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RESEARCH ARTICLE

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Effect of Irrigation with Waste Water on Soil Characteristics and Bean Yield: A Case Study of University of Eldoret Farm

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Abstract

Experimental field treatments were set up at the University of Eldoret farm that is next to the wastewater treatment plant. The farm is located in Uasin Gishu County, Kenyan North Rift part. The field experiments were carried out between June and October 2018. The irrigation was supplemental to the reducing rainfall amounts. The key objective of the study was to evaluate the effect of wastewater irrigation on soil physical and chemical characteristics, and bean crop yield. The approach took a randomised complete block design (RCBD) where the treatments were replicated twice. For the treatments, wastewater with four levels of NPK% (0%, 25%, 50%, and 75%) and freshwater with five levels of NPK % (0%, 25%, 50%, 75%, and 100%) were applied to the plots. The freshwater at 100% NPK was considered as the control experiment. For all the plots, supplemental irrigation was carried out where equal amounts of water were applied based on crop water requirement and growth stages for the crop. CROPWAT and CLIMWAT were used as the models to simulate the correct crop water requirement and develop an irrigation schedule. Wastewater samples were collected from the tertiary pond and tested in the chemistry laboratory. Also, soil samples were collected before and after the planting period and tested in the soil science laboratory. Results showed that plots under 25% NPK and 50% NPK WW yielded more beans compared to fresh water. The soil physical structure improved while components like Nitrogen, Potassium, and Phosphorous increased with significant amounts. The use of wastewater for irrigation around the Eldoret area calls for these optimum conditions to guarantee the food sufficiency in the region and Kenya at large. The irrigation schedule can be used as a decision-making tool for the local farmers to achieve an optimum irrigation efficiency. More research and awareness is required for the cultural aspect that surrounds use of waste water irrigation in the local communities.

Keywords: CROPWAT, Decision Making Tool, RCBD, Wastewater, Water Recycling and Irrigation Scheduling

INTRODUCTION

Reduced rainfall amounts, industrialisation, and demand for better living standards have made reliance on water to increase. As a result, management practices have been proposed to safeguard the available capacity and achieve effective and efficient use (Loucks *et al.*, 2005). Some of these practices include recycling, treating, and minimal usage, where applicable (Kimenyi, 2002). As it stands, Kenya is a water-scarce country with a per capita renewable amount of freshwater of less than 647 m^3 per year (Food Agricultural Organisation, 2010). Further, the rapid growth in population implies a lurking danger over time.

The reuse and recycling of waste water has been a key area of concern over the year as the debate of water scarcity continues (Lawston *et al*., 2015). In most parts of the country, water shortage continues to be an issue, which is worsened by the reduced rainfall amounts that have led to food shortage (Loucks & Van Beek, 2017). The need to alleviate this with correspondence to Kenya's big four agenda, one being food security, calls for an urgent alternative in water conservation other than water harvesting (Kiziloglu *et al*., 2008). The biggest volume of the generated waste water, 80%, is released into rivers and lakes, which leads to underground water population (JICA, 1998). The reuse of this water for irrigation, under the correct measures and tools, can predominantly improve water efficiency.

Sustainable sources of water are relevant to cater to the intensifying needs of Kenyans. The Kenyan population is projected to reach 50 million based on the 2019 national census (Marshall, 2011). Key to note, Kenya is one of the developing countries that depend on agriculture for income and staple meals. Therefore, informed reuse of wastewater is prudent when it comes to solving the issues of water scarcity among Kenyans societies (Wakhungu, 2016).

Use of waste water for irrigation has been used in Kenya under unregulated methods, which leads to contamination of food and prevalent illnesses. Hence, there is need for a decision-making tool on the best policies that can be adopted to use waste water for irrigation. In essence, water scarcity has paved the way for a dire need to seek an alternative source of water, especially to support arable farming. Notably, the 860,000 m^3 per day demand of water in large cities is projected to rise to about 1.2 million m^3 per day by 2035 owing to the expansion of the sustained investments that call for a higher volume of water supply to meet the four key agendas. Also, 20% of the supplied water turns into wastewater as effluent, the amount of wastewater producible is projected to grow from the current 172,000 m^3 per day to approximately 600,000 m^3 per day by 2035. As more waste water is generated, there is need for further research on its effect on soil physical and chemical characteristics and crop yield. This is with a specific focus on the nutrient constituent of the treated waste water at the university's treatment plant.

