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Optimization of biosolids as a substrate for tomato transplant production

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Key words: biosolids, quality, seedling growth, *Solanum lycopersicum* L., substrate, tomato.

Abstract: The need to recycle waste and increasing pressure against peat extraction and importation, have led to increasing interest in substituting peat with organic wastes. Use of biosolids substrate would be a low cost alternative substrate to peat for commercial production of transplants. The objective of this study was to determine the effect of biosolids-forest soil mixture ratios on tomato 'Maxim F1', transplants emergence and growth. A randomized complete block design with four replications was used in this study. The treatments were: biosolids (BS) mixed with forest soil (FS) at rates of 0% 10%, 20%, 30%, 40%, 50% and 60% (v/v), tea compost (TC) and coco peat (CP). Five tomato seeds were planted in four 250 cm^3 pots, grouped into four to form an experimental unit. Results showed that biosolids (BS) at rate of 30% registered significantly (*p*<0.05) higher seedling emergence (94%), leaf numbers (4.5), height (16.5 cm), collar diameter (6.3 mm), chlorophyll content (25 index units), root volume (2.0 cm^3) and root/shoot dry matter (10.2 % and 16.3%, respectively) than the rest of the substrates except tea compost (TC). Sodium was significantly (*p* < 0.05) higher in BS at rates of 50% (350 mg kg^{-1}) and 60% (376 mg kg^{-1}) and this raised EC (4.5) and lowered pH of the media to 4.4. At 30% BS enhanced tomato transplant production to similar level as tea compost, hence recommended for commercial use.

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All relevant data are within the paper and its Supporting Information files.

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The authors declare no competing interests.

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1. Introduction

Tomato (*Solanum lycopersicum* L.) can be established in the field by direct seeding or transplanting. Tomato production by transplanting has been done over the past two decades to increase resource use efficiency and reduce environmental impact on seeds planted (Restrepo *et al.*, 2013). Cultivation from transplants has many advantages including earlier harvest; more efficient use of land, time, energy, and seeds; and healthy and homogenous production (Pascual *et al.*, 2018). In comparison with direct sowing, transplanting is a more reliable method of ensuring higher plant survival, faster establishment, improved plant uniformity, early maturity, and reduced cost of production (Gogo *et al.,* 2012). The production of tomato seedlings, especially in sub-Saharan Africa with great expansion of open field and greenhouse crops, is a highly competitive business. Besides, uniform and rapid seed emergence and quality are essential prerequisites to increasing tomato yield, quality, and profits (Wachira *et al*., 2014). In addition, tomato seeds especially F1 hybrids are expensive and farmers in developing countries cannot tolerate poor germination as a result of poor soil conditions (HCD, 2017). Use of ideal transplant substrates with appropriate physicochemical properties, is therefore critical (Sterrett, 2001).

In transplant production, the main purpose of a substrate is to satisfy the needs for good seedling growth within the limited space of a container and to prepare the seedlings for successful transplanting into the field (Pascual *et al*., 2018). The quality of growing media is one of the main factors influencing the success of horticultural nursery activity (Raviv and Lieth, 2008), and it is also directly linked to the quality of the materials utilized in growing media formulations (Reis and Coelho, 2007). The choice of appropriate substrate is therefore an important factor in promoting the optimum growth of plants. A number of potential substrates have been identified, of which Peat moss has long been the primary component of transplant and potting media for both vegetable and ornamental plants. This has been mainly due to its physical and chemical properties (Raviv *et al*., 1986): adequate free air space (FAS) at 0-10 cm water suction; high water content at low tension at 10-100 cm water suction; and high cation exchange capacity (CEC) minimizing loss of nutrients and facilitating adequate mineral nutrition (Colla *et al.,* 2007). However, peat also has some notable disadvantages; being conducive for the development of some soil-borne plant pathogens such as *Pythium* and *Rhizoctonia* (Hoitink and Kuter, 1986). Furthermore, Peat moss is normally harvested from wetland ecosystems at rates considered non-sustainable by wetland ecologists (Buckland, 1993). These drawbacks have motivated horticulturists throughout the world to seek alternatives like coir (coco peat) which has several qualities: high water-holding capacity, excellent drainage, absence of weeds and pathogens, renewable resource, with no ecological drawbacks to its use, acceptable pH, cation exchange capacity (CEC) and electrical conductivity (EC) and easier wettability (Cresswell, 1992). Under nursery conditions, coco peat and peat moss have been used as reliable media for organic production of lettuce transplants (Colla *et al*., 2007). However, coco peat has become more expensive and its properties are more variable (Chrysargyris *et al*., 2013). Thus, it is important to look for high quality, locally available and low-cost alternative substrates.

