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RESEARCH ARTICLE

AN ECONOMIC STUDY OF THE IRRIGATION PERIODS' EFFECTS ON SOME SOIL PROPERTIES AND FABA BEAN CROP PRODUCTIVITY

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ABSTRACT

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This study aims to economically evaluate the water use efficiency at three rates of irrigation (1, 2, and 3) with the comparison between using 11.9 ton ha⁻¹ application rate of the biochar and/or compost along with the mineral fertilization on the yield and quality of the faba bean crop. Two field experiments were conducted at El-Qantara Sharq farm Ismailia Governorate, Egypt, (winter seasons of 2020/2021 and 2021/2022) in a split-plot design with three replicates. The main factor F1 was the irrigation rates: rate 1 (3571.43 m³ ha⁻¹), rate 2 (4761.90 m³ ha⁻¹), and rate 3 (5952.38 m³ ha⁻¹) while the sub-factor F2 was the type of the soil additive (biochar, compost or mineral). The soil-available N (mg kg⁻¹) has increased relative to that before cultivation in the range 11.3 – 55.5% that was non-significant due to the irrigation rates (main factor F1) but a significant due to the soil additives (sub-factor F2). The studied irrigation rates as well as the soil additives have increased the soil-available concentration (mg kg⁻¹) of K, Mn, and Zn significantly and the available P, and Fe but non-significantly at $p < .05$. The most significant relative increase compared to the soil-available content (mg kg⁻¹) before cultivation was found for the compost at the irrigation rate 3 by 6.9% for K, 78.3% for Mn, and by 44.1% for Zn. The increase in the available nutrients followed the order irrigation rate 1 (3571.43 m³ ha⁻¹) < rate 2 (4761.90 m³ ha⁻¹) < rate 3 (5952.38 m³ ha⁻¹) and the order mineral < biochar < compost. The increased yield (ton ha⁻¹) of pods and seeds at the rate 3 relative to rate 1 was by 6.1% and 28.4% for the mineral fertilization, by 11.6% and 13.4% for the biochar, and by 15.0% and 26.1% for the compost, respectively. This increase was dependent on both factors F1 and F2 since their interaction was highly significant. At the irrigation rate 3, the total costs increased in the direction biochar (13095 LE) < compost (13333 LE) < mineral (14404 LE). The maximum net return was at the irrigation rate 2 for the compost (36837 LE) followed by the biochar (34010 LE) then at the rate 3 for the mineral fertilization (28326 LE). The return and net return with respect to the costs were also increased in the same order: rate 2 (compost) > rate 2 (biochar) > rate 3 (mineral). The application of the compost and/or the biochar is more efficient at the rate 2 than the single use of the mineral fertilization that need greater level of the irrigation water otherwise the yield decreases. The maximum water unit return has increased by 32.3% and 21.9% for the compost and biochar at rate 2, respectively, relative to the mineral at rate 1.

KEYWORDS

Biochar; Compost; Irrigation rates; Faba Bean; Water use efficiency (WUE)

1. INTRODUCTION

The climate changes leading to the drought and desertification are severely affecting the agricultural sector. The elevated evapotranspiration rates of plants in the arid regions cannot be replenished by rains making the irrigation a fundamental practice. The water resources worldwide and particularly in Egypt have been decreased from ~ 2500 to 700 m³ capita/year during the years 1950's/2015 and is expected to be 250 m³ by the year 2050 due to the continuously increasing population. The irrigated agriculture along with the water deficit is a challenge in Egypt being more than 95% of its area is a desert soil (El-Habashy et al 2021; Min et al., 2016).

Agriculturally, the water stress negatively affects the plant metabolic processes and the most sensitive cellular expansion and development that lead to morphological traits like the reduced leaf area and stem diameter (Efeoglu et al., 2009). Developing policies and technologies for an advanced irrigation-saving knowledge are required to improve the use efficiency of the irrigation water with the quantitative and qualitative keeping of crop production (Pereira et al., 2012; Abd El-Mageed et al., 2021).

Surface irrigation is the traditional irrigation method applied in about 80% of the irrigated area in Egypt with greater water losses. The farmers usually pump irrigation water from the Nile River and its tributaries so that the water pricing is a complicated topic due to economic and political reasons. The economists think about the value of the secondary products of the irrigation water as good cost estimation and a measure of a firm's returns obtained by the last unit of a productive factor employed. For the studied crops, the value can be derived from the previously estimated linear and double logarithmic production functions (El-Shahat et al., 2013).