Hypothesis

H_0: $\mu_{treatment\ 1} \neq \mu_{treatment\ 2} \neq 0$, all the irrigation treatments result in different crop yields.

H_a: All the population means (crop yield) for the given irrigation treatments are the same.

MATERIALS AND METHODS

Study Area Location

The empirical study was carried out at the University of Eldoret farm, main campus. The location is 2,100 m above sea level and 0˚31' N Latitude and 35˚17' E Longitude (Figure 1). Also, the area around the University farm registers an average temperature of 16.6˚C, while the average high temperatures are 22˚C, and average low temperatures are 9˚C, and the total annual precipitation averages 1,103 mm.

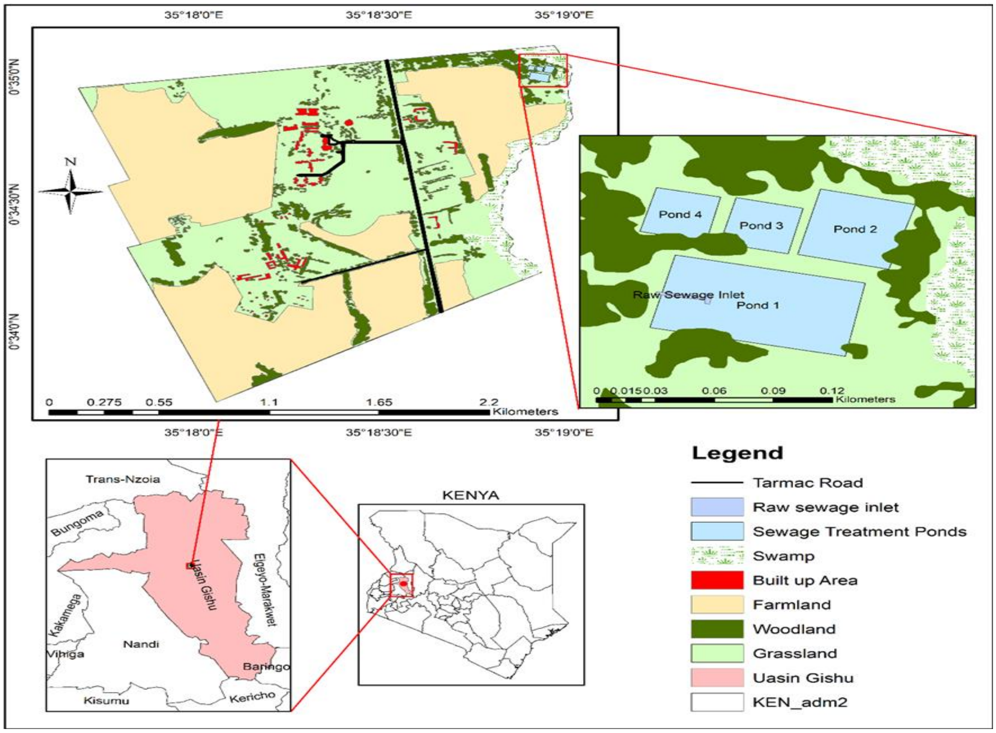

Figure 1: Study Location.

Experimental Design and Treatments

Bean crop was identified for the study and was grown at 20 cm crop spacing with a 10 cm raw spacing. The field treatment took a Randomised Complete Block Design (RCBD) approach with nine treatments replicated twice to yield 18 plots (Table 2). Every plot size was 3 m × 1.5 m. The spacing left between each replication and plots was approximately 40 cm and 50 cm, respectively. The treatments involved waste water and freshwater at different levels of NPK (Table 1) Soil moisture and crop data was collected from the plots throughout the growth season. In each treatment, the estimated root zone was refilled to field capacity (abbreviated as FC) where soil water in the root area came close to 45% of all the water available referred to as TAW.

