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Sustainable Agricultural Techniques for Pepper (*Capsicum annuum* L.) Production under Greenhouse Conditions

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ABSTRACT

A field experiment was conducted, during 2020 and 2021 growing seasons, on pepper plants (*Capsicum annuum* L.), under net covered greenhouse conditions. Two factors were studied, (a) organic fertilizers and (b) irrigation levels. The fertilization treatments were: the application of a half dose of mineral fertilizers combined with different types of organic fertilizer i.e., compost, vermicompost and organic manure in rice straw; compared with soil. The irrigation treatments were: three irrigation levels i.e., 70, 85 and 100 % based on reference evapotranspiration (ETo). Both (a and b) factors were distributed in a complete randomized block design with three replicates. Results indicated that both soil temperature and moisture were more suitable for plant growth in rice straw after adding compost under 85% irrigation. Growth parameters (plant length, number of leaves, leaf area, number of branches, stem diameters and fresh and dry weight of plants) were enhanced by using compost under 85% irrigation level. The same trend was obtained in chemical composition of pepper plants i.e., chlorophyll, N, P, K and vitamin C in fruits. The yield of fruits, in rice straw treatment with 85% irrigation level, combined with compost, slightly increased compared with clay soil (control). Water productivity is considered water use efficiency (WUE), was increased in irrigated rice straw, with compost as fertilizer, with 85% of ETo. The study stated that, using affordable agriculture crop residues, as cultivation medium, plus organic fertilizers, instead of mineral fertilizers, it achieved higher sustainable production of green pepper.

***Keywords*:** Sustainable Agriculture, Green Pepper, Rice straw, irrigation levels, organic fertilizers

INTRODUCTION

Sustainable agriculture concerned with three main goals i.e., environmental health, economic profitability and social equity. The Farm to Fork Strategy aims to accelerate our transition to a sustainable food system (Schebesta *et al*, 2020). The increases in agricultural production over recent decades depended mainly on mineral fertilizers. In addition, subsidy schemes have made mineral fertilizers much cheaper in many developing countries trying to improve food security. So far, the focus on nitrous oxide (N_2O) emissions and their impact on climate change, insufficient attention has been paid to the adverse effects on the soil and the environment, which resulted from improper use of mineral and unsuitable fertilizers. (FAO, 2015).

Egypt produces between 30 and 35 million tons of agricultural waste annually, of which only 7 million tons are used as animal feed and 4 million as organic manure. After harvest, these crops produce leaves, stems, and shelves, which are classified as coarse (and large) plant by products with low chemical protein and fat levels. It also contains a lot of lignin and cellulous material. (Abou Hussein and Sawan 2010). The contents of rice straw's lignin, hemicellulose and cellulose were about 12%, 28% and 60%, respectively (Stahl and Ramadan 2007).

By enhancing the moisture-retention capacity of the soil, organic matter in the soil controls the flow of water and supplies vital nutrients to plants and bacteria. (Liu, et al., 2021). On the other hand, human use of herbicides results in a drop in soil water content, which happens more quickly in places with less vegetation. Additionally, soil organic matter enhances and regulates the stability of the soil structure and the quantity of necessary aggregates. Regarding the link between soil microorganisms and agricultural productivity, nutrient cycling is a crucial component, and the number of soil bacteria has a significant impact on the turnover of organic matter. (Chen, et al., 2019 & Haq, et al., 2021). The application of organic manure contributes significantly to the enhancement of the biological, physical, and chemical properties of soil, the maintenance of agricultural yield, and soil biodiversity (Ou-Zine et al., 2021, Piñar et al., 2021, Cano-Ortiz et al., 2021)

In many parts of the world, water for agriculture is in short supply and/or its getting worse. Overdraft of groundwater results in disturbance of key riparian zones, while overdraft of surface water supplies threatens future irrigation capacity. Water can be used more effectively in sustainable agriculture ecosystems by managing soils and crops to prevent water loss and using reduced-volume irrigation systems. Abdel–Sattar (2004 & 2005) published a new technique, for the first time in Egypt, for growing some vegetable crops, such as cucumber, tomato, pepper, melon and strawberry, in greenhouse and open field on compacted rice straw bales, using only dissolved fertilizers.

The present research deals with the possibility of using rice straw residue as an alternative cultivation medium, instead of traditional soils, to improve the productivity of green pepper plants, in order to escape the problems inherent in the natural soils.

