (*Spodoptera frugiperda*) in the 2016-2017 season only [21].

### Plant sampling and analysis

Leaves in five randomly selected maize plants were sampled from each plot at the tasselling stage. The stems of the sampled plants were kept and included to the plants used for the determination of dry matter. All leaves samples were kept in well-labeled paper bags, and oven-dried at 50°C to constant weight, ground to < 0.5 mm using Fritsch Pulverisette mortar grinder. The ground plant samples were digested following nitric-perchloric acid digestion method [22].

Briefly, 0.5 of dried plant material was digested with 7 ml nitric acid at 180ºC, brought up to volume in a 100 ml volumetric flask and analysed for P, K, Ca and Mg. Total N was determined by dry combustion method [23] and analysed with flash 2000 organic elemental analyser (CHNS-O analyser, Thermo Scientific, United States). Maize grain yield was only determined in the 2016-2017 season. In the 2017-2018 season, monkeys only ate the cobs before maturity and harvesting. Total uptake of N, P, K, Ca and Mg was calculated separately by the following formula:

$$\text{Uptake of N, P, K, Ca, Mg (kg ha}^{-1}) = \frac{(\text{N, P, K, Ca, Mg})\%\ \text{X dry matter ( kg ha}^{-1})}{100}$$

Selected physicochemical soil parameters after maize

Five soil samples were collected from the 0-20 cm depth of each plot using a bucket auger and mixed thoroughly to make a composite sample. The samples were air-dried and sieved to pass through 2 mm sieve, before analysis. Soil pH was measured in water at 1:2.5 (soil: water ratio) [24]. Total N was determined using the Kjeldahl digestion method [25]. Plant available P was extracted with Bray 1 extraction solution [26] followed by analysis on a Continuous Flow Auto Analyser 3, *SEAL* Analytical, Australia. Exchangeable K was extracted with 1M Ammonium acetate solution ($NH_4OAc$) adjusted to a pH of 7.0 [27;28] and analysed with an ICP (ICPES-9820, Plasma Atomic Emission Spectrometer, Shimadzu Corporation, Japan).

**Statistical analysis**

The data for maize dry matter, grain yield, uptake of N, P, K and soil concentration of N, P, K, OC, pH were subjected to two-way analysis of variance (ANOVA) based on the randomised complete block design, with seven combination of N levels, using Genstat statistical software (18$^{th}$ edition, VSN International, 2016). The data for the two seasons (2016-2017 and 2017-2018) were analysed across seasons. Separation of means was done using Tukey's HSD at $p \leq 0.05$. Pearson's correlation analysis was done to correlate with maize dry matter with uptake of N, P, K and with soil concentrations of total N, available P, exchangeable K for each season using Genstat statistical software (18$^{th}$ edition).

**Results**

Dry matter and grain yield

Maize dry mater and grain yields in treatments were significantly different ($p \leq 0.05$) in both seasons (Table 1). In the 2016-2017 season, the highest dry matter was in the treatment (48/72) followed by the 72/48 and 120/0. In the 2017-2018 season, the highest dry matter was in the (0/120) treatment followed by the (120/0) treatment. In both seasons the control (0/0) had the least dry matter yields. Ths 48/72 and 72/48 treatments had similar dry matter yields. The 72/48 and 96/24 treatments had similar dry matter yields in the 2017-2018 season. Maize dry matter yield was higher in the 2017-2018 than the 2016-2017 season for most treatments except the 48/72 and 72/48 treatments, which had the same yields for both seasons. The highest grain yield was in BGS/CF treatments of 0/120 (CF only) and 48/72 treatments and the least being the 0/0 treatment. The other treatments were in the order 120/0 > 72/48 > 24/96 > 96/24 (Table 1).

Uptake of nitrogen, phosphorus, potassium, calcium and magnesium

In both seasons, the treatments showed significantly different ($p \leq 0.05$) N uptake by maize (Table 1). In 2016-2017, the highest N uptake was from treatment of 72/48 followed by the other treatments in the order 48/72 = 120/0 > 0/120 > 24/96 = 96/24 > 0/0. In 2017-2018, the highest N uptake was from the BDS only (120/0) treatment and the least being the cotrol treatment (0/0). The other treatments were in the order of 48/72 = 72/48 > 96/24 > 24/96 > 0/0. The 2017-18 season had higher uptake of N than the 2016-2017. However, the 48/72 and the 72/48 treatments were among the top three in both seasons.

