Effects of treated greywater irrigation regimes and mulches on yield of *Capsicum chinense* under surface drip irrigation system

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Abstract. A field study was conducted to determine the effects of combine treatment of greywater application rates and mulches types on growth and yield of *Capsicum chinense* in Omu-Aran, Nigeria. Greywater (GW) was treated using a pilot-scale horizontal sub-surface flow constructed wetlands (HSSF CW) vegetated with *Canna indica* plants. Four irrigation levels (60, 80, 100 and 120% of ETc) and four mulches types (Black plastic film BM, Silver plastic film SM, Rice straw RS and un-mulched Control) were applied to the potted plants. The experiment was laid out in a split-plot design, with main plots as irrigation levels and mulches types as sub-plots. *C. indica* plants were found to be effective in GW Phytoremediation treatment in CW. The maximum fruit yield was observed for T₁₀ (I₁₀₀SM) 4666.70 kg/ha due to reflective mulch ability to increase light and heat to plant resulting to a higher yield. Significant difference was observed between the mean yield of I₆₀ and other irrigation regimes, whereas between I₈₀ to I₁₂₀ there was no significant difference in mean yield recorded. Silver mulch combined with full irrigation with treated greywater effluent was found to be the best of all treatments in the study.

1. Introduction

*Capsicum chinense* is cultivated in all the agro-ecological zones and exhibits the widest variation in performance. The plant does well in warm climate and temperature ranging between 18 to 27°C during the day and 15 to 18°C at night [1]. A typical *C. chinense* is shown in figure 1. Pepper is a vegetable that is sensitive to water deficit. This sensitivity is shown more during the flowering and fruiting stages, with the effect on the quantity and the quality of the fruits [2,3]. Worldwide, there is an increasing interest in other sources of nutrients for plant as a replacement for chemical fertilizers [4]. The use of treated greywater with high nutrients will help reduce the cost of fertilizer and manure. Appropriate water-saving irrigation and soil water conservation techniques is essential for food security and environmental protection [5]. There is also a challenge of climate change which makes rainfall to be unevenly distributed and unpredictable. It is essential to estimate crop water requirement due to the continuous increase in worlds population and the need to produce more food [6]. More attention recently was towards alternative and sustainable water resources which reduce pressure on freshwater especially in regions with limited water supply [7]. An example of this alternative and sustainable water source is residential wastewater which is generated all-year-round in most places.
Residential wastewater can be classified as Blackwater and Greywater. Blackwater (BW) is the spent water from toilets and urinals with high concentrations of bacteria and organic contaminants in addition to pathogens and ingested chemicals. Greywater (GW) is wastewater obtained from daily domestic chores with no contact with faeces and little contact with urine during bathing. They are obtained from showers, dishwashers washing machines, wash-hand basins and kitchen sinks [8]. GW makes up about 50-80% of total domestic wastewater with a high reuse potential due to its availability and its low pollutants composition, as compared to mixed sewage [9]. Untreated GW reuse can impact human and environmental health. Pathogens in GW can cause diseases through direct human contact, accidental ingestion or inhalation through human contact. Proper GW treatment processes are needed before it is recycled. Phytoremediation of soils and polluted waters in CWs have gained acceptance as a low-cost method of water treatment [10]. It has been reported that the warm temperature in the tropics favours microbial activities and plant growth [11,12].

The practice of actual, surplus and deficit irrigation techniques combined with drip irrigation system and mulching appears to be very promising in realizing the goal of increasing market supply and attracting more profits from pepper production. The negative impact of an increase in global temperature is increased in evaporation from soil surface which in turn leads to an increase in irrigation frequency and interval. Selection of appropriate combination of mulching materials and irrigation water amount will help in reducing the afore mentioned costs. This study is aimed at determining the effects of combined treatments of treated greywater drip irrigation application rates and mulches types on growth pattern and yield characteristics of C. chinense grown in a plastic pot-culture.