Recycling of the agricultural wastes such as crops residues has produced two types of the effective soil amendments that enhance the soil fertility, quality and productivity, which are the compost and biochar. Compost has been prepared by a long-time (>90 days) bio-oxidative processes in which the microorganisms play an essential role to mineralize the organic matter producing a stabilized final product containing humic substances (complex organic molecules) that is free of pathogens and toxics. Biochar has been made by the slow pyrolysis ~ 350 °C with a short-residence time of few hours in which the start organic residues become more mineral-like upon heating. Such mineral transformations create a skeletal structure

looks like a carbon sponge (Liu et al., 2021). The organic carbon in the biochar is from the re-condensed vapours along with the incompletely carbonized char prepared at low temperature. It is the black carbon produced due to the incomplete combustion of the organic matter (OM) resistant to the decomposition and degradation because of its condensed aromatic structure (Schulz and Glaser, 2012). Biochar is a highly hydrophobic carbonaceous residue produced by the thermal breakdown of organic materials under limited conditions of oxygen. It is characterized by hydrophobic groups such as acid anhydrides (C-C and C-O); carboxylate (CO₂), aromatic ketones (C=O), silanol (Si-O-H), and carbonates (C-O) (Duarte et al., 2019).

Some agricultural soils may lose between 25% to 75% of their original organic carbon because of the nitrogen (N) fertilization along with the tillage that accelerates the microbial respiration and burn up the soil carbon faster than it is replaced. These soils need repeated feed with irrigation water, mineral nutrients, and pesticides to produce crops. Both the compost and biochar can remediate the soil providing some benefits like reducing the bulk density, increasing the water holding capacity and support the microbial life and biodiversity. They enrich the soil organic carbon, increase the retention of nutrients dissolved from the fertilizer for the absorption by plant with decreasing their leaching loss that increase the crop yield (Rosenani, et al., 2014).

The soil amendments such as the biochar and compost can be used to reduce the applied water quantities. Biochar improves the water retention by soil and its available water AW. This is commonly observed in the coarse-textured soils (El-Habashy et al., 2021). The biochar application rates of 5 and 10 tons ha⁻¹ had significantly increased the seed yield by 25.8 and 38.7%, respectively, compared to the control. It had improved the soil properties, plant growth, physiological response, N, P and K contents in soil and faba bean plant under deficit irrigation (Abd El-Mageed et al., 2021).

Compost applied to a desert soil improves the organic matter (OM) and reduces the evaporation from the surface that maintains the soil moisture available for the plant (Curtis and Claassen 2005). Combined application of compost with mineral nitrogen fertilizers slightly decreased the pH in the tested soil and increased the available N, P, K, Fe, Mn and Zn content of saline soil and uptake in straw and grain (Taha et al., 2016; Ibrahim et

al., 2011).

Faba bean (*Vicia faba* L.) is one of the most important legume food crops being a source of plant protein and as a good break crop in the intensive cereal farming systems. The planted area in Egypt during the recent five years perhaps is more than 270 ha producing about 3504.8 kg ha⁻¹ (~9.2 arday/feddian) with a continuous demand and need to improve its quality and productivity (FAO, 2019). This study aims to evaluate economically the water use efficiency at three rates of irrigation (1, 2, and 3) with the comparison between using the biochar and compost along with the mineral fertilization on the yield and quality of the faba bean crop.

2. MATERIALS AND METHODS

Two field experiments have been carried out at El-Qantara Sharq, Ismailia governorate, Egypt, during the winter seasons of 2020/2021 and 2021/2022. The main factor F1 was the irrigation rates: rate 1 (3571.43 m³ ha⁻¹), rate 2 (4761.90 m³ ha⁻¹), and rate 3 (5952.38 m³ ha⁻¹) while the sub-factor F2 was the type of the soil additive (biochar, compost or mineral). Triplicate treatments were distributed in a split-plot design.

The irrigation water was from El-Salam canal (Nile water mixed with agriculture darning 1:1) applied via a surface-flow irrigation system consists of line pipes connected to a meter for measuring the applied water volume. The available water (AW) in soil was calculated as the difference between the field capacity (FC) and the wilting point (WP) assuming that the extracting depth of the faba bean roots is from 0.15 to 0.30 m.

Biochar and compost additives were prepared from some plant sources such as the straw of rice, wheat, maize, and faba bean along with the trees' leaves then applied to soil 15 day before the sowing at 11.9-ton ha⁻¹ application rate.

Air-dried surface soil samples (0–30 cm) were crushed and sieved by a 2 mm sieve then kept for analysis before cultivation. Some properties of the experiment soil before sowing, irrigation water, biochar, and compost were presented in Table 1 according to the standard methods described by (Klute, 1986; Cottenie et al., 1982; Page et al., 1982; Brunner and Wasmer, 1978).

