Abstract: The bean is an important crop in feeding the global population. In the northeast of Brazil, it is of particular importance, since it is a staple food, which also generates employment and income. The low productivity of the northeast in recent years due to the water crisis combined with the cost of energy has compromised technical and economic viability. This study aimed to evaluate production parameters of cowpea (Vigna unguiculata (L.) Walp.) under different alternative production systems in the northeast of Brazil. The study was carried out in the experimental area of the sewage treatment plant (STP) in the district of Tianguá, Ceará. The experiment comprised six production systems (treatments) divided into split plots distributed in a completely randomised design with fifteen replications. The systems irrigated with wastewater and amended with different of fertilisers were no fertiliser (S2A0), mineral fertiliser (S2A1) and organic fertiliser (S2A2), as well as systems irrigated with drinking (S1A0, S1A1 and S1A2). It was found that under the systems irrigated with wastewater, the average productivity was 1468.8 kg ha$^{-1}$, whereas under the systems irrigated with drinking water, it was 984.1 kg ha$^{-1}$. The production systems that used wastewater (S2A0, S2A1 and S2A2) resulted in greater productivity compared to the production models irrigated with drinking water with organic fertiliser (S1A2) and with no fertiliser (S1A0). All the production models irrigated with wastewater yielded similar results to the conventional system with mineral fertiliser, showing that treated wastewater contains sufficient nutrients to potentially replace mineral fertilisers in cowpea production in the northeast of Brazil. The use of treated domestic effluent increases the productivity of irrigated crops.

Keywords: fertilisers; production parameters; Vigna unguiculata (L.) Walp; wastewater

1. Introduction

Cowpea (Vigna unguiculata (L.) Walp.) is a legume grown in the semi-arid tropics of Africa, Brazil and the United States [1]. According to Assefa et al. [2], it is a crop of great economic importance, in addition to its importance in feeding low-income populations around the world. The planted area is around 12.5 million hectares worldwide, 64% (8 million hectares) of which are in South Africa.

In Brazil, it is one of the principal crops in the north and northeast. It is especially important in the semi-arid region since it is a staple food, which also generates employment and income [3]. According
to the National Supply Company (Conab), [4], the planted area in Brazil has increased in recent years (1247 ha in 2015/16; 1409 ha in 2016/17 and 1527 ha in 2017/18).

Benvindo et al. [5] pointed out that although the cowpea (*Vigna unguiculata* (L.) Walp.) is well adapted to the various soil and climate conditions and cropping systems, in relation to other legumes, it does not always achieve a good level of productivity. For Locatelli et al. [6], the scarcity of water resources and the low level of nutrients, characteristic of the climate and most soils in the semi-arid region, respectively, has affected crop performance.

Rosales et al. [7] emphasised that water deficit is one of the principal limiting factors in agricultural production. In addition, according to the National Water Agency-ANA [8], the question of energy represents a large part of the total cost of production, which can reach 35% with electrical energy for irrigation, making it unviable to grow crops of low profitability.

For Scheierling et al. [9], the global population living in areas with a water scarcity could reach 44% by 2050; as the world experiences an intense water shortage, the use of wastewater is seen as an important option for increasing the available water supply.

The growing production of household waste is a challenge, where much of it, destined for unsuitable sites, has a negative impact on ecosystems [10]. Ouyang et al. [11], called for the elaboration of methodologies that combine waste disposal and the reduction of environmental impacts, to make a balanced and sustainable system. Agricultural irrigation is one of the most established applications of the reuse of wastewater in the world [9]. Israel reuses around 85% of domestic sewage after treated for irrigation, while Spain, which ranks second in water reuse, is 20% [12].

As such, the use of wastewater in agriculture to reduce the consumption of drinking water and the environmental impact of inappropriate waste disposal is a worldwide trend. Freitas et al. [13], in research with wastewater associated with mineral fertiliser in cowpea (*Vigna unguiculata* (L.) Walp.) cultivation, demonstrated the possibility of completely replacing mineral fertilisers. Salgado et al. [14], in a study of treated domestic sewage in agriculture, found it to be an alternative for minimising environmental impact and optimising the use of water resources.

The search to implement production systems that are based on the principles of economic, social and environmental sustainability, as opposed to conventional agricultural models, is a demand of the global market. Therefore, within the concept of new production models, the analysis of renewable and non-renewable input resources from nature and the economy used in agricultural systems is essential for consolidating a sustainable agricultural model. As such, it is assumed that the interaction between wastewater and organic fertiliser will result in the development of agriculture, which is more efficient and ensures the conservation of natural resources.

The present study highlights the establishment of a more sustainable model of agricultural production for the future, using wastewater associated with organic fertiliser and photovoltaic solar energy. In addition, the possibility of verifying the behaviour of organic fertiliser with wastewater should be highlighted, since understanding the dynamics of the interaction between wastewater and fertiliser is essential for the development of sustainable agricultural systems with a view to the rational use of natural resources.

In view of the above, this study aimed to evaluate production parameters in cowpea (*Vigna unguiculata* (L.) Walp.) under different alternative production systems in the northeast of Brazil.

2. Materials and Methods

2.1. Location of the Experimental Area

The study was carried out in the experimental area of the sewage treatment plant (STP) belonging to the Water and Sewage Company of the State of Ceará (CAGECE), located in the district of Tianguá, CE, at 3°44′ S and 40° 59′ W, at an altitude of 740 m (Figure 1). According to the Koppen classification, the climate is type Aw, tropical with a dry season, a mean annual temperature of 26 °C and mean annual rainfall of 1350 mm.
2.2. Experimental Design and Composition of the Treatments

The purpose of this study was to compare different agricultural systems of cowpea (*Vigna unguiculata* (L.) Walp.) production. The experiment comprised six production systems (treatments), in which the experimental design was divided into split plots distributed in a completely randomised design with fifteen replications, in a $2 \times 3$ factorial scheme of two sources of water and energy (wastewater + photovoltaic solar energy and drinking water + electricity from the electrical grid) and different sources of fertiliser (mineral and organic), in addition to the control (no fertiliser).