2. Materials and methods

2.1 Description of greywater treatment system

The treatment system used for the GW treatment was the horizontal sub-surface flow constructed wetlands (HSSF CW) vegetated with C. indica plant. The pilot-scale HF CWs were constructed as described in [13]. The raw greywater from the student hostels was analysed for different parameters before feeding it into the CWs. The GW was allowed to remain in the CWs for 3days (HRT) after which the treated water samples were collected and analysed in a laboratory for the all sets of parameters earlier tested for. Samples were collected in clean plastic bottles with a lid. Samples were filtered immediately and preserved and analysed for physicochemical parameters, like BOD₅, COD, TDS, pH, electrical
conductivity (EC), total nitrogen (TN), total phosphorous (TP), Metals (Mg, Al, Ca and Fe) and sodium adsorption ratio (SAR). Metals (Al, Ca, Fe and Mg) were analysed using Atomic Absorption Spectrometer (AAS SearchTech AA320N, UK). The pH, EC and Ca were performed for the original samples. EC and pH were determined in the field using portable instruments (multifunction meter-WA2015). TN and TP (colorimetric, Palintest Photometer 7100). The five-day Biochemical Oxygen Demand (BOD)$_5$ was calculated from the difference between the initial and final DO measurements. Seeding of the wastewater was done by the addition of 1 ml of settled sewage from the nearby septic tank. BOD$_5$ were determined using (MW600 Standard Portable Dissolved Oxygen Meter) instruments method. All parameters were determined based on standard methods prescribed by American Public Health Association [14]. The sodium adsorption ratio (SAR) was determined using Equation (1) [15].

\[
SAR = \frac{[\text{Na}^+]}{\sqrt{([\text{Ca}^{2+}] + [\text{Mg}^{2+}]])},
\]

where $[\text{Na}^+]$, $[\text{Ca}^{2+}]$ and $[\text{Mg}^{2+}]$ are concentrations in mg/L. SAR is in meq/L

Campbell scientific weather station was used in recording the different meteorological data used in reference evapotranspiration calculation.

2.2 Site soil analysis

Soil samples for the experiment were analysed before planting. A composite soil samples were collected for the analyses at soil depths of 0–15 cm. The soil sample was air dried, ground and made to passed through 2 mm sieve and analysed for different physicochemical properties of soil.

2.3 Planting pots preparation

Plastic buckets used as planting pots were bought from the local market. Drainage holes were made at the bottom of the pots. They were then filled with crushed stones (25 mm) covering the bottom before being filled with soil. The soil earlier mixed with poultry manure in the ratio 3:1 (soil: manure) and left to mineralize for four weeks before transplanting was done.

2.4 Construction of a drip system

A 16-mm drip tape was acquired and connected through a connector to the mainline made from 38 mm PE pipe. The system was gravity fed from a holding tank located at a height of 2 meters above the ground level. The drip tapes have pressure compensating emitters embedded within it to allow uniform discharge under variable water head from the holding tank. The specification of the surface drip system used in the experiment includes Dripper flow rate – 0.8 L/H, Distance between drippers – 0.3 m and Distance between Laterals – 0.6 m.

2.4.1 Crop details.

Crop: Sweet Pepper (Capsicum chinense)
Family: Solanaceae
Variety: Rodo variety- NH Ca(R) C9)
Spacing: 0.3 m × 0.6 m.

2.5 Materials for mulching

Materials used for mulching in this study were, black plastic mulch (BM), silver plastic mulch (SM), rice straw mulch (RS) and no mulch (C) was taken as a control. The thickness of the plastic mulches was 25 microns. They were purchased in the market close to the research location and the rice straw was brought in from the teaching and research farm of Landmark University. Mulches were applied a week after transplanting (7 WAS) on 5th January, 2018.
2.6 Determination of drip emission uniformity

The drip emission uniformity of the drip setup and the discharge through all the emitter were measured for ten minutes at a constant operating pressure (pressure compensating emitters). Emission uniformity was estimated using a formula by [16] in Equation 2.

\[ Eu = 100 \left( \frac{Q_{\text{min}}}{Q_{\text{ave}}} + \frac{Q_{\text{ave}}}{Q_{\text{max}}} \right) \frac{1}{2} \]  

(2)

where, \( Eu \) = Emission uniformity (%), \( Q_{\text{min}} \) = Minimum emitter flow rate (lph), \( Q_{\text{max}} \) = Average of the highest 1/8th of the emitter flow rate (lph), \( Q_{\text{ave}} \) = Average emitter flow rate (lph).