Table 1: Main characteristics of the experiment soil at EL-Qntara Sharq, the irrigation water from El-Salam Canal, biochar and compost

| Soil | Coarse sand (%) | Fine sand (%) | Silt (%) | Clay (%) | Texture | Moisture content (%) | | | OM (%) | CaCO ₃ (%) | |
|--|--------------------|--------------------------|--------------------------------|------------------|-----------------|-------------------------------|-------------------------------|-----------------|-------------------------------|-----------------------|-------|
| | | | | | | FC | WP | AW | | | |
| | 15.62 | 62.50 | 8.30 | 13.58 | Loamy sand | 20.80 | 10.55 | 13.55 | 0.67 | 4.88 | |
| Chemical analysis | pH | EC (dS m ⁻¹) | Cations (meq L ⁻¹) | | | Anions (meq L ⁻¹) | | | | | |
| | | | Ca ⁺² | Mg ⁺² | Na ⁺ | K ⁺ | HCO ₃ ⁻ | Cl ⁻ | SO ₄ ⁻² | | |
| Soil | 7.95* | 5.30 | 10.62 | 17.90 | 23.63 | 0.85 | 7.40 | 19.84 | | 25.78 | |
| Water | 7.98 | 1.59 | 2.10 | 5.19 | 8.10 | 0.51 | 1.66 | 7.58 | | 6.66 | |
| Biochar | 7.99 | 4.20 | (C/N = 20.64) | | | Moisture = 20% | | | | | |
| Compost | 7.22 | 3.50 | (C/N = 21.85) | | | Moisture = 20% | | | | | |
| Nutrients | | | | | | | | | | | |
| | N | | P | | K | | Fe | | Mn | | Zn |
| Soil (Available, mg kg ⁻¹) | 33.70 | | 7.39 | | 175.00 | | 3.44 | | 1.20 | | 0.59 |
| Water (Soluble, mg L ⁻¹) | 7.40** 14.88*** | | 6.39 | | 10.44 | | 1.22 | | 0.86 | | 0.24 |
| Biochar (g kg ⁻¹) | 14.0 | | 19.8 | | 29.5 | | 0.259 | | 0.088 | | 0.050 |
| Compost (g kg ⁻¹) | 18.2 | | 8.8 | | 24.5 | | 0.124 | | 0.079 | | 0.044 |

*(1:2.5) soil: water suspension ** NO₃-N *** NH₄-N

Faba Bean (*Vicia faba* L.) seeds Giza 843 were obtained from the Legume Department, Field Crops Research Institute, Agricultural Research Center, Giza, Egypt and sown on the 20th of November (2020/2021 and 2021/2022). The area of the experimental unit was 5 × 4 m² divided into 75 cm separated rows. Three to four seeds were sown in holes of 5 cm depth and 25 cm distance. After 31 day of sowing, the plants in each hole were thinned to one plant.

Mineral fertilization has included the super phosphate (15.5% P₂O₅ - 476.19 kg ha⁻¹) applied during the soil tillage, urea (46% N - 71.43 kg ha⁻¹) three equal doses applied 31, 45 and 65 days after sowing, in addition to the potassium sulphate (48% K₂O - 178.57 kg ha⁻¹) two equal doses

applied 31 and 45 days after sowing. The three irrigation rates (rate 1 = 3571.43 m³ ha⁻¹, rate 2 = 4761.90 m³ ha⁻¹, and rate 3 = 5952.38 m³ ha⁻¹) were applied during the planting seasons.

Some climatic elements of the experiment location like the air temperature (T, °C), mean relative humidity (RH, %), wind speed (U₂, m sec⁻¹), evaporation pan (Ep, mm d⁻¹) and rainfall (Rf, mm) during the two growing seasons are presented in Table 2. The climatic data were recorded by El-Quantara Sharq climatic Station The water use efficiency (WUE) was calculated according as follows: The crop yield (Y, Kg ha⁻¹) / the applied rate of the irrigation water (m³ ha⁻¹) to (FAO, 1982).

Table 2: Some climatic elements of the experiment location like the air temperature (T, C°), mean relative humidity (RH, %), wind speed (U2, m sec⁻¹), evaporation pan (Ep, mm d⁻¹) and rainfall (Rf, mm)

| Month | Temperature (°C) | | | Relative humidity (%) | Wind speed (mm sec ⁻¹) | Evaporation pan (mm d ⁻¹) | Rainfall (mm month ⁻¹) |
|-------|------------------|-------|-------|-----------------------|------------------------------------|---------------------------------------|------------------------------------|
| | Mix | Min | Mean | | | | |
| Nov | 23.45 | 13.88 | 18.70 | 72.90 | 0.85 | 3.10 | 00.00 |
| Dec | 18.90 | 9.80 | 14.35 | 78.30 | 0.66 | 5.29 | 75.89 |
| Jan | 17.44 | 7.40 | 12.42 | 81.40 | 0.58 | 4.22 | 88.40 |
| Fab | 19.20 | 5.40 | 12.30 | 82.10 | 0.77 | 2.18 | 90.49 |
| Mars | 22.88 | 12.88 | 11.92 | 79.44 | 0.85 | 3.50 | 77.40 |
| Apr | 28.40 | 17.25 | 22.82 | 73.98 | 1.08 | 5.12 | 35.87 |
| May | 31.86 | 20.18 | 26.02 | 78.60 | 1.02 | 3.66 | 00.00 |

At harvest, ten plants from each plot were selected randomly as a representative sample to measure the plant height (cm), number of branches/plant, weight of pods/plant (g), weight of seeds/plant (g), 100 seed weight (g), yield of pods and seeds (ton ha⁻¹).

