SUITABILITY OF CONSTRUCTED WETLAND TREATED DOMESTIC WASTEWATER AS SOURCE OF IRRIGATION WATER AND NUTRIENTS ON COMMON BEANS (PHASEOLUS VULGARIS) PERFORMANCE IN MOROGORO, TANZANIA

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ABSTRACT

The study was conducted from November 2014 to March 2015 at Mafisa Waste Stabilization Ponds site in Morogoro to assess the suitability of using Constructed Wetland (CW) treated wastewater as a source of nutrients and irrigation water. A yellow coloured local common bean variety ('Kigoma') was sown on July 27, 2014 at a spacing of 50cm between rows and 10cm between plants. The experiment was laid out as a Split-Plot in Randomized Complete Block (RCB) Design with four treatment categories namely, (i) Waste water (WW) only (ii) WW + NPK (iii) Tap water (TW) only (iv) TW + NPK in 4 replicates. Quantitative data were collected on yield and yield components namely, biomass, flowering percentage, number of beans, weight of beans, plant height, leaf length and number, fertile and sterile pods. Analysis of Variance (ANOVA) was accomplished using General Statistics (GENSTAT) software while differences between treatments categories was accomplished using Student Keul Test at ($p \leq 0.05$) using INSTAT 3 statistical package. Plots irrigated with WW only resulted in relatively higher yields (0.78ton/ha) as a result of more seed weight compared to plots irrigated with Tap Water only which yielded 0.12 ton/ha only. This was attributed to the presence of nutrients in WW. The plots that received WW and NPK resulted in more foliage biomass and sterile pods implying that there was nutrients overload. More studies using improved varieties in different growing season were recommended.

Keywords: Mafisa, Constructed Wetland, Treated wastewater, beans, Waste Stabilization Ponds, irrigation

1. INTRODUCTION

Irrigation using effluent has been practiced for centuries in different parts of the world (Shuval *et al.*, 1986). It provides farmers with a nutrient enriched water supply and the society with a reliable and inexpensive system for wastewater treatment and disposal (Feigin *et al.*, 1991). Many countries have included wastewater reuse as an important factor in water resources planning. In the more arid areas of Australia and USA, wastewater is used in agriculture, releasing high quality water supplies for potable use (FAO, 1992). Some countries, for example the Hashemite Kingdom of Jordan, Israel and the Kingdom of Saudi Arabia, have a national policy to reuse all treated wastewater effluents and have already made considerable progress towards this end (FAO, 1992). In China, use of sewage in agriculture has developed rapidly since 1958 and now over 1.33 million hectares are irrigated with treated sewage effluent. It is generally accepted that wastewater use in agriculture is justified on agronomic and economic grounds although care must be taken to minimize adverse health and environmental impacts (Hussain *et al*., 2002; Kimwaga et al., 2013; Outwater et al., 2013). However, reuse of wastewater is not a common practice in Tanzania, as such this study is one of the ongoing efforts to popularize the use treated waste water in Tanzania is one of climate change coping strategies Common bean (*Phaseolus Vulgaris* L.) is one of the crops being studied since it is the main grain legume crop grown in Tanzania as an important relish food and cash crop but whose production is done mostly by small-holder farmers in monoculture and also intercropped with maize and other staples such as cassava and banana. Bean cultivation occupies approximately 800,000 million hectares in Tanzania thus coming third as one of the largest cultivated crop after maize and cassava. Driven mostly by population growth, increase in domestic and regional bean demand, its production levels has been growing gradually between 2003 and 2012 from 794 to 1745.5 Kgs respectively (Letaa et al., 2014). However, its yield is low and therefore does not meet the increasing demand.

Beans are grown in most areas of Tanzania, but the crop does not tolerate prolonged periods without moisture, so supplementary irrigation is required to obtain reliable yields in drier areas. The main areas of production are therefore the mid to high altitude areas of the country, which experience more reliable rainfall and cooler temperatures. The most suitable areas for bean cultivation in Tanzania are in the northern zone particularly Arusha Region, the Lake Regions and the Southern Highlands (Namugwanya et al., 2014).

While bean yield is estimated at 1500–3000 kg/ha in cool regions in higher latitudes, the average stands at 799 kg ha^{-1} while the average yield for Tanzania is only between 500-700 kg ha^{-1} mainly due to lack of improved varieties as well as prevalence of both biotic and abiotic stresses (Graham and Ranalli, 1997) including drought. The average yields in Tanzania and other developing countries are below 600 $kgha^{-1}$ which is far below the potential yield of 1500-3000 kg ha^{-1} found elsewhere (Hillocks et al., 2006). To increase bean productivity (both in hectarage and yield per unit area), there must be concerted initiatives towards irrigation to maximize production.

