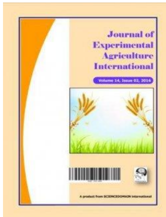

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Effect of Liquid Digestate on Agricultural Soil – I: Growth Dynamics of *Zea mays* Plant

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Authors' contributions

This work was carried out in collaboration among all authors. Author HOS designed and supervised the study, author CBO performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Author GOA managed the analyses and co-supervised of the study. Author CJU managed the literature searches and references. All authors read and approved the final manuscript.

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ABSTRACT

The study was designed to model the effect of liquid digestate on growth dynamics of *Zea mays* plant. Maize seeds were subjected to various concentrations of liquid digestate (between 0% and 72%) using One-Factor Response Design with a total of ten (10) runs in 10L-capacity plastic pots containing 10kg of loamy soil. One set of experimental runs were treated with one-time application of the corresponding digestate concentration (OTDA). Another set of experimental runs were treated with two-time application of the corresponding digestate concentration (TTDA). The first application of the liquid digestate (for OTDA and TTDA) was conducted two weeks after sowing while the second application (for TTDA alone) was conducted three weeks after the first application. The height of maize plant in all set-ups was monitored for a period of 70 days. After the 70-day period, the plants were harvested for biomass estimation. In the soil set-ups treated with OTDA, crop growth rate (1.077cm/day) and biomass yield (22.37g/kg of digestate) of *Zea mays* plant peaked

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with 48% digestate after 70 days. In the soil set-ups treated TTDA, crop growth rate (1.321cm/day) and biomass yield (29.95g/kg) of *Zea mays* plant peaked with 72% digestate after the same period. Optimum response generated for the crop growth rate of *Zea mays* plant was approximately 1.038 cm/day with a standard error of 0.014 for the OTDA treatment and 1.165cm/day and a standard error of 0.006 for the TTDA treatment at digestate concentration of 50% with a desirability of 0.928 respectively. Optimum response generated for biomass yield of the *Zea mays* plant was approximately 22.488 (g/kg) with a standard error of 0.621 for the OTDA treatment and 27.292 (g/kg) with a standard error of 0.399 for the TTDA treatment at digestate concentration of approximately 47.1% and a desirability of 0.930 respectively. The result suggests that the TTDA treatment method may have enhanced the growth of the maize plant better than the OTDA treatment method.

Keywords: Liquid digestate; Mode of application; Growth dynamics and Zea mays.

1. INTRODUCTION

Anaerobic digestion process produces three valuable components from organic matter namely, biogas, liquid digestate and solid digestate [1]. Biogas production from anaerobic digestion of organic matter has increased in recent years, therefore, the application of digestates to the soil as biofertilizers has become more common [2]. Both liquid and solid digestates are rich in nitrogen (N), phosphorus (P), and potassium (K) but contain lower total carbon [3,4,5,6]. As an organic fertiliser, it provides a sustainable substitute to synthetic fertilisers for organic crop production [7,8,9,10, 11,12]. Furthermore, mechanical solid-liquid separation of digestates efficiently leads to an enrichment of phosphorus (P) in the solid phase, whereas nitrogen (N) is often found in higher concentrations in the liquid phase [13]. Because of this, the effect of these forms of digestates on soil ecosystems may vary [14]. Anaerobic digestion process uses only the C, but the N, P, K, and other micronutrients remain intact [15].

All organic fertilisers have the potential to stimulated organic food production when applied to the farming ecosystem. However, different feedstocks and anaerobic digestion treatments generate digestates of differing chemical composition compared to undigested organic matter. This may affect the soil microbial ecosystem and plant growth differently when used as fertilisers [7,16,17]. Moreover, the presence of macro and micro elements in most digestates make them excellent form of fertilizer when applied correctly [18,19,20,21,22,23,24, 25]. In order to fully exploit biogas digestate in crop production, it is necessary to test its performance in the soil-plant ecosystem by investigating its effect on different soil types, plant growth and greenhouse gas (GHG) emission [26,27,28,29,30,31,32]. As organic farming prohibits the use of synthetic fertilizers on agricultural soils, digestate from anaerobic digestion of organic matter seem to offer a better alternative to these as well as undigested organic matter, which are sometimes used [24,33,34,35, 36]. This is because the digestate have properties that are different from that of undigested organic matter and considering the pros and cons, digestate does have positive effects for the climate, the environment and for the farmer compared to the use of undigested organic matter as fertiliser [37]. This study aimed to model the effect of liquid digestate on growth dynamics of maize (*Zea mays*) plant.