2.1 Plant Analysis

Faba bean seeds and straw were oven-dried for 48 h at 70 °C and ground. A half gram of the powdered seeds and/or straw was acid digested using the mixed H₂SO₄/HClO₄ (4:2) (Chapman and Pratt, 1961). The N, P, K, Fe, Mn and Zn concentrations in the plant extracts were measured using the Kjeldahl apparatus, colorimetrically by the UV-Vis. Spectrophotometer, by flame photometer, and by the ICP Spectrometry (ICP-*Ultima 2 JY Plasma*), respectively (Cottenie et al., 1982; Page et al., 1982). All results were the average values of the two seasons.

The photosynthetic pigment Chlorophyll (a, b) as well as the carotenoids were estimated in the fresh leaves as described by (Witham et al., 1071). The total carbohydrates were determined in the dry leaves according to (Dubois et al., 1956). The seeds' protein (%) was calculated as the N (%) × 6.25 (Hymowitz et al., 1972).

The obtained data were statistically analysed to calculate the treatments statistical significance (LSD) at $P < .05$ using the COSTAT program (Gomez

and Gomez, 1984).

3. RESULTS

3.1 Effect of The Irrigation Rates and Soil Additives on The Soil-Available Nutrients

The soil-available N (mg kg⁻¹) has increased relative to that before cultivation in the range 11.3 – 55.5% that was non-significant due to the irrigation rates (main factor F1) but a significant due to the soil additives (sub-factor F2) according to the Table 3. The studied irrigation rates as well as the soil additives have increased the soil-available concentration (mg kg⁻¹) of K, Mn, and Zn significantly and the available P, and Fe but non-significantly at $p < .05$. The most significant relative increase compared to the soil-available content (mg kg⁻¹) before cultivation was found for the compost at the irrigation rate 3 by 6.9% for K, 78.3% for Mn, and by 44.1% for Zn. The increase in the available nutrients followed the order irrigation rate 1 (3571.43 m³ ha⁻¹) < rate 2 (4761.90 m³ ha⁻¹) < rate 3 (5952.38 m³ ha⁻¹) and the order mineral < biochar < compost. The factors F1 and F2 showed an independent effect on the available N, P, K, Fe, and Zn since the F1 × F2 interaction was non-significant. The significant increase of the Mn available in soil may be dependent on both the irrigation rate and the soil additives.

Table 3: Soil-available concentrations (mg kg⁻¹) of the macro- and micro-nutrients after harvesting

| Irrigation rates (m ³ ha ⁻¹) | Treatments | Available nutrients (mg kg ⁻¹) | | | | | |
|---|------------|--|------|--------|------|------|-------|
| | | N | P | K | Fe | Mn | Zn |
| 3571.43 | Mineral | 37.50 | 7.95 | 176.40 | 3.77 | 1.67 | 0.63 |
| | Biochar | 39.59 | 8.06 | 179.40 | 3.80 | 1.75 | 0.69 |
| | Compost | 41.33 | 8.54 | 180.57 | 3.93 | 1.83 | 0.72 |
| 4761.90 | Mineral | 44.39 | 8.12 | 177.12 | 3.86 | 1.86 | 0.67 |
| | Biochar | 45.84 | 8.16 | 182.55 | 3.98 | 1.95 | 0.77 |
| | Compost | 46.40 | 8.95 | 185.30 | 4.09 | 2.09 | 0.78 |
| 5952.38 | Mineral | 45.72 | 8.33 | 178.75 | 3.94 | 1.99 | 0.72 |
| | Biochar | 48.50 | 8.66 | 184.70 | 4.07 | 2.05 | 0.79 |
| | Compost | 52.40 | 9.13 | 187.10 | 4.15 | 2.14 | 0.85 |
| LSD _{5%} Irrigation levels | | ns | ns | 2.31 | ns | 1.06 | 0.009 |
| LSD _{5%} Soil additives | | 1.41 | ns | 1.37 | ns | 1.06 | 0.019 |
| Significance of Interaction | | ns | ns | ns | ns | *** | ns |

Similar studies have mentioned that the compost and biochar application may increase the fertilizer efficiency and the available N, P and K in soil under different levels of irrigation water by decreasing the nutrients loss (Cong et al., 2022; Adugna, 2016). It had been found that the increased irrigation water period from El-Salam canal gave increments in the micronutrients content in a saline soil (Abou Hussien and Shaban, 2008; Mousa and Shaban, 2017; Ibrahim et al., 2011).