However, Tanzania has insufficient water resources but has tremendous irrigation potential with some 44 million hectares (Mha) deemed suitable for irrigation; but only 10 Mha (23%) is actually cultivated and of that only 227,000 hectares (ha) is irrigated (Evans et al., 2014). This irrigation potential is not being realized due to limited capacities of financial resources and knowledge of the millions of smallholder farmers who constitute the majority of the agricultural sector in most Tanzanian farmers who are currently unable to take advantage of improved irrigation techniques and technologies, reuse of treated wastewater inclusive. Wastewater ruse is not a common practice in Tanzania (Balkema et al., 2010).

Irrigation for this study was designed to use effluent from Constructed Wetland as a source of irrigation water and nutrients to promote increased bean production. The study was conducted with a goal to extend bean growing area coverage and season in Morogoro using available wastewater from MORUWASA/UDSM Constructed wetland.

2. MATERIALS AND METHODS

Study site

The research study was conducted in Mafisa Village, Morogoro Urban, Tanzania where Morogoro Rural and Urban Wastewater Supply and Sanitation Authority (MORUWASA) operates its Waste Stabilization Ponds (WSP) (Fig. 1). The MORUWASA-WSP collects municipal sewage and household wastewater which flows directly into oxidation ponds through the main sewerage pipe system and by tankers. The sewerage system area is situated in lowland with pockets of undulating valley having fertile alluvial clayey soils but most elevated areas in Mafisa have red laterite soils which are also low in nutrients notably phosphorus and Nitrogen. This research was one component of a multidisplinary project on increasing crops productivity through reuse of Wastewater whereby the University of Dar es Salaam-Waste Stabilization Ponds (UDSM-WSP) Research Group constructed an artificial wetland that cleaned wastewater intercepted from Waste Stabilization Pond No. 2 of the 6 waste water treatment ponds and delivers it to the experimental fields through a closed pipe. An irrigation pump model SE-50X; with a delivery volume of 600L/minute having a total head of 30M and Power speed of 2.0Kw Plate 2) was used to deliver waste water (WW) from this Constructed Wetland to the experimental field through a hose pipe.

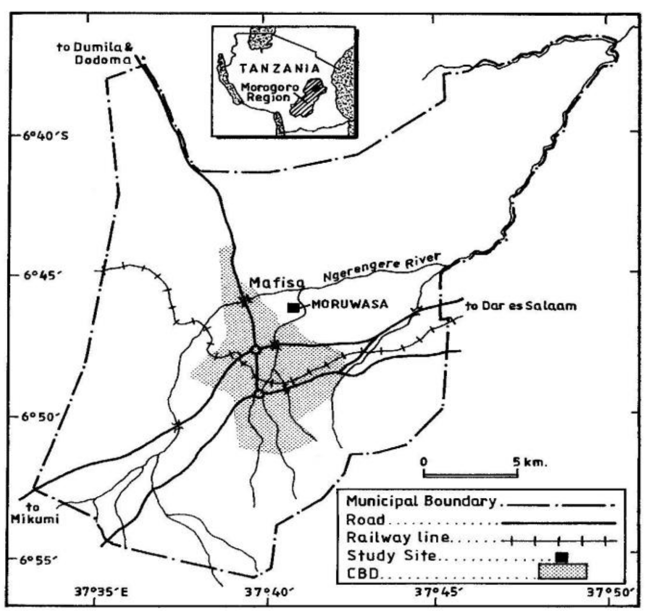

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Figure1. A Map of Morogoro showing the experimental site of the study

Experimental layout

A total of 40 plots (20 plots for wastewater and 20 plots for fresh water from a tap) measuring $3m^2$ each (2m long x 1.5m wide) were prepared and used for this study. Wastewater and freshwater plots were spatially separated by furrows with raised bund to block contamination. A yellow coloured local common bean variety ('Kigoma') was sown on July 27, 2014 at a spacing of 50cm between lines and 10cm between plants. One week after emergence, 20 plots were irrigated using wastewater and the other 20 plots were irrigated using freshwater from the tap. The experimental layout was designed as Split Plot, the main plots being No fertilizer or an NPK fertilizer (15:9:20) at planting at a rate of 350gm/plot. The subplots were the recipients of irrigation water namely tap water (TW), waste water (WW). Overall the treatments were WW only, WW+NPK, TW only and TW+NPK). All the treatments were replicated 4 times.