The BGS/CF treatments showed significant differences ($p \leq 0.05$) in uptake of P, K, Ca and Mg for both seasons. The 2017-2018 season had higher uptake of P, K, Ca and Mg for each treatment than the 2016-2017 season, with the 48/72 and the 72/48 being among the top three in both seasons. Phosphorus uptake in 2016-2017 was highest from 72/48 treatment followed by BGS only (120/0) and the least was from the control treatment (0/0). The other treatments were in the order 48/72 = 0/120 > 96/24 > 24/96. In 2017-2018, highest P uptake was from the BGS only (120/0) treatment followed by 48/72 and 72/48 treatment and the least was from the control treatment (0/0). The other treatments were in the order 24/96 > 96/24. In 2016-2017, the highest K uptake was from 72/48 treatment followed by 120/0 and the least was from the treatment of 0/0 in both seasons. The other treatments were in the order 48/72 = 0/120 > 24/96 = 96/24. In 2017/2018, the highest K uptake was from BGS only (120/0) treatment and the least was from treatment of 0/0. The other treatments were in the order of 48/72 > 72/48 > 0/120 = 96/24 > 24/96.

The highest Ca uptake was from treatment of BGS only (120/0) followed by 48/72, while the least was from the control treatment (0/0) in both seasons. The 96/24 treatment had similar Ca uptake to the CF only (0/120) treatment in 2016-2017 season. The other treatments were in the order 72/48 > 24/96. In the 2017-2018, the other treatments were in the order 48/72 > 72/48 > 24/96 = 96/24. In 2016-2017, Mg uptake was high from the treatment of BGS only (120/0) followed by treatment of 72/48 and the least was from treatment of (0/0). The other treatments were in the order 24/96 = 48/72 > 96/24 > 0/120. In 2017/2018, the highest Mg uptake was from treatment of 72/48 followed by 48/72 and the least was from treatment of (0/0). The other treatments were in order 24/96 = 120/0 > 96/24. Overall, the CF only treatment had the lowest Ca and Mg uptake for both seasons than the other treatment combinations.

**Table 1**: Effect of co-application of biogas slurry and chemical fertiliser on dry matter yield, grain yield and uptake of N, P, K, Ca and Mg by maize for 2016-2017 and 2017-2018 planting season.

| | | Dry matter yield | Grain yield | N | P | K | Ca | Mg |
|---|---|---|---|---|---|---|---|---|
| **Season** | **Treatments** | -------------x$10^3$ kg $ha^{-1}$------------- | | ------------------------------ kg $ha^{-1}$ ------------------------------ | | | | |
| **2016-2017** | **T1** | $2.84^{A}$ | $0.76^{A}$ | $5.55^{A}$ | $3.78^{A}$ | $15.8^{B}$ | $8.54^{B}$ | $8.40^{A}$ |
| | **T2** | $5.06^{CD}$ | $2.98^{F}$ | $62.4^{C}$ | $8.40^{D}$ | $39.1^{D}$ | $14.4^{C}$ | $15.6^{B}$ |
| | **T3** | $4.56^{BC}$ | $1.82^{C}$ | $45.9^{B}$ | $5.12^{B}$ | $30.9^{C}$ | $16.1^{D}$ | $21.8^{E}$ |
| | **T4** | $6.94^{F}$ | $2.95^{F}$ | $75.4^{D}$ | $8.75^{D}$ | $40.4^{D}$ | $19.0^{F}$ | $21.0^{E}$ |
| | **T5** | $6.35^{E}$ | $2.24^{D}$ | $90.4^{E}$ | $10.9^{F}$ | $63.3^{G}$ | $17.6^{E}$ | $29.5^{G}$ |
| | **T6** | $4.41^{B}$ | $1.41^{B}$ | $38.0^{B}$ | $6.08^{C}$ | $30.6^{C}$ | $14.7^{C}$ | $18.6^{C}$ |
| | **T7** | $6.31^{E}$ | $2.59^{E}$ | $79.1^{D}$ | $9.87^{E}$ | $58.0^{F}$ | $19.9^{G}$ | $31.8^{H}$ |
| **2017-2018** | **T1** | $3.18^{A}$ | - | $3.08^{A}$ | $6.73^{C}$ | $8.84^{A}$ | $3.37^{A}$ | $19.8^{D}$ |
| | **T2** | $10.18^{H}$ | - | $99.3^{F}$ | $13.4^{G}$ | $60.1^{F}$ | $16.1^{D}$ | $25.7^{F}$ |
| | **T3** | $5.28^{D}$ | - | $109^{G}$ | $14.7^{H}$ | $46.6^{E}$ | $25.5^{H}$ | $39.6^{J}$ |
| | **T4** | $6.95^{F}$ | - | $165^{I}$ | $25.4^{K}$ | $68.6^{H}$ | $34.8^{J}$ | $49.2^{K}$ |
| | **T5** | $6.43^{EF}$ | - | $166^{I}$ | $21.5^{J}$ | $64.1^{G}$ | $32.3^{I}$ | $54.6^{L}$ |
| | **T6** | $5.93^{E}$ | - | $147^{H}$ | $18.7^{I}$ | $59.8^{F}$ | $25.3^{H}$ | $33.5^{I}$ |
| | **T7** | $8.03^{G}$ | - | $236^{J}$ | $31.1^{L}$ | $128^{I}$ | $44.0^{K}$ | $39.4^{J}$ |