3.2 The effect of the irrigation rates and soil additives on the Faba bean productivity

ata presented in Table 4 indicate that both the studied irrigation rates and soil additives significantly increased the plant height (cm), number of

branches/plant, weight of pods/plant (g), weight of seeds/plant (g), weight of 100 seeds (g) as well as the yield of pods and seeds (ton ha⁻¹). The significant increase in the mentioned parameters at $p < .05$ followed the order irrigation rate 1 (3571.43 m³ ha⁻¹) < rate 2 (4761.90 m³ ha⁻¹) < rate 3 (5952.38 m³ ha⁻¹). The increased yield (ton ha⁻¹) of pods and seeds at the rate 3 relative to rate 1 was by 6.1% and 28.4% for the mineral fertilization, by 11.6% and 13.4% for the biochar, and by 15.0% and 26.1% for the compost, respectively. This increase was dependent on both factors F1 and F2 since their interaction was highly significant. These results are in consistence with previous studies (Atta et al., 2002; Mousa and Shaban 2017; Poormansour and Razzaghi, 2018; Poormansour et al., 2019; Rezaie et al., 2019).

Table 4: The effects of the irrigation rates and/or soil additives on the Fababean productivity

| Irrigation rates (m ³ ha ⁻¹) | Treatments | Plant height (cm) | No. branches /plant | Weight of pods /plant (g) | Weight of seeds /plant (g) | Weight of 100 seeds (g) | Yield of Pods (ton ha ⁻¹) | Yield of seeds (ton ha ⁻¹) |
|---|------------|-------------------|---------------------|---------------------------|----------------------------|-------------------------|---------------------------------------|--|
| 3571.43 | Mineral | 79.40 | 4.30 | 85.30 | 55.30 | 70.22 | 3.93 | 2.50 |
| | Biochar | 85.40 | 5.88 | 88.00 | 58.33 | 74.20 | 4.48 | 2.69 |
| | Compost | 94.30 | 6.88 | 93.22 | 63.20 | 77.50 | 4.60 | 2.83 |
| 4761.90 | Mineral | 87.10 | 5.29 | 89.40 | 59.30 | 75.40 | 4.02 | 2.74 |
| | Biochar | 96.30 | 7.34 | 99.60 | 65.30 | 83.00 | 5.07 | 3.48 |
| | Compost | 104.98 | 8.10 | 105.20 | 74.60 | 88.40 | 5.33 | 3.71 |
| 5952.38 | Mineral | 93.90 | 5.88 | 90.39 | 62.49 | 77.40 | 4.17 | 3.21 |
| | Biochar | 110.00 | 6.29 | 96.34 | 63.90 | 77.60 | 5.00 | 3.05 |
| | Compost | 115.30 | 7.55 | 99.10 | 69.00 | 82.50 | 5.29 | 3.57 |
| LSD_{5%} Irrigation levels | | 1.18 | 0.46 | 2.62 | 0.007 | 2.57 | 0.070 | 0.068 |
| LSD_{5%} Soil additives | | 1.46 | 0.49 | 2.85 | 1.19 | 1.45 | 0.028 | 0.044 |
| Significance of Interaction | | *** | ns | ns | ** | ** | *** | *** |

3.3 The effect of the irrigation rates and soil additives on the total concentration of the macro- and micro-nutrients in the faba bean seeds

As the irrigation rate increased from the rate 1 (3571.43 m³ ha⁻¹) to the rate 3 (5952.38 m³ ha⁻¹), the nutrients' concentration in the faba bean seeds was increased significantly (except for the N that was non-

significant respecting the irrigation) for the studied soil additives as presented in Table 5. The seeds' N content (g kg⁻¹) was increased at rate 3 relative to rate 1 by 18.2%, 38.3%, and 46.1% for the mineral, biochar, and compost, respectively. Also, the seeds' P and K contents (g kg⁻¹) were increased by 28.9 and 18% for the mineral, 26.2 and 7.3% for the biochar, and by 28.9 and 8.5% for the compost, respectively.

Table 5: Total concentration of the macro- and micro-nutrients in the faba bean seeds

| Irrigation rates (m ³ ha ⁻¹) | Treatments | Total concentration | | | | | |
|---|------------|--------------------------------------|--------------|--------------|---------------------------------------|-------------|-------------|
| | | Macronutrients (g kg ⁻¹) | | | Micronutrients (mg kg ⁻¹) | | |
| | | N | P | K | Fe | Mn | Zn |
| 3571.43 | Mineral | 27.5 | 3.8 | 24.4 | 75.70 | 43.20 | 24.90 |
| | Biochar | 29.8 | 4.2 | 27.5 | 77.80 | 45.30 | 27.50 |
| | Compost | 31.0 | 4.5 | 28.3 | 79.00 | 48.50 | 28.94 |
| 4761.90 | Mineral | 29.7 | 4.4 | 27.5 | 79.30 | 44.99 | 25.39 |
| | Biochar | 32.8 | 4.8 | 27.9 | 82.60 | 46.40 | 30.22 |
| | Compost | 39.5 | 5.3 | 29.5 | 84.30 | 53.80 | 35.89 |
| 5952.38 | Mineral | 32.5 | 4.9 | 28.8 | 81.40 | 46.30 | 27.80 |
| | Biochar | 41.2 | 5.3 | 29.5 | 85.30 | 49.20 | 35.10 |
| | Compost | 45.3 | 5.8 | 30.7 | 87.40 | 55.30 | 39.00 |
| LSD_{5%} Irrigation levels | | ns | 0.013 | 0.015 | 0.44 | 1.15 | 0.49 |
| LSD_{5%} Soil additives | | 4.5 | 0.008 | 0.017 | 1.74 | 1.68 | 1.47 |
| Significance of Interaction | | ns | ns | *** | ns | ns | ** |

