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Assessing the Productivity and Heavy Metal Levels in *Telfaria occidentalis* Hook, f. (Fluted Pumpkin) Grown with Fish Culture Waste Waters

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Abstract

The phenomenal growth in the aquaculture industry is encouraging farmers to re-use fish culture waste water to irrigate vegetable gardens particularly during the dry season in southeastern Nigeria. The performance of *Telfaira occidentalis* production when irrigated with fish culture wastewater as well as the mineral and heavy metal levels in the plant were assessed. *T. occidentalis* seedlings were transplanted into beds and separately exposed to four (4) treatments which were irrigation with wastewater once daily (WW1D, irrigation with wastewater twice per week (WW2W), irrigation with borehole water once daily (BW1D), irrigation with borehole water twice per week (BW2D) The levels of various minerals and heavy metals were determined in the borehole water (BW), wastewater (WW), soil and the leaves of harvested *T. occidentalis*. The concentrations Ca, K, Na, P, and N were significantly higher by (127.70%), K (191.39%), Na (129.20%), P (177.46%) and N (188.96%) respectively in the WW than those in the BW, however the mineral concentrations in both WW and BW were within the safe levels recommended by WHO/FAO except for K and P contained in the WW. Daily irrigation with wastewater increased the soil concentrations of Ca, Mg, K, Na, P and N by 78.76%, 0.47%, 131.25%, 47.44, 45.60% and 117.51% respectively over that of borehole water. Growing *T. occidentalis* by using fish culture waste water for irrigation increased the concentrations of Pb, Fe, Cr, and Cd on its leaves to 0.38mg/kg, 0.58mg/kg, 0.04mg/kg, and 0.24mg/kg respectively. Economic yield of *T. occidentalis* in terms of leaf number was 44.5% higher when grown with fish culture waste water than the borehole water at 6 WAS. Using Fish culture wastewater to grow vegetables provides fertilization and increases crop performance and this practice is recommended for resource-poor farmers and when water shortage and fertilizer pose limitations. Such a practice presents a risk of significantly elevating heavy metal concentrations in the plant and the soil as well as causing soil salinization particularly with prolonged usage.

Key words: Irrigation, Efficacy, Minerals, Physicochemical, salinization, fish culture

Introduction

The growing population and need for adaptation measures against climate change have increased the drive of countries in sub-Saharan Africa to increase crop yield and conserve water in the face growing water shortages (USEPA, 1992; Jaramillo and Restrepo, 2017).Many farmers are resorting to farming practices such as irrigation and dry season farming to bridge the food gap and make up for production deficit. Wastewaters from domestic, commercial and industrial sources, including that from fish culture are being reused to irrigate more areas of agricultural land(Lazarova and Bahri, 2005; Qadir *et al.,* 2007; Asano *et al.,* 2007; Khalid *et al.,* 2018). This sort of measure has become a valuable response to growing shortage of water in arid and sub-arid regions caused by climate change (Udoh and Iren, 2016). Farmers in urban and semi-urban areas in many developing countries which are having difficulty in securing sufficient water for irrigation are resorting to using wastewater. It is estimated that agricultural schemes account for 45% of all identified municipal wastewater reuse (Bixio *et al*., 2005). Crop growers in urban centers even purposely use undiluted wastewater as it is considered to have the benefit of being veritable source of nutrients in addition to being a cheaper source of water among resource-poor farmers (Scott *et al.,* 2004; Keraita and Drechsel, 2004; FAO, 2012). The use of wastewater for irrigation is reported to have positive impacts on soil structure, crop performances and saving fertilizer cost (Balkhair *et al.,* 2013). According to Jimenez (2005), wastewater often contains higher levels organic carbon (OC), nitrogen (N), phosphorus (P), potassium (K) and magnesium (Mg) capable of contributing to significant increases in crop yields when used for irrigation. Nutrients in wastewater could emanate from feed products, cleaning products, fertilizers, health supplements, medicines and ointments, faeces and urine etc. (Tjandraatmadja *et al.,* 2010).Unfortunately, these waste waters are commonly reused in the same state they were discharged from production sources with little or no treatment. Re-using untreated wastewater presents negative effects on the soil, crop and the environment in general (Mara and Sleigh, 2010; Khalid *et al.,* 2018).

