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GROWTH, YIELD AND ROOT-SHOOT ASSIMILATE DISTRIBUTION IN *Amaranthus cruentus* L. AS INFLUENCED BY DIFFERENT URINE-WATER DILUTIONS

[*1,2]Udemba I.O., [3]AdeOluwa O.O. and [4]AyanfeOluwa O.E.

[1]Department of Crop and Horticultural Sciences, University of Ibadan, Nigeria
[2]Institute of Agricultural Research and Training,
Obafemi Awolowo University, Moor Plantation, Ibadan, Nigeria
[3]Department of Soil Resources Management, University of Ibadan, Nigeria
[4]Department of Agriculture, Federal College of Agriculture, Moor Plantation, Ibadan, Nigeria

*Corresponding author's email: idowuibukunolu2012@yahoo.com

ABSTRACT
The agronomic performance of Amaranthus cruentus L. improves with the application of fertilizers. Wastes, including human urine, which often contribute to environmental pollution, can be recycled into cost-effective fertilizers for amaranth cultivation. Therefore, this study evaluated the response of A. cruentus to NPK (15:15:15), urine-water dilutions (UWD) at ratios of 1:2, 1:4 and 1:6 and a control with no nutrient additive. The treatments except control were applied at 100 kg N ha^{-1}; and all were laid using randomized complete block design with four replicates. Data on plant height, stem girth and number of leaves were collected at 3 and 4 weeks after sowing (WAS); and yield components at 4 WAS. Amaranth in NPK-treated soil had highest plant height (62.66 cm) and stem girth (2.71 cm) at 4 WAS, and compared statistically with 1:2 UWD treatment. The maximum number of leaves at 4 WAS (16.63) was obtained from 1:6 UWD treatment, differing significantly from other treatments except NPK and 1:4 UWD. Meanwhile, 1:4 UWD gave the highest dry weight of edible part (0.70 g plant^{-1}), though statistically at par with 1:2 and 1:6 UWDs. Notably, the highest percentage of root in whole plant (13.14%) was recorded from control followed by NPK fertilizer (7.76%). The urine water dilutions influenced growth of A. cruentus positively and resulted into more assimilate partitioning to the edible parts. However, 1:4 UWD is recommended for its highest edible part and could be adopted as fertilizer for A. cruentus cultivation.

Key words: *Amarantus cruentus*, nitrogenous organic fertilizer, nutrient recycling, urine-water dilution, vegetable growth

INTRODUCTION
Amaranthus cruentus L. is a fast-growing plant; widely distributed throughout the world (Sarker *et al*., 2020). It is highly nutritious and rich in protein, carotenoids, dietary fibre, vitamins, minerals and antioxidants (Sarker and Oba, 2020). In addition to its use as a vegetable, it can be an effective alternative to drug therapy in people with hypertension, diabetes, ulcers and cardiovascular diseases (Baraniak and Kania-Dobrowolska, 2022). *A. cruentus* can grow in poor soils but yield has been reported to be enhanced by fertilizer application (Mohil and Jain, 2014; Olowoake and Ojo, 2014). Specifically, Alonge *et al*. (2007) reiterated that the yield of amaranth and consequently economic return to farmers can be increased by appropriate and timely fertilizer application. This is sequel to the fact that overuse of chemical fertilizer on farmlands results in soil toxicity and degradation; contamination of surface and underground water and other environmental problems with a boomerang effect on crop yield. Consumption of produce from such cropping systems can also lead to health problems such as chronic kidney diseases (Ranasinghe *et al.,* 2016). Meanwhile, the current global economic recession has made fertilizers unaffordable to most peasant farmers, many of whom have no or limited access to fertilizers at critical periods of the cropping seasons (Dubey *et al*., 2016). Hence, the increasing thrust of research in development of low-cost, eco-friendly, effective and readily available fertilizers for amaranth's production (Ebido *et al*., 2024).