The micronutrients in the faba bean seeds in Table 5 showed a similar behavior under the effect of the studied factors. Their concentrations (mg kg⁻¹) have increased at the irrigation rate 3 relative to rate 1 as follows: the Fe, Mn, and Zn were increased by 7.5, 7.2, 11.6% for the mineral, by 9.6, 8.6, 27.6% for the biochar, and by 10.6, 14, and 34.8% for the compost, respectively. The K and Zn concentration in seeds was dependent on both the irrigation rates and soil additives as their statistical interaction was significant at $p < .05$. In contrast, the individual effect of the irrigation rates was independent of that of the soil additives for the N, P, Fe, and Zn content in seeds since their interaction was non-significant.

It had been found that biochar and compost application significantly increased the uptake of the N, P, and K by the Stover and grains. The uptake was significantly affected by the irrigation regimes (Abd El-Kader et al., 2010; Awadalla et al., 2018; Abdel Azeem, 2020; Gomaa and Afifi, 2021).

3.4 The effect of the irrigation rates and soil additives on the protein (%), carbohydrate (%) and chlorophyll (mg g f.w⁻¹) in the faba bean seeds

The faba bean seeds' contents of the protein (%); carbohydrate (%) and chlorophyll (mg g f.w⁻¹) shown in Figures 1, 2, and 3 respectively were almost significantly increased in the direction mineral < biochar < compost affected by the irrigation rates 1, 2, and 3. The protein has increased at rate 3 relative to rate 1 by 18.2%, 38.2%, 46.1% for the mineral, biochar, and compost, respectively. The increase in the carbohydrates was by 7.9%, 7.8%, 9.9% and the chlorophyll by 19.1%, 6.9%, and 10.7% for the mineral, biochar, and compost, respectively. The interactive effect of the irrigation rates and soil additives was complementary for the seeds protein as their interaction was significant but independent for the carbohydrates and chlorophyll with non-significant interaction.