Among the organic substrates for transplants production, Vermicompost is a promising substitute for peat especially in the production of seedling, but not a sustainable solution for management of organic wastes (Ivanka and Tsvetanka, 2012). Use of biosolids from treated sewage, has been proven to be promising (Vyas, 2011; Giannakis *et al*., 2014). The effects of biosolids on seedling emergence and growth have been investigated by Chrysargyris and Tzortzakis (2015) and their results indicated that application of boisolids as a substrate in marigold (*Tagetes erecta* L.) and basil (*Ocimum basilicum* L.) seedlings production has potential. Similarly, use of organic urban waste compost for tomato (*Solanum lycopersicum* L.) transplant production has been reported to result in quality transplants in the seedbed (Herrera *et al*., 2008). Chrysargyris and Tzortzakis (2015) specified biosolids as an ideal component of mixed-peat substrates for eggplant (*Solanum melongena* L.) seedlings, at a rate less than 30% in a substrate mixture. In another study on cucumber transplants production, Mami and Peyvast (2010) recommended the use of biosolids at 5% and below on peat mixture. However, the use of biosolids as substrates depending on the ratios may have negative effects as a consequence of its high salt content, unsuitable physical properties (texture, structure, moisture content, porosity etc.), heavy metal toxicity, and variable quality and composition (Papamichalaki *et al*., 2014). The appropriate amount of biosolids added in growth medium needs to be determined to improve plant growth. Therefore this study investigated the the effect of biosolids-forest (BS: FS) soil mixing rates on tomato transplant emergence and growth.

2. Materials and Methods

Site description

This study was conducted in two trials at the Horticulture Research Field, Egerton University, Kenya during January to February and March to April, 2018. The site is located on latitude 0 23’ S and longitude 35 35’ E in the lower highland III (LH3) agro ecological zone at an altitude of 2238 m above sea level (Jaetzold *et al*., 2012). The experiments were done in an area measuring 1.2 m by 3.5 m within a plastic greenhouse size 8 m by 60 m and a height of 3 m. The greenhouse covering material was UV stabilized polythene sheet gauge 150 µm from Amiran, Co Ltd Nairobi Kenya. Greenhouse microclimatic condition, temperature and relative humidity averages were as follows; day (6:00 AM-6:00 PM) and night (6:00 PM-6:00 AM) air temperatures inside the greenhouse during the experiment were 24.5±0.9°C and 13.3±4°C, respectively. Average day and night relative humidity inside the greenhouse were 55±6% and 80±6%, respectively.

Biosolids and forest soil sample collection, substrate preparation and analysis

Biosolids (BS) were collected from a lagoon pond at Egerton University Wastewater Treatment Plant and forest soil obtained from typically tropical forest. The substrates for transplants production were prepared by mixing the biosolids and forest soil (BS: FS at rates of 0, 10, 20, 30, 40, 50 and 60% (v/v). Samples from each rate, tea compost (TC) and coco peat (CP) as reference commercial substrates were comprehensively analysed in a laboratory to determine the physico-chemical characteristics of the substrates (Table 1). Porosity of each substrate was calculated from the ratio of the determined bulk density and of known particle density (2.65 g cm^{-3}) as given in the equation given below (Okalebo *et al.,* 2002):

$$\text{Porosity (\%)} = 1 - (\text{Bulk density} / \text{Particle density}) \times 100).$$

Experimental set up and design

The experimental design was randomized complete block design (RCBD), replicated four times. The treatments included seven BS: FS soil mixtures at different rates and two commercial substrates TC and CP. In the experiment, plastic pots (250 cm^3) were used for potting the substrates. An experimental unit composed of four pots, each planted with four tomato 'Maxim F1' seeds.

Transplants establishment and Irrigation schedule

Tomato seeds were planted in the pots in the evening and substrates watered to saturation point. After 24 hours each substrate was irrigated with 15 ml of water after every 12 hours for the first 15 days. The volume of water was increased to 20 ml for the next 10 days, then 25 ml for the remaining days of the experiment.

Determination of seedling emergence and growth

The number of emerging seedlings was recorded. Based on the number of planted seeds (20), seedling emergence percentages were computed progressively after 7, 9 and 11 days after planting (DAP). Germination percentage was determined using equation adopted by Atif *et al.* (2016), with modification

Table 1 - Physico-chemical characteristics of the substrate used for tomato transplant production