The human urine can be a potential alternative to synthetic fertilizers for amaranth's production (Martins *et al*., 2020). It is cheap, readily available, contains a considerable amount of major plant fertilizer nutrients and low level of pathogens (Nwite, 2015). On average, nitrogen, potassium, phosphorus and sodium concentrations in human urine are 3.07±1.15 g L^{-1}, 1.7± 0.2 g L^{-1}, 0.02± 0.004 g L^{-1} and 1.17± 0.12 g L^{-1}, respectively (Ranasinghe *et al*., 2016). The efficiency of human urine as a fertilizer for the production of some crops (including vegetables) relative to commercial inorganic fertilizers have been investigated (AdeOluwa and Cofie, 2012; Maggi and Daly, 2013; Ranasinghe *et al*., 2016; Amoah *et al*., 2017). Findings from the different studies showed that

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human urine is an ideal substitute for inorganic fertilizers in crop production, sequel to comparable or better performance of the former than the later. Moreover, the use of human urine for production of amaranth may indirectly contribute to changes in societal perception about indiscriminate urine disposal to the environment which could consequently prevent pollution of the environment (Amoah *et al*., 2017).

Notably, the human urine is rich in nitrogen obtained from hydrolysis of urea to ammonia (Martins *et al*., 2020). Nitrogen fertilization had been averred to critically influence root and shoot communication which is important for optimized plant productivity and agronomic application (Gu *et al*., 2018). However, conflicting reports exist in literature on the impact of nitrogen concentration of applied fertilizer on growth, assimilate distribution from source to sink and subsequent influence on root-shoot biomass. Some researchers submitted that excessive nitrogen application restricts the distribution of roots within the soil layer of fertilizer application thus, promoting nutrient absorption and increased photosynthetic capacity of plants (Zhang *et al*., 2017; Chen *et al*., 2020). Under this aforementioned soil nutrient status, transportation of photosynthetic assimilates to the sink (root) reduces with subsequent decline of roots growth while growth of the source systems in the leaves becomes the priority (Zhou *et al*., 2011). Gaudin *et al*. (2011) and Min *et al*. (2014) noted that low soil nitrogen levels enhanced root elongation and resulted to higher fresh root biomass sequel to increased water absorption in root and declined nitrogen uptake which lowered fresh shoot biomass. Conversely, the report of other authors indicated that nitrogen deficiency inhibits root growth and subsequently shoot growth (Alonge *et al*., 2007; Mohil and Jain, 2014). Meanwhile, dilution of urine before soil application had been averred to prevent inhibition of plant growth resulting from accumulation of urine inherent sodium or nitrogen in the soil (Sene *et al*., 2013). Sequel to paucity of information on the appropriate dilution rate of urine for fertilizer purposes, this research investigated the effect of different urine water dilution ratios on growth and assimilate partitioning to specific yield components of *A. cruentus*.

MATERIALS AND METHODS

The experiment was conducted at the experimental field of the Department of Agronomy, University of Ibadan, Nigeria, with coordinates Lat. 7˚27′06.4″N and Long. 3˚53′46.1″E. Soil sample collected from the experimental site was subjected to laboratory analysis using standard procedure. The soil was low in nitrogen (0.7 g kg^{-1}), high in phosphorus (22 mg kg^{-1}) moderate in potassium (0.3 cmol kg^{-1}) while its textural class was sandy loam (Table 1). Human urine collected from a student hostel in the University was cured by storing it in airtight containers for one month, as recommended by WHO (2006), to ensure hygiene and safety in its handling). Subsequently, the cured urine was subjected to laboratory analysis using standard procedure. Its nutrient composition before soil application is presented in Table 2.

The urine contained considerable amount of primary macronutrients (nitrogen, phosphorus and potassium), urea and ammonia (nitrogen sources). Constant volume (3 litres) of the cured urine, which was to supply 100 kgN ha^{-1} (as recommended by AdeOluwa and AyanfeOluwa (2015) for amaranth) was diluted with varying volume of water in the ratio 1:2, 1:4 and 1:6. Each urine water dilution treatment was applied (one treatment per seed bed) to soil on prepared seed beds (1 m × 1.5 m) two days before sowing (to ensure mineralization). Subsequently, amaranth seeds were sown by drilling using inter row spacing of 0.1 m, and thinned to 280 plants per bed to achieve the expected plant population. Inorganic fertilizer (NPK 15:15:15) was applied to another seed bed two weeks after sowing (WAS) amaranth while control (no soil nutrient additive) served as a check. All the experimental treatments were replicated four times and laid using randomized complete block design. Insect pests were controlled with neem extract while weeding was done as and when due through rogueing. At 3 and 4 WAS, data were collected on plant height (measured with a meter rule), stem girth (evaluated by tying a twine around the stem to determine its circumference and subsequent determination of twine length on a ruler) and number of leaves, done by counting the number of leaves produced by each plant. Following destructive harvesting at 4 WAS, the plants were partitioned into edible part (all the leaves and succulent part of the stem), lignified stem, and root. These were weighted fresh and after oven drying using a sensitive scale, to determine their fresh and dry weights. Subsequently, percentage of root weight in whole plant weight was estimated. Data collected were subjected to analysis of variance using GenStat software Version 3 and significant means were separated using standard error difference of means at 5% level of probability.