The experimental plot consisted of one row, 16.8 m in length, with 42 plants, at a spacing of 0.4 m between plants and 1.0 m between rows; this was subdivided into three subplots for the different sources of fertiliser. Each subplot had 14 plants and an area of 5.6 m$^2$. The total experimental area was 504 m$^2$ and the total working area, 216 m$^2$, with only the central plants of each subplot being considered for data collection, where each subplot represented one replication. The treatments representing the six irrigated production systems with different sources of water, energy and fertiliser are shown in Figure 2.

The six central plants of each subplot of the experimental unit were used as the working area of the subplot, giving a total of 18 plants per plot. As such, each alternative production system (treatment) contained 15 experimental subplots, with a total area of 84 m$^2$ and a working area of 36 m$^2$. 

![Figure 1. Location of the state of Ceará in Brazil and the experimental area in the district of Tianguá, Ce.](image-url)
Figure 2. Plan of the experimental area and layout of the treatments.

2.3. Irrigation System and Management

The irrigation method employed a localised drip system, using Amanco drip tape (manufacturer Mexichem Brasil Plastic Processing Industry Ltda, Joinville-SC-Brazil), with an internal diameter of 16 mm, a spacing between emitters of 20 cm and nominal flow of 1.6 L h\(^{-1}\), which had been previously evaluated in the field under normal operating conditions, as per the methodology of Keller and Karmelli [15].

In the photovoltaic pump irrigation system (SPVI), the Anauger P100 photovoltaic solar motor pump assembly was used, consisting of a motor pump, a driver and two 95 Wp photovoltaic panels, giving a total of 190 Wp. The choice of the motor pump assembly took various factors into consideration, such as the amount of power required, the flow rate and efficiency of the unit. The motor pump associated with the photovoltaic system was of the submergible type, which can operate in photovoltaic generating systems with a capacity of 100, 130 and 170 Wp.

A conventional irrigated production system was also installed using drinking water and driven by power from the electrical grid; this was associated with different sources of fertiliser. For this system, a Dancor model CAM W-6C 0.75-hp motor pump assembly was used.
Irrigation was managed by determining the reference evapotranspiration using the Penman–Monteith method (Equation (1)) [16]. This was then multiplied by the crop coefficient (Kc) to obtain the crop evapotranspiration (ETc) and determine the irrigation depth to be applied. However, the efficiency of the irrigation system must be taken into account when defining the total depth of the water.

\[
ET_o = \frac{0.408\Delta(Rn - G) + \gamma \frac{900}{T+237} u_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34 u_2)} \]

where \( ET_o \)—reference evapotranspiration (mm day\(^{-1}\)); \( Rn \)—net radiation at the crop surface (MJ m\(^{-2}\) day\(^{-1}\)); \( G \)—soil heat flux, (MJ m\(^{-2}\) day\(^{-1}\)); \( T \)—mean daily air temperature at a height of 2 m (°C); \( u_2 \)—wind speed at a height of 2 m (m s\(^{-1}\)); \( e_s \)—saturation vapour pressure (kPa); \( e_a \)—current saturation vapour pressure (kPa); \( e_s - e_a \)—saturation vapor-pressure deficit (kPa); \( \Delta \)—slope of the vapour pressure curve against temperature (kPa °C\(^{-1}\)). \( \gamma \)—psychrometric constant, (kPa °C\(^{-1}\)).

ET\(_o\) data using the Penman–Monteith method were obtained from the weather station at Tianguá, CE. The crop coefficients (Kc) adopted for the cowpea (\textit{Vigna unguiculata} (L.) Walp.) crop are shown in Table 1.

| Crop Coefficient (Kc) | Days After Planting (DAP) |
|-----------------------|---------------------------|
| 0.70                  | 12 days                   |
| 0.81                  | 13 to 33 days             |
| 1.20                  | 34 to 54 days             |
| 0.77                  | 55 days to the end of the cycle |

Source: [17].

Irrigation time was determined from Equation (2), for a daily irrigation interval at a water depth equivalent to 100% of the potential crop evapotranspiration or to complement the rainfall.

\[
T_I = \frac{ET_{pc} \times A}{CUD \times q_g \times N_q} \]

where \( T_I \)—irrigation time (h); \( ET_{pc} \)—potential crop evapotranspiration (mm); \( A \)—cultivated area (m\(^2\)); \( CUD \)—uniformity coefficient; \( q_g \)—dripper flow rate (L h\(^{-1}\)); \( N_q \)—number of drippers per plant.

2.4. Planting and Cultivating the Crop

First, the area was cleaned, followed by conventional soil preparation using a harrow; finally, the area was fenced off, and the plots measured and marked out. Holes were then opened to apply organic compost to those subplots using organic fertiliser, it being necessary to leave time for the compost to react with the soil.

The water used in the conventional system came from the public supply in the district of Tianguá, CE, managed by CAGECE, and which originates in the Jaburu dam. The wastewater (treated domestic effluent) used in the renewable system came from the sewage treatment plant (STP) in the district of Tianguá, Ceará, Brazil, with treatment technology employing stabilisation ponds, comprising one anaerobic, one optional and three maturation ponds.

The chemical and organic fertilisers were applied based on the chemical analysis of the soil, the organic compost and the wastewater, the latter for those treatments irrigated with treated domestic effluent. The chemical fertiliser was based on the Recommendations Manual for Fertiliser and Liming of the state of Ceará [18]. The organic fertiliser was based on the recommendations for organic fertiliser as calculated from the nutrient mineralisation, using the equation proposed by [19]. Half of the nitrogen and potassium doses were applied when sowing and the other half 30 days after planting, whereas all
the phosphorus was applied when planting. The fertilisers were applied in furrows, 5 cm in depth and spaced 5 cm away from the plants.