2.6.1 Scheduling of irrigation through the drip system. Daily scheduling of irrigation for C. chinense was done based on the report of [6], which was on irrigation scheduling based on the growth-stage specific crop coefficient. The crop factors for the three growth stages of C. chinense were used in the calculation of daily evapotranspiration (ETc) according to the equation (3) [17];

\[ ETc = Kc \times ETo \]  

(3)

where: \( ETc \) = crop water requirement (mmd\(^{-1}\)), \( Kc \) = crop coefficient, \( ETo \) = reference evapotranspiration (mmd\(^{-1}\)). The daily evapotranspiration was related to the specification of the drip tape emitter precipitation rates measured to obtain the duration for running of the drip system for the different level of treated GW regimes (0.6 ETc, 0.8 ETc, 1.0 ETc and 1.2 ETc). The amount of water to apply was calculated daily. For the average emitters discharge rate of (0.4 lph), the duration of water application was estimated using the equation 4.

\[ \text{Duration of Irrigation} = \frac{\text{Emitter discharge (l/h)}}{\text{Emitter spacing } \times \text{Inline spacing}} \]  

(4)

2.6.2 Precipitation rate for the drip system. The Application Rate of a drip line irrigation system was calculated using equation 5 [18].

\[ PR = 231 \times \frac{Qe \times Eff}{Rowx \times Emity} \]  

(5)

where: \( PR \) = Precipitation rate (in/hr), \( Qe \) = Drip emitter flow rate (gal/hr), \( Eff \) = Irrigation efficiency (decimal, 0.95 for drip system). \( Rowx \) = Distance between drip rows (lines) (in), \( Emity \) is the distance between 2 emitters. (in). The PR was later converted to (mm/hr) from (in/hr).

2.7 Experimental details and layout

The experiment was laid out in a split plot design with the main plots as Irrigation levels and mulches types in sub-plots, with three replications. The treatments were randomly allotted to different plots using random number table of [18]. The experimental layout and the treatments allocation and other experimental details are shown in Figure 3 and Table 1.
Figure 2. Experimental layout of the drip system

The field experimental setup for all treatment combinations (irrigation levels and mulches) and its detailed description of treatments is shown in Table 1. The flow in each sub-plot was controlled by means of clips as shown in Figure 2.
Table 1. Detailed description of treatments

| Treatments | Description | Notation |
|------------|-------------|----------|
| T1         | Irrigation with 60% ET and No mulch (C) | I60C     |
| T2         | Irrigation with 60% ET and Silver Mulch | I60SM    |
| T3         | Irrigation with 60% ET and Black Mulch | I60BM    |
| T4         | Irrigation with 60% ET and Rice Straw  | I60RS    |
| T5         | Irrigation with 80% ET and No mulch (C) | I80C     |
| T6         | Irrigation with 80% ET and Silver Mulch | I80SM    |
| T7         | Irrigation with 80% ET and Black Mulch | I80BM    |
| T8         | Irrigation with 80% ET and Rice Straw  | I80RS    |
| T9         | Irrigation with 100% ET and No mulch (C) | I100C    |
| T10        | Irrigation with 100% ET and Silver Mulch | I100SM   |
| T11        | Irrigation with 100% ET and Black Mulch | I100BM   |
| T12        | Irrigation with 100% ET and Rice Straw  | I100RS   |
| T13        | Irrigation with 120% ET and No mulch (C) | I120C    |
| T14        | Irrigation with 120% ET and Silver Mulch | I120SM   |
| T15        | Irrigation with 120% ET and Black Mulch | I120BM   |
| T16        | Irrigation with 120% ET and Rice Straw  | I120RS   |

2.8 Agronomic Measures

The nursery was prepared in the teaching and research farm of Landmark University. Seeds were treated with fungicide Bavestin 1 g per kg seed before sowing. Seeds were sown on 17th of November 2017. Pepper in the nursery was irrigated by means of the watering can. The seedlings were transplanted on the 29th of December 2017 (6 Weeks After Sowing, WAS). Transplanting was done at the space of 0.3 m x 0.6 m with three seedlings per pot but later thinned to two after they have been well established. It was done after 4 pm to protect the seedling from the heat scourge from the sun. Fresh Irrigation water was applied throughout the period of seedling establishment. Plant protection measures were adopted to control major insect pest like a variegated grasshopper, using insecticides like Ambush and Fungicides Diathane.
2.9 Total Yield (Kg/ha)

Harvesting of fruits was done for 5 consecutive weeks and cumulative values for each treatment was recorded. The weight of fruits harvested from each pot in each treatment at every harvesting was recorded and the total yield per treatment plot in kg was worked out.