Hassan, (1988), used straw substrate of wheat and barley for cucumber and tomato under greenhouses in some European and Arab countries. Choe, et al. (1991), studied the effect of rice straw treatment to improved soil characters for growing green

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pepper, under greenhouse conditions. The application of quality irrigation water and organic manure fertilizers improved soil properties, such as water holding capacity and soil microbial biomass C: N: P under stress climatic conditions (Bhanwaria et al., 2022).

Vermicompost enhanced the growth and yield performance of pepper plants, followed by poultry manure, over control and FYM. Chemical fertilizers, however, had similar yield as the previous mentioned treatments, but was slow in its flowering and fruiting behavior (Adhikari et al., 2016 & Khandekar et al., 2017).

The aim of the present work is to study some affordable sustainable agriculture methods, using domestic residues of agricultural crops, such as paddy rice straw and different kinds of organic fertilizers, to improve green pepper productivity. In addition, measuring water consumptions, for these cultivation mediums, will help in reducing both water and nutrients leaching, with the result of alleviating the negative impacts of future climate changes on agriculture production.

MATERIALS AND METHODS

Experimental layout:

Field experiments were conducted, to improve the productivity of green pepper (Capsicum annuum L., Super Noura F1 hybrid), in the summer seasons of 2020 and 2021, at El-Dokki experimental station, Central Laboratory for Agricultural Climate (CLAC). Pepper seeds were sown in the nursery on February 15 and transplanted, after 45 days (four-leaf stage), on 1st of April for the two growing seasons under greenhouse conditions. The spacing between rows was 0.75 m and between plants was 0.5 m. The area of greenhouse is 360 m^2 (9 m x 40 m) covered with screen net. The cultivation area was divided into five equal parts; each part was 40 m^2 (1m width x 40 m length). Three parts were selected, each divided into four equal area (1m width x 10m length). Three parts were dug to create ditches with 0.5 m depth. Ditches were covered with black plastic mulch and filled with separated rice straw bales. The fourth part of each area was left to make raised bed (1m width x 10m length) for the control treatment.

Preparation of rice straw bales

Straw bales were first irrigated for six hours to wash soil particles, and then the dissolved fertilizers ammonium and potassium sulphate and phosphoric acid 85 % were injected daily through the irrigation system, 10-12 days before planting for rice straw fermentation. A half dose (50%) of chemical fertilizers was added to each rice straw treatments combined with the double amount (1.4 m^3) of used organic fertilizer, vermicompost, compost and organic manure, respectively, also were added to the rice straw substrate plots two weeks before transplanting.

Experimental treatments

Fertilization treatments

Four different fertilization treatments were used as follows:

1- Rice straw + 50% chemical fertilizers + vermicompost.
2- Rice straw + 50% chemical fertilizers + compost.
3- Rice straw + 50% chemical fertilizers + organic manure.
4- Control treatment (clay soil +100% chemical fertilizers + 50% organic manure).

The chemical fertilizers mixture was 10 Kg calcium super phosphate + 3.5 Kg ammonium sulphate + 6.5 Kg calcium sulphate + 6.5 Kg potassium sulphate. Organic manure was added to the clay soil, two weeks before transplanting, at the rate of 0.7 m^3 (Technical Bulletin, 2016).

The chemical analysis estimates of the experimental site soil, of the rice straw and of the different organic fertilizers, are presented in Tables (1, 2 and 3), respectively, according to A.O.A.C., (2005).

Table 1. Characteristics of the soil of experimental site.

Particle size distribution		Texture	pH	EC (dS/m)	Ca CO3 (%)	OM (%)
Silt 16.7	Clay 26	Sandy clay loam	8.2	2.4	16.0	0.35
Soluble cations and anions (soil paste ext.) (meq/l)						
Ca++	Mg++	Na+	K+	Cl-	HCO3-	
6.0	3.0	20.1	1.2	13.0	2.6	

Table 2. Characteristics of the rice straw substrate of the experiment.

Moisture (%)	C/N ratio	EC dS/m	Ashe (%)	Protein (%)	N %	P %	K %	Cellulose (%)	Lignin (%)
8.4	61.25	2.3	19.3	5.3	0.8	0.6	0.4	35	12.2

Table 3. Characteristics of organic manure, compost and vermicompost were used in the experiment.