In the systems irrigated with drinking water, both the mineral and organic fertiliser corresponded to 100% of the recommended dose, based on an analysis of the soil and the nutritional demand of the crop; whereas in the systems irrigated with treated domestic effluent, fertilisation was only complementary, since wastewater contains a significant amount of nutrients. In these systems, therefore, fertilisation was based on an analysis of the soil as well as of the applied wastewater. Table 2 shows the values for the applied mineral and organic fertilisers.

Table 2. Recommendations of mineral and organic fertiliser for the different treatments.

| Mineral Fertiliser                  | Systems Irrigated with Drinking Water | Systems Irrigated with Wastewater |
|-------------------------------------|--------------------------------------|----------------------------------|
| Nitrogen (urea)                     | 20 kg ha\(^{-1}\)                    | 6.0 kg ha\(^{-1}\)               |
| Phosphorus (single superphosphate)  | 80 kg ha\(^{-1}\)                    | 52 kg ha\(^{-1}\)                |
| Potassium (potassium chloride)      | 20 kg ha\(^{-1}\)                    | 9.0 kg ha\(^{-1}\)               |
| Organic fertiliser                 |                                      |                                  |
| Organic compost                     | 19,525 kg ha\(^{-1}\)                | 5925 kg ha\(^{-1}\)              |

Planting was carried out manually on 6 November 2017 at a spacing of 1.0 m × 0.4 m, using three seeds per hole. After germination, the plants were thinned manually, leaving two plants per hole. The Setentão 596 cultivar of the cowpea (\textit{Vigna unguiculata} (L.) Walp.) was used. This is a semi-prostrate plant with a cycle of 65 to 70 days and a productivity of 800 kg ha\(^{-1}\) under rainfed conditions and 1200 kg ha\(^{-1}\) when irrigated [20].

Harvesting was carried out manually 74 days after sowing, once the pods had matured, with the plant material being collected from the 6 central plants of each subplot of the experimental units. The collected material was placed in previously identified paper bags and taken to the Federal Institute of Education, Science and Technology of Ceará, Tianguá Campus for further drying at room temperature.

2.5. Analyzed Variables

Physicochemical and microbiological analysis of the wastewater and drinking water was carried out before applying them in the treatments, to characterise the quality parameters for irrigation. One-litre samples were collected in sterilised flasks from the tank containing the reused water and from the supply source, as per methodology Environmental Sanitation Technology Company (CETESB) an environmental agency in the State of São Paulo, Brazil [21].

The attributes were determined at the Environmental Health Laboratory (LABOSAN) of the Federal University of Ceará. The Standard Methods for the Examination of Water and Wastewater [22] were adopted for each analysis (chemical, physical and microbiological). Table 3 shows the physicochemical and microbiological analysis of the wastewater and drinking water during the study period.

The reference values for reuse established by State Council of the Environment (COEMA—Conselho Estadual do Meio Ambiente) indicate the standards to be met in using wastewater for agricultural purposes, as specified in the normative resolution. Therefore, if the treated domestic effluent contains parameters which characterise the water quality that are greater than the values specified in the resolution, it cannot be used for crop irrigation.

Initially, before planting the crop, an analysis of the experimental area was carried out to characterise the soil, in addition to recommending fertiliser based on the chemical analysis for some of the treatments under study. Samples were collected at three depths (0–20, 20–40 and 40–60 cm) and were sent to the laboratory at UFC/FUNCEME to determine the physicochemical parameters. An analysis was carried out at the beginning of the experiment and another at the end of the study for the
treatment that received wastewater with no fertiliser (S2A0) to verify nutrient input to the soil and any problems resulting from use of the effluent.

Table 3. Physicochemical and microbiological analysis of the wastewater and drinking water used during the experiment with irrigated cowpea (*Vigna unguiculata* (L.) Walp.) in Tianguá, CE.

| Parameter          | Unit | Drinking Water | Wastewater | Reference for Reuse * |
|--------------------|------|----------------|------------|-----------------------|
| pH                 | -    | 6.50           | 7.10       | 6–8.5                 |
| Electric conductivity | dS m⁻¹ | 0.28           | 1.32       | 3.0                   |
| Total nitrogen     | mg L⁻¹ | 0.02           | 13.44      | 30.2                  |
| Total phosphorus   | mg L⁻¹ | 0.05           | 13.19      | 14.6                  |
| Potassium          | mg L⁻¹ | 6.00           | 35.00      | 36.8                  |
| Calcium            | mg L⁻¹ | 13.33          | 24.48      | 74.0                  |
| Magnesium          | mg L⁻¹ | 3.91           | 0.40       | 32.2                  |
| Sodium             | mg L⁻¹ | 35.33          | 174.0      | 142.5                 |
| Chlorides          | Mg L⁻¹ | 77.76          | 223.46     | not specified         |
| Total coliforms    | Org 100 mL | 0.001     | 0.24 × 10⁵ | 1.0 × 10⁵             |

* Resolution nº. 02 of State Council of the Environment (COEMA—Conselho Estadual do Meio Ambiente) [23].

For the initial sample, one composite sample was taken comprising 15 single samples zigzagged throughout the experimental area, while for the final sample taken only from the system irrigated with wastewater with no fertiliser (S2A0), a composite sample was obtained from the single sampling of six randomly chosen experimental subplots in this production system.