2. MATERIALS AND METHODS

2.1 Cultivation of *Zea mays* (TZESR-W Variety)

Collection and characterisation of the liquid digestate and the loamy soil used for cultivation of the test plant (*Zea mays*) were carried out as described by [38]. The liquid digestate was obtained from a pilot-scale anaerobic digester (AD_H) treating organic municipal solid waste while the loamy soil was obtained from an agricultural field at the Nigerian Institute for Oil Palm Research (NIFOR) in Edo State, Nigeria. In order to model the effect of the liquid digestate on growth dynamics of *Zea mays* (the test plant), we subjected the *Zea mays* (TZESR-W; early maturing streak resistant white grain variety) to various concentrations (ranging from 0% to 72%) of the digestate using One-Factor Response Design (Design Expert version 9.0) as described by Ogbonna et al. [38]. After completely loading the pots with the loamy soil, two seeds of the *Zea mays* were sown into the soil in each of the pots at a depth of 5cm per hole. The independent variable selected was digestate concentration

(%) while the dependent variables were the crop growth rate (cm/day) and biomass yield (g/kg) of the maize plant. After sowing, one set of experimental runs were treated with a one-time application of the corresponding digestate concentration. This was tagged "One-time Digestate Application (OTDA)". However, the other set of experimental runs were treated in such a way that the total amount of the liquid digestate required for each pot was divided into two equal halves and applied at different times instead of applying all of it at once. This was tagged "Two-time Digestate Application (TTDA)". The first application of the liquid digestate (for OTDA and TTDA) was conducted two weeks after sowing while the second application (for TTDA alone) was conducted three weeks after the first application [38]. The liquid digestate (as bio-fertiliser) was applied by spraying into the soil in the pots. The growth (i.e., height) of maize plant in all the set-ups was monitored for seventy (70) days.

2.2 Analysis of Growth Parameters of *Zea mays* Plant

Growth parameters of *Zea mays* plant were determined as described by Laekemariam and Gidago [39]. The average height of maize plants in the set-ups was estimated using a thread and a meter ruler with time. The growth rate of maize plant was estimated using the formula in equation one (1). At the end of the 70-day observation period, the maize plants in each experimental set-up were uprooted from the soil in the pots and loosed soil attached to the root of the plants was washed off. Afterwards, the plants were blotted to remove free surface moisture. Next, the plants were respectively weighed on a digital weighing scale to determine their wet weight. The plants were placed in an oven set at low heat (45°C) overnight to dry them. Next, the maize plants were allowed to cool-off before weighing them on the digital weighing scale to determine their dry weight. Dry biomass yield of the plant (concerning the concentration of the digestate applied) was estimated using the formula in equation 2.

Crop growth rate (cm/day) = (Total height reached by maize plant/ Total number of days it took to reach the height) (1)

Plant biomass Yield (g/kg) = (Weight (or mass) of dry maize plant/ The total mass of liquid digestate applied) (2)

2.3 Statistical Analysis

Within the Design Expert (DX version 9.0) software environment, the data of one-factor response design was subjected to regression analysis in other to obtain the parameters required for modelling the crop growth rate and biomass of *Zea mays* plant concerning digestate concentration.