Wastewater and soil samples analyses

Wastewater from MORUWASA–Waste Stabilization Pond No. 2 was sampled in 1L capacity plastic containers each of which were first thoroughly washed with 1M HCL and rinsed several times with deionized water prior to sample collection according to Allen (1989). Wastewater sampling was conducted using the grab method whereby WW was scooped from the pond. Samples were kept in tight bottles in an ice chest (temp =4 ºC) and immediately taken to the laboratory for further processing. The samples were then filtered and acidified to pH 2 using 6 M HNO_3 and stored at 4º C for subsequent analyses of various physical-chemical parameters namely pH, EC, C.E.C, organic matter content, available phosphorus, total nitrogen, and soil texture according to APHA (1998). Soil samples from the area were collected from two points along the center-line at a depth of 0–10cm, and 10–20cm. The samples were then homogenized into a composite sample which was weighed separately, kept in polythene bags, properly sealed to prevent contamination and loss of moisture.

Yield and yield components recording and data analyses

Data on yield components were collected bi-weekly during the plant growth and development phase namely: plant height, number of leaves and leaf area at flowering, flowering percentage, number of fertile and number of sterile pods/plant, number of beans/pod, and bean weight/plot, trash biomass and seed yield. Plant height was measured in cm from the ground level to the plant apex. Leaf length was measured from the plant petiole to the end of the trifoliate leaflet. Flowering percentage was estimated at 50% flowering. The numbers of fertile and sterile pods were counted at the time of harvesting and so was the bean weight and weight of trash remaining after seeds extrusion.

Analysis of Variance (ANOVA) of the data was accomplished using INSTAT software to find means of multiple variables and Newmann-Keul Test was computed to test differences between treatment means at $p<0.05$.

3. RESULTS

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Physical-chemical qualities of the Wastewater soils at the experimental site

The physical-chemical properties of wastewater and soils used as a source of irrigation water at the experimental field are as shown in Tables 1 and 2. As shown in Table 1 the quality of wastewater delivered to the experimental site was within the threshold values recommended by FAO (2004) for agricultural use in terms of Total Soluble Solids (TSS), Phosphorus, Nitrates, Biological Oxygen Demand (BOD), faecal coliforms and total Ammonia.

Table 1. Physical-Chemical Composition of Wastewater before and after passing through the constructed wetland

Parameter	Source of Sample			
	Anaerobic Pond Inlet	Anaerobic Pond Outlet	Maturation Pond Outlet	Threshold levels for irrigation water
TSS (mg/L)	250	120	50	0-2000
Phosphorus (mg/L)	2.69	2.71	2.78	10-500
Nitrates (mg/L)	0.345	0.635	0.653	50
BOD5 (mg/L)	410	150	120	200
Ammonia (mg/L)	6.07	6.24	6.05	5-50
Faecal Coliforms (MPN/100ml)	4.2×10^6	2.8×10^5	3.6×10^3	< 1000
EC(dS/m) 0. 866		0.7-3.0		

The Physical-chemical properties of the soil samples collected at the experimental site i.e. pH are as shown in Table 2 i.e. pH 8.2±0.04, 0.71±0.023 total nitrogen, while P was 0.5±0.03.mg/100g. The organic matter was2.3±0.08% and CEC measured to 57.9± 0.57meq/100g. The soil texture was categorized as silt loam and very low in N and P. It is evident that the fertility level of the soil at this site was very low.

Table 2. Physical–Chemical properties of the soil sampled from the experimental site

Properties	Mean values obtained
pH	8.2 ±0.04
Total N(mg/1)	0.71 ±0.023
Organic matter (%)	2.3 ±0.08
P (mg/100g)	0.5 ±0.03
C.E.C (meq./100g)	57.9 ±0.57
Sand (%)	7.7 ±3.84
Silt (%)	75.7 ±17.84
Clay (%)	23.3 ±11.67

Vegetative Growth of the beans

Beans in plots treated with waste water (WW) plus NPK planting time produced significantly bigger leaves (mean leaf length 9.71cm) than beans in plots irrigated with tap water only (mean

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leaf length 9.35cm) while beans in plots treated with tap water plus NPK at planting time produced smaller leaves with mean length of leaf 6.3cm only (Figure 1 a). The number of leaves on plants treated with WW only was greater (9) but plants in NPK treated plots and irrigated with WW and tap water produced same number of leaves (8), while plants which were irrigated with tap water only produced fewer number of leaves (7) (Figure 1 b).
Plant height was significantly higher (20.55 cm) in plots irrigated with WW only than in tap water irrigated plots (Figure 2a).