Table 1: Irrigation Treatments

SN	Waste Water (WW)	Fresh Water (FW)
1	A-0 % NPK	E-0 % NPK
2	B-25 % NPK	F-25 % NPK
3	C-50 % NPK	G-50 % NPK
4	D-75 % NPK	F-75 % NPK
5		**I-Control treatment 100 % NPK**

Table 2: A Layout of the Random Complete Block Design

1	C-50% NPK	10	D–75% NPK
2	D-75% NPK	11	B-25% NPK
3	F-25% NPK	12	G-50% NPK
4	E-0% NPK	13	H-75% NPK
5	A-0% NPK	14	F-25% NPK
6	B-25% NPK	15	I-100% NPK
7	G-50% NPK	16	C–50% NPK
8	H-75% NPK	17	E-0% NPK
9	I–100% NPK	18	A-0% NPK
BLOCK 1		BLOCK 2	

Determining Waste Water Physical and Chemical Characteristics

For the sake of determining waste water's physical and chemical characteristics, samples were sourced from the third pond at the University of Eldoret treated waste water plant. Samples were filled in clean bottles to determine characteristics such as water temperature, colour, and odour, solids that are water suspended, pH, the ratio of sodium absorption, metals like zinc, aluminium, and copper, chemical and nutrient loads and electoral conductivity. Parameters like Nitrates, bases, Phosphates, and Chlorides were tested in the university laboratories.

Determining the Crop Water Requirement

Bean crop has four growth stages: Initial, Development, Flowering, and Ripening. For each stage, there is a different crop factor K_c as derived from the FAO Paper for irrigation and drainage (Table 3). Based on the historical climatic data for the study location, and calculation of reference evapotranspiration ET_o, crop water need was simulated through the CROPWAT model to get the amount of water for each growth stage. Using the Penman-Monteith equation, the actual evapotranspiration was estimated and used to compute the crop water requirement. Irrigation schedules chart was generated from the CROPWAT after feeding the input files like soil, crop, crop water requirement, and climate data. With this, irrigation schedules that ensured that the required water amount was applied to the plots.

Table 3: Bean Crop Growth Stages Food and Agricultural Organisation (2009)

	Initial Stage	**Crop Development**	**Flowering**	**Ripening**
Length (Days)	15	25	45	20
Kc	0.35	0.70	1.10	0.30
Planting date: 18th June 2018				

Soil Sampling and Characteristics

Various soil samples were collected from the farm after the bean growing season through the random sampling technique. The samples were in two groups, those from waste water plots and those from fresh water plots. The samples were put in clean bags and labelled based on the samples then taken to the soil science laboratory and their physical and chemical characteristics determined using respective methods. To compute water retention characteristics, different soil physical parameters like the moisture holding capacity were evaluated (Martín *et al*., 2018).

Irrigation Scheduling

An irrigation schedule was formulated from the historical climatic data and the

CROPWAT and CLIMWAT models. Soil-water-atmosphere balance was determined from Equation 1. The FAO-Penman Equation of ET_o was used to simulate the crop water requirement for each bean growth stage. Based on the irrigation calendars, it was possible to adjust the irrigation timing and the depth during the growing season to the actual weather condition and also when severe shortage in the supply of irrigation water occurs. The soil-water-atmosphere balance, Equation 1, has been applied throughout the bean growth season to enhance irrigation scheduling.

$$P + I = ET + DR + RO - (\Delta W) \qquad \text{(Eqn. 1).}$$

Where:
P = Precipitation
I = Irrigation
ET = Evapotranspiration
DR = Drainage
RO = Surface Runoff
ΔW = Change in water storage within the soil profile

During the initial days of growth, or at the beginning of the season, soil moisture content (Equation 2) was very close to the permanent wilting point SW_0 = PWP. The initial soil water content (SW_0) and the soil water content during the planting period were measured, recorded, and eventually monitored throughout the experiment. SW_O was calculated using the gravimetric methods while SW_c was taken at 20 cm of the root zone to determine the moisture content.