2.10 Statistical analysis

The experiment was laid out in a split-plot design. The data obtained on various characters under study were analysed statistically by using the method of analysis of variance for split-plot design and significance was tested by F-test [20]. In each pot, three plants were selected and mean values and standard error (S.E.) of the mean were estimated. Duncan’s Multiple Range Test (DMRT) was used to separate means. The data were suitably illustrated with graphs and figures.

3. Results and discussions

3.1 Climatic condition

The monthly reference evapotranspiration, ETo, was computed by Penman-Monteith method [21] using CROPWAT 8.0 for the dry season of 2017/2018 are illustrated in Figure 4. The summary of crop actual evapotranspiration (ETc) data and other important data in irrigation scheduling for each month during the planting period (November to March) are listed in Table 2. The Kc values for initial, mid and end stages of growth of C. chinense adopted were those obtained in [6]. The crop coefficient values were found to be 0.32-0.7, 1.02-1.45 and 0.76-0.9 respectively.

3.1.1 Physicochemical properties of the soil in the study area

The physicochemical properties of the soil used for the study is presented in Table 3. The data of the composition of soil revealed that the soil of the plot was loamy sand, containing 82.96%, 12.72% and 4.32% of sand, silt and clay respectively. The nutrient content was found to be low but was later improved by adding organic manure to raise its level.

![Figure 3. Monthly (ETo) in the study area (Landmark University)](image)

3.2 Drip system uniformity

The emission uniformity (EU) data obtained during the evaluation of the drip system is shown in Table 4. The approximate discharge per emitter was found to be 0.4 l/h. This is different from the manufacturer specification of 0.8 l/h. The reason is the clogging of the drip line due to failure to subject it to flushing after its previous usage. This has led to build up of biomass which reduces the opening of the orifice. However, the discharge for the drip irrigation system was based on recorded emission rate which is 0.4 l/h. The EU value for the emitter was 84.1%, implying that there was no uniformity problem originating from hydraulics and it is completely good [22]. The new precipitation rate obtained was 2.28 mm/h.
Table 2. Table of value of irrigation monthly scheduling parameters for the study area.

| Parameter          | November | December | January | February | March |
|--------------------|----------|----------|---------|----------|-------|
| ETo (mm day\(^{-1}\)) | 5.15     | 5.74     | 5.96    | 6.57     | 6.86  |
| Growth Stage (GS)  | Initial  | Development | Dev/Mid | Mid      | Late/end |
| Kc for GS          | 0.7      | 0.5      | 1.4     | 1.5      | 0.9    |
| ETc (mm day\(^{-1}\)) | 3.61     | 2.87     | 8.34    | 9.86     | 6.17  |
| ETc (mm month\(^{-1}\)) | 108.3    | 88.97    | 250.2   | 295.8    | 185.1 |

Table 3. Physicochemical properties of the soil used for the study.

| Parameters                  | Mean       |
|-----------------------------|------------|
| Sand (%)                    | 82.96      |
| Silt (%)                    | 12.72      |
| Clay (%)                    | 4.32       |
| Textural class              | Loamy sand |
| Bulk density (g/cm\(^3\))   | 0.76       |
| Total porosity (%)          | 56.9       |
| pH (H\(_2\)O)               | 6.11       |
| EC (mS/cm)                  | 0.7        |
| N (%)                       | 0.19       |
| K (mol Kg\(^{-1}\))        | 0.2        |
| Ca (mol Kg\(^{-1}\))       | 4.24       |
| P (ppm)                     | 14.28      |
| Mg (mol Kg\(^{-1}\))       | 7.12       |
| Na (mol kg\(^{-1}\))       | 1.28       |

3.3 Scheduling of Irrigation
The evapotranspiration-based irrigation scheduling was used to compute the run time of the drip irrigation scheduling for *C. chinense* plants with Kc for different growth stages obtained in [6]. The complete irrigation schedule is presented in Table 4. Drip irrigation was applied daily according to the different treatments calculated based on daily ETc.