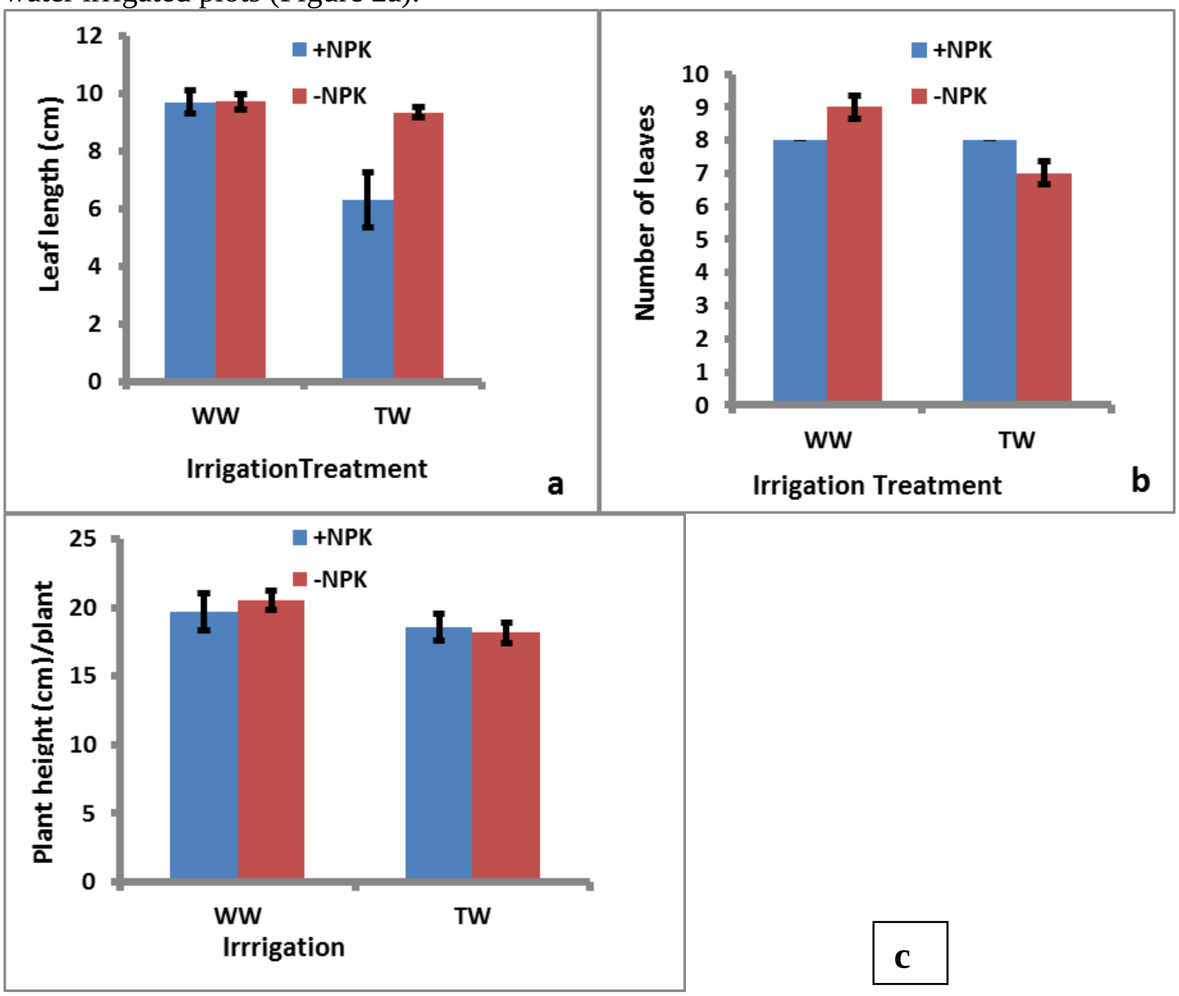

Figure 1. Effect of irrigation using wastewater and additional NPK on (a) Leaf Length(cm), (b) Number of leaves/plant and (c) Plant height (cm)

Overall, the flowering percentage was low (10-12%) and did not seem to be affected by the applied treatments (Fig 2a). WW irrigated plots produced significantly less number of fertile pods/plant (10) than tap water irrigated plots (12) irrespective of the additional NPK at applied at planting. Likewise, the number of sterile pods/plant were significantly higher in WW treated plots plus additional NPK than in WW treated plots but without additional NPK as well as in TW irrigated plots with or without additional NPK (Figure 2b). The number of beans per plant was significantly higher in WW irrigated plots (40) than tap water irrigated plots (30) irrespective of NPK (Figure 2d). Bean weight was significantly higher in WW only irrigated plots (0.07·T ha^{-1}) as well as WW treated plus additional NPK (0.078T·ha^{-1}) while TW treated with NPK produced 0.045 Kg/plot and plants irrigated with TW produced only 0.038T·ha^{-1} (Figure 3a).