$$\Theta_m = \frac{M_{s+w} - M_s}{M_s} \times 100 \qquad \text{(Eqn. 2).}$$

Where:
Θ_m = mass water content (mass %)
M_{s+w} = mass of wet soil sample (g)
M_s = total dry mass of sample (g)

Irrigation Method

A drip irrigation method was used as it minimises the contact between the crops and the waste water. In this case, the issue of contamination is safeguarded to ensure the beans are appropriate for harvesting and consumption. The system consisted of a PVC main line and sub main lines of diameters 50 mm and 32 mm respectively. Polyethylene drip lines (laterals) of 25 mm in diameter was used to irrigate the beans. The drip lines had built-in emitters with a nominal discharge of 1.2 l/hr spaced 20 cm from each other. Additionally, control valves were installed at the entry of each plot to adjust and control the amount of irrigation water delivered to each plot.

Crop Management

During the entire growth period, certain crop management practices like weeding, spraying, and protection from predators was carried out to ensure optimum growth of the bean crop. Also, the irrigation schedule was followed closely to allow water efficiency and crop water requirement based on the weather patterns. Aspects such as the crop vegetative characteristics, germination rates per plot, crop height, and colour of the leaves were noted for each treatment. After the growth period, the dry beans were harvested on the 105 day, the dry beans were weighed and recorded appropriately.

RESULTS

Waste Water Physical and Chemical Characteristics

From Table 4, the collected water was suitable for irrigation purposes. Also, the comparison with NEMA report guidelines for irrigation indicates that the parameters are within the allowable limits. It was assumed that the quality was constant because of the treatment methods and regular maintenance and by the University.

Table 4: Table Showing Waste Water Physical and Chemical Characteristics

Parameter	**NEMA limiting value**	**Observed value**
pH	6.5-8.5	7.1
Chloride	0.010 (mg/L)	0.005
Arsenic	0.10 (mg/L)	0.00
Boron	0.10 (mg/L)	0.00
Cadmium	0.50 (mg/L)	-
Aluminium	5.0 (mg/L)	3.5
Chromium	1.50 (mg/L)	0.5
Iron	1.00 (mg/L)	-
Copper	0.05 (mg/L)	0.035
E.coli	Nil/100 ml	-
Fluoride	1.00 (mg/L)	-
Total Dissolved Solids	1200 (mg/L)	310
Lead	5 (mg/L)	-
Selenium	0.19 (mg/L)	-
Sodium Absorption Ratio (SAR)	6.00 (mg/L)	-
Cobalt	0.10 (mg/L)	0.08
Zinc	2.00 (mg/L)	-

Irrigation Scheduling

After the soil analysis of the farm was done, it was determined that it was composed of 28% clay, 60% sand, and 12% silt. With these respective results, it can be determined that the soil's classification is that of sandy clay loam based on the USDA system (Martin *et al*., 2018) It involved the excavation of three profile pits from random points in the field. Soil that is undisturbed was collected from 0.5 m depth using a Kopecky ring of 100 $cm^{3.}$ Next, the total mass of the soil samples were dried in the oven at 110°C for 24 hours and later weighed. From this, the bulk density of the soil was calculated, which was used to get the soil water holding characteristics (Table 5).

Table 5: Soil Physical Characteristics

Soil Depth	**Soil Texture**	**Field Capacity (FC) (vol %)**	**Saturated hydraulic conductivity (mm/day)**	**Permanent wilting point (WP) (vol %)**	**Point of Saturation (vol %)**	**Total Available water mm/m**	**Bulk Density g/cm^3**
20 cm	Sandy clay Loam	24	270	15.4	40.3	86	1.4

Calculations:

For the Sandy Clay soil, the total water holding capacity (TAM) is 10 (Θ_{FC} - Θ_{WP}) per meter depth of soil.