Telfairia occidentalis belonging to Cucurbitaceae family is one of the commonest herbs grown as vegetable mainly in South-eastern Nigeria because it does well at lower altitudes with medium to high rainfall and on sandy-loam soils with fair supply of fertilizers. *T. occidentalis* is a perennial climber with very nutritious leaves and seeds often grown in home gardens and raised along fences or trees as support (Schippers, 2000). The shoots and leaves may be harvested from one month after germination followed by 3-4 weeks intervals when new shoots are formed. *T. occidentalis* has been recognized as a very nutritious vegetable, rich in protein, amino acid, vitamins and mineral supplement (Akube, 1990; Obeagu, 2014). As a result of its recognition as a good source of important nutrients, and high demand as vegetable for domestic cooking in the south east region, *T. occidentalis* is now popularly grown in wet and dry seasons in the region. The increasing popularity of household aquaculture and the higher nutrient levels contained in its effluent have made wastewater from fish culture valuable source of irrigation water in most places where *T. occidentalis* is grown particularly in dry season.

Materials and Methods

Study Area

The study was conducted at a research farm near the Fish Farm of Michael Okpara University of Agriculture, Umudike, Abia State. Umudike community (5°6′N and 6°34′N; 6°38′E and 8°08′E) located southeast Nigeria experiences wet season (March-October) and dry season (November-February) yearly with a mean rainfall of 2,351mm and a minimum diurnal temperature of 22.9^{o}C. The Fish farm has twenty nine (29) units of concrete and seven (7) units of earthen ponds. Three types of African catfish species are grown in the Farm include: *Clariasgariepinus*, *Heterobranchus longifilis* and *Heteroclarias* species (hybrid of Tilapia and *Heterobranchus spp*). Routinely, the effluent from the concrete ponds is discharged into a nearby farmland and the ponds recharged with borehole water every week while feeding the fish with extruded fish feed is done daily.

Method

Seeds of *T. occidentalis* obtained from same pod were sown 2cm deep into prepared 12 beds (2m x 1m) in the Research farm near the Fish Farm. The 12 beds were prepared and arranged in a Randomized Complete Block Design constituting 4 treatments and 3 replicates. The treatments include Irrigation with waste water once every day – WW1D, Irrigation with waste water twice of the week – (WW2W i.e. Wednesdays and Saturdays), Irrigation with Borehole water once every day – BW1D (Control) and Irrigation with Borehole water twice a week (BW2W). *T. occidentalis* in the different beds were separately irrigated twice weekly and once daily with wastewater discharged from the concrete ponds or with borehole water according to a previously determined random allocation of treatments to beds. Irrigation for both borehole and wastewater was done using a 20-litre bucket to maintain identical moisture level in all beds during the growth of *T. occidentalis*. Manual weeding was performed uniformly in the plots to eliminate weed competition.

Before the commencement of the experiment, samples were collected from the effluent from the concrete pond and borehole water in a 100ml polypropylene bottle and added with 1ml of concentrated Nitric acid (HNO_3) and taken to the laboratory to analyze for N, P, K, Ca, Mg and Na contents. Also the water samples were analyzed for pH, turbidity, alkalinity, conductivity, Total Dissolved Solids (TDS), Dissolved Oxygen (DO), Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), and Biological Oxygen Demand (BOD) by standard methods described in APHA (American Public Health Association in 2005).