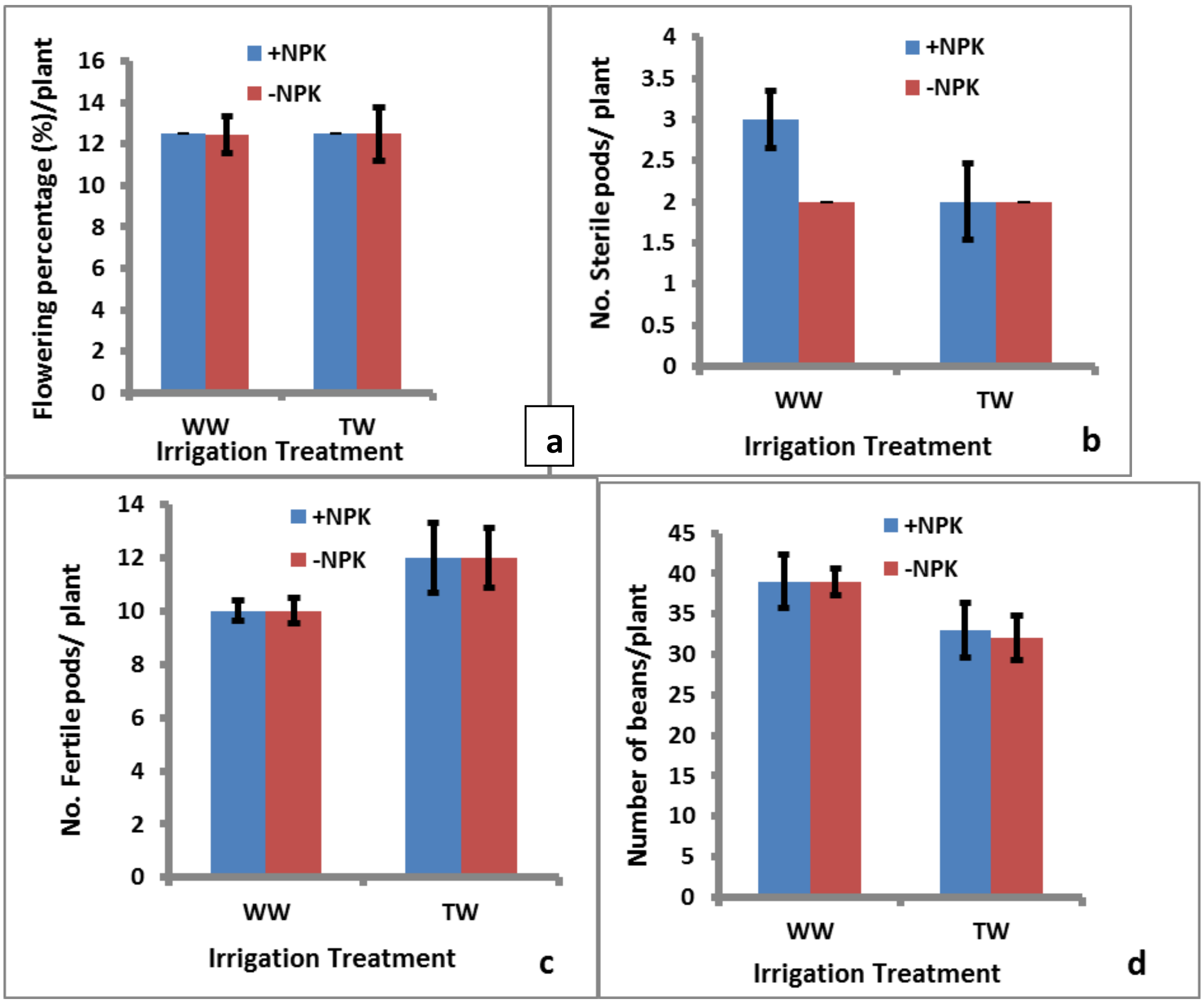

Figure 2. Effect of irrigation using wastewater and additional NPK on (a) Flowering percentage (b) No. sterile pods/plant, (c) No. of fertile pods/plant and (d) No. of beans/plant.