Hence, TAM = 10 (24 - 15.4)

= 86 mm/m-soil depth

The Allowable Depletion (AD) or Readily Available Soil Moisture (RAM) = p.TAM, where p is the fraction of total available soil moisture that a crop can extract from the soil without suffering water stress.

Hence, RAM = 0.45 (86) = 38.7 mm/m-soil depth

Considering the maximum root depth of the bean crop is 0.7 m, hence, the RAM at this depth is;

38.7 x 0.7 = 27.09 mm. During the irrigation treatment, it was critical to refill the root zone to field capacity. Hence, the analysis derived an irrigation schedule of 21 irrigation events (Figure 2). The interval was derived to be after every three days based on the crop water requirements. The highest irrigation water demand is derived to be during the flowering stage, also referred to as the mid-season stage and the yield formation period. Hence, the chart presents its respective growth stages per number of days.

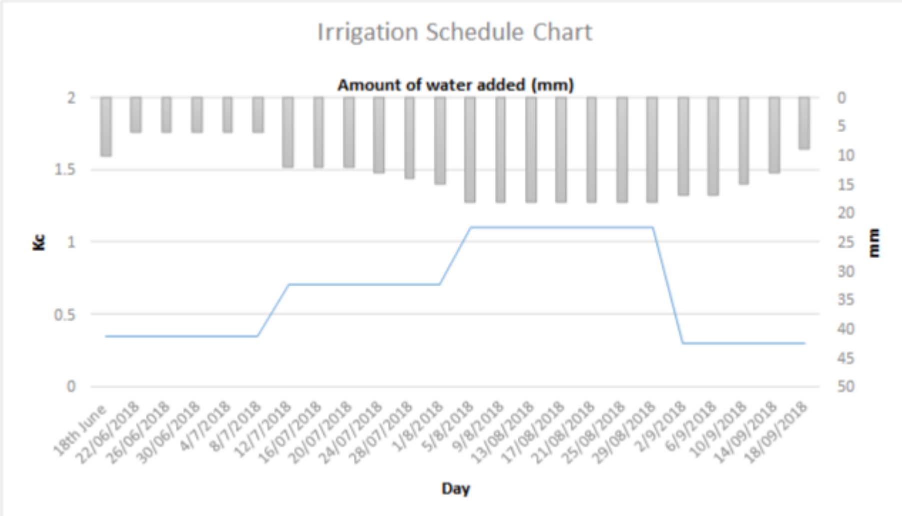

Figure 2: Irrigation Schedule Chart.

Effect of Waste Water on Physical and Chemical Soil Characteristics

Soil physical and chemical soil characteristics are tabulated based on the treatment levels and the plot numbers. The chemical soil characteristics that were presented graphically (Figure 3) were compared between the waste water and fresh water treatments.

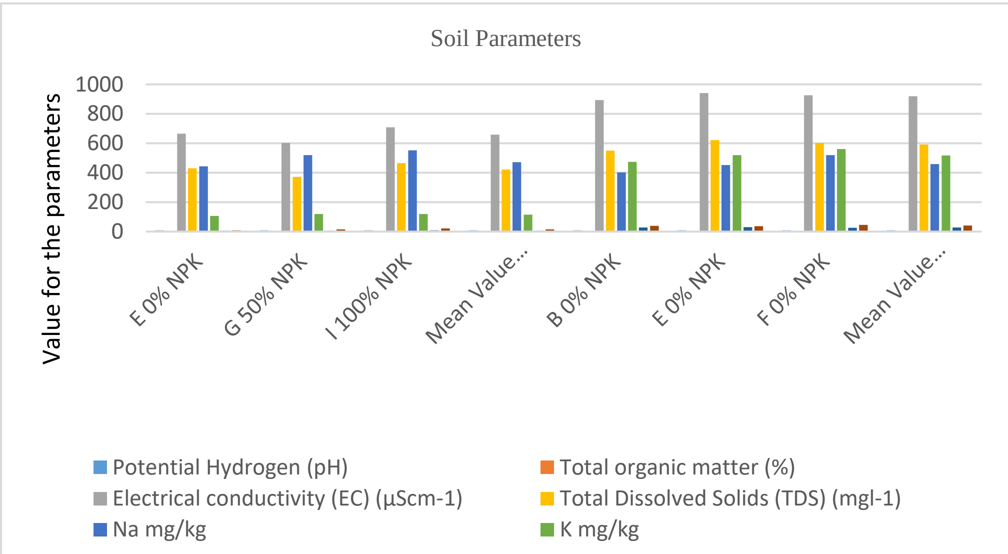

Figure 3: Physical and Chemical Soil Characteristics.