Table 1: Chemical properties and particle size distribution of soil sown to amaranth

Parameters		Values
pH-H$_2$O		7.4
Org. C (g kg^{-1})		3.0
Total N (g kg^{-1})		0.7
Available P (mg kg^{-1})		22.0
Exchangeable cations (cmol kg^{-1})	Ca	7.7
	Mg	2.0
	K	0.3
	Na	0.3
Exchangeable acidity		0.2
Extractable micro-nutrients (mg kg^{-1})	Mn	67.0
	Cu	4.0
	Fe	47.0
	Zn	14.0
Particle size distribution (g kg^{-1})	Sand	792.0
	Silt	74.0
	Clay	134.0
Soil texture		Sandy loam

Table 2: Proximate composition of human urine used for the experiment

Parameters	Values (%)
pH	9.2
Moisture content	96.8
Total solids	3.2
Urea	0.05
Ammonia	0.03
Total Nitrogen	0.48
Potassium	0.01
Phosphorus	0.01
Sodium	0.03
Chloride	0.25

RESULTS

A significant increase in amaranth growth was observed with upsurge in plant age from 3 to 4 WAS (Figures 1-3). Notably, amaranths in the control (with no fertilizer application) consistently had significantly least growth and yield (Figures 1-5) with the exception of percentage of root in whole plant (Figure 6). At 3 WAS, amaranth plants in 1:2 urine water dilution (UWD) treatment were tallest with height (33.44 cm) that compared statistically with only amaranth in NPK 15:15:15 treatment (Figure 1). Conversely, the maximum height of amaranth at 4 WAS (62.66 cm) was obtained from mineral fertilizer (NPK 15:15:15) treatment and differed significantly from height recorded from other treatments with the exception of 1:2 urine water dilution (UWD) (Figure 1). At 3 WAS stem girth of amaranth in 1:2 UWD (2.06 cm) treatment was thickest and statistically at par with girth of plants from mineral fertilizer (1.99 cm) and 1:4 UWD (1.94 cm) treated seeds beds (Figure 2). Meanwhile, seed beds to which NPK 15:15:15 was applied produced amaranth with the highest stem girth at 4 WAS (2.71 cm) though not significantly different from value of 2.51 cm recorded from 1:2 UWD treatment for this growth parameter (Figure 2).

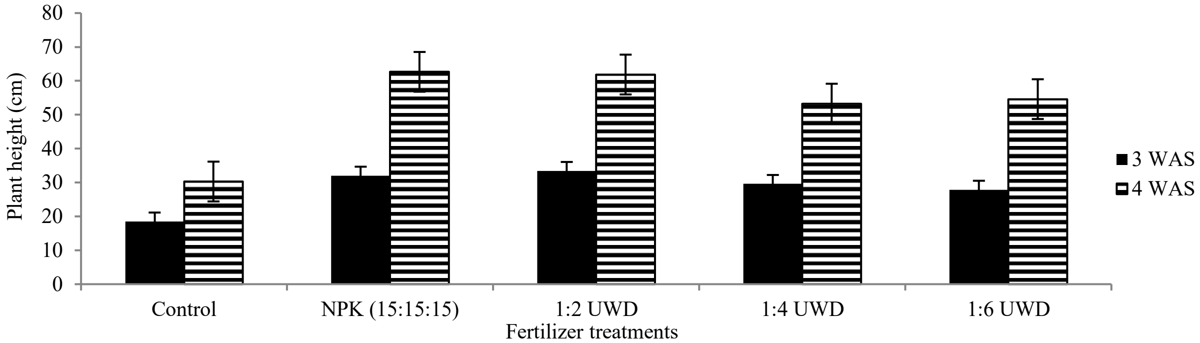

Figure 1: Influence of NPK (15:15:15) fertilizer and different urine water dilutions (UWDs) on plant height (cm) of *A. cruentus* at 3 and 4 weeks after sowing