The physical analysis was carried out using the pipette method [24]. The pH was measured in water (1:2.5) by potentiometry. The levels of total nitrogen (TN), available phosphorus (P), potassium (K⁺), sodium (Na⁺), calcium (Ca²⁺), magnesium (Mg²⁺), aluminium (Al³⁺) and hydrogen + aluminium (H⁺+Al³⁺) were determined as per the manual for chemical analysis of the soil [25]. The Ca²⁺ and Mg²⁺ content were extracted with 1 mol L⁻¹ KCl and determined by titration with EDTA. The total N concentration was determined by the semi-micro Kjeldahl method in extracts of sulphur digestion. Extraction of the available P⁻, K⁺ and Na⁺ was carried out using Mehlich 1, and their content was determined using spectrophotometry for the available P⁻, and by flame photometry for the K⁺ and Na⁺. H⁺+Al³⁺ was extracted by calcium acetate and determined by titration with NaOH.

Table 4 shows the physicochemical analysis from the beginning and end of the study, the latter only for subplots that were irrigated with treated domestic effluent with no fertiliser (S2A0).

Physicochemical characterisation of the organic compost was also carried out in the Soil Laboratory of UFC, due to the need to determine the attributes and recommend the organic fertiliser (Table 5).

At the end of the crop cycle, the six central plants were collected from each subplot to analyse the following: the number of pods per plant (NPP); number of grains per pod (NGP), obtained from five sub-samples of 20 pods each, giving a total of 100 pods per subplot; 100-grain weight (W100), obtained from five sub-samples from each sub-plot; and mean crop yield for the production parameters in relation to the cultivated area.
Table 4. Physicochemical attributes of the soil of the experimental area at the start and end of the study in Tianguá, CE.

| Depth (cm) | Course Sand | Fine Sand | Silt | Clay | Natural Clay | Textural Class |
|-----------|-------------|-----------|------|------|--------------|----------------|
| 0–20      | 380         | 438       | 155  | 27   | 20           | Loamy sand     |
| 20–40     | 275         | 495       | 83   | 147  | 71           | Sandy loam     |
| 40–60     | 329         | 409       | 86   | 176  | 30           | Sandy loam     |

| Attributes | Start | End * |
|------------|-------|-------|
|            | 0–20 cm | 20–40 cm | 40–60 cm | 0–20 cm | 20–40 cm | 40–60 cm |
| EC (dS m⁻¹) | 0.35 | 0.22 | 0.11 | 1.13 | 0.83 | 0.82 |
| pH         | 5.0 | 4.7 | 4.8 | 5.1 | 5.3 | 4.9 |
| Ca²⁺ (cmol, kg⁻¹) | 1.0 | 0.4 | 0.3 | 1.5 | 1.0 | 0.7 |
| Mg²⁺ (cmol, kg⁻¹) | 0.5 | 0.5 | 0.3 | 1.2 | 0.8 | 0.5 |
| Na⁺ (cmol, kg⁻¹) | 0.05 | 0.06 | 0.07 | 0.29 | 0.40 | 0.44 |
| H⁺ + Al³⁺ (cmol, kg⁻¹) | 3.30 | 3.47 | 3.80 | 2.15 | 1.98 | 2.64 |
| Al³⁺ (cmol, kg⁻¹) | 0.60 | 1.05 | 1.40 | 0.30 | 0.20 | 0.35 |
| S (cmol, kg⁻¹) | 1.8 | 1.1 | 0.8 | 3.2 | 2.0 | 1.9 |
| T (cmol, kg⁻¹) | 5.1 | 4.6 | 4.6 | 5.3 | 4.4 | 4.5 |
| V (%) | 35 | 24 | 17 | 60 | 55 | 42 |
| m (%) | 25 | 49 | 64 | 9.0 | 8.0 | 15 |
| PST | 1.0 | 1.0 | 2.0 | 5.0 | 9.0 | 10 |
| K⁺ (cmol, kg⁻¹) | 0.22 | 0.16 | 0.13 | 0.19 | 0.22 | 0.27 |
| NT (g kg⁻¹) | 0.56 | 0.39 | 0.32 | 0.94 | 0.59 | 0.36 |
| available P (mg kg⁻¹) | 7.0 | 14 | 5.0 | 49 | 68 | 45 |
| C/N | 11 | 10 | 9.00 | 9.0 | 10 | 10 |
| C (g kg⁻¹) | 6.06 | 3.84 | 2.94 | 8.85 | 5.84 | 3.54 |

* END—refers only to the subplots treated with S2A0; EC—electrical conductivity; pH—hydrogen potential; Ca²⁺—calcium; Mg²⁺—magnesium; Na⁺—sodium; H⁺ + Al³⁺—hydrogen + aluminium; Al³⁺—aluminium; S—sulphur; T—cation exchange capacity at pH 7.0; V (%)—percentage base saturation; m (%)—percentage aluminium saturation; PST—exchangeable sodium percentage; K⁺—potassium; NT total nitrogen; available-P—available phosphorus measured by Mehlich-1; C/N—carbon/nitrogen ratio; C—carbon.

Table 5. Physicochemical attributes of the organic compost used in the experiment in Tianguá, CE.

| N | P | K⁺ | Ca²⁺ | Mg²⁺ | B | Mn | Na⁺ | pH | CEC | Moisture | C/N |
|---|---|----|------|------|---|----|------|----|-----|----------|-----|
| % | mg kg⁻¹ | % | - | - | - | - | - | % | - | - | - |
| 1.34 | 1.43 | 0.77 | 2.44 | 0.88 | 19 | 393 | 735 | 6.5 | 28.9 | 51.3 | 14.8 | 11 |

N—total nitrogen; available-P—available phosphorus measured by Mehlich-1; K⁺—potassium; Ca²⁺—calcium; Mg²⁺—magnesium; B—boron; Mn—manganese; Na⁺—sodium; pH—hydrogen potential; CEC—capacity exchange cations; C—carbon; C/N—carbon/nitrogen ratio.