The varying pH value of the soil samples from the plots represents the acidity or alkalinity degree. The analyses revealed that pH values for the irrigated soils ranged from 8.09 to 8.26 for freshwater irrigation and between 7.53 and 7.72 for wastewater irrigated soil samples. A universally recognized pH standard of between 6 and 6.5 optimally favours a wide spectrum of crops because of the wide ready availability of most plant nutrients. Therefore, the extensive use of treated wastewater for irrigation could eventually lower the soil pH beyond the survival point of a bigger assortment of relevant soil nutrients.

Irrigation with wastewater led to an increasing EC value for soils from 894 to 926 µS/cm and a mean of 920.33 µS/cm whereas the average for the freshwater irrigation ranged between 601 and 709 and a mean of 658.67 µScm$^{-1.}$ Notably, treated wastewater registered remarkably high organic matter contents of about 2.02% as compared to a mean rate of 1.21% in freshwater irrigated soils. It is a vivid implication that wastewaters significantly contain organic matter compounds compared to freshwaters. The findings concur with many scholars who postulate that treated wastewaters prolifically contributes to the levels of organic matter content in. Other nutrients like Nitrogen, Potassium, and Phosphorous are observed to be at slightly higher amounts in the soils irrigated with waste water as compared to those irrigated with fresh water.

Effect of Waste Water Irrigation on Crop Yield

Yield in Tonnes per hectares was recorded in a table for each treatment for easier analysis using the ANOVA table. The results for block A and block B were tabulated for analysis. Bean yield was presented as a graph (Figure 4) to show a clear difference between WW and FW yields.

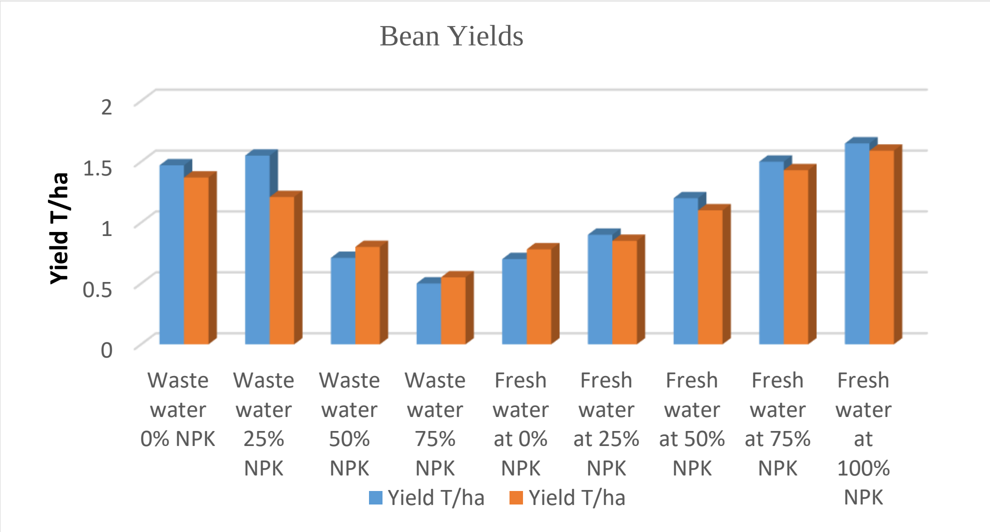

Figure 4: Effect of Waste Water Irrigation on Crop Yield.