Organic fertilizer	EC (dS / m)	pH (1:2.5)	Total C (%)	N (%)	P (%)	K (%)	C/N ratio
Organic manure	1.50	7.72	32.5	1.71	0.65	2.81	19.01
Compost	3.65	7.16	20.5	2.42	0.74	1.26	8.5
Vermicompost	6.88	7.56	17.3	3.50	0.85	1.52	4.9

Irrigation treatments:

Three irrigation levels were applied (70, 85 and 100 %) based on reference evapotranspiration (ETo) under greenhouse conditions.

Estimation of irrigation requirements:

The values of evapotranspiration during the growing season of pepper plant (from April to September) were provided by the meteorological station of the Central Laboratory for Agricultural Climate (CLAC) under open field conditions. Then, the evapotranspiration under greenhouse estimated according to (Abou-Hadid and El-Beltagy, 1992). As follow:

$$ETGH = 0.7 \times ETo$$

Where:

ETGH = the evapotranspiration under greenhouse conditions, mm/day

ETo = the evapotranspiration in the open field conditions, mm/day

Drip irrigation system was used for irrigation, according to the evapotranspiration (ETc) values and soil water balance (Doorenos and Pruitt, 1977) as follow:

$$ETc = ETGH \times Kc$$

Where:

ETc = the water requirements for pepper plant under greenhouse conditions, mm day-1

ETGH = the evapotranspiration under greenhouse conditions, mm day-1

Kc = the crop coefficient for pepper plant

The Kc was used according to FAO, (1998); the Kc values were varied throughout different plant growth stages and increased from 0.5 up to 1.1 from transplanting to the beginning of fruit harvest, then decreased again from 1.1 to 0.8 at the end of the growing season. The different irrigation requirements for each treatment was calculated according to FAO, (1998). Drip irrigation, consisted of disk filter, flow meter, fertilizer units, PE valves, sub main PVC line 63 mm, and 16 mm PE lateral (GR 4l / h), and used from April 1st up to the end of the growing season. The total amount of drip irrigation was estimated by water meter for each treatment and the total amount of each irrigation treatment is presented in Table 4.

Table 4. Seasonal irrigation volume for each irrigation treatment:

Period	70% ETo	85% ETo	100% ETo
April	13230	16065	18900
May	21410	25998	30586
June	29946	36363	42780
July	36560	44394	52229
August	41987	50984	59982
September	32371	39308	46244
Total (L / GH)	175504	213112	250720
Total (m^3/ GH)	176	213	251

Weather conditions:

The following meteorological variables were recorded daily during the growing seasons of 2020 and 2021: maximum and minimum air temperature (°C), air relative humidity (%), and evapotranspiration (ETo), using a meteorological station (Digital thermo /hygrometer Art. No. 30.5000/30.5002, Produced by TFA, Germany), located at the CLAC Dokki experimental site, and the data are presented in Table 5.

Table 5. Meteorological data during 2020 and 2021 growing seasons under greenhouse conditions.

Month	2020				2021			
	T max (oC)	T min (oC)	RH (%)	ETo (mm day-1)	T max (oC)	T min (oC)	RH (%)	ETo (mm day-1)
April	27.6	15.4	55.8	3.89	29.6	15.0	48.0	4.03
May	33.0	19.4	47.3	4.67	34.8	21.0	43.6	4.69
June	35.5	21.9	48.8	4.68	34.7	22.5	51.2	5.28
July	36.7	24.1	60.5	4.13	36.6	25.2	53.9	5.13
Aug.	36.5	25.0	59.8	4.32	37.0	25.5	56.0	4.68
Sept.	35.2	25.2	62.9	4.33	34.0	23.4	56.5	3.66

Recorded data

During the two growing seasons, the average soil temperature (ºC) was calculated at a depth of 20 cm and in the rice straw medium for all treatments. In addition, the soil moisture (%) was estimated under different irrigation levels and organic fertilizer applications, during both growing seasons, using digital thermo/hygrometer (Art. No. 30.5000/30.5002, Produced by TFA, Germany).