Characterization/substrates	FS	BS 10%	BS 20%	BS 30%	BS 40%	BS 50%	BS 60%	TC	CP
Bulk density (g cm^{-3})	1.7	1.6	1.5	1.3	1.3	1.3	1.3	1.3	1.2
Porosity (%)	35.9	39.6	43.4	50.9	50.9	50.9	50.9	50.9	54.7
Moisture content (%)	25.8	34	40.8	42.8	44.5	45.1	45.9	44.7	45.3
EC (mS m^{-1})	2.6	3.2	3.6	4.4	5.1	5.2	5.4	4.3	5.2
pH	7.4	6.2	6.6	6.5	6.4	5.6	5.4	7.4	7.4
Organic matter (g kg^{-1})	157.7	197.8	196.7	210	209.8	220	222.9	207.2	171.4
C:N	21.3	19.7	15.4	9.6	12.7	14.7	12.5	7.6	10.8
Total Carbon (mg g^{-1})	91.7	115.0	114.4	122.1	122.0	127.9	129.6	120.5	99.6
Total N (g kg^{-1}) **(0.1)** ^{y}	4.3	5.9	7.4	12.9	9.6	8.9	10.5	16.3	9.2
Total P (mg k g^{-1}) **(70)** ^{y}	69.1	83	90.3	101	95.9	79.3	70.3	116.1	33.8
K (mg kg^{-1}) **(700)** ^{y}	132.5	412.3	419.9	427.8	422.4	403.7	403.5	369.6	344.1
Ca (mg kg^{-1}) **(1000)** ^{y}	21.9	24	22.8	29.5	27	28.5	27.5	43.5	38.5
Mg (mg kg^{-1}) **(700)** ^{y}	131.1	126.1	117.7	119.1	113.8	47.7	37.2	126.6	114.6
Na (mg kg^{-1})	62.9	254.8	342.1	252.8	348.3	349.8	376.3	114.8	164.4
Mn (mg kg^{-1}) **(20)** ^{y}	69.6	530.4	524.8	539.4	553.9	551.9	544.8	167	29.8
Fe (mg kg^{-1})	27	2490	2473.9	2479.1	2471.5	1184.1	852.5	207.4	114.1
Zn (mg kg^{-1})	4.7	47.4	44	44	45.9	24.4	25.4	21.9	16.4
Cu (mg kg^{-1}) **(100)** ^{z}	4.4	12.2	12.7	10.3	12.7	13.1	13.3	14	6.5
Cd (mg kg^{-1}) **(1)** ^{z}	0.0023	0.0128	0.0115	0.0117	0.0122	0.0122	0.0122	0.0122	0.0121
Pb (mg kg^{-1}) **(150)** ^{z}	109.6	2.8	2.1	5.1	3.1	6	2.5	20.1	4.3

^{y} Recommended levels of nutrient in soil for tomato production according to Sainju *et al*. (2003).

^{z} Maximum ceiling values of heavy metals for agricultural land application according to NSW EPA (2000).

as given below:

$$G\ (\%) = (S_2 / S_1) \times 100$$

Where G is the germination percentage, S_1 is total seeds planted and S_2 seeds germinated.

Ten tomato seedlings were randomly selected and tagged for data collection on growth parameters. Seedling height, collar diameter, leaf number and leaf chlorophyll content were determined 14, 21 and 28 DAP. Seedling height was determined using a measuring tape from the ground level to the tip of the seedling. For stem diameter, a stainless hardened 150 mm LCD electronic digital vernier mark (Grainger, USA) was used. The unit of measurement was millimeters (mm). The stem diameter was measured on the main stem of the plant at 1 cm above the substrate. Number of leaves was determined by counting the true leaves.

Determination of transplant leaf chlorophyll content

This was determined using a chlorophyll content meter (CCM-200) plus; Opti-Sciences, Tyngsboro, MA). Estimate of chlorophyll content was in chlorophyll concentration index units (CCls). Three readings of chlorophyll content were taken on the third newly developed leaflet from the top of each tomato plant and means were computed for each replication. The Leaf chlorophyll was measured using SPAD chlorophyll meter (Minolta SPAD502 meter, Tokyo, Japan). Pengfei (2017) reported that SPAD values have a direct linear relationship with extracted leaf chlorophyll therefore, SPAD value was used to describe leaf chlorophyll index units (CCls) in the current study.

Determination of root volume and root/shoot dry weight

During seedling harvesting on the fourth week (28 DAP), four seedlings were randomly selected and carefully uprooted. The roots were washed clean in running tap water on a sieve of pore diameter of 1 millimeter. Separation of tomato transplant roots and shoot was done at the crown level. Root volume, was determined by scanning plant roots using Epson Expression 10000XL color image scanner and analyzed using Winrhizo software (LA 2100-Regent Instruments Inc.) as described by Mwamlima *et al*. (2019).

Separated shoot and root plant parts were dried in an oven to constant weights at 60°C for 24 h as described by Hossain *et al.* (2008). Mean weights of dried samples were taken as shoot and root biomass per plant. The roots and the shoots of the randomly selected four plants were also used to determine dry weight. This was done by oven drying the roots and shoots of the seedlings at 105°C until constant weight was achieved. Percentage dry root and shoot weight was then computed based on the initial fresh weight according to equation below (Atif *et al*., 2016):

$$RDMA\ (\%) = DW\ (g) / FW\ (g) \times 100$$

where RDMA; root dry matter accumulation in percentage, DW; dry weight (g) and FW; fresh weight (g).