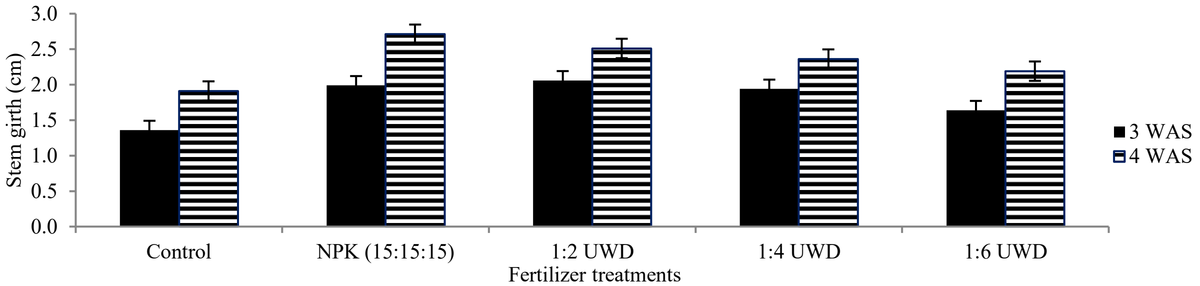

Figure 2: Stem girth (cm) of *A. cruentus* at 3 and 4 weeks after sowing as influence by NPK (15:15:15) fertilizer and different urine water dilutions (UWDs)

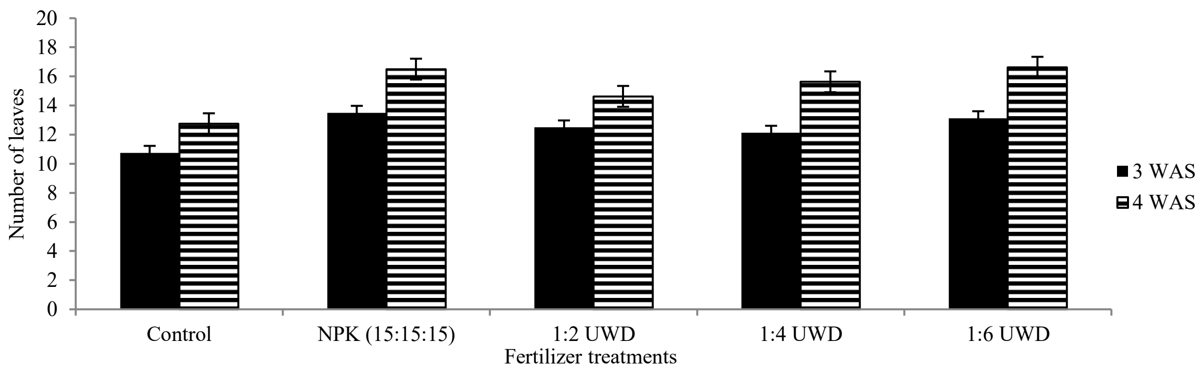

Figure 3: Effect of NPK (15:15:15) fertilizer and different urine water dilutions (UWDs) on number of leaves produced by *A. cruentus* at 3 and 4 weeks after sowing

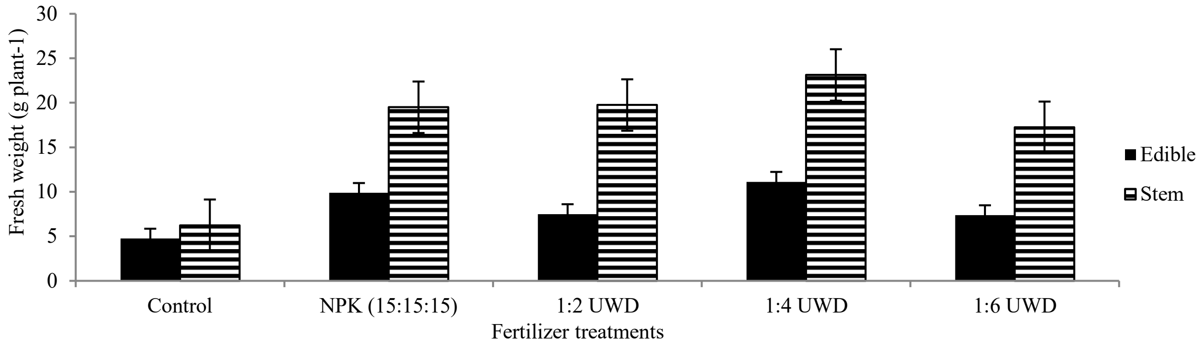

Figure 4: Influence of different NPK (15:15:15) fertilizer and urine water dilutions (UWDs) on fresh weight of edible parts and lignified stems of *A. cruentus* at 4 weeks after sowing (g plant^{-1})