Regarding growth parameters, a sample of three pepper plants from each replicate in different treatments were collected, after 60 days from transplanting, to determine the following characteristics: plant length, number of leaves, stem diameter, leaf area, number of branches, fresh and dry weight of plant and chlorophyll reading (SPAD). The total fruit yield per square meter was estimated in both growing seasons. Vitamin C (ascorbic acid) (mg / 100 cm3 juice), was determined in the fresh fruits using the 2, 6 di-chlorophenol indophenol method described in A. O. A. C. (1990). The N, P and K percentages were determined in leaf samples after drying at 70 oC, in an air forced oven, for 48 hours. Dried leaves were digested in H2SO4 and the following mineral contents were estimated: phosphorous, potassium in the acid digested solution by Colorimetric method, Ammonium molybdate by Spectrophotometer and Flame Photometer (Chapman and Pratt, 1961. Total nitrogen was determined by Kjeldahl method according to the procedure described by FAO, (1980).

Water use efficiency (WUE):

According to Srinivas et al. (1989), water use efficiency was calculated, for fresh yield of pepper fruits for different treatments using the following equation:

WUE = Total yield (Kg) / Total water consumption (m3)

Data analysis:

All data were subjected to statistical analysis using ANOVA test, reported by Snedecor and Cochran, (1989). The means were compared statistically using Duncan`s multiple range test at 5% level of probability in both seasons of experimentation.

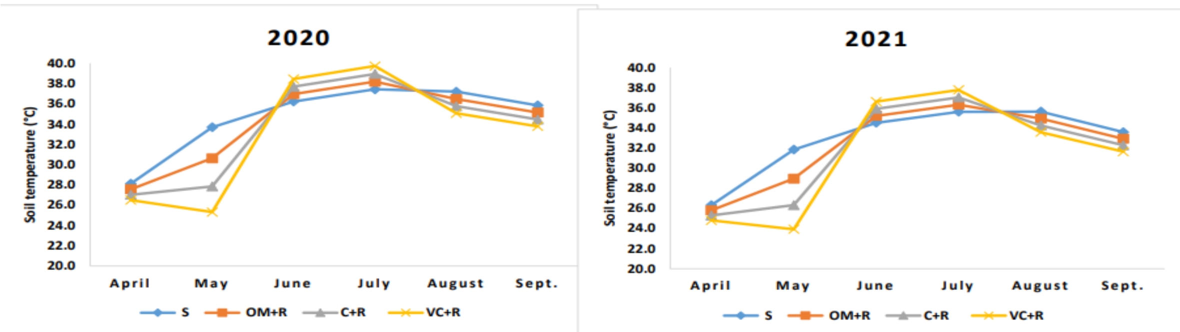
RESULTS AND DISCUSSION

Results

Climatic Data:

Root zone temperature (°C)

Results in Figure 1, presented the effect of different organic fertilizers in root zone, in conventional soil as well as in rice straw. Soil and rice straw cultivated medium temperature were low at beginning of the growing season in April. Then, root zone temperature for clay soil and rice straw increased from May to August and decreased again from September to the end of the growing season. However, at the beginning of the season root zone temperature was higher than rice straw temperature, then increased in rice straw treatments from mid-season compared with the temperature in conventional soil. The application of different organic fertilizers enhanced the values of root zone temperature. Applying organic fertilizer rice straw caused higher rate of root zone temperature than the control. The application of organic manure to rice straw increased temperature followed by compost and then vermicompost in both growing seasons. At the end of the growing seasons the clay soil temperature was higher than rice straw temperature with all other organic fertilizer treatments.

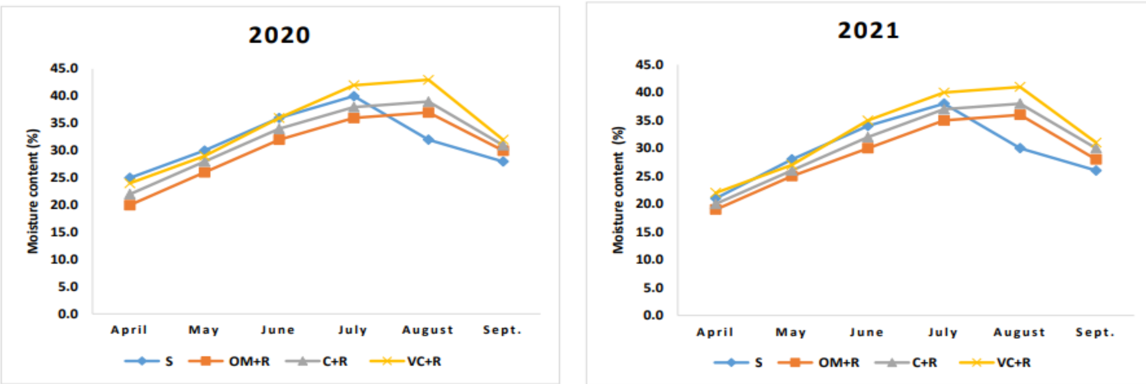


S control- OM+R: organic manure+ rice straw- C+R: compost+ rice straw- VC+R: vermicompost+ rice straw

Figure 1. Effect of organic fertilizers on root zone temperature (°C) during 2020 and 2021 growing seasons.