Data analysis

Data analysis was carried out using statistical package SAS version 9.1 (SAS Institute, Cary Inc., 2001). Data for the two trials were pooled and subjected to analysis of variance (ANOVA) at $p \leq 0.05$ and means for significant treatments separated using Tukey's Honestly Significant Difference (HSD) test at $p < 0.05$. The model fitted for the experiment was $Y_{ij} = \mu + \beta_i + \alpha_j + \varepsilon_{ij,}$ where, y_{ij} = tomato response, μ = overall mean, β_i = effect of the i^{th} block, α_j = effect of the j^{th} level of substrates ε_{ij} = random error term, i = 1, 2, 3, 4; j= 1, 2, 3 …9.

3. Results

Seedling emergence

The substrates tested influenced the emergence of tomato seedlings differently (Fig. 1). Tea compost (TC) and biosolids (BS) at 30% had the highest emer-

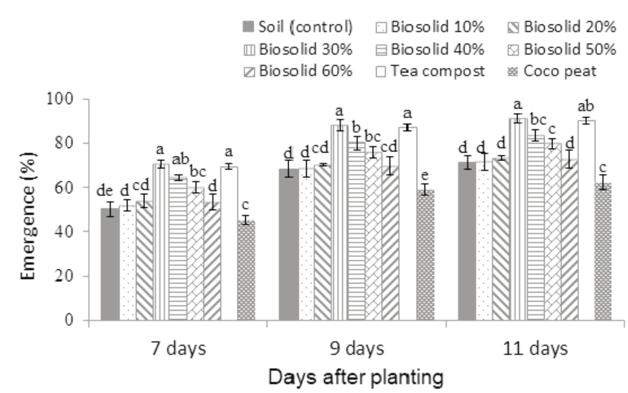

Fig. 1 - Effect of biosolids on emergence of tomato seedlings. Means ± standard deviation followed by the same letter within a day after planting are not significantly different according to Tukey's HSD test (p<0.05). FS = Forest soil; BS = Biosolids; TC = Tea compost; CP= Coco peat.

gence percentage compared to the rest of the substrates throughout the evaluation, while Coco peat (CP) had the lowest emergence percentage. From day 7 to day 11 after planting, BS at 30% was significantly ($p<0.05$) higher (90-95%) in seedling emergence and this was not significantly ($p<0.05$) different from that of TC (commercial substrate). At day 7, the control forest soil (FS) was not different from CP (another commercial substrate).

Plant height

Biosolids (BS) application rates influenced tomato seedling height during the growing period. A part from BS at the rate of 30% and TC, which produced the tallest transplants, there were no significant ($p<0.05$) difference among the rates of 20%, 40% 50% and 60% in plant height. Biosolids at 30% was consistently similar to tea compost (TC) in producing taller tomato seedlings 14, 21 and 28 days after planting (DAP). However, the shortest plants were obtained with forest soil (FS) and coco peat (CP) (Fig. 2).

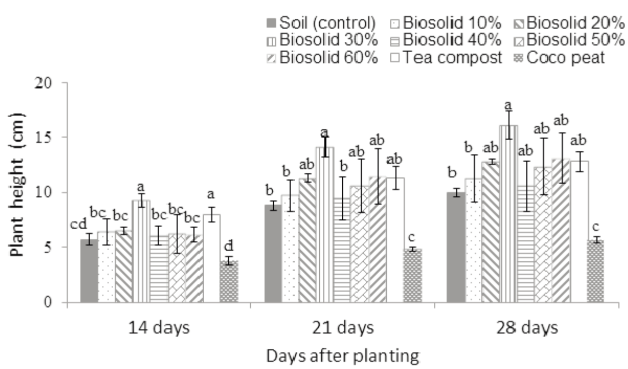

Fig. 2 - Effect of biosolids on tomato seedling height. Means ± standard deviation followed by the same letter within a day after planting are not significantly different according to Tukey's HSD test ($p<0.05$).

Leaf number

On tomato leaf number, BS at the rate of 30% was similar to TC in recording significantly ($p<0.05$) higher number of leaves per tomato plant throughout the period of the experiment (Fig. 3). However, there was no significant difference between BS rates within the range of 10% to 40% on 14, 21 and 28 DAP. The lowest tomato leaf number was obtained with FS and CP. Biosolids at 50 and 60% resulted in significantly ($p<0.05$) lower number of leaves than BS at 30% on 14 and 28 DAP.