Means with different letters in the same column are significantly different at $p \leq 0.05$. The treatments are BGS/CF ratios in terms of nitrogen supplied, with T1 = (0/0), T2 = (0/120), T3 = (24/96), T4 = (48/72), T5 = (72/48), T6 = (96/24) and T7 = (120/0).

Soil nutrients after maize harvest

The BGS/CF treatments showed significant differences ($p \leq 0.05$) in soil pH, total N, organic C, extractable phosphorus and exchangeable K, Ca and Mg (Table 2). The soil after harvest had higher pH (except for 0/120 and 0/0 treatments), organic C, exchangeable Ca and Mg in the 2017-2018 than in the 2016-2017 season. Soil pH increased with increase in the proportion of BGS in both seasons, with the highest pH in the BGS only (120/0) treatment and the lowest in 0/120 and 0/0 treatments. The highest soil C was in BGS only (120/0) treatment for both seasons and 48/72 in 2017-2018 season while the least was in the 0/0 treatment in both seasons. The other treatments were in the order 60/40 > 40/60 = 0/120 > 24/96 = 96/24 in the 2016-2017 and 60/40 > 96/24 = 24/96 > 0/120 in the 2017-2018 season.

Total soil N was highest in the CF only (0/120) treatment with the least in the 0/0 in the 2016-2017 season. The other treatments were in the order BGS only (120/0) > 48/72 = 72/48 > 24/96 = 96/24. In the 2017-2018 season, the highest total N was in the 72/48 treatment and the least in the 0/0 treatment. The other treatments were in the order 48/72 > 120/0 > 0/120 > 24/96 = 96/24. Where the proportion of BGS was higher than CF, the total soil N after harvest was higher in the 2017-2018 than 2016-2017 season.

The highest soil extractable P was in 48/72 treatment followed by 72/48 in both seasons with the least being in the control treatment (0/0) in both the 2016-2017 and 2017-2018 seasons. The other treatments were in the order 120/0 > 96/24 > 0/120 > 24/96 in 2016-2017 and 0/120 > 120/0 > 24/96 = 96/24 in the 2017-2018 season. Overall extractable P was lower in the 2017-2018 than the 2016-2017 season, except the CF only (0/120) and 24/96 treatments. The exchangeable K was highest in the BGS only (120/0) treatment in both seasons and least in the the control (0/0) in both seasons. The other treatments were in the order 72/48 > 48/72 > 24/96 = 96/24 > 0/120 in 2016-2017, while in 2017-2018 the order was 72/48 > 48/72 > 0/120 > 24/96 = 96/24. Overall exchangeable K was lower in the 2017-2018 than the 2016-2017 season, except the CF only (0/120) and BGS only (120/0) treatments.

In both the 2016-2017 and 2017-2018 seasons, the highest exchangeable Ca were in the CF only (0/120) treatment and the least being the control (0/0). The other treatments were in the order 48/72 > 120/0 > 72/48 > 24/96 > 96/24 in 2016-2017 while in 2017-2018 the order was 120/0 > 48/72 = 72/48 > 96/24 > 24/96. The highest exchangeable Mg were in the CF only (0/120) treatment and the least being 0/0 in both 2016-2017 and 2017/2018 seasons. In 2016-2017 season, the other treatments were in the order 48/72 = 72/48 > 120/0 > 24/96 > 96/24 while in the 2017-2018 season the order was120/0 > 72/48 > 48/72 > 96/24 > 24/96. Overall exchangeable Ca and Mg were lower in the 2017/2018 than the 2016/2017 season for each treatment.