ANOVA Model (Kim, 2014)

$$Y_{ijk} = \mu + ح_i + \beta_j + (ح\beta)_{ji} + \epsilon_{jik}$$ (Eq. 3).

I = 1, 2,...a.
J = 1, 2,...b
K =1, 2,..n

Where: Y_{ijk} = observation taken under the i_{th} level of factor A and j_{th} level of factor B in the k_{th} replicate

µ – Overall mean

حi - effect of the i_{th} level of factor A

β_j – effect of the j_{th} level of factor B – 0 ij – effect of the interaction between τ_i and β_j

ε_{ijk} – Random error component

As a recap, the formulated hypothesis was generated from the following details: Four similar methods that can determine the bean yields from the irrigation treatments are compared. There are two different types irrigation available, that is from irrigation with waste water and irrigation with fresh water. It is assumed that the two types of irrigation with yield varying results from each other. Also, from the RCBD, the blocking factor is the type of irrigation, hence Table 6 is generated. The main question for the hypothesis is whether there is any evidence at 5% level of significance, one or two of the treatments will give higher yields?

Table 6: ANOVA Table Analysis

Source of Variation	**SS**	**DF**	**MS**	**F_{OB}**	**$F_{critical}$**
Treatments (A)	SS_A =0.01	(a-1) $2-1=1$	$\frac{SS_A}{a-1} = \frac{0.01}{1} = 0.01$	$\frac{MS_A}{MS_E} = \frac{0.01}{0.609} = 0.0164$	$F(1,3)_{0.05} = 10.13$
Methods (B)	SS_B =0.08	(b-1) $4-1=3$	$\frac{SS_B}{b-1} = \frac{0.08}{3} = 0.0267$	$\frac{MS_B}{MS_E} = \frac{0.0267}{0.609} = 0.0438$	$F(3,3)_{0.05} = 9.28$
Error	SS_E =1.827	(a-1)(b-1) $1\times3=3$	$\frac{SS_E}{(a-1)(b-1)} = \frac{1.827}{3} = 0.609$		
Total	SS_T =1.917	(ab-1) $(2\times4)-1 = 7$			

For both cases of the irrigation types, waste water and fresh water, F Critical is greater than F observed. That is 10.13 > 0.0164 and 9.28 > 0.0438. Hence, one can accept the null hypothesis and deduct that all the treatments result in different crop yields.

The residual effect of waste water applications significantly led to increase in plant height. According to Drewa *et al*. (1993), sewage nutritional contents increases chlorophyll content and oxygen evolution. Waste water irrigated seeds germination percentage was 93% compared with fresh water irrigated seeds (84%) (Figure 5). The number of seeds that were planted and those that germinated were recorded from two specific treatments. Based on comparison, it is evident that irrigation with waste water results in a higher germination rate compared to fresh water.

Apart from the germination percentage, other parameters that were observed to vary include the leaf colour, leaf size, number of pods, and the number of beans in each pod. In case of plants irrigated with waste water, the plants were more vegetative, hard dark green colour, and with a higher number of pods per plant. The beans were also bigger in size and were more in each pod compared to plants from fresh water irrigation.