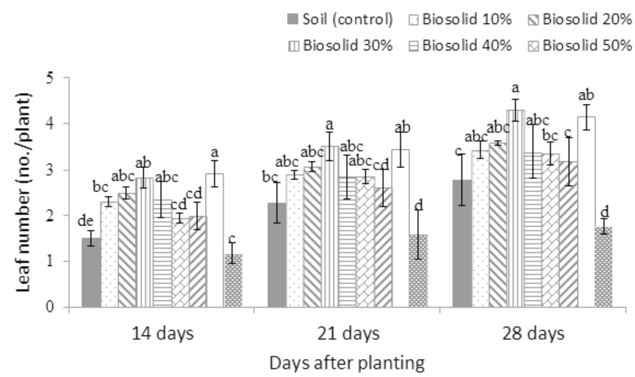

Fig. 3 - Effect of biosolids on tomato seedling leaf number. Means ± standard deviation followed by the same letter within a day after planting are not significantly different according to Tukey's HSD test ($p<0.05$).

Collar diameter

Application of biosolids at 30% resulted in the widest collar diameter of tomato seedlings throughout the period of the experiment (Fig. 4). At 14 DAP, all the treatments except tea compost recorded significantly ($p<0.05$) narrower collar diameter than BS at 30%.

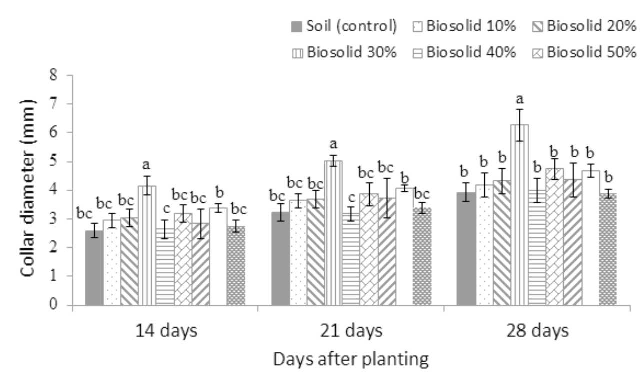

Fig. 4 - Effect of biosolids on tomato seedling collar diameter. Means followed by the same letter within a day after planting are not significantly different according to Tukey's HSD test ($p<0.05$).

Leaf chlorophyll content

Tomato transplants grown on biosolids at 30% had significantly ($p<0.05$) higher leaf chlorophyll content compared to the rest of the treatments (Fig. 5). Using coco peat (CP) resulted in transplants with the lowest chlorophyll content. However, there was no much difference in physical appearance of the leaf colour (Plate 1).

Root volume

Tomato transplants root volume was affected by use of biosolids (Fig. 6, Plate 2). Biosolids at 30% resulted in significantly (p<0.05) higher root volume than the forsest soil, coco peat and the other tested rates of BS. However, there was no significant difference in root volume between tomato transplants grown on biosolids at 30% and tea compost.

Root and shoot dry weight

There was similar response of transplants to different substrates in terms of roots and shoot dry weight (Fig. 7). Transplants grown on biosolids at 20% or 30% had significantly (p<0.05) higher root dry weight, which was similar to that obtained with tea compost. In addition, biosolids at 30% and tea compost similarly recorded significantly (p<0.05) higher shoot dry weight than all the other treatments. Forest soil and coco peat resulted in the lowest root and shoot dry weight.

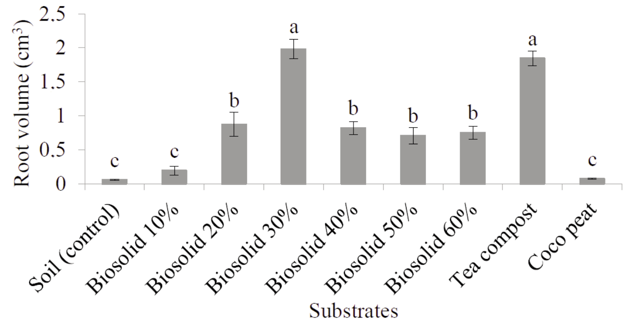

Fig. 6 - Effect of biosolids on tomato root volume. Means ± standard deviation followed by the same letter are not significantly different according to Tukey's HSD test (p<0.05).

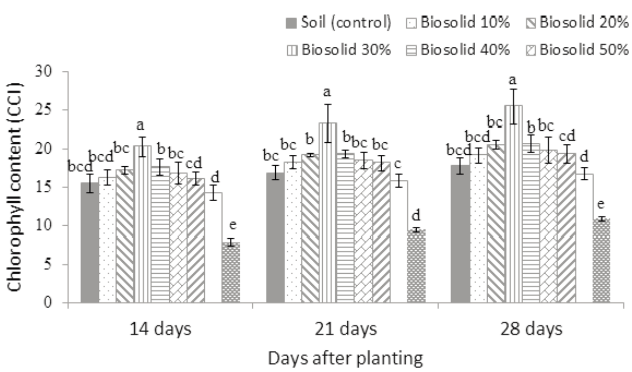

Fig. 5 - Effect of biosolids on tomato seedling leaf chlorophyll content. Means ± standard deviation followed by the same letter within a day after planting are not significantly different according to Tukey's HSD test (p<0.05).