A significantly higher trash biomass (0.07 T·ha^{-1}) was observed in both plants irrigated with WW only and in WW plus additional NPK at planting while the lowest trash biomass was found in TW irrigated plots with or without additional NPK(0.045-0.05T· ha^{-1})(Fig.3b).

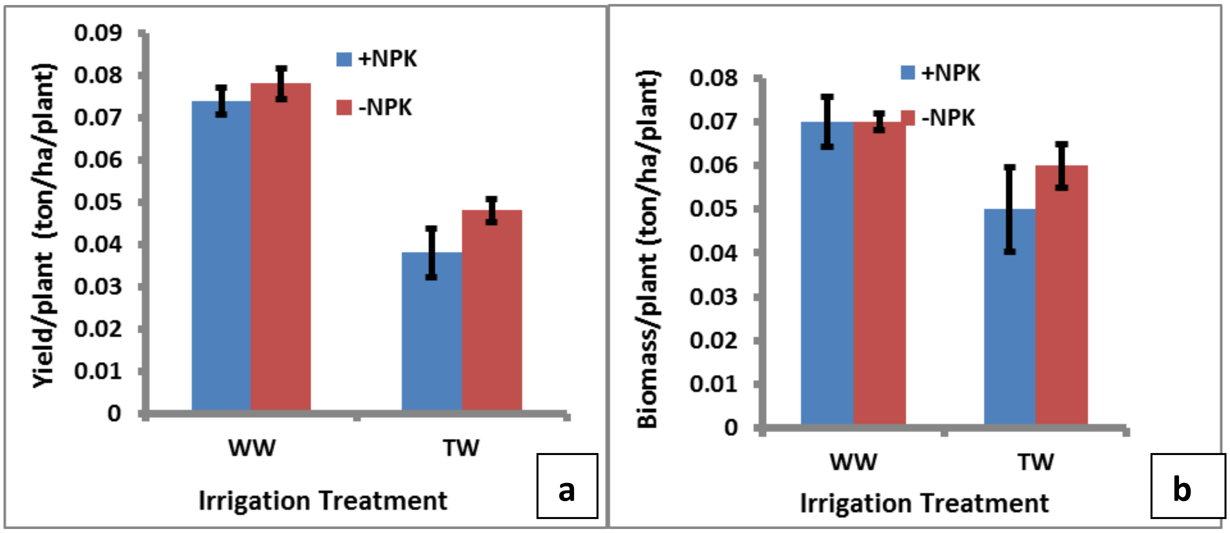

Figure 3. Effect of irrigation using wastewater and additional NPK on (a) Bean yield (T· ha^{-1}) and (b) Bean trash biomass (T· ha^{-1}).

4. DISCUSSION

The vegetative phase of any crop including beans comprises of the major yield components i.e. plant height, flowering percentage, number of pods/plant, and the number of seeds/pod, which are the determinants of seed yield in the case of beans. The 3 vegetative parameters, the plant height the number and length of bean leaf are important to give the foliage needed for maximum light absorption for photosynthesis which translates into biomass including that of the seed yield. According to Parvatha Reddy (2015)increasing atmospheric CO_2 concentrations can also directly affect plant physiological processes of photosynthesis and transpiration. Therefore, this ensures dry matter production and yield of the plant. Both of these parameters responded positively to irrigation with WW and to the additional inorganic NPK that was applied at the time of planting. The production of these parts has been influenced by treatments used from constructed wetlands (WW, WW+NPK) and tap water (TW, TW+NPK), both were aimed to ensure plant health and maximum production. TW is lacking nutrients but it was used as a control while TW+NPK contained nutrients N, P, K which was added as NPK fertilizer to promote the growth and production. Wastewater sludge composting have been proposed as techniques to reduce pathogens and organic contaminants while generating a valuable product rich in plant nutrients (Fernández-Luqueño et al. 2010).The availability of these nutrients in WW while promoted luxurious vegetative growth (leaves, flowers, plant height, sterile pods), also produced highest bean yield and biomass production than non-treated with WW and NPK plots, therefore, showing the effectiveness of WW in promoting yield potential of the *Phaseolus vulgaris*. Similar results were obtained by the author in rice yields (Nyomora, 2015).