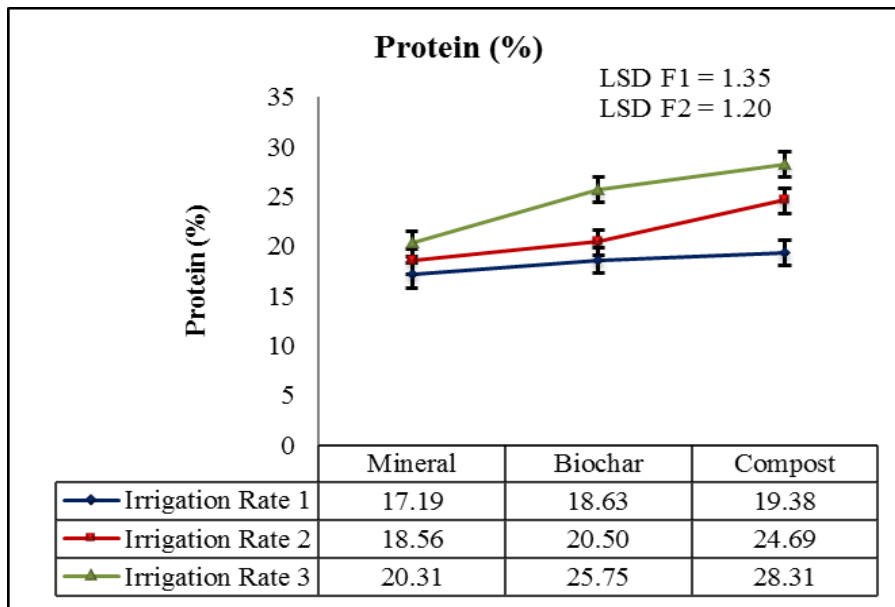


Figure 1

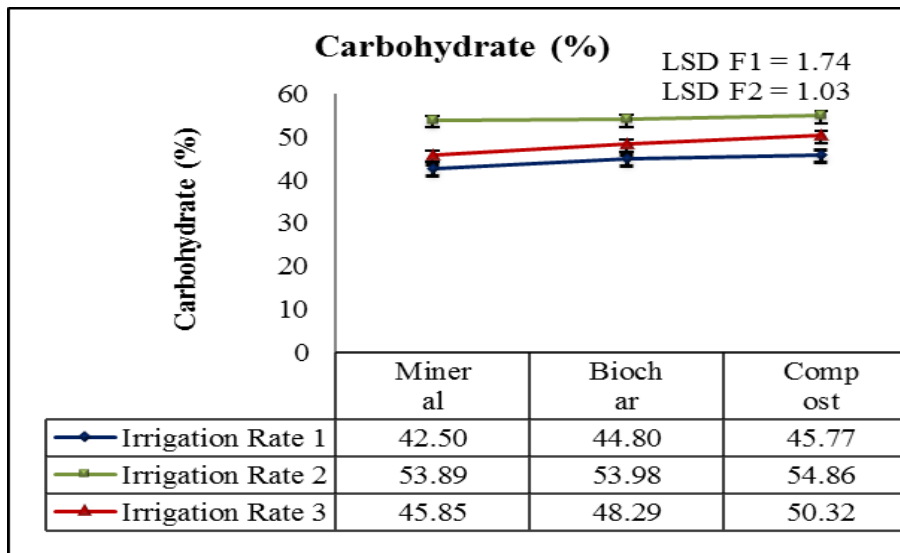


Figure 2

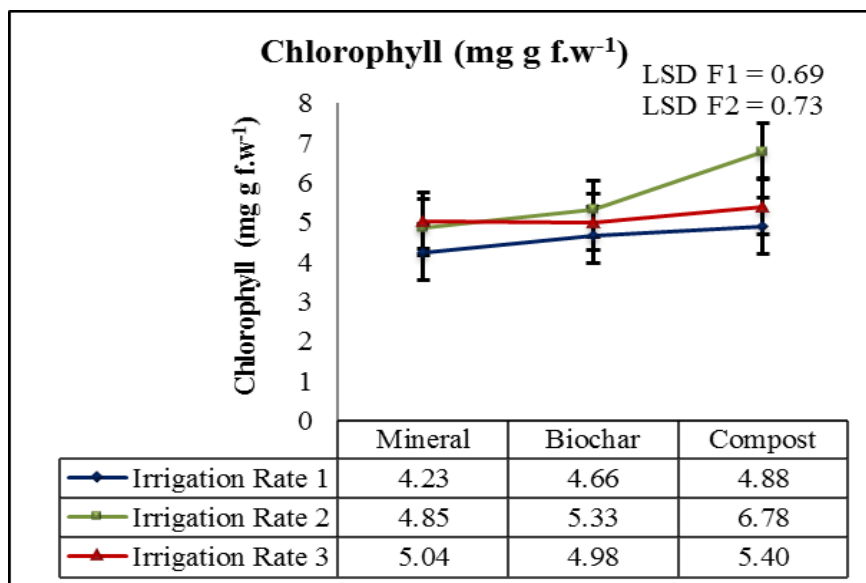


Figure 3

It has a reported that the increased amount of irrigation water during the vegetative and reproductive growth of faba bean enhances the photosynthesis resulting in more synthesis and accumulation of food

material which leads to higher yield and its components (Awadalla et al, 2018).

3.5 Water use efficiency (WUE)

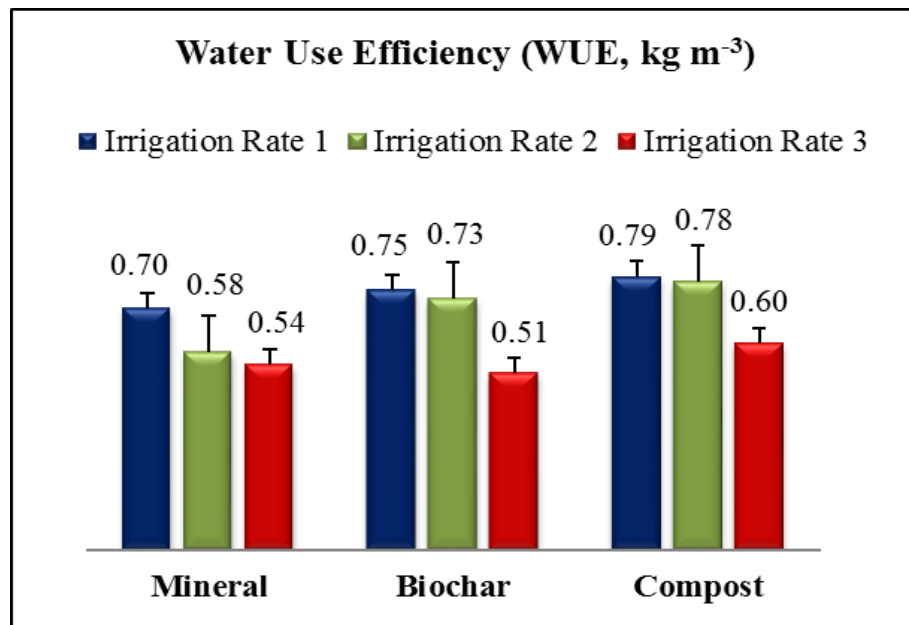


Figure 4

The WUE (kg m⁻³) was decreased as the irrigation rate increased as mentioned by the Figure 4 for the mineral, compost, and biochar applications. At the rate 3, the WUE was decreased by 22.86%, 32%, and

by 24.05% relative to the rate 1 for the mineral, biochar, and compost, respectively (Fayed et al., 2018; Noah et al., 2010; Dong et al., 2019; Aly 2020).