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**Table 2**: Soil chemical properties after maize harvest for 2016-2017 and 2017-2018 planting season.

| | | pH ($H_2O$) | TN | OC | Extractable P | Exchangeable K | Exchangeable Ca | Exchangeable Mg |
|---|---|---|---|---|---|---|---|---|
| **Season** | **Treatments** | | -------------- % ------------- | | ---- mg/kg ---- | ------------------------------ cmol(+)/kg ---------------------------- | | |
| **2016-2017** | **T1** | 5.83$^{A}$ | 0.026$^{A}$ | 0.532$^{B}$ | 3.52$^{B}$ | 0.120$^{A}$ | 4.01$^{C}$ | 3.04$^{B}$ |
| | **T2** | 5.84$^{A}$ | 0.103$^{J}$ | 0.979$^{DE}$ | 14.89$^{E}$ | 0.224$^{D}$ | 9.95$^{L}$ | 5.58$^{K}$ |
| | **T3** | 6.26$^{B}$ | 0.054$^{C}$ | 0.955$^{D}$ | 7.50$^{C}$ | 0.263$^{F}$ | 6.95$^{H}$ | 4.60$^{H}$ |
| | **T4** | 6.41$^{C}$ | 0.064$^{DE}$ | 0.995$^{EF}$ | 73.02$^{K}$ | 0.339$^{H}$ | 8.56$^{K}$ | 4.84$^{I}$ |
| | **T5** | 7.04$^{E}$ | 0.061$^{D}$ | 1.06$^{G}$ | 49.29$^{J}$ | 0.350$^{I}$ | 7.39$^{I}$ | 4.85$^{I}$ |
| | **T6** | 6.67$^{D}$ | 0.056$^{C}$ | 0.955$^{D}$ | 15.89$^{F}$ | 0.268$^{F}$ | 6.69$^{G}$ | 4.31$^{F}$ |
| | **T7** | 7.09$^{E}$ | 0.069$^{F}$ | 1.10$^{H}$ | 18.98$^{H}$ | 0.358$^{J}$ | 8.26$^{J}$ | 4.81$^{I}$ |
| **2017-2018** | **T1** | 5.93$^{A}$ | 0.031$^{B}$ | 0.118$^{A}$ | 2.54$^{A}$ | 0.138$^{B}$ | 3.09$^{A}$ | 2.94$^{A}$ |
| | **T2** | 5.83$^{A}$ | 0.074$^{G}$ | 1.01$^{F}$ | 17.27$^{G}$ | 0.228$^{D}$ | 8.67$^{K}$ | 5.05$^{J}$ |
| | **T3** | 6.54$^{C}$ | 0.068$^{EF}$ | 1.14$^{I}$ | 11.18$^{D}$ | 0.191$^{C}$ | 4.01$^{B}$ | 3.08$^{B}$ |
| | **T4** | 7.03$^{E}$ | 0.096$^{I}$ | 1.23$^{K}$ | 31.42$^{I}$ | 0.239$^{E}$ | 5.33$^{E}$ | 3.60$^{D}$ |
| | **T5** | 7.55$^{F}$ | 0.118$^{K}$ | 1.19$^{J}$ | 17.56$^{G}$ | 0.325$^{G}$ | 5.30$^{E}$ | 4.03$^{E}$ |
| | **T6** | 6.78$^{D}$ | 0.065$^{DE}$ | 1.13$^{HI}$ | 10.59$^{D}$ | 0.195$^{C}$ | 4.70$^{D}$ | 3.19$^{C}$ |
| | **T7** | 7.75$^{G}$ | 0.086$^{H}$ | 1.24$^{K}$ | 15.37$^{EF}$ | 0.590$^{K}$ | 6.32$^{F}$ | 4.45$^{G}$ |

Means with different letters in the same column are significantly different at $p \leq 0.05$. The treatments are BGS/CF ratios in terms of nitrogen supplied, with T1 = (0/0), T2 = (0/120), T3 = (24/96), T4 = (48/72), T5 = (72/48), T6 = (96/24) and T7 = (120/0).

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Maize dry matter showed a strong positive correlation with uptake of N, P, K, Ca and Mg in both seasons except for the 2017-2018 when a weak positive correlation with Mg uptake was observed (Table 3). Soil parameters showed positive concentrations for the different elements in both seasons. In 2016-2017 season, only exchangeable K showed a strong positive correlation with drymatter, while in the 2017-2018 all measured soil parameters showed a strong positive correlation with drymatter, except total N (Table 3).