Water deficit during the pod formation period gives rise to small, short discoloured pods with malformed beans. Also, the fibre content of the pods is higher and seeds lose their tenderness. Good commercial yield in favourable environments under irrigation is 1.5 to 2 ton/ha dry seed

(FAO, 2002). In the current study, seed yield was not very much promoted by the wastewater irrigation. Bean weight was significantly higher in WW only irrigated plots (0.07 T· ha^{-1}) as well as WW treated plus additional NPK (0.078 T· ha^{-1}) while TW treated with NPK produced 0.045 Kg/plot and plants irrigated with TW produced only 0.038 T·ha^{-1}. It has been observed that farmers field produces about 0.5 T·ha^{-1} as opposed to 1.2 T· ha^{-1} found in the cool regions or 1.5-2 T· ha^{-1} found in experimental research stations. This implies that possibly there were other factors which contributed to limited yield performance. First, the prevailing temperature at the time of flowering and fruit maturity was 26ºC (http://climatevo.com/2014, Morogoro**)**. This was followed by excessive rains that caused flooding in the area. It could only be speculated that this contributed to washing out nutrients. In an on-farm bean variety evaluation trial conducted by Bucheyeki and Mbaga (2013) in Kigoma, Kasulu district using five beans varieties: Lyamungo 90, Jesca, Uyole 94, Kablanketi, and Kigoma yellow, the Kigoma yellow variety which was also used in the current study recording the lowest yield. It is evident that the variety used had lower yield potential to start with.

Production of common bean (*Phaseolus vulgaris*) is often limited by the low availability of soil phosphorus (Namayanja et al, 2013). It is a general rule that low N levels severely impacts yield performance. Even for beans which are leguminous and fix atmospheric N into organic molecules that can be available for metabolism, there is a minimum N that needs to be available in the soil to boost optimal growth. In the current study the soil P and N levels determined in the soil and WW were 0.5 mg/100g and 2.88 mg/L respectively. This could explain the comparatively higher performance in plots irrigated with WW and which received additional inorganic NPK at planting. This nutrient delivery system should be taken advantage of since it would cost the farmer much less than the conventional inorganic fertilizers.

5. CONCLUSIONS

Yields of common bean plants cultivated in plots irrigated with WW and WW+NPK were higher than those cultivated in plots irrigated with TW and TW+NPK. The irrigation rate of the WW increases bean yield and improving the health status of the plant. Irrigation of WW has further improved plant development and increased yield compared with beans cultivated in TW irrigated plots. The total numbers of beans were large in WW irrigated plots which has determined higher total yields to beans plant irrigated with WW than TW. WW not only provides the needed irrigation water but also improves bean yields.

It has been estimated that about40%of bean production in Africa takes place in environments subject to moderate to severe mean water deficit (Broughton et al., 2003). The recorded yield was above the national beans yield of 741 kg ha^{-1}(FAO, 2008. The study has demonstrated that WW offers an opportunity of supplying both irrigation water and some supplementary nutrients that can be useful for crop production. A parallel study (Outwater et al, 2015) on pest and diseases associated with the system gave a clean report for the WW to be used for agricultural purposes. It remains to deal with the stigma associated with ad lib usage of WW as a moisture and nutrient source in farming systems.

REFERENCES

APHA 1992. Standard methods for the examination of water and wastewater,18th edition, American Public Health Association, Washington, D.C. APHA AWWA and WPCF./6ed.

Balkema A. Njau KN, Romijna H, deRuijter R. 2013. Socio-economic analysis of constructed wetlands systems for hygienic sanitation in Tanzania Evans, A. E. V.; Giordano, M.; Clayton, T. (Eds.). 2012. Investing in agricultural water management to benefit smallholder farmers in Tanzania. AgWater Solutions Project country synthesis report. Colombo, Sri Lanka: International Water Management Institute. 34p. (IWMI Working Paper 146).doi: 10.5337/2012.208

Broughton, W.J., G. Hernandez, M. Blair, S. Beebe, P. Gepts and J. Vanderleyden, 2003.Beans (*Phaseolus* spp.)–model food legumes. Plant and Soil 252: 55–128.

Bucheyeki, T.L and Mbaga, T.E. 2013. On-Farm Evaluation of Beans Varieties for Adaptation and Adoption in Kigoma Region in Tanzania

FAO 1992. *Wastewater treatment and use. Environmental Management Corporation (2001).* Study on reuse technology of discharge water from municipal

FAO 2002. Bean: Crop water Information. http://www.fao.org/nr/water/cropinfo_bean.html. Accessed 10/01/2017

FAO 2008."Production data," http://faostat.fao.org/faostat

Feigin, A., I. Ravina and J. Shalhevet. 1991. *Irrigation with Treated Sewage Effluent.* Management for Environmental Protection.Advanced Series in Agricultural Sciences **17**. Springer-Verlag. 224pp.