2.6. Statistical Analysis

Descriptive statistics were used to analyse the following parameters: mean, standard deviation, variance, coefficient of variation, asymmetry and kurtosis; data normality was analysed using the coefficients of asymmetry and kurtosis. An analysis of variance was then carried out for any data that showed normality, and when significant, these were compared by the least significant difference test (LSD) at 5% significance (Tukey’s test).

We used only a single model to variance analysis in each production indicator. Due to problems during the data collection field, some plots of the experiment were lost, and the number of samples was different in each component. Although the number of samples was different in each of the analysis of variance, it did not make the analysis unfeasible since the number replications were high (15 replications). The data were analysed using Minitab v16 software.
3. Results and Discussion

The descriptive analysis of production indicators in cowpea (Vigna unguiculata (L.) Walp.) under different production systems (treatments) is shown in Table 6. It was found that the treatments irrigated with wastewater (S2A0, S2A1 and S2A2) showed better productive performance compared to the systems irrigated with drinking water with organic fertiliser (S1A2) and with no fertiliser (S1A0), since the amount of nutrients present in the treated domestic effluent, particularly nitrogen and phosphorus, probably met the nutritional demand of the crop.

Table 6. Descriptive statistics of the number of pods per plant, number of grains per pod, 100-grain weight and productivity.

|                          | Drinking Water with no Fertiliser-S1A0 | Drinking Water with Mineral Fertiliser-S1A1 | Drinking Water with Organic Fertiliser-S1A2 | Wastewater with no Fertiliser-S2A0 | Wastewater with Mineral Fertiliser-S2A1 | Wastewater with Organic Fertiliser-S2A2 |
|--------------------------|---------------------------------------|--------------------------------------------|-------------------------------------------|-----------------------------------|----------------------------------------|----------------------------------------|
|                          | $n$ | Me    | SD    | Var | CV  | Max | Min | As  | K     | $n$ | Me    | SD    | Var | CV  | Max | Min | As  | K     | $n$ | Me    | SD    | Var | CV  | Max | Min | As  | K     | $n$ | Me    | SD    | Var | CV  | Max | Min | As  | K     |
| NPP                      | 12  | 9.16  | 3.46  | 11.98 | 37.76 | 16.10 | 5.50 | 0.89 | 0.02  | 12  | 17.07 | 4.23  | 17.86 | 24.76 | 24.10 | 10.17 | 0.26 | −0.59 | 12  | 12.14 | 3.37  | 11.36 | 27.76 | 29.83 | 29.00 | 8.50 | 0.75 | 1.66  |
| NGP                      | 15  | 14.48 | 0.41  | 0.17 | 2.85 | 15.12 | 13.78 | −0.05 | −0.90 | 15  | 15.11 | 0.60  | 0.36 | 4.00 | 15.72 | 13.42 | −1.79 | 4.16  |
| W100 (g)                 | 15  | 20.22 | 0.64  | 0.41 | 3.15 | 21.42 | 18.73 | −0.51 | 1.70  | 15  | 20.77 | 0.71  | 0.50 | 3.42 | 22.02 | 19.94 | 0.37  | −1.36 |
| PROD (kg ha$^{-1}$)      | 15  | 675.8 | 246.0 | 60,532.7 | 36.41 | 1229.4 | 400.4 | 1.02 | 0.72  | 12  | 1336.5 | 291.0 | 84,680.9 | 21.77 | 1942.7 | 829.1 | 0.44 | 0.15  |
| NPP                      | 12  | 17.34 | 5.17  | 26.75 | 29.83 | 29.00 | 8.50 | 0.75 | 1.66  | 12  | 15.74 | 6.83  | 46.60 | 36.43 | 30.75 | 10.13 | 0.51 | −1.00 |
| NGP                      | 15  | 15.52 | 0.36  | 0.13 | 2.31 | 16.26 | 14.62 | −0.49 | 2.95  | 15  | 15.10 | 0.54  | 0.29 | 3.60 | 16.20 | 14.20 | 0.35  | −0.15 |
| W100 (g)                 | 15  | 20.88 | 0.44  | 0.20 | 2.13 | 21.64 | 19.96 | −0.40 | 0.07  | 15  | 21.10 | 0.67  | 0.45 | 3.18 | 22.22 | 19.41 | −1.11 | 2.11  |
| PROD (kg ha$^{-1}$)      | 12  | 1383.1 | 321.8 | 10,3547 | 23.27 | 2019.1 | 674.2 | −0.07 | 1.11  | 12  | 1502.0 | 518.0 | 26,8429 | 34.49 | 2488.0 | 793.0 | 0.51  | −0.72 |
| NPP                      | 12  | 18.74 | 6.83  | 46.60 | 36.43 | 30.75 | 10.13 | 0.51 | −1.00 |
| NGP                      | 15  | 15.10 | 0.54  | 0.29 | 3.60 | 16.20 | 14.20 | 0.35  | −0.15 |
| W100 (g)                 | 15  | 20.60 | 1.06  | 1.12 | 5.13 | 22.03 | 18.17 | −0.75 | 0.85  | 15  | 15.54 | 0.56  | 0.32 | 3.63 | 16.30 | 14.24 | −1.03 | 0.81  |
| PROD (kg ha$^{-1}$)      | 12  | 1521.0 | 431.0 | 18,5853 | 28.34 | 2407.0 | 750.0 | −0.05 | 0.54  |

$n$—number of samples; Me—mean value; SD—standard deviation; Var—variance; CV—coefficient of variation; Max—maximum value; Min—minimum value; As—coefficient of asymmetry; K—coefficient of kurtosis. NPP—number of pods per plant; NGP—number of grains per pod; W100—100-grain weight; PROD—productivity.