**Table 3**: Correlation coefficients (*r*) for parameters affecting dry matter yield in the maize field

| Parameter | Plant uptake | |
|---|---|---|
| Season | 2016-2017 | 2017-2018 |
| N Uptake | 0.886 | 0.958 |
| P Uptake | 0.814 | 0.974 |
| K Uptake | 0.877 | 0.888 |
| Ca Uptake | 0.872 | 0.936 |
| Mg Uptake | 0.902 | 0.534 |
| | Soil parameters | |
| Total N | 0.336 | 0.296 |
| Extractable P | 0.390 | 0.859 |
| Exchangeable K | 0.822 | 0.899 |
| Exchangeable Ca | 0.349 | 0.649 |
| Exchangeable Mg | 0.227 | 0.771 |

## Discussion

Dry matter yield was attributed to uptake of N, P, K, Ca, and Mg that supported plant growth in both 2016-2017 and 2017-2018 seasons but to a lesser extent Mg in the 2017-2018 season. This was supported by a strong positive correlation between dry matter and N, P, K, and Ca. The BGS/CF treatments of 48/72 and 72/48 resulted in more readily available plant nutrients, which supported nutrient uptake and plant growth in both seasons. Dry matter yield in BGS/CF treatments of 48/72 and 72/48 resulted in 6.9 and 6.3 t ha$^{-1}$, respectively, compared to 5.0 t ha$^{-1}$ of CF only (0/120) and 2.8 t ha$^{-1}$ of (0/0) in the 2016-2017 season. These results were in agreement with findings of [12], who indicated that plant biomass yield of baby corn was higher in the BGS/CF treatment at 50/50% ratio than the other corresponding treatments, especially CF only (100%) treatment. Farmers could apply BGS/CF at 48/72 to take advantage of the reduced CF in the first season of planting. However, the advantage in terms of dry matter yield is lost in the second season with BGS/CF treatments of 48/72 and 72/48 having 6.9 and 6.4 t ha$^{-1}$ respectively, compared to 10.1 t ha$^{-1}$ in CF (0/120).

The huge difference from the CF only (0/120) treatment compared to 48/72, 72/48 in the 2017-2018 season can be attributed to the fact that the CF only (0/120) treatment provided nutrients at a more available form than the treatemnts of 48/72 and 72/48. The lack of differences between the two seasons for BGS/CF treatments 48/72 and 72/48, showed that the benefits of the application of BGS with CF would help in sustaining crop production and subsequently would lead to higher dry matter yields in a long term. The fact that BGS/CF treatments of 24/96 and 96/24 were among the lowest compared to other treatment combinations other than the control (0/0) for all parameters measured, suggests that these ratios may not be the best for BGS use, with limited variations as a result of seasonal differences.

The higher maize grain yield, particularly in the BGS/CF treatments of 0/120, (2.9 t ha$^{-1}$) and 48/72, (2.9 t ha$^{-1}$) in the 2016-2017 season, could be attributed to uptake of N, P, K, Ca and

Mg. This view was supported by the increased dry matter yield and high correlation between nutrient uptake and dry matter in the first season of planting. The higher dry matter yields and plant nutrient uptake obtained from the BGS/CF treatments 48/72 and 0/120 translated to higher grain yield. There is a significant benefit of co-applying the two resources at 48/72 than BGS alone in terms of maize grain yield. The reduction of CF by 40%, (48/72), resulted in a similar yield as CF alone, which could significantly reduce fertiliser costs while maintaining grain yields. Higher grain yields from BGS/CF treatments of 48/72 and 120/0 than any other treatment could be explained by higher N uptake from these particular treatments. However, the higher grain yields from BGS/CF treatment of 0/120 in the first season could not be explained by the lower N uptake observed from in that treatment. These results agreed with [29] and [30], who reported that the application of BGS/CF at 50/50% ratio resulted into similar cabbage yields when compared to CF only (100%) treatment. Contrary to these results, [12] reported that the ratio of 50/50% (BGS/CF) in an Inceptisol yielded higher grain yield for baby corn than CF only (100%) treatment, where BGS was from anaerobic digested cattle dung. The differences between the results in the literature could be a result of the quality of the BGS used.