Soil samples were taken at 0-20cm depth from the experimental plots before and after the experiment for analysis. Collected soil samples were first oven dried (40^{o}C) and finely ground (<0.01) and then ashed in a crucible. One gram ash was digested with concentrated HCL and HNO_3 successively in a ratio of 3:1. The flask was heated gently until the samples were digested; this was indicated by the formation of a clear solution above the soil residue. The mixture was reduced to a volume of 1ml and filtered through Whatman no. 1 and 42 filter papers. Double distilled water was added to make up volume of filtrate to 100ml. Digested soil samples were analyzed for Calcium (Ca), Magnesium (Mg), Potassium (K), Sodium (Na), Nitrogen (N) and Phosphorus(P). Also, data were collected at weekly interval after 2 weeks of planting on the leaf number per stand. The fresh shoot yield for each sample plot was obtained at maturity by harvesting and weighing of

T. occidentalis. The harvests were done with no disturbance to the root system at the time of maturity. The plant samples were dried at room temperature until a constant weight was achieved and then powdered separately according to treatments before storing at ambient temperature in well labeled (according to sample plots) glass containers for analyses.

Results and Discussion

The borehole water and wastewater from fish culture had differing physical and chemical characteristics which affected the growth and chemical quality of *T. occidentalis* when both waters were used for crop irrigation. The borehole water and fish culture wastewater had pH values of 7.14 and 8.24 respectively indicating that the fish culture wastewater was alkaline, a feature largely occasioned by the feed materials and metabolic activities of the fish population. Nonetheless, the pH values of both the borehole and effluent waters used for irrigating the *Telfairia* were within the WHO/FAO acceptable range of 6.5-8.5 recommended for agricultural purposes. Waters with notable low or high pH pose challenges over a period as they tend to corrode equipment and other instruments which they make contact with during agricultural operations (Schafer *et al.*, 2010).A BOD value of 0.19mg/l was detected in the Borehole water (BW) while 1.38mg/l was the BOD value recorded from wastewater (WW). The BOD level in the fish culture waste water was seven times higher than that of the borehole water. BOD is an indication of the level of organic pollution in the water (Roa,1993). Though these values do not exceed the WHO/FAO recommended maximum permissible limit of between 6-9mg/l, the difference in BOD between the two water samples is statistically significant. Similarly a significantly lower COD value of 0.02mg/l was detected in the borehole water than that recorded in waste water (3.24 (unit)) (Table 1).

The turbidity values detected for both BW and WW were 0.50NTU and 2.12 NTU respectively. The turbidity level indicates the quantity of suspended solid particles in the water. The mean turbidity value obtained from the borehole water was quite low. The stronger and more concentrated the wastewater, the higher its turbidity because it is a measure of light emitting property of water. The values were within the WHO/FAO guideline for turbidity in irrigation water, which is 5 NTU.

Table 1. Physiochemical properties of Borehole Water (BW) and Wastewater (WW) from the fish culture used for irrigation of *T. occidentalis*

Properties	Mean concentration for water samples		Maximum permissible limits	
	Borehole water	Waste water (Fish pond water)	FEPA	WHO/FAO STD
pH	7.14	8.24	-	6.5-8.5
Turbidity (NTU)	0.50	2.12	5	5
Alkalinity (mg/l)	111.40	24.26	200	200
Conductivity (us/cm)	42.30	214.48	500	1000
TDS (mg/l)	20.60	204.00	500	1000
TSS (mg/l)	11.00	248.00	30	30
DO (mg/l)	7.83	5.42	5	7.5
COD(mg/l)	0.02	3.24	-	7.5
BOD(mg/l)	0.19	1.38	-	7.5

The Dissolved Oxygen value recorded in the BW was 7.83mg/l which is higher than that of fish culture wastewater. The DO indicates the extent of oxygen available in the water. . The DO value of the WW is below the FAO/WHO permissible limit of 7.5mg/l.

The total dissolved solid (TDS) of the effluent from the fish culture was 204mg/l which is ten (10) times higher than that of borehole water (20.6mg/l). . The TDS is a measurement of organic, inorganic and other dissolved materials in water (Phyllis and Lawrence, 2007). The mean TDS value obtained for WW in the current study is lower than the values (450-3000mg/l) reported by Esmail *et al*., (2009). This low value is an indication that the WW contained low concentration of soluble organic and inorganic matters.