The renewable system with no fertiliser (S2A0) was similar to the renewable systems with mineral (S2A1), organic (S2A2) fertiliser and conventional system with mineral fertiliser (S1A1). It was therefore apparent that treated domestic effluent has enough nutrient load to meet the nutritional demand of the crop completely, or at least make a significant contribution.
Rebouças et al. [26] found that the amount of nitrogen in the wastewater was enough to meet the nutritional demand of cowpea (*Vigna unguiculata* (L.) Walp.) in the absence of mineral fertiliser, increasing dry biomass production and other growth variables.

The lowest productivity, 675.8 kg ha\(^{-1}\), was seen under the conventional production system with no fertiliser (S1A0); this was less than the mean yield for cowpea (*Vigna unguiculata* (L.) Walp.) under irrigated conditions (1200 kg ha\(^{-1}\)). The greatest values for crop yield were seen under the systems irrigated with wastewater (S2A0, S2A1 and S2A2), with a productivity of 1383.1 kg ha\(^{-1}\), 1502 kg ha\(^{-1}\) and 1521 kg ha\(^{-1}\), respectively. In addition, the conventional system with mineral fertiliser (S1A1) showed similar results to those models irrigated with wastewater with a productivity of 1336.5 kg ha\(^{-1}\).

Freitas et al. [13] employed wastewater in cultivating cowpea (*Vigna unguiculata* (L.) Walp.) and found a high yield of 935.8 kg ha\(^{-1}\) in treatments irrigated with treated domestic sewage, which was significantly different from the treatments irrigated with well water, 842.4 kg ha\(^{-1}\). In a comparative analysis of the renewable system with no fertiliser (S2A0) and the conventional system with mineral fertiliser (S1A1), no statistical difference was found in production indicators for these two production models, with yields of 1383.1 kg ha\(^{-1}\) and 1336.5 kg ha\(^{-1}\), respectively.

Under the renewable system with organic fertiliser (S2A2), productivity was 1521 kg ha\(^{-1}\), similar to the models (S2A0 and S2A1) and greater than the systems (S1A2 and S1A0), since the treated domestic effluent together with the organic fertiliser enhanced nutrient availability to the plants due to the improved condition of the soil.

Bertoldi et al. [27] pointed out that adding organic compost to the soil provides not only the immediate availability of nutrients to the plants but also an improvement in soil structure, enabling mobilisation of the nutrient to the plant, and allowing for a more sustainable balance in the soil.

Research involving fertiliser with organic materials refers to the use of manure to promote improvements in the soil and to supply nutrients [28]. Organic fertilisers are able to provide essential nutrients to plants [29], which are indispensable for the productivity of legumes. The use of organic fertilisers has been effective in increasing productivity in cowpea (*Vigna unguiculata* (L.) Walp.) [30].

Cavallet et al. [31], while studying the effect of the use of wastewater, saw an improvement in soil fertility and an increase in grain yield in maize for each treatment where wastewater was applied, due to the presence of nutrients.

In a comparative analysis of the conventional system with mineral fertiliser (S1A1) and the conventional system with organic fertiliser (S1A2), it was found that the S1A1 system gave better results, with a mean productivity of 1336.5 kg ha\(^{-1}\) compared to 940 kg ha\(^{-1}\) for the S1A2 system. As such, it was seen that the organic fertiliser did not show the same behaviour as under the renewable systems. Synchronising the release of nutrients by the organic matter in the soil, a result of the mineralisation process, and supplying the nutritional demand of the plant is a challenge.

Similar results to those of the conventional systems were seen by Beltrão Júnior et al. [32] when studying the yield of cowpea (*Vigna unguiculata* (L.) Walp.) fertilised with different doses of organic and chemical fertiliser, where they found that the chemical fertiliser gave higher values for all the variables under analysis in relation to plots fertilised with organic fertiliser, since the compost used had a C to N ratio of 42:1, very high, indicating incomplete maturation, which may have interfered with nutrient absorption by the plant.

Magalhães et al. [33], in a study of the production indicators of cowpea (*Vigna unguiculata* (L.) Walp.) under different doses of organic and mineral fertiliser, found that the number of pods per plant and the 100-grain weight had a more significant response to the organic fertiliser compared to the mineral. As such, the results are similar to those of the renewable systems and differ from conventional systems.

The analysis of variance of the number of pods per plant (NPP) as a function of the factors of water, fertiliser, and their interaction, can be seen in Table 7. It should be noted that there was a significant difference at the level of 5% for the factors of water, fertiliser, and for the interaction (water and fertiliser).
Table 7. Analysis of variance of the production indicators in the study with cowpea (*Vigna unguiculata* (L.) Walp.) in Tianguá, CE.

| Source of Variation | DF  | SS      | MS   | F    | p   |
|---------------------|-----|---------|------|------|-----|
|                     |     | per Plant |      |      |     |
| Water source        | 1   | 557.0   | 557.0| 19.15| 0.001|
| Error               | 70  | 2036.5  | 29.1 |      |      |
| Fertiliser type     | 2   | 259.6   | 129.8| 3.84 | 0.026|
| Error               | 69  | 2334.0  | 33.8 |      |      |
| Water × Fertiliser (S × A) | 5  | 958.2   | 191.6| 7.73 | 0.001|
| Error               | 66  | 1635.3  | 24.8 |      |      |
| Total               | 71  | 2593.5  |      |      |      |

| Source of Variation | DF  | SS      | MS   | F    | p   |
|---------------------|-----|---------|------|------|-----|
|                     |     | per Pod  |      |      |     |
| Water source        | 1   | 4.759   | 4.759| 15.81| 0.001|
| Error               | 85  | 25.592  | 0.301|      |      |
| Fertiliser type     | 2   | 1.539   | 0.769| 2.24 | 0.112|
| Error               | 84  | 28.812  | 0.343|      |      |
| Water × Fertiliser (S × A) | 5  | 10.542  | 2.108| 8.62 | 0.001|
| Error               | 81  | 19.809  | 0.245|      |      |
| Total               | 86  | 30.351  |      |      |      |