4. Discussion and Conclusions

The response of tomato transplant growth parameters to various rates of biosolids (BS) in this study depended on the physico-chemical characteristics of the substrate. Although numerous authors have reported the beneficial effects of the addition of biosolids to peat mixes (Herrera *et al.*, 2008; Mami and Peyvast, 2010; Chrysargyris and Tzortzakis, 2015), limited number of studies, have reported the use of biosolids (BS) in forest soil (FS) mixture as a substrate. Our results show that use of BS at 30% can support tomato transplant. This can be attributed to its characteristic of higher availability of plant nutrients such as N, P, K, Mg, Fe, Mn, B and Mo (Table 1).

Biosolids application in the tested rates served

Plate 1 - Tomato leaf Chlorophyll observed in biosolids BS at 30% and 40% compared to at CP (Coco peat) substrate. Leaf colour appearance of tomato transplants grown on various substrates.

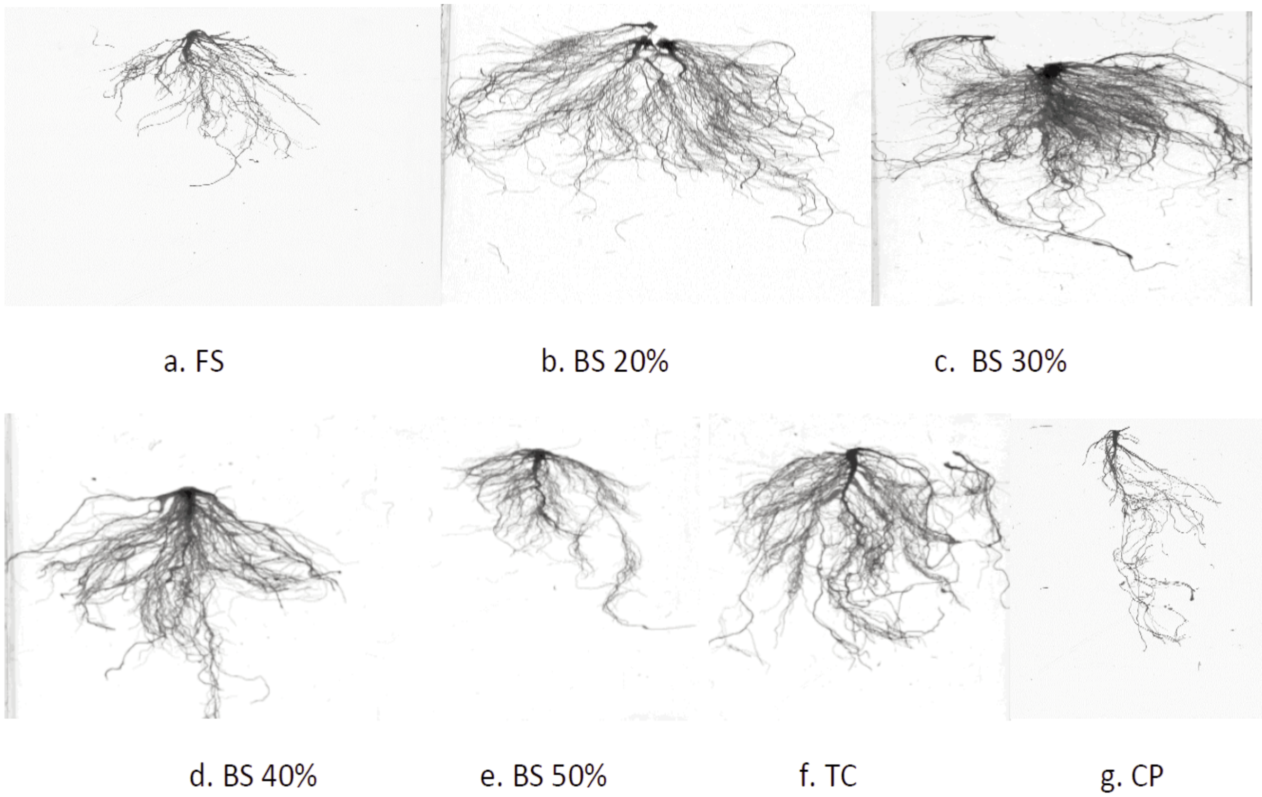

Plate 2 - Characteristics of tomato transplants root development in substrate tested, scanned from WinRhizo, for determination of root volume and density. Responses of roots development to different substrate, FS= Soil control; BS= Biosolids rates; TC= Tea compost; CP = Coco peat.