Additional assessments showed that minerals and their corresponding concentrations in the fish culture WW were as follows: Ca (152.8mg/l), Mg (32.5mg/l), K (336.5mg/l), Na (136.4mg/l), P (17.6%) and N (8.10%) and the concentrations of these minerals were significantly higher than those in the Borehole water by 127.70%, 14.29%, 191.39%, 129.20%, 177.46% and 188.96% respectively. The concentrations of these minerals in the borehole water were within safe levels as all were far below the permissible limits (Table 2). WHO/FAO permissible limits for calcium, magnesium, potassium, phosphorus and nitrogen are 200mg/l, 150mg/l, 200mg/l, 200mg/l, 5E.C%, and 10% respectively; indicating that K, and P were occurring in excess. Continuous irrigation with WW from fish culture having excess of these minerals over a period of time may create soil salinity problems (Shrivastava and Kumar, 2015). On another hand, the elevated levels of these minerals in the fish culture effluent may be considered as beneficial source. It can serve as good fertilization source when applied for irrigation purposes. Some of the plant nutrients such as phosphorous and nitrogen are reported to be deficient in most soils of southeastern Nigeria; therefore using the fish culture wastewater for irrigation will enhance the supply of these nutrient to the soil as well as crop growth

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Table 2: Mineral content of the Borehole Water (BW) and Waste Water (WW) from fish culture used for irrigation of *T. occidentalis*

Properties	**Mean concentration for water samples**		**Maximum permissible limit**	
	Borehole water	Waste water	FEPA	WHO/FAO STD
Calcium (Ca^{+2}) (mg/l)	33.72	152.84	75-200	200
Magnesium(Mg^{+2}) (mg/l)	28.14	32.47	50-150	150
Potassium (K^{+}) (mg/l)	7.40	336.46	-	200
Sodium (Na^{+}) (mg/l)	29.35	136.46	-	200
Phosphorus (P) (%)	1.05	17.58	-	5(EC)
Nitrogen (N) (%)	0.23	8.10	5-30	10

Analyses done on the mineral contents of the soil after the experimentation showed that the mineral levels in the soil increased following the application of fish culture wastewater compared to the values obtained before the trial (Table 3). The soil concentrations of Ca, Mg, K, Na, P and N before the trials were 20.3 mg/l, 12.4 mg/l, 45.6 mg/l, 32.5mg/l, 9.7%, and 0.17%. Daily irrigation with effluent from fish culture significantly increased the soil concentrations of Ca, Mg, K, Na, P and N by 78.76%,0.47%, 131.25%, 47.44%, 45.60% and 117.51% respectively over those pre-trial values; and the differences were significant except in the case of Mg. Daily irrigation with borehole water slightly increased soil concentration of k, Na, P, and N by 8.1%, 18.8%, 7.2% and 11.7% over the pre-trial values however, the Ca and Mg levels declined by 4.9% and 45.9% respectively. The results from the analyses confirm the potency of the fish culture wastewater to enhance the nutrient status and productivity of the soils when used for irrigation purposes. Apart from elevations introduced by fish culture wastewater on the levels of minerals in the receiving soils, another report indicated the soil pH also increases with the initial exposure to wastewater but this effect becomes reduced even with more irrigation frequency because of the buffering effect of organic matter (Udoh and Iren, 2016)

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Table 3: Mineral content of soils irrigated with Borehole Water and Waste Water discharged from the fish pond at the experimental site

	Mineral Contents					
Treatments	**Ca (mg/kg)**	**Mg (mg/kg)**	**K (mg/kg)**	**Na (mg/kg)**	**P %**	**N %**
BW1D	19.264	6.688	49.290	38.620	10.400	0.1890
BW2W						
WW2W	32.146	11.082	160.420	43.840	13.910	0.4280
WW1D	46.642	12.482	220.000	52.650	15.430	0.6620
Soil Before Planting	20.286	12.424	45.660	32.460	9.700	0.1720
Waste Water	152.841	32.716	336.460	136.460	17.580	0.8060
LSD 0.05	0.3579***	0.4045***	0.7792***	0.6308***	0.2422***	0.03574
WHO Recommended max. Conc in soil (mg/kg)	300-3,100	1,300-3,500	200-24,000	400-37,000	_	_