Table 4. Drip daily run time

| Month | ET<sub>60</sub> | ET<sub>80</sub> | ET<sub>100</sub> | ET<sub>120</sub> |
|-------|----------------|----------------|------------------|------------------|
| November | 2.16           | 2.88           | 3.6              | 4.32             |
| Run time* (min/day) | 57             | 76             | 95               | 114              |
| December | 1.74           | 2.32           | 2.9              | 3.48             |
| Run time (min/day) | 46             | 61             | 76               | 92               |
| January | 4.98           | 6.64           | 8.3              | 9.96             |
| Run time (min/day) | 131            | 175            | 218              | 262              |
| February | 5.94           | 7.92           | 9.9              | 11.88            |
| Run time (min/day) | 156            | 208            | 261              | 313              |
| March | 3.72           | 4.96           | 6.2              | 7.44             |
| Run time (min/day) | 98             | 131            | 163              | 196              |

* Run time based on the ratio of ETc (mm/day) and precipitation rate (2.28 mm/h.).

3.4 Treated greywater quality

The values of the inflow and outflow GW after the 3-day HRT as compared to USEPA standard is show in Table 5. The table shows that all parameters monitored were below the restricted limit an indication that the treated GW was suitable for recycling in irrigation except for the COD and BOD before treatment. Elevated values of EC were recorded in the treated GW. It can also be deduced that the nutrients in the GW were low before and after phytoremediation treatment. Consequently, there will be need for an addition of nutrients from appropriate sources to raise the nutrient level in the effluent.

Table 5. Treated greywater quality and USEPA standard for reuse (Source: [23])

| S/N | Parameters | Unit | Range | Mean ± SE | Range | Mean ± SE | USEPA Std* |
|-----|------------|------|-------|-----------|-------|-----------|------------|
| 1   | EC         | μS/cm| 616.4-3272.7 | 1739 ± 363.1 | 592-1856 | 1361 ± 206 | 700        |
| 2   | TN         | mg/L | 1.42-29 | 12.11 ± 4.5 | 2.1-8.2 | 5.63 ± 0.9 | 45*        |
| 3   | TP         | mg/L | 0.8-2.81 | 2.0 ± 0.4 | 0.43-2.74 | 1.04 ± 0.4 | 30*        |
| 4   | pH         |      | 7.57-8.82 | 8.1 ± 0.2 | 7.11-8.07 | 7.64 ± 0.2 | 6-8        |
| 5   | SAR        | meq/L| 48.6-410.70 | 194.8 ± 54.1 | 182.4-853.0 | 387.59 ± 95.8 | 9*         |
| 6   | TDS        | mg/L | 347-900 | 504 ± 84.8 | 163.5-511.0 | 393.1 ± 59.5 | < 450      |
| 7   | Al         | mg/L | 0.37-4.70 | 1.2 ± 0.8 | 0.11-0.91 | 0.44 ± 0.2 | 5          |
| 8   | Fe         | mg/L | 0.45-4.30 | 2.2 ± 0.7 | 0.3-1.74 | 1.11 ± 0.2 | 5          |
| 9   | Mg         | mg/L | 29-50 | 23.4 ± 6.6 | 4.0-15.0 | 8.43 ± 1.6 | 100*       |
| 10  | Ca         | mg/L | 33-36 | 31.3 ± 8.8 | 4.0-9.0 | 8.42 ± 2.0 | 230*       |
| 11  | BOD        | mg/L | 2.1-39 | 27.9 ± 6.0 | 15.0-31.0 | 23.50 ± 2.5 | 20-30      |
| 12  | COD        | mg/L | 576-1120 | 848 ± 92.7 | 214.2-430.0 | 452.8 ± 3.5 | 100*       |