| Source of Variation | DF  | SS      | MS   | F    | p   |
|---------------------|-----|---------|------|------|-----|
|                     |     | Weight |      |      |     |
| Water source        | 1   | 3.268   | 3.268| 5.38 | 0.023|
| Error               | 85  | 2036.5  | 29.1 |      |      |
| Fertiliser type     | 2   | 3.130   | 1.565| 2.54 | 0.085|
| Error               | 84  | 51.772  | 0.616|      |      |
| Water × Fertiliser (S × A) | 5  | 7.272   | 1.454| 2.47 | 0.039|
| Error               | 81  | 47.630  | 0.588|      |      |
| Total               | 86  | 54.902  |      |      |      |

| Source of Variation | DF  | SS      | MS   | F    | p   |
|---------------------|-----|---------|------|------|-----|
|                     |     | Productivity |     |      |     |
| Water source        | 1   | 5,287,171| 5,287,171| 33.03| 0.001|
| Error               | 88  | 14,085,944| 160,068|      |      |
| Fertiliser type     | 2   | 2,281,188| 1,140,594| 5.81 | 0.004|
| Error               | 87  | 2334.0  | 33.8 |      |      |
| Water × Fertiliser (S × A) | 5  | 8,773,846| 1,754,769| 13.91| 0.001|
| Error               | 84  | 10,599,271| 126,182|      |      |
| Total               | 89  | 19,373,118|      |      |      |

DF—Degrees of freedom; SS—Sum of squares; MS—Mean square; F—Statistic F and p—Value p.

From the analysis of variance of the number of grains per pod (NGP), it was found that for the factor water there was a significant difference at a level of 5%, similar to the interaction of water and fertiliser, due to the wastewater, since the treated domestic effluent resulted in a significant increase in each of the variables (Table 7).

Alves et al. [34], in a study of the tomato irrigated with wastewater from pig farming, found that crude wastewater gave a greater increase in plant height, stem diameter, leaf length and leaf width. Similar to the behaviour of the variance analysis for NGP, the 100-grain weight (W100) showed no significant difference at a level of 5% for fertiliser (Table 7). For the factors water and the interaction (water and fertiliser) there was a significant difference at the level of 5%. As such, the type of fertiliser did not interfere with the behaviour of these variables, especially under the renewable systems (S2A0, S2A1 and S2A2), since the treated domestic effluent provided a satisfactory nutritional contribution to the crop, and both the mineral and the organic fertiliser, particularly in these systems, only played a complementary role to the wastewater.

Rodrigues et al. [35], evaluating production parameters in a crop of maize submitted to organic and mineral fertilisers, found that the 100-grain weight showed no significant difference for the fertiliser.
The analysis of variance for the component productivity showed a similar behaviour to the NPP, for which there was a significant difference at a level of 5% for both factors under analysis (Table 7). Therefore, both the fertiliser and the interaction (water and fertiliser), had a significant influence on the performance of this variable.

Galbiatti et al. [36], studying the common bean (*Phaseolus vulgaris* (L.)) under biofertiliser and mineral fertiliser, found that there was a statistical difference between the mean values under study for productivity only.

From the mean-value test shown in Table 8, no significant difference was found with respect to the organic (A2) or mineral (A1) fertiliser in systems irrigated with wastewater. However, there was a statistical difference in productivity only, between the two types of fertiliser in the systems irrigated with drinking water. Furthermore, it was found that all the treatments irrigated with treated domestic effluent were statistically equal to the S1A1 system, and both were different from the conventional system with no fertiliser (S1A0) for the production indicators NPP, NGP and PROD.

**Table 8.** Test of mean values of the production indicators in the study with cowpea (*Vigna unguiculata* (L.) Walp.) in Tianguá, CE.

| Systems | NPP | NGP | W100 (g) | PROD (kg ha$^{-1}$) |
|---------|-----|-----|----------|---------------------|
| S2A1    | 12  | 18.74 a 1.58 | 15 | 15.10 a 0.13 | 15 | 21.60 a 0.14 | 12 | 1502.1 a 13.36 |
| S2A2    | 12  | 18.99 a 1.34 | 15 | 15.54 a 0.14 | 15 | 20.60 ab 0.23 | 12 | 1521.4 a 11.05 |
| S1A1    | 12  | 17.07 ab 1.02 | 15 | 15.11 a 0.15 | 15 | 20.77 ab 0.15 | 12 | 1336.5 a 7.95 |
| S1A2    | 12  | 12.14 bc 0.96 | 15 | 15.14 a 0.11 | 15 | 20.45 ab 0.20 | 12 | 940.0 b 7.58 |
| S2A0    | 12  | 17.34 ab 1.24 | 15 | 15.52 ab 0.09 | 15 | 20.88 ab 0.09 | 12 | 1383.1a 8.65 |
| S1A0    | 12  | 9.17 c 1.14 | 15 | 14.48 b 0.10 | 15 | 20.22 b 0.14 | 12 | 675.8 b 9.46 |

$n$—number of samples; Me—mean value; SE—Standard error; NPP—number of pods per plant; NGP—number of grains per pod; W100—100-grain weight; PROD—productivity; Mean values followed by the same letter do not differ statistically by least significant difference (LSD) using Tukey’s test at a significance level of 5%.

Agreeing with the results, Mohamed et al. [37] considered that the application of treated domestic effluent altered the nutritional properties of the soil due to both the nutrient-richness of the organic residue itself and the nutrients readily available to be absorbed by the plants or made available through mineralisation. Galbiatti et al. [36], growing common bean (*Phaseolus vulgaris* (L.)) under organic and mineral fertiliser, observed that treatments which received biofertiliser and the treatment with only one complete dose of mineral fertiliser were statistically equal and superior to the treatments with an interaction.