There were significant differences in terms of mineral content of the *T. occidentalis* leaves following irrigation with fish culture wastewater. The concentration of Ca in *T. occidentalis* leaves for BW1D, BW2W, WW1D, and WW2W treatment were 60.12mg/kg,56.57mg/kg, 92.35mg/kg and 98.152mg/kg respectively. The levels of Mg in BW1D, BW2W, WW1D, and WW2W were 8.27mg/kg, 10.26mg/kg, 14.40mg/kg and 18.94mg/kg respectively. The concentrations of Ca and Mg in the *T. occidentalis* leaves irrigated with fish pond effluent were significantly higher by at least 53.6% and 40.4% respectively than those irrigated with borehole water (Table 4).

Table 4. Mineral content of *Telfairia occidentalis* leaves irrigated with Borehole Water (BW) and WasteWater (WW) discharged from the fish pond.

	Mineral Content					
Treatments	**Ca (mg/kg)**	**Mg (mg/kg)**	**K (mg/kg)**	**Na (mg/kg)**	**P %**	**N %**
BW1D	60.12	8.27	75.600	23.270	10.28	0.18
BW2W	56.56	10.26	66.260	33.68	7.68	0.13
WW1D	92.352	14.400	261.560	77.120	13.530	0.482
WW2W	98.152	18.941	312.420	80.000	13.680	0.670
WASTE WATER	152.841	32.716	336.460	136.460	17.580	0.860
LSD 0.05	0.7831***	0.5739***	0.4137***	1.528***	0.3062***	0.03195***

Similarly, the mean concentrations of phosphorous (P) in BW1D, BW2W, WW1D and WW2Wwere 10.280%, 9.680%, 13.530% and 13.680% respectively. Usually, phosphorus uptake by plants is very low because of soil absorption. This could be a major reason the phosphorus was not as high as Ca and K in its value recorded for the four treatment plots. The level of nitrogen in the leaves of *T. occidentalis* irrigated daily with fish culture wastewater (WW1D) was 0.48% while that of borehole water (BW1D) was 0.18%. Potassium recorded in BW1D, BW2W, WW1D and WW2Wwere 75.600mg/kg, 66.26mg/kg, 261.560mg/kg and 312.42mg/kg respectively. The above data show that the concentrations of N, P and K were at least higher in the leaves of *T. occidentalis* irrigated with effluent than those irrigated with borehole water by 166%, 31.7% and 246% respectively.

There are reports showing the ability of wastewater usage to supply sufficient quantities of macronutrients (N, P and K) to the soil and plants and because of this, more poor farmers are attracted to irrigate their crops with it (Murtaza *et al* 2010; Scot *et al.,* 2010). They also reported that wastewater reduces cost of crop production by as much as 20% in addition to supplying nutrients. Potassium helps to build disease resistance in vegetable species and enhances the quality of their fruits. Potassium is usually demanded in larger quantity than most elements except Nitrogen (N).

Table 5:Concentration of Heavy metals in the Borehole water and Fish Pond Effluent used for irrigation of the experiment.

	Heavy Metals Concentration				
Treatments	Pb (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Cr (mg/kg)	Cd (mg/kg)
Borehole	ND	0.04	ND	ND	ND
Fish Effluent	0.43	0.88	0.28	0.09	0.25
WHO/FAO	0.05	0.30	1.00	0.05	0.01

The borehole water had no detectable level of Pb, Cu, Cr and Cd from the assessment but had 0.04mg/kg of Fe. On the other hand the levels (mg/kg) of Pb, Fe, Cu, Cr and Cd in the fish pond effluent were 0.43, 0.88, 0.28, 0.86 and 0.25 respectively (Table 5). This indicates that there is substantial availability of heavy metal in the fish culture wastewater.

It was not surprising that the use of the fish effluent water for irrigation of *T. occidentalis* production resulted in elevated levels of these heavy metals in the leaf samples. Watering with fish pond effluent once every day increased the level of Pb, Fe, Cu, Cr and Cd in *T. occidentalis* leaves by 168%, 139%, 826%, 957% and 101% respectively over that of borehole water (Table 6). This trend poses serious human health risk considering the ability of these heavy metals building up in these irrigated soils which are often intensively used and the strong preference of *T. occidentalis* to other vegetable species particularly in southern Nigeria. Some reports have also shown that untreated wastewater irrigation leads to heavy metal accumulation in crops and to the development of low quality agricultural products (Paranychianakis *et al.,* 2011; Zhang and Shen, 2017).