3. RESULTS AND DISCUSSION

3.1 Properties of the Digestate and the Soil

The properties of the liquid digestate and the loamy soil used to cultivate the maize plant are presented in [38]. This particular result showed that elements (or compounds) such as carbon (as total organic carbon), total nitrogen, ammonial nitrogen, phosphorus, potassium, calcium, magnesium, manganese, zinc, copper, nickel, cobalt, iron, and molybdenum, which are known to be beneficial for plant growth at the appropriate concentrations were higher in the digestate compared to the soil [40]. Some heavy metals such as copper, zinc, lead, cadmium, mercury and chromium were also present in the digestate. However, their concentrations appeared to be very low [38].

3.2 Growth Dynamics of Maize Plant

The response surface plots presented in Fig. 1, Fig. 2, Fig. 3 and Fig. 4 for set-ups treated with OTDA and TTDA respectively show how crop growth rate (cm/day) and biomass yield (g/kg) of *Zea mays* plant varied as a function of digestate concentration (%). For each response, the dotted lines represent the 95% confidence band on the mean prediction at any given digestate concentration (%). The solid line represents the mean prediction according to the model in Equation 3, 4, 5 and 6 for crop growth rate and biomass yield of the *Zea mays* plant concerning digestate concentrate (%). The points on the response surface plot represent the actual response. In the control (with 0% digestate application), crop growth rate and biomass yield of *Zea mays* plant was 0.624cm/day and 8.46g/kg of the liquid digestate after 70 days respectively. In the soil set-ups treated with one-time digestate application (OTDA), crop growth rate (1.077cm/day) and biomass yield (22.37g/kg of digestate) of *Zea mays* plant peaked with 48% digestate after 70 days (See Figs. 1 to 4). However, in the soil set-ups treated with two-time digestate application (TTDA), crop growth rate (1.321cm/day) and biomass yield (29.95g/kg of digestate) of *Zea mays* plant peaked with 72% digestate after 70 days (See Figs. 1 to 4).

Two-way ANOVA showed that there was a significant a difference (P<0.05) in crop growth rate (cm/day) of *Zea mays* plant with respect to the concentration (%) of digestate however, there was no significant difference (P>0.05) in crop growth rate with respect to the mode of application (i.e., OTDA or TTDA) of the digestate. Furthermore, there was a significant difference (P<0.05) in biomass yield of *Zea mays* plant concerning the concentration (%) and mode of application of the liquid digestate respectively. This suggests that the concentration and mode of application of the liquid digestate (as organic fertilizer) may have significantly influenced biomass yield of the crop with time [27,28,29, 30,31,32,41]. It also suggests that the two-time mode of digestate application (TTDA) may have promoted the growth of the *Zea mays* plant better than the one-time digestate application (OTDA) treatment mode.

3.3 Optimization of Growth Parameters of the *Zea mays*

ANOVA for the Response quadratic models shown in equation 3 and equation 4 suggests that the regression models fitted to the first response (i.e., crop growth rate of *Zea mays* of the plant) in set-ups treated with OTDA and TTDA respectively are statistically significant (at $p < 0.05$). Their adjusted R^2 (0.9561 for OTDA and 0.9968 for TTDA) show that the models could adequately explain about 95.61% and 99.68% of the variation observed in crop growth rate of *Zea mays* in set-ups treated with OTDA and TTDA concerning the concentration (%) of the liquid digestate. Furthermore, ANOVA for the Response sixth and fifth models shown in equation 5 and equation 6 suggest that the regression models fitted to the second response (i.e., biomass yield of *Zea mays* of the plant) in set-ups treated with OTDA and TTDA respectively are statistically significant (at $p < 0.05$). Their adjusted R^2 (0.9639 for OTDA and 0.9979 for TTDA) show that the models could adequately explain about 96.39% and 99.79% of the variation observed in biomass yield of *Zea mays* in set-ups treated with OTDA and TTDA concerning the concentration (%) of liquid digestate. The final equations regarding actual factors, which describe how crop growth rate (cm/day) and biomass yield (g/kg) of *Zea mays* changed with digestate concentration (%) for OTDA and TTDA treatments are presented below.