3.6 An economic evaluation of the Faba Bean productivity under the effect of the studied irrigation rates combined with the applied soil additives

Table 6: The most important economic variables for the Faba bean cultivation and harvesting

| Treatments | Mineral | | | Biochar | | | Compost | | |
|---|---------|--------|--------|---------|--------|--------|---------|--------|--------|
| Irrigation rates (m ³ ha ⁻¹) | 3571.4 | 4761.9 | 5952.4 | 3571.4 | 4761.9 | 5952.4 | 3571.4 | 4761.9 | 5952.4 |
| Tillage Costs (L.E. ha ⁻¹) | 1785.7 | | | | | | | | |
| Sowing Costs (L.E. ha ⁻¹) | 2381.0 | | | | | | | | |
| Employment Costs (L.E. ha ⁻¹) | 3571.4 | | | | | | | | |
| Fertilizers Price (L.E.) | 2381.0 | | | | | | | | |
| Fuel price (L.E.) | 2857 | 3571 | 4285 | 2261 | 2619 | 2976 | 2357 | 2857 | 3214 |
| Total costs | 12976 | 13690 | 14404 | 12381 | 12738 | 13095 | 12476 | 12976 | 13333 |
| Productivity of Seeds (ton ha ⁻¹) | 2.50 | 2.74 | 3.21 | 2.69 | 3.48 | 3.05 | 2.83 | 3.71 | 3.57 |
| Productivity of Pods (ton ha ⁻¹) | 3.93 | 4.02 | 4.17 | 4.48 | 5.07 | 5.00 | 4.60 | 5.33 | 5.29 |
| Seeds price (L.E.) | 12065 | | | | | | | | |
| Pods price (L.E.) | 948 | | | | | | | | |
| Revenue (L.E.) | 33888 | 36869 | 42681 | 36701 | 46792 | 41538 | 38504 | 49813 | 48086 |
| Net Return (L.E.) | 20912 | 23179 | 28326 | 24320 | 34010 | 28443 | 26028 | 36837 | 34753 |
| Return/Cost (L.E.) | 2.61 | 2.69 | 2.96 | 2.96 | 3.67 | 3.17 | 3.09 | 3.84 | 3.61 |
| Net Return/Cost (L.E.) | 1.61 | 1.69 | 1.97 | 1.96 | 2.67 | 2.17 | 2.09 | 2.84 | 2.61 |
| Water productivity (kg m ⁻³) | 0.70 | 0.58 | 0.54 | 0.75 | 0.73 | 0.51 | 0.79 | 0.78 | 0.60 |
| Water unit Return (LE/1000 m ³) | 5855 | 4863 | 4759 | 6810 | 7142 | 4774 | 7298 | 7747 | 5841 |

The economic calculations of the present study are based on the average costs during the recent three years. Of course, it shall be continually updated to match the annual rising in prices on local and international scales. From cultivation to harvesting the faba bean crop, there are constant and variable costs as mentioned in Table 6. Increasing the irrigation rates from rate 1 (3571.4 m³ ha⁻¹) to rate 3 (5952.4 m³ ha⁻¹) lead to an increase in the variable fuel costs in addition to the constant costs of the tillage, sowing, employment, and fertilizers that increase the total costs during the cultivation season. At the irrigation rate 3, the total costs increase in the direction biochar (13095 LE) < compost (13333 LE) < mineral (14404 LE). Calculating the revenue from multiplying the prices of the seeds and pods by their yield has indicated that the maximum net return was at the irrigation rate 2 for the compost (36837 LE) followed by the biochar (34010 LE) then at the rate 3 for the mineral fertilization (28326 LE). The return and net return with respect to the costs were also

increased in the same order: rate 2 (compost) > rate 2 (biochar) > rate 3 (mineral). Since the WUE expressed as the water productivity decreases as the irrigation rate increases, it can be said that the application of the compost and/or the biochar is more efficient at the rate 2 than the single use of the mineral fertilization that need greater level of the irrigation water otherwise the yield decreases. The maximum water unit return has increased by 32.3% and 21.9% for the compost and biochar at rate 2, respectively, relative to the mineral at rate 1.

4. CONCLUSION

The WUE (kg m⁻³) was decreased as the irrigation rate increased for the mineral, compost, and biochar applications. At the rate 3, the WUE was decreased by 22.86%, 32%, and by 24.05% relative to the rate 1 for the mineral, biochar, and compost, respectively. the application of the

compost and/or the biochar is more efficient at the rate 2 than the single use of the mineral fertilization that need greater level of the irrigation water otherwise the yield decreases. The maximum water unit return has increased by 32.3% and 21.9% for the compost and biochar at rate 2, respectively, relative to the mineral at rate 1.

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