Table 6: Concentration of Heavy metals in *Telfaria occidentalis* leaves irrigated with Borehole water and waste water discharge from the fish pond at the experimental site

	Heavy Metals Concentration				
Treatments	**Pb (mg/kg)**	**Fe (mg/kg)**	**Cu (mg/kg)**	**Cr (mg/kg)**	**Cd (mg/kg)**
	0.117	0.115	0.019	0.007	0.067
BW1D	0.120	0.106	0.010	0.002	0.043
BW2W					
	0.312	0.205	0.153	0.042	0.130
WW2W					
	0.314	0.275	0.176	0.074	0.135
WW1D					
LSD 0.05	0.009***	0.009***	0.002***	0.0018***	0.002***

The capacity of fish pond effluent to enhance vegetal growth Regarding the number of leaves of *T. occidentalis* which was measured as a productivity parameter by counting the number of leaves per stand in the different treatment plots.

The mean number of leaves recorded for the treatment plots BW1D, BW2W, WW2W and WW1D at 5WAS were 25.3, 26.6, 32.23, and 33.50 respectively. The mean number of leaves recorded for the treatment plots BW1D, BW2W, WW2W and WW1D at 6WAS were 44.2, 39.8, 59.2, and 63.9 respectively. Also at 6WAS, the LSD at 0.05 with a value of 4.313 was very highly significant (***).

Table 7. Effect of Borehole Water and Waste Water from fish culture on the number of leaves of *T. occidentialis* grown at the experimental site

Weeks After Sowing (WAS)					
Treatment	**2**	**3**	**4**	**5**	**6**
BW1D	3.3	8.3	18.9	25.3	44.2
BW2W	3.7	9.1	14.5	26.6	39.8
WW1D	3.50	14.10	14.43	33.50	63.87
WW2W	4.03	9.40	16.03	32.23	59.17
LSD 0.05	1.403NS	5.410NS	3.250NS	2.304***	4.313***

NS: Not Significant ***, <0.001, very highly significant

The yield in terms of number of leaves of *T. occidentalis* was 31.6% and 44.5% higher when grown with fish culture waste water than the borehole water at 5 and 6 WAS respectively. There is strong evidence of enhanced crop productivity as a result irrigation with fish culture waste water, and such high output is a major attraction to farmers who are eager to expand the application of the waste water for vegetable crop production. A similar result was reported when pond wastewater was used to grow garden eggs, as the reported to have yield was observed to be better than poultry litter and NPK fertilizer when applied at a rate that supplied N at a rate of 150 -300 $kgha^{-1}$ (Udoh, 2016).

It was reported earlier in this study that Ca, Mg, K, Na, P and N concentrations in the fish culture waste water were significantly higher than those in the Borehole water by 127.70%, 14.29%, 191.39%, 129.20%, 177.46% and 188.96% respectively, and these would have contributed to the enhanced productivity of *T. occidentalis* when the waste water was used to irrigate the crop.

Conclusion

Fish culture effluent applied for irrigation was beneficial as it enhanced the growth and productivity of *T. occidentalis*. This, to a large extent can be attributed to higher level of minerals which the fish culture waste water contained compared to the Borehole water. The use of this fish culture effluent mainly supplies Ca, K, Na, P, and N. The levels of these minerals were within the recommended standard of WHO/FAO except for Na and P. For resource-poor farmer fish culture waste water could be used for crop production particularly where water is scarce and soil fertility is low.

However there is substantial availability of heavy metal in the fish culture wastewater and also their elevated levels in the leaf sample of *T. occidentalis* indicating a likelihood of toxicity with persistent usage. Also, soil salinization may occur where irrigation with fish culture effluent is used over a prolonged period due to high level of sodium (Na).

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