3.5 Capsicum chinense yield from treatments combination

The result of the mean values of fruit yield as influenced by different levels of irrigation combined wit
different mulches types taken from 20 to 26 WAS are presented in Figure 8. The total fruit yield ranged from 1194.45 to 4666.70 kg per ha. Significantly, maximum fruit yield per ha was recorded in T10-I100SM (4666.70 kg) followed by T14-I120SM (3962.99 kg) and T8-I80RS (3851.88 kg). The minimum fruit yield per ha was obtained in T3-I60BM (1194.45 kg). The highest yield under T10 (I100SM) and the next treatment (T14-I120SM) might be due to Silver mulch as a reflective mulch which increases the amount of light available to plant and stabilizes air temperature and photosynthesis which mean better growth. Reflective mulch utilizes the entire spectrum thereby improving the available amount of light and heat to plant resulting in higher yield. It also helps to retard weeds and conserve moisture like other plastic mulches. The colour of mulch determines its energy radiating behaviour and its influence on the micro-climate around the vegetable plant [24].

The ANOVA table of the effect of treatments on yield is shown in Table 6. Since the calculated F-value was greater than the F-tabulated at 5% level of significance but less than that of one percent (1%) level of significance, the treatment difference significantly affects the yield. The statistical analyses of results are shown in the ANOVA Table 7 for the 4 X 4 factorial experiment in a split-plot design.

| Sources of variation | df | SS              | MSS             | Fcalc | Ftab 5% | Ftab 1% |
|----------------------|----|-----------------|-----------------|-------|--------|--------|
| Replication          | 2  | 17739721.8      | 8869860.9       |       |        |        |
| Treatments           | 15 | 44191339.2      | 2946089.3       | 2.3*  | 2.0    | 2.6    |
| Error                | 32 | 41377478.6      | 1293046.2       |       |        |        |
| Total                | 47 | 85568817.9      |                 |       |        |        |

* = Treatment differences significant at 5% level

Figure 4. Effect of combined treatment on fruit yield of Capsicum chinense.
Table 7. ANOVA of a 4 X 4 factorial experiment in a split-plot design

| Sources of variation | Degree of Freedom | Sum of Square | Mean Square | Calculated F | Tabular F 5% | Tabular F 1% |
|----------------------|------------------|--------------|-------------|--------------|--------------|--------------|
| replication rep.     | r-1= 2           | 25,135,611.26| 12,567,805.63|              |              |              |
| Irrig. Levels (A)    | a-1= 3           | 23,854,410.39| 11,927,205.19| 5.20*        | 4.76         | 9.78         |
| Error (a)            | (r-1)(a-1)= 6    | 13,765,824.34| 2,294,304.06 |              |              |              |
| Mulches (B)          | b-1= 3           | 21,508,272.45| 7,169,424.15 | 8.59**       | 3.01         | 4.72         |
| A X B                | (a-1)(b-1) = 9   | 9,253,095.54 | 1,028,121.73 | 1.23NS       | 2.30         | 3.25         |
| Error (b)            | a(r-1)(b-1)=24   | 20,020,411.09| 834,183.80   |              |              |              |
| Total                | rab-1= 47        | 113,537,625.07|             |              |              |              |

*b* = Treatment differences that are significant at 5% level, *b* ** = Treatment differences significant at 1% level, *NS* = Treatment differences not significant, *cv (a) = 13.5%, cv (b) = 9%*

The value of cv(b) is expected to be smaller than that of cv(a) because the factor assigned to the main plot is expected to be measured with less precision than that assigned to the subplot [20]. From the data analysis done in SPSS 22. The Duncan multiple range test mean separation shows that of the 4 treatment levels of irrigation level, (I60) was significantly different from the rest of the treatments. The yield obtained for others (I80 to I120) were at par. On the mulches, all treatment levels are at par. Greywater is a supplementary supply of water to reduce water shortage [25].

### 4.0 Conclusion

The study reveals that treated greywater can serve as supplementary source of nutrient for *C. chinense* cultivation, but it may not provide enough for the plant growth. *C. indica* was found to be effective in greywater treatment (Phytoremediation) for reuse in *C. chinense* cultivation. The maximum fruit yield was observed for T10(I100SM) due to reflective mulch ability to increase light and heat to plant resulting in higher yield. There was a significant difference between the mean yield of I60 and other irrigation application regimes, whereas between I80 to I120 there was no significant difference in mean yield recorded. Silver mulch was found to be the best of all mulches type investigated in the study.

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