$$CGR_{OTDA} = 0.58690 + 0.020376*D - 2.27214E\text{-}004*D^2 \quad (3)$$

$$GR_{TTDA} = 0.61389 + 0.013659*D - 5.29119E\text{-}005*D^2 \quad (4)$$

$$BY_{OTDA} = 8.5299 - 0.42097*D + 0.14354*D^2 - 9.83512E\text{-}003*D^3 + 2.96252E004*D^4 - 4.03071\text{-}E006*D^5 + 2.00907E\text{-}008*D^6 \quad (5)$$

$$BY_{TTDA} = 8.39283 + 0.661708*D - 0.054134*D^2 + 2.50630E\text{-}003*D^3 - 4.15732E\text{-}005*D^4 + 2.27160E\text{-}007*D^5 \quad (6)$$

Where CGR is crop growth rate, BY is biomass yield, OTDA is one-time digestate application and TTDA is two-time digestate application.

The optimum response (in Fig. 5) generated for crop growth rate of *Zea mays* plant was approximately 1.038 cm/day with a standard error of 0.014 for the OTDA treatment and 1.165cm/day with a standard error of 0.006 for TTDA treatment at digestate concentration of 50% and desirability of 0.928 respectively. The optimum response (in Figure 6) generated for biomass yield of *Zea mays* plant was approximately 22.488 (g/kg of digestate) with a standard error of 0.621 for the OTDA treatment and 27.292 (g/kg of digestate) with a standard error of 0.399 for TTDA treatment at digestate concentration of approximately 47.1% and a desirability of 0.930 respectively.

In set-ups treated with one-time digestate application (OTDA) and two-time digestate application (TTDA), the correlation between crop growth rate (cm/day) of maize plant and concentration of the liquid digestate was positive. However, this positive relationship was moderate ($r = 0.646$) for OTDA treatment mode but very strong ($r = 0.993$) for TTDA treatment mode. Likewise, the relationship between biomass yield (g/kg) of maize plant and concentration of the digestate (%) was positive for OTDA and TTDA treatment modes. However, this positive relationship was moderate ($r = 0.503$) for OTDA treatment mode but very strong ($r = 0.975$) for TTDA treatment mode.