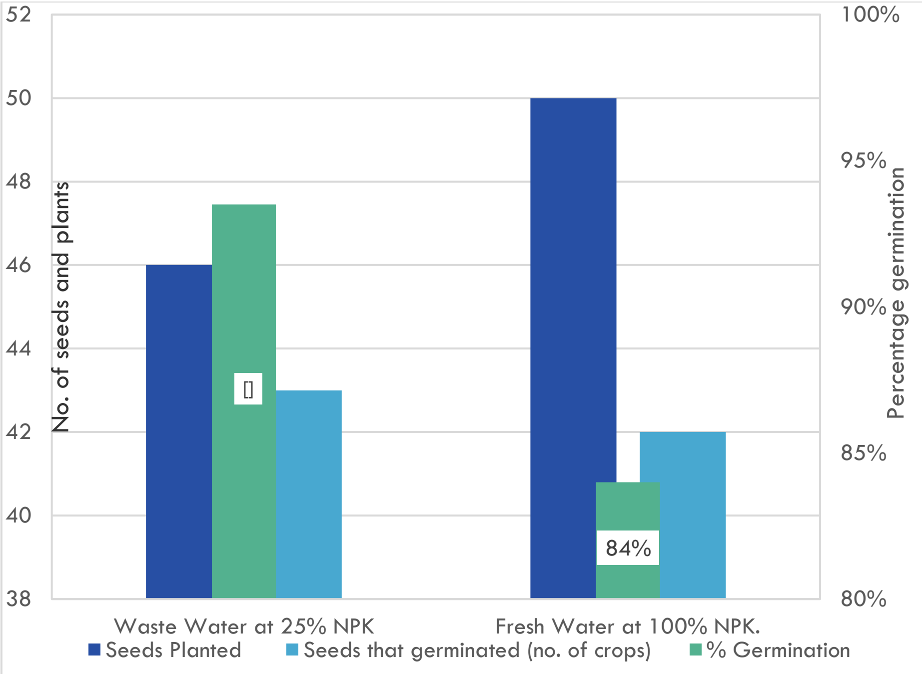

Figure 5: Germination Percentage for WW at 25% and Fresh Water at 100%.

When the municipal wastewater is properly planned and used, it helps significantly to remove surface water pollution challenges. It also helps conserve valuable water sources and allowing farmers to take advantage of the nutrients found in the sewerage system to grow and irrigate their crops. The phosphorous and nitrogen residual in the sewerage system may help minimise or get rid of the need to purchase fertilisers (Al-Hamaiedeh & Bino, 2010). It is beneficial to consider the reuse of effluent water and also consider wastewater collection and treatment and disposal planning to optimise sewerage system design in regards to effluent treatment and transport methods. Further, due to the reducing rainfall amounts, water harvesting may not be an effective approach compared to water recycling. Water collected is very low compared to the amount of water being disposed into lakes and rivers (Aljaloud, 2010). Further, waste water production is continuous whether the rains are there or not, hence, there can never be a ‘dry’ period when using wastewater for irrigation. Other than this, with a correct guidance from the local government, the farmers will harvest more yields that can significantly contribute to a higher GDP.

The range is the highest possible condition for maximising the yield of bean crops in Eldoret through wastewater supplemental irrigation. High NPK concentrations in WW have a reduction impact on bean yield. Hence, it can be formulated that high amounts of NPK are not conducive for plant growth. Recycling of waste water is viable enough to provide the correct nutrients for bean crop growth.

DISCUSSIONS AND CONCLUSIONS

It is evident that waste water that has been treated has varying physical and chemical characteristics. Some of the available nutrients range from Nitrogen, Phosphorous, and Potassium. Other than this, it has a significant amount of total dissolved solids and organic matter. The tests carried out for the simple metals showed some traces of zinc, aluminium, copper, and cobalt. However, there were no traces of boron and arsenic. In comparison to NEMA 2018 guidelines on irrigation water. The WW collected at the University of Eldoret plant was found to fall within these standards, and hence, could be used for irrigation. The high electrical conductivity was attributed to the presence of dissolved ions in the water.

Bean was the crop selected for the research for the area due to its suitability in the area in terms of climate, soils, and weather parameter. Bean crop water requirement is dependent on its four growth stages, initial, development, flowering, and ripening. Each stage was found to have a different crop factor, and hence, varying crop water requirement. More water was required for the flowering and ripening stages. Through the historic climatic data collected for 20 years, a frequency analysis enabled one to get the probability of exeedance for the wet, normal, and dry periods. Hence, a good decision-making tool was formulated to guide farmers on effective waste water irrigation.

Waste water has a significant effect on crop yield. WW at 25% NPK yields a significant high amount of yield. It can be concluded that WW can be used as an alternative to the inorganic fertilisers due to the availability of nutrients required for plant growth. However, a suitable policy should be formulated to achieve acceptance of WW use in the farms.

Apart from improving bean productivity, WW is also essential to the soils as it improves structure and adds the required nutrients for soil fertility.

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