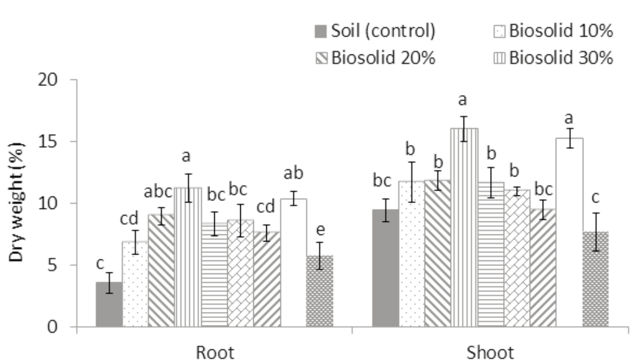

Fig. 7 - Effect of biosolids on tomato seedling root and shoot dry weight at week 5 after planting. Means ± standard deviation followed by the same letter within root or shoot are not significantly different according to Tukey's HSD test ($p<0.05$).

several purposes in the substrate. It improved the texture and water holding capacity, making conditions more favorable for root growth and increased emergence on tomato seedlings. The application of BS at 30% also supplied nutrients essential for plant growth, including N, P and K and Mg, as well as some essential micro nutrients like Zn, Fe, Cu, B and Mo (Table 1). As reported by Tzortzakis *et al*. (2012), nutrients in the biosolids offer several advantages over those in inorganic fertilizers because they are in organic form hence are released slowly to growing plants. Moreover in organic form, nutrients are less water soluble and therefore least likely to leach into groundwater or run-off into surface waters. This is in agreement with the findings of Zhao *et al*. (2010) in relation to the benefits associated with increased organic matter content in the soil. In line with this, Shiralipour *et al*. (1992) earlier reported that organic matter contribute to increased nutrient, total pore space, aggregate stability, erosion resistance, temperature insulation and reduced soil bulk density. These factors play a major role during germination and emergence of seedlings. Soil temperature and moisture content equally play a critical role during germination and emergence of tomato seedlings (Weaver *et al*., 1988). In concurrence with the present study, findings by Chrysargyris and Tzortzakis (2015) revealed that biosolids enhance seed germination and emergence in eggplant transplants. The ability of biosolids to improve physical properties of a good media is related to increased organic matter content (Zhao *et al*., 2010). In regards to the current study, tomato seeds are small and therefore require fine and light media, a rhizophere created with BS at 30%, which possibly enhanced germination and emergence of the seedlings.

Plant height, leaf number and girth of the seedling were highest in seedlings grown in BS at 30% and apparently not very pronounced in TC (Fig. 3, 4). Abdel-Mawgoud (2007) reported plant growth and yield as a function of nutrients supply provided that all other conditions are met. In this study, there was clear positive trend of increasing plant height, leaf numbers with increased rates of BS. The results obtained with BS at 30%, may be attributed to its nutrient content as reported by Otieno *et al*. (2019). Enhancement of plant growth as a result of increasing nutrients in organic amendments has been reported by Sainju (2003). These results are in agreement with the work of Oyinlola and Jinadu (2012), where nitrogen rates in the soil increased tomato plant height. The nutrients not only encourage vegetative growth but also enhance photosynthesis, chlorophyll density and plant root respiration which result in greater plant growth when applied (Tan and Binger, 1986). The findings of this study suggest that the optimum rate of BS to use as soil amendment should not exceed 30% for transplant production. The difference between the BS at 30% and TC substrate seems to have been caused by the reduced level of K in the latter (Table 2). Potassium is an essential element during plant growth and development (Ortas, 2013). Since K is a vital element in many physiological processes, it may have been involved in transplant stem thickness. It is known that K plays a major role in physiological and biochemical processes such as enzyme activation; metabolism of carbohydrates and protein compounds Zhen *et al*. (1996). Besides, K has a significant role to play in the plant energy status for storage of assimilates and tissue water relation. Potassium is also needed in photosynthesis and the synthesis of proteins, hence its deficiency in plants will show as slow, stunted growth and in some crops, weak stems and lodging (Uchida, 2000).