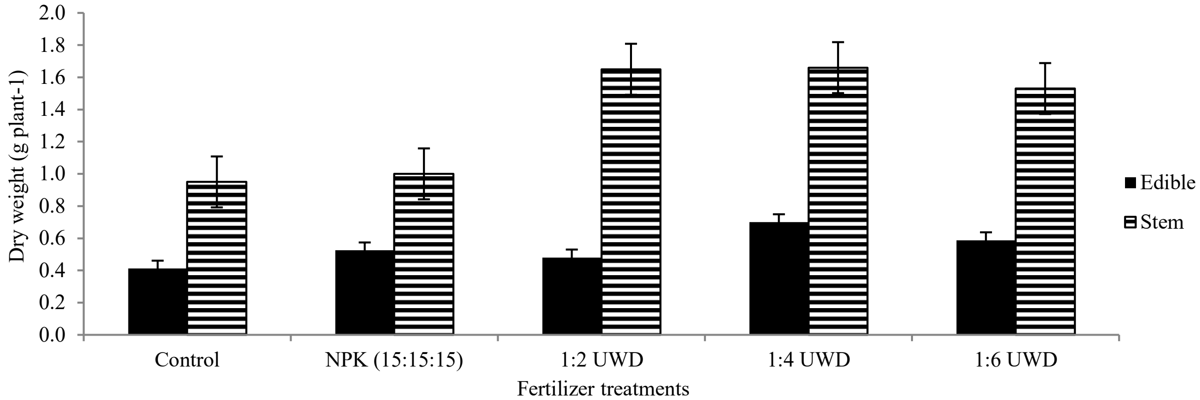

Figure 5: Dry weights (g plant^{-1}) of edible parts and lignified stem of *A. cruentus* at 4 weeks after sowing as influence by NPK (15:15:15) fertilizer and different urine water dilutions (UWDs)

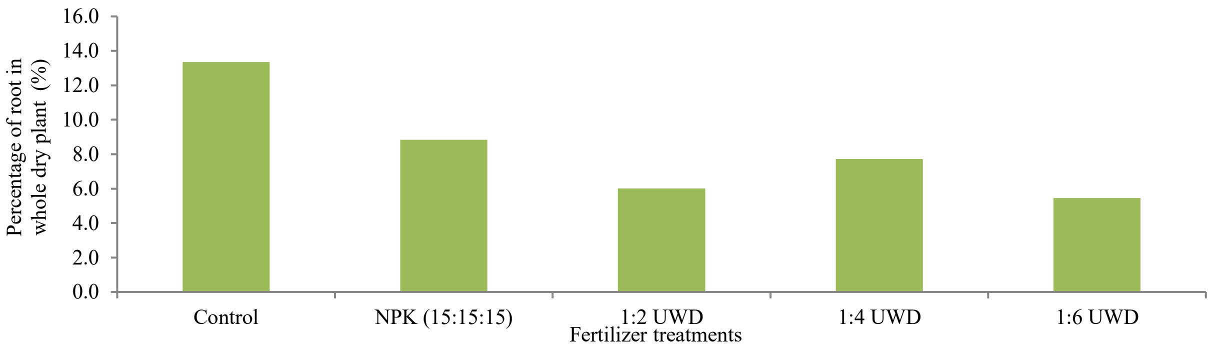

Figure 6: Percentage of *A. cruentus* root weight in the whole plant weight as influence by different urine water dilutions (UWDs) and NPK (15:15:15) fertilizer