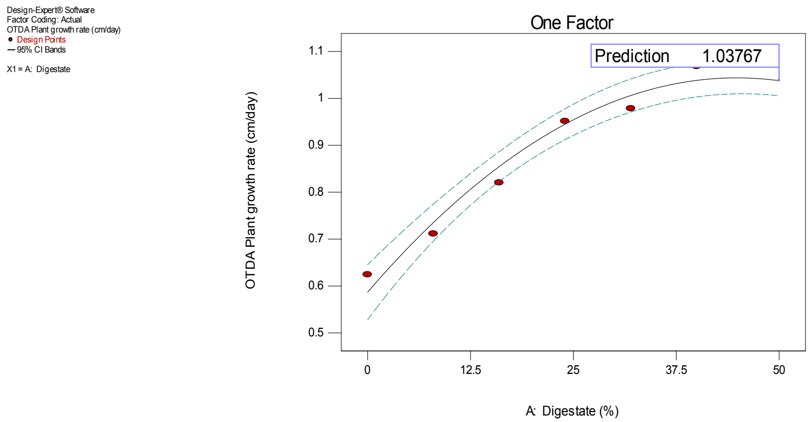

Fig. 1. Growth rate of *Zea mays* after 70 days for OTDA Set-up

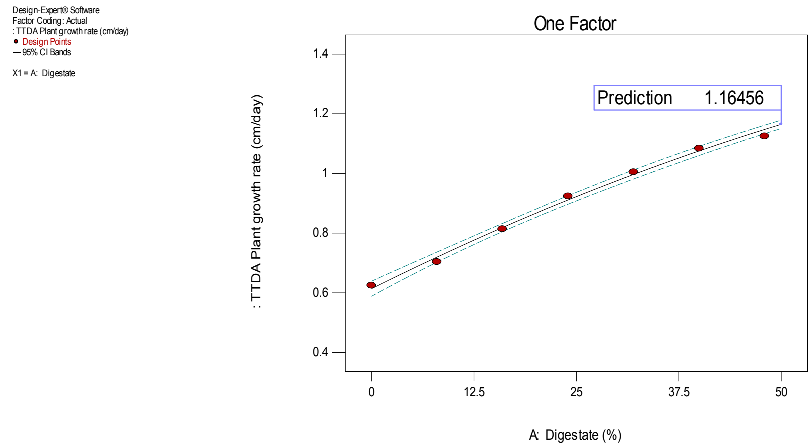

Fig. 2. Growth rate of *Zea mays* after 70 days for TTDA Set-up

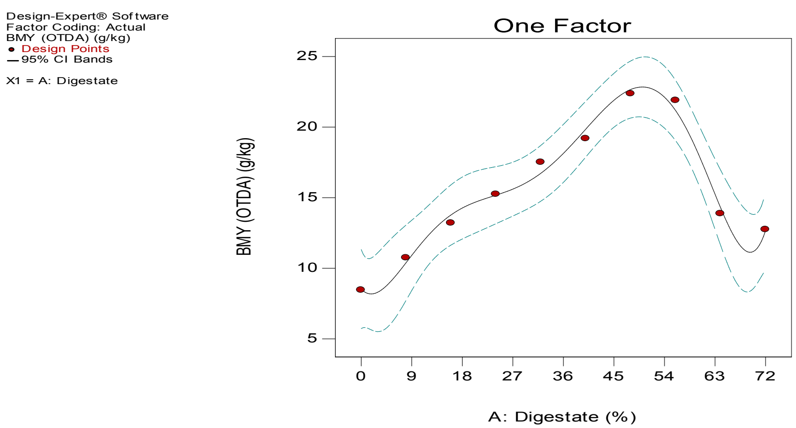

Fig. 3. Biomass yield of *Zea mays* after 70 days for OTDA

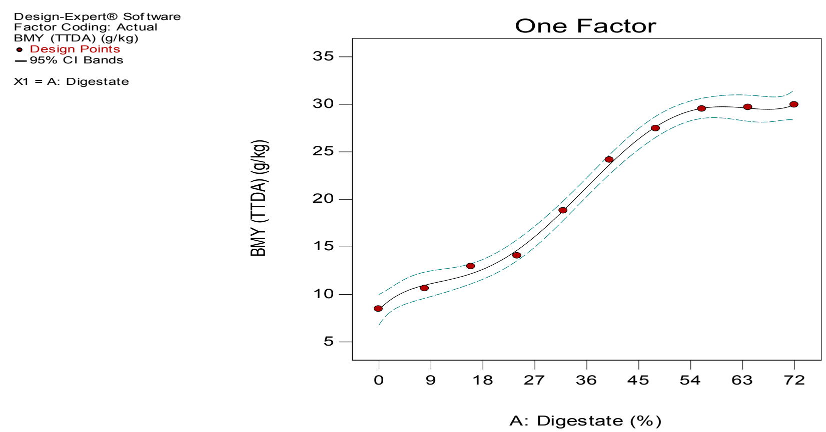

Fig. 4. Biomass yield of *Zea mays* after 70 days for TTDA

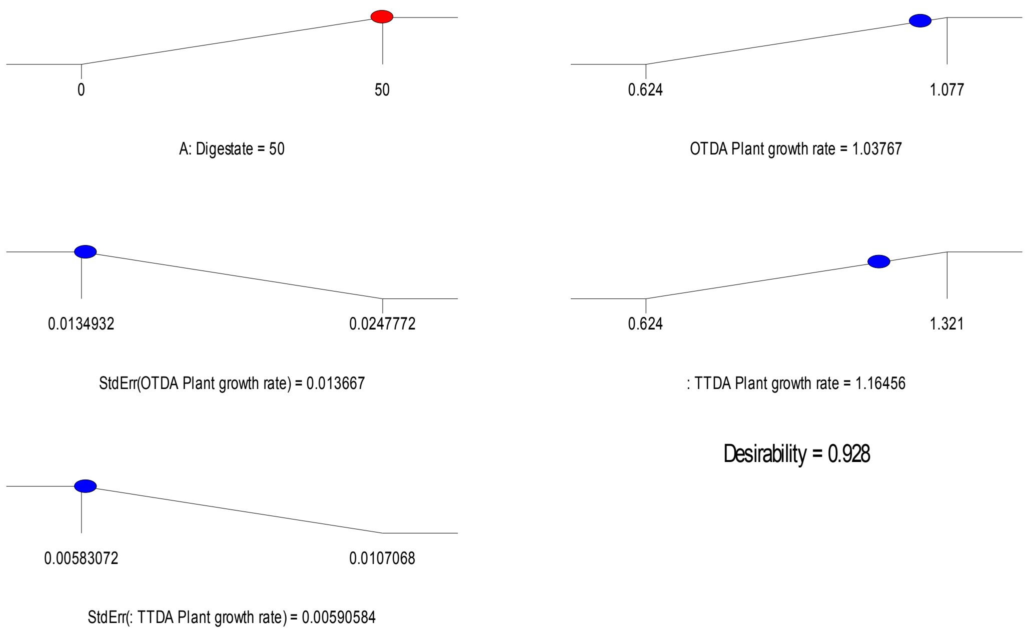

Fig. 5. Ramps of solution for optimum digestate concentration (%) and the corresponding growth rate of maize plant (cm/day) for OTDA and TTDA respectively.

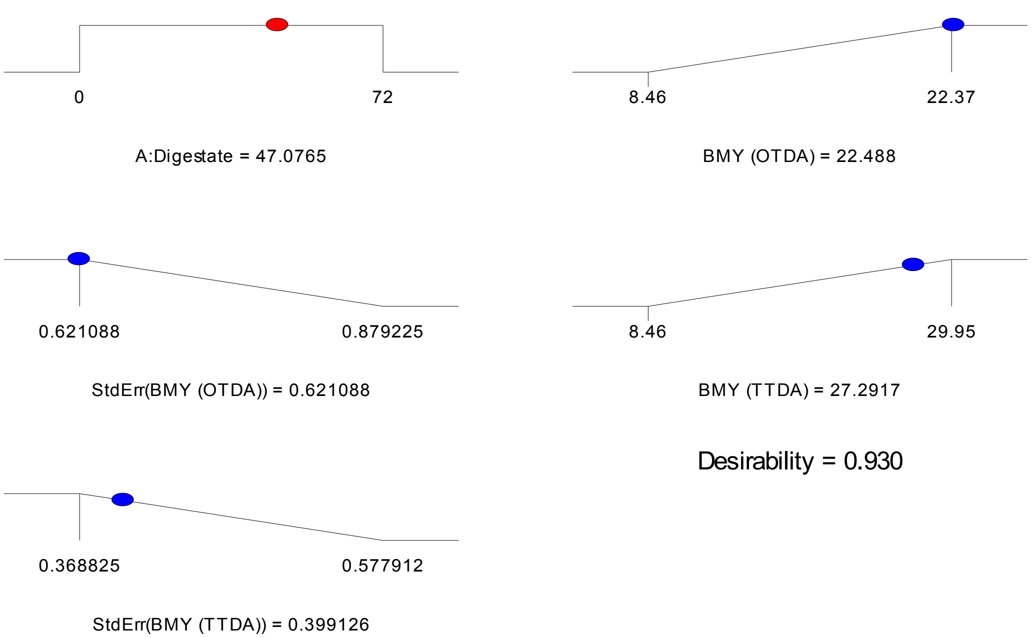

Fig. 6. Ramps of solution for optimum digestate concentration (%) and the corresponding biomass yield of maize plant (g/kg of digestate) for OTDA and TTDA respectively.

4. CONCLUSION

The result suggests that the TTDA treatment method may have enhanced the growth of *Zea mays* plant better than the OTDA treatment method. Therefore, it can be concluded that the two-time mode of digestate application (TTDA) performed better than the one-time mode of digestate application (OTDA) in regards to the height gained with time and biomass yield respectively.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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