Higher N uptake from BGS/CF treatments of 48/72, 72/48 and 120/0 than the CF only (0/120) and corntol (0/0) treatments in both seasons demonstrates the benefits of BGS. Higher N uptake observed from these treatments especially in the 2016-2017 season translated into higher dry matter yields. These results were in agreement with the findings by [12], who reported that the application of BGS/CF at 50/50% ratio resulted in higher N uptake than CF only (100%) treatment. The higher N uptake in the second season, than the first, could be attributed to possible build-up of soil total N in the second season that resulted in higher N uptake and increased dry matter yields. Higher soil total N after maize harvest in the 2017-2018 season suggests that BGS results in build-up of soil N. The results of this study were contrary with findings of [30], who reported that variation in rate of BGS/CF did not have any effect on the amount of residual total N especially after cabbage harvest. [30], explained that because cabbage in nature is a heavy feeder of N and P, therefore, the change in residual N is difficult to monitor. [7], suggested that in a single season (one), the application of BGS/CF could not result in major effects, which was the case in the first season of the current study.

Higher P uptake by maize from BGS only (120/0), 48/72 and 72/48 treatments than the CF only treatment (0/120) and the treatment of (0/0) could be explained by the increase in soil pH, which made P available for plant uptake. Soil pH observed in the first season from BGS/CF treatments of 48/72 and 72/48 was 5.93 and 6.41, respectively, that resulted in increased P availability. Most P becomes available at a pH range of 6.5 and 7.5 [31] and hence higher extractable soil P was observed from these treatments. The pH was in the optimal range in these two treatments than any other treatments with a higher and lower proportion of BGS. The highest extractable P in the treatments of 48/72 and 72/48 supports the view that high P uptake by maize in these treatments, was a result of greater availability. However, higher soil pH (pH > 7.0) observed in the second season from BGS/CF treatments of 120/0, 48/72 and 72/48 could have decreased extractable P than the first season for these treatments, due to precipitation of Ca phosphates [31].

Higher K uptake from BGS/CF treatments of 48/72 than 0/120 can be attributed to high K that was contained in BGS, hence higher K uptake. The higher uptake of K, Ca and Mg in the second season than the first, for all treatments suggested rapid accumulation of these elements that subsequently led to higher dry matter. The higher Ca uptake from BGS only (120/0), 48/72 and 72/48 treatments than CF only (0/120) and (0/0) could be attributed to the total Ca supply by the BGS resource. The higher exchangeable Ca and Mg in soil from the CF only treatment in the 2016-2017 season could be explained by lower uptake by the maize. High Mg uptake from BGS/CF treatments of 48/72, 72/48 and 120/0 in both seasons could be attributed to Mg supplied by BGS.

The higher OC, exchangeable Ca and Mg in the 2017-2018 season than 2016-2017 shows the inclusion of BGS will result in the increase in these parameters, and improve soil quality, over time. The higher soil organic C in maize from the treatment of BGS (120/0) than CF only (0/120) and other treatment combinations can be attributed to higher organic C supplied BGS. The addition of organic amendments enhances soil organic C concentration that is an important indicator of soil quality and crop productivity [32]. [33] and [34] reported that an increase in soil organic C occurs after a long-term application of organic fertiliser and that decomposition of soil organic matter in soil depends on soil pH [35]. The relatively higher soil pH in treatment that contained BGS was because of the liming effect of BGS that had pH 9.10 when compared to CF only (0/120) treatment that was relatively lower in both seasons. The digestion process during biogas production could have increased the production of ammonia, causing an increase in pH of the BGS [36;37]. The lower pH from the treatments of CF only (0/120) and (0/0) could be attributed to the nitrification process.

**Conclusion**

Co-application of BGS with CF at 48/72 and 72/48 ratios improved maize dry matter than the two resources applied separately, while only the 48/72 had the highest grain yield, similar to CF alone. In the first season, co-application at 48/72, 72/48 and BGS only (120/0) increased maize uptake of N, P, K, Ca and Mg when compared with CF, and all treatments with BGS resulted in greater uptake of these nutrients than CF and the control (0/0). There is no advantage of co-application on uptake of other nutrients when compared to BGS alone. After maize harvest, soil pH and total N increased with the proportion of BGS, and treatments with BGS, particularly the BGS only, 72/48 and 48/72 had higher organic C, extractable P, and exchangeable K with no benefit of co-application on exchangeable Ca and Mg. Smallholder farmers could apply 40-60% of the recommended $Nha^{-1}$ of CF and supplement with BGS for maximum dry matter and grain yields. Smallholder farmers could take advantage of using BGS with the reduced CF fertiliser for higher maize yields and improved soil quality. Long-term research is needed on the effect of co-application of BGS and CF on crop yields and soil quality under dryland field conditions, as practised by smallholder farmers in Sub-Saharan Africa.

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