For both weeks of evaluation an inverse relationship was observed between stem girth and urine dilution ratio as stem girth increased with decrease in dilution ratio (Figure 2). Result showing effect of the fertilizer treatments on number of leaves produced by amaranth at 3 and 4 WAS is presented in Figure 3. The result shows that at 3 and 4 WAS, the highest number of leaves were produced by amaranth in seed beds treated with mineral fertilizer (13.50) and 1:6 UWD (16.63), respectively (Figure 3). Notably, at the two plant ages the number of leaves counted on amaranth growing in the two immediately mentioned best performed treatments were statistically at par, but differed significantly from other treatments with the exception of 1:4 UWD at 4 WAS (Figure 3). Moreover, at 4 WAS the number of leaves produced by amaranth in the UWD treatments increased with corresponding increase in the urine water dilution rate, and amaranths in 1:6 UWD produced the highest number of leaves among the UWDs treatment at both weeks (Figure 3). However, fresh and dry weights of amaranth edible part from 1:4 UWD treatment were highest and significantly comparable with weights recorded from NPK (15:15:15) and 1:2 UWD treatments for fresh weight; and 1:2 and 1:6 UWD treatments for dry weight (Figures 4 and 5). Similarly, fresh and dried lignified stems of amaranths from 1:4 UWD treatment were weightier than samples from other treatments; and statistically at par with only NPK treatments for fresh weight (Figures 4 and 5). The highest percentage of root weight in whole plant weight was obtained from the control (13.14%) followed by mineral fertilizer treatment (7.76%) while the UWD treatments gave less values with 1:4 UWD accounting for the highest (Figure 6).

DISCUSSION

The growth and yield of *A. cruentus* was enhanced by the applied urine water dilutions. Earlier, Makinde *et al*. (2007) and Uko *et al*. (2009) averred that crops respond to fertilizer application in soils with low nutrient content than soil with high nutrient reserve. Hence, the positive response of amaranth to UWDs and NPK (15:15:15) application may not be unconnected to low nitrogen status of the soil at the experimental site as revealed by the result of the chemical analysis. The plants in the control relied solely on the native nutrients in the soil which was not sufficient and decreased overtime as the plants grew. Therefore, these plants were shorter, had fewer leaves, smaller stem girth, lower fresh and dry weight; but longer and weightier roots than amaranth in fertilizer treated seed beds. This observation affirms the assertion of Olowoake and Ojo (2014) and Sanni (2016) that nitrogen is a limiting factor for amaranth production and most Nigeria soils have low nitrogen (N). Specifically, Aigbe *et al*. (2023) reiterated that N deficiency is prevalent in the rainforest agro-ecology (environment of this present study) due to N loss via erratic rainfall, excessive runoffs and leaching. Moreover, Makinde (2012) and Olowoake and Ojo (2014) noted that amaranth responds to good soil fertility and application of fertilizer enhances its growth and yield. Hence, application of fertilizers for soil fertility amelioration should be an integral part of amaranth production in Nigeria where continuous cropping on the same land is on the increase due to population pressure and competitive use of land for purposes other than crop production.

The augmented values recorded for amaranth's growth parameters from 3 to 4 WAS corroborate the previous submission of Fonge *et al*. (2016) that amaranth has high nutrient uptake rate, grows quickly and produces high biomass within a short time. This rapid growth rate of amaranth with increase in plant age can be linked to division and enlargement of cells in the plant (Lastdrager *et al*., 2014), which was enhanced to different extent by the applied fertilizer treatments. Specifically, N-containing fertilizers had been reported to promote foliage production, photosynthetic activities and consequently vegetative growth of leafy vegetables (Tijani-Eniola *et al*., 2000; AdeOluwa *et al*., 2009; Anika *et al*., 2012; Leghari *et al*., 2016). Across the world, application of mineral fertilizer to crops (including amaranth) have been observed to increase yield (Kunene *et al*., 2019). However, continual dependence on chemical fertilizers for crop production have severe economic implications and may be accompanied by a fall in soil organic matter content, increase in soil acidity, degradation of soil physical properties and increased rate of soil erosion due to instability of soil aggregates (Rahman and Zang, 2018). Meanwhile, urine contains urea which degrades to ammonium and nitrate (absorbable forms of Nitrogen for plants). Usage of UWD (which is organic in nature) as fertilizer for amaranth production can mitigate the aforementioned boomerang negative environmental effect of synthetic fertilizer on farmlands while simultaneously enhancing yield of amaranth. Thus, application of UWDs in this study increased the amount of nitrogen available to amaranth during growth period, which consequently stimulated its vegetative growth, increased number of leaves (which intercepted more sunlight during photosynthesis) resulting to higher biomass production and dry matter accumulation in amaranth from treated seed beds in comparison to the control. The comparable or better growth and yield performance of *A. cruentus* in UWDs treated seed beds relative to NPK (15:15:15) aligns with analogous observation by AdeOluwa and Cofie (2012), Kurnia and Azis (2016) and Adejumo *et al*. (2019) while utilising urine as a fertilizer for amaranth. This suggests that the nutrients in the UWDs were in readily available forms for amaranth absorption and uptake; and the UWDs can supply the nutrient need of amaranth to the same or better extent than NPK (15:15:15) (Dubey *et al*., 2016). However, disparity in performance of amaranth in response to the applied UWDs suggests that the UWD treatments differentially influenced the amaranth growth and yield parameters.