Fernández-Luqueño, F., V. Reyes-Varela, C. Martínez-Suárez, G. Salomón-Hernández, J. Yáñez-Meneses, J. M. Ceballos-Ramírez, and L. Dendooven. 2010. "Effect of Different Nitrogen Sources on Plant Characteristics and Yield of Common Bean (Phaseolus Vulgaris L.)." *Bioresource Technology* 101 (1). Elsevier Ltd: 396–403. doi:10.1016/j.biortech.2009.07.058.

Graham,P. H. and Ranalli,P. 1997."Common bean (Phaseolus vulgaris L.)," Field Crops Research, vol. 53, no. 1–3, pp. 131–146, 1997.View at Publisher · View at Google Scholar · View at Scopus

Hillocks, R. J., C. S. Madata, R. Chirwa, E. M. Minja, and S. Msolla. 2006. "Phaseolus Bean Improvement in Tanzania, 1959-2005." *Euphytica*. doi:10.1007/s10681-006-9112-9.Hussain I.L.

Raschid; M. A. Hanjra; F. Marikar; W. van der Hoek. 2002.Wastewater use in agriculture: Review of impacts and

methodological issues in valuing impacts. (With an extended list of bibliographical references). Working Paper 37. Colombo, Sri Lanka: International Water Management Institute.

IPCC, 2001. Climate change 2001: The scientific basis. Contribution of working group I to the third assessment report of the Intergovernmental Panel on Climate Change (IPCC). J.T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden & D. Xiaos (Eds.), Cambridge, University Press, Cambridge, UK.

Kimwaga,R.,Nyomora,A.M.S.,Mwegoha,W.,Mahenge,A. and Gastory, L. 2013.Dissemination of the Sustainable Wastewater Technology of Constructed Wetlands in Tanzania: Opportunities for Reuse of Treated Effluent and Vilarization of by-Products. Accessed at http://www.constructedwetlands.net/IR3-Water-related%20Diseases_FIN.pdf..VLIR -UOS Belgium South Initiatives 2011-2013.

Letaa.E.,Kabungo, C., Katungi E, Ojara M and Ndunguru A. 2014. Farm level adoption and spatial diffusion of improved bean varieties in Sothern Highlands of Tanzania. Country technical Report for PBRAApril 2009 – September 2014 PHASE REPORT

Magelanga, A. A. 2013. Effects of phosphorus levels on yield and yield components of drought resistant bean lines in Southern highlands of Tanzania MScThesis, SUA,2014.

Namugwanya,Margaret, John Stephen Tenywa, Erasmus Otabbong, Drake N Mubiru, and Twaha Ali. 2014. *Development of Common Bean (Phaseolus Vulgaris L .) Production Under Low Soil Phosphorus and Drought in Sub-Saharan Africa : A Review*. Vol. 7. doi:10.5539/jsd.v7n5p128.

Outwater, A.H ,NyomoraA.M.S., Outwater,A.B., Zachariah,A. and Katima, J.H.Y.2015. Potential of Constructed Wetland (CW) to Remove Helminths from Wastewater: A Case Study of A Coupled Waste Stabilization Pond (WSP) and CW inMorogoro, Tanzania. Water Science and Technology (In Press.)

Outwater A.O., Pamba S, Outwater A.B. 2013. Water-related Diseases of People using Municipal Wastewater: Risks, Exposure, Control Approaches and Effects on Health in Tanzania. Accessed at http://www.constructedwetlands.net/IR3-Water-related%20 Diseases_FIN.pdf.South Initiatives VLIR-UOS. Belgium

Parvatha P.Reddy. 2015. *Climate Resilient Agriculture for Ensuring Food Security*. Bangalore, India: Springer. doi:10.1007/978-81-322-2199-9.

Rao, I. & G. Cramer, 2003. Plant nutrition and crop improvement in adverse soil conditions. In: M. Chrispeels& D. Sadava (Eds.), *Plants, Genes, and Crop Biotechnology*. Published in partnership with the American Society of Plant Biologists and ASPB Education Foundation. Jones and Bartlett Publishers, Sudbury, Massachusetts, USA, p. 270–303.

Shuval, H.I., A. Adin, B. Fattal, E. Rawitz and P. Yekutiel.1986. Wastewater irrigation in developing countries.Health effects and technical solutions. World Bank Tech. Pap. 51, 32

Wortmann, C.S., R.A. Kirkby, C.A. EleduandD. J. Allen, 1998. Atlas of Common Bean in Africa.CIAT, Cali, Colombia.