For the number of pods per plant, the renewable system with no fertiliser (S2A0) proved to be the same as the conventional system with mineral fertiliser (S1A1), which suggests that the nutritional contribution of the wastewater can completely replace mineral fertiliser in the cowpea crop. Sousa Neto et al. [38] found that treated domestic effluent completely replaced mineral fertiliser when growing cotton. Freitas et al. [13], growing cowpea (*Vigna unguiculata* (L.) Walp.) irrigated with treated domestic sewage, pointed out that it can replace commercial fertilisers by up to 100%.

From the mean-value test for the number of grains per pod, it was found that the treatments with wastewater, irrespective of the type of fertiliser, and the conventional treatments with mineral (S1A1) and organic fertiliser (S1A2), were the same, and that both differed from the conventional system with no fertiliser (S1A0).

Lima et al. [39], in a study of the reuse of water as an irrigation and nutritional strategy for cowpea (*Vigna unguiculata* (L.) Walp.) in Tianguá, Ceará (CE), compared the mean number of grains per pod and found a significant difference between the types of water, with the water from treated sewage showing a higher mean value for NGP in relation to well water. Teixeira et al. [40], studying the productive performance of the BRS Marataoa cultivar cowpea (*Vigna unguiculata* (L.) Walp.), found similar values to those found in this study, with an average of 12 grains per pod.
From the mean-value test for 100-grain weight, it is seen that for the interaction, the renewable system with mineral fertiliser (S2A1) had the highest mean, 21.1g, differing only from the conventional system with no fertiliser (S1A0), with the latter being equal to the remaining treatments (Table 8). Lima et al. [39] found lower values in cowpea (*Vigna unguiculata* (L.) Walp.), 18.98 and 19.10 g, with well water and treated domestic sewage, respectively.

From the mean-value test for productivity shown in Table 8, it was found that under the systems irrigated with wastewater with organic fertiliser (S2A2), with mineral fertiliser (S2A1) and no fertiliser (S2A0) there was no statistical difference in relation to the system irrigated with drinking water and mineral fertiliser (S1A1). However, there was a significant difference in relation to conventional systems with organic fertiliser (S1A2) and with no fertiliser (S1A0). Therefore, the significant contribution of nutrients from the treated domestic effluent to the crop can readily be seen. Deon et al. [41] pointed out that the linear increase in productivity as a function of the increase in irrigation depth is mostly due to the nitrogen content of the treated domestic effluent.

According to Nascimento and Fideles Filho [42], irrigation with treated effluent resulted in greater productivity in cotton in relation to the other treatments, emphasising its use in agriculture. Bezerra et al. [43], cultivating sunflower irrigated with treated domestic effluent and with different doses of nitrogen, found a significant increase in the productivity of plants that were irrigated with the treated domestic effluent. Mohamed et al. [37] found that the production of sunflower grains was as satisfactory as in treatments with NPK mineral fertiliser.

In the treatment irrigated with treated domestic effluent with no fertiliser (S2A0), a significant difference was seen in the production indicators NPP, NGP and PROD, compared to the production system irrigated with drinking water with no fertiliser (S1A0), showing that the nutritional contribution of the treated effluent resulted in a significant response in these production parameters.

Freitas et al. [13] showed that the use of wastewater has a positive influence on the production variables of cowpea (*Vigna unguiculata* (L.) Walp.). Hermman et al. [44] reported that sunflower was more productive when fertilised with treated domestic sewage than with NPK mineral fertiliser.

Among the renewable production systems, the treatment with organic fertiliser (S2A2) showed statistically equal in all production indicators in relation to the treatments with no fertiliser (S2A0) and with mineral fertiliser (S2A1). This behaviour is attributed to the mineralization of organic fertiliser. However, the opposite effect may occur if the plant needs a nutrient at any given time, and the process of mineralisation does not provide the amount required by the crop, as seen under the conventional system with organic fertiliser (S1A2), especially in the most sensitive variables to nutritional deficiency, such as the number of pods per plant, and consequently, productivity.

Furthermore, the process of leaching and volatilisation may have not affected the availability of nitrogen (N) from the mineral fertiliser to the plants in production systems (S2A1) and (S1A1), compared to system irrigated with organic fertiliser (S2A2), since, there was no statistical difference between these models for any of the production indicators.

Freitas et al. [45], working with sugar cane irrigated with two water sources, drinking water and treated domestic effluent, found greater vegetative variables in the sugarcane irrigated with treated domestic sewage. Sousa et al. [46] also found higher productivity in the castor bean irrigated with treated domestic sewage.

4. Conclusions

The production systems that used wastewater (S2A0, S2A1 and S2A2) resulted in greater productivity compared to the production models irrigated with drinking water with organic fertiliser (S1A2) and with no fertiliser (S1A0).

All the production models irrigated with wastewater (S2A2, S2A1 and S2A0) yielded similar results to the conventional system with mineral fertiliser (S1A1), showing that treated wastewater contains sufficient nutrients to potentially replace mineral fertilisers in cowpea (*Vigna unguiculata* (L.) Walp.) production in the Northeast of Brazil.
The type of fertiliser had no influence on the production indicators in the fertilised systems irrigated with wastewater (S2A1 and S2A2), but there was a significant difference in productivity in the fertilised systems irrigated with drinking water (S1A1 and S1A2).

Treated domestic effluent increases the productivity of irrigated crops due to the contribution of nutrients.

The association of wastewater, organic fertilisers and photovoltaic solar energy made it possible to establish a profitable and sustainable production model, resulting in more efficient agriculture and better conservation of natural resources.

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