The quantity and quality of the edible part of amaranth will be of utmost interest to buyers and consumers of amaranth. Quality of harvest has been opined to be dependent on the availability of essential minerals in balanced proportion in the soil (Bekele, 2018). Also, fertilizer from organic sources support organisms in the soil that release phytohormones which stimulates plant growth, absorption of nutrient and dry matter accumulation (Liang *et al*., 2005). Amaranth in 1:4 UWD treatments yielding significantly best fresh and dry weight of edible part highlights the agronomic and economic importance of this treatment for amaranth production. Notably, this treatment compared favourably with mineral fertilizer for fresh weight of edible part but yielded significantly higher dry weight of edible part than NPK (15:15:15). Thus, can be better substitute for the later for the cultivation of amaranth due to its cheapness, availability and prospect for enhanced farmers' profitability index (Dubey *et al*., 2016). The statistical comparable dry weight of amaranth edible parts from the three UWDs suggests that the treatments influenced dry matter accumulation in leaves and succulent part of the amaranth stem to the same extent, and the numerical variation in weight was just by chance. However, the finding of 1:6 UWD producing the highest number of leaves among the UWDs; and 1:4 and 1:6 UWD treatments been statistically at par for number of leaves and dry weight of edible parts implies that higher dilution rate of urine (up to 1:6) enhances foliage production; and dry matter partitioning to edible parts of amaranth (which will consequently result to better vegetable quality). Conversely, lower dilution rate (1:2) promotes elongation and thickness of amaranth's stem which was evident in highest plant height and stem girth of amaranth from 1:2 UWD among the UWDs treatments. Meanwhile, stems of amaranth (after removing the edible part) are a source of high protein feed to livestock which enhances their litter size (Sleugha *et al*., 2001; Alegbejo, 2013).

Root growth was differentially affected by applied fertilizer in this study. The highest percentage of root in weight of whole plant from the control (13.14%) suggests that the organo-liquid soil amendments investigated generally had a phytotoxic effect on the amaranth crop (Okorie *et al*., 2017). Another possible reason is that low soil nitrogen levels enhance root elongation (while in search for nutrient), lower fresh shoot biomass and increase fresh root biomass (Chen *et al*., 2020). However, this finding contradicts the report of Mohil and Jain (2014) that nitrogen deficiency inhibits root growth. Lower percentage of root in whole plant weight recorded from the UWDs indicates that the distribution of Amaranth's roots in these treatments were restricted within the soil layer of fertilizer application thus promoting nutrient absorption and increased photosynthetic capacity of plants. Smaller roots of plants from UWDs treatments are advantageous as the shoot of the amaranth plant accounts for its economical yield.

CONCLUSION

From the response of *Amaranthus cruentus* to the urine water dilution treatments, it can be concluded that all the urine water dilution treatments were dilution of well-balanced and fast acting plant nutrients. Growth and yield of amaranth was influenced to different extents by the urine water dilution treatments. The performance of Amaranth in the urine water dilution treatments were at par with mineral fertilizer and even better for dry weight of edible parts. Notably, the urine water dilutions favoured more assimilate partitioning to the shoot and less to the root than mineral fertilizer. Thus, can be a good substitute for the latter. However, the choice of best performed UWD treatment is a function of the interest of the farmers. The adoption of these urine water dilution treatments by farmers for *A. cruentus* production will help reduce environmental pollution, cost of production and increase farmers' income.

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