Application of BS especially at 30% enhanced leaf chlorophyll as indicated by higher chlorophyll concentration index units (Fig. 5). One of the critical physiological developments responsible for seedling growth is photosynthesis. The quantity of chlorophyll per unit area is an indicator of photosynthetic capacity of a plant and this explains the better growth observed in tomato seedlings grown in BS at 30%. In other studies, Zuba *et al*. (2011) and Ilupeju *et al*. (2015), postulated that, the rates of organic amendment applied in growing media were linked to the nutrient element levels in the substrate. In regards to this study, plant nutrient availability may have enhanced the amount of chlorophyll in the plants, as exhibited by the presence of mineral elements such as N, P, Mg, Fe and Zn in biosolids in large quantities. These nutrient elements have been reported to be high in biosolids from organic part of municipal solid wastes (Chrysargyris and Tzortzakis, 2015). Other studies have also reported that biosolids are able to increase nutrient availability in soils (Shiralipour *et al*., 1992; Xu *et al*., 2012). In a related study on eggplant seedlings production, Chrysargyris and Tzortzakis (2015) observed that leaf chlorophyll content increased with addition of organic solid waste and similar results were earlier observed by Tzortzakis *et al.* (2012).

The underground part is very important in transplant life and determines whether it can survive when transferred to field environment or not. The roots in particular play a pivotal role in the plants life cycle (Somkuwar *et al*., 2012; Zhi *et al*., 2017). Roots are also known to provide an important link between soils and plants (McMichael *et al*., 2010; Xi *et al*., 2013). Furthermore, root systems have important physiological and biological functions for crop growth and yield (Liang *et al*., 2003; Yang *et al*., 2010). The ability of roots to develop perfectly depends on the medium or substrate status. Root growth is linked to the physico-chemical properties and nutrient availability in a substrate. The ability of a plant to absorb water and mineral nutrients from the substrate depends on its capacity to develop an extensive root system. In the present study, BS at 30% substrate significantly enhanced tomato transplant root growth and morphology (Table 1). In tomato, the tap root formed at an early stage extends deeply into the soil followed by secondary and tertiary, then delicate root hairs, which require water and air among the three phases (solid-liquid-gas) of the substrate (Manahan, 2000). The phases are very essential in water and plant nutrient absorption, based on porosity of the media as demonstrated by the BS at 30%.

Furthermore, the supply of O_2 is essential for root growth and metabolism. Generally, as roots grow through the soil they follow soil vailable pores and this is a contribution of the air space and the level of organic matter as evident in BS at 30%. This is also in agreement with Abad *et al.* (2001) and Pascual *et al*. (2018) who reported on the range of bulk density required for good root development in a substrate. Biosolids at 30% was therefore identified as an ideal substrate, in terms of producing many fibrous and dense root systems than the rest of the substrates (Plate 2 c, e). Additionally, based on the porosity of the studied substrates, it appears that BS at 30% not only created air space for the root development to enhance nutrient use efficiency, but also availed organic matter, which is connected to higher water holding capacity (Otieno *et al*., 2019). This is a critical factor for reducing irrigation schedule as in the case of the present study, making BS 30% a better substrate than the rest. The result of this study also suggests that the BS with rates as low as 10% may need frequent irrigation schedule. On the other hand, even though there was further increase in organic matter as the BS rates increased above 30%, increase in EC was observed (Table 1). This normally has a profound effect on the plant function, especially in reverse osmosis, which may subsequently affect continuous water flow and transpiration in the plant, leading to retarded growth (Mengel and Kirkby, 2001).

The enhanced shoot and root dry weight exhibited by BS at 30% was an indication of the potential of the BS as a soil amendment and its ability to improve the physico-chemical quality of the substrates for transplant development. Forest soil mixed with BS at 30% created room for root respiration and development. The plants had better chance for nutrient absorption hence increased dry matter compared to the other substrates tested. Phosphorous which occurred in high quantities in BS at 30% is involved in the formation of energy rich compounds, including adenosine triphosphate and adenosin diphosphate which in turn derive various bio-chemical reactions within the plant (Memon, 1996). As one of the vital plant macronutrient, phosphorus plays a vital role in the root and shoot development and this contributed immensely to the subsequent increase in shoot biomass of plants grown in BS at 30%. Biosolids analysis in this work also indicated the presence of Zn, Cu, Fe and Mn in significant quantities especially in BS 30%. As advocated by Atif *et al*. (2016), balanced presence of these essential micro elements may have promoted the growth of the seedlings in BS at 30%. These results are in agreement with work of Reis *et al*. (2017), who observed that addition of biosolids in soil resulted in significant increase in total root and shoot dry weight of *Leptospermum scoparium* in a pot experiment. Furthermore, Sainju *et al*. (2003) earlier reported that vigorous root growth stimulated by P helps in better utilization of water and other nutrients in the soil and promotes a sturdy growth of stem and healthy foliage which may subsequently contribute to roots and shoot dry matter.

The results in this study demonstrated that application of biosolids substrate was beneficial in the tomato transplants production. The influence of biosolids at 30% was significant and specifically on leaf number, plant height, chlorophyll content and root development. It is therefore a potential high quality, locally available and low cost substitute for peat and coir substrates in transplant production. Biosolids applied at moderate levels (30%) in forest soil mixture could not only improve the physic-chemical properties of the substrates but also reduce environmental pollution.

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