Moisture content (%)

Figure 2 shows the effect of different organic fertilizers on root zone moisture contents (%) in both growing seasons. At the start of the growth season, the root zone moisture in the clay soil was better than in the rice straw. The root zone moisture content increased with plant growth in all treatments. At the mid of the growing season the moisture content were static, after that were decreased at the end of the season. In addition, the treatments with organic fertilizers increased moisture content in the rice straw medium. Moisture contents of rice straw were enhanced by applying the different organic fertilizers. The average root zone moisture content were 42, 36 and 31 % for Vermicompost, compost and organic manure, respectively, in the two growing seasons.



S: control - OM+R: organic manure+ rice straw- C+R: compost+ rice straw- VC+R: vermicompost+ rice straw

Figure 2. Effect of organic fertilizers on root zone Moisture contents (%) during 2020 and 2021 growing seasons.

Vegetative growth:

Data in Tables 6 &7 presented the effect of irrigation level, organic fertilizers and their interactions on the growth characters of pepper plants. Concerning the effect of irrigation, level 85% of ETo gave the highest values of growth parameters i.e., plant height, stem diameter, no. of branches, no. of leaves, leaf area and plant fresh weight in both growing seasons. While, 100% ETo treatment came in the second rank, whereas, 70% irrigation level presented the worst values in both rice straw and clay soil treatments. Regarding the organic fertilizers, the application of compost with rice straw gave the highest increments followed by cultivation in clay soil (control). The lowest values obtained using vermicompost with rice straw in both growing seasons. The interaction between fertilizers and irrigation, the highest values of growth parameters were obtained by use of 85% of irrigation level with compost in rice straw, followed by 85% irrigation level in clay soil. In the contrary, the application of 70% irrigation level with vermicompost gave the lowest values for growth parameters in both growing seasons.

Nutrients content (%)

The presented results in Table 8 obtained the effect of irrigation levels, organic fertilizers as well as the interaction between them on the nutrient contents (N, P and K) in plant leaves during the growing seasons of 2020 and 2021. The irrigation level of 85% ETo resulted in the highest concentration of N, P and K in plant leaves during both growing seasons. Regarding the effect of organic fertilizer, the compost application in rice straw medium provided the highest values of nitrogen, phosphor and potassium in the leaves, followed by clay soil. Whereas, the lowest nutrient contents in plant leaves obtained using the vermicompost in rice straw medium. Regarding the interaction between irrigation levels and organic fertilizer applications, nutrients content (%) in leaves increased using 85% irrigation level when combined with compost. On the contrary, irrigation level of 70%, when combined with vermicompost in rice straw, gave the lowest concentration of nitrogen, phosphor and potassium in plant leaves, during 2020 and 2021 seasons.

Table 6. Effect of irrigation levels and organic fertilizers on plant height, stem diameter and leaves fresh weight in 2020 and 2021 seasons.

						2020						
	Plant height (cm)				Stem diameter(cm)				Plant fresh weight (g/plant)			
OF / IL	70% ETo	85% ETo	100% ETo	Mean	70% ETo	85% ETo	100% ETo	Mean	70% ETo	85% ETo	100% ETo	Mean
VC+R	68.4j	91.9d	80.8g	80.4D	7.6d	12.4a	10.8b	10.2D	486.0 l	685.9d	585.4h	585.8D
CO+R	77.4h	108.4a	101.8b	95.8A	10.3b	13.6a	13.1a	12.3A	552.2i	752.9a	735.2b	680.1A
OM+R	71.2i	88.7e	83.4f	81.1C	8.9c	11.8b	11.2b	10.6C	503.4k	668.0e	615.5g	595.6C
C	75.3h	97.2c	85.4f	86.0B	10.2b	12.9a	11.4b	11.5B	533.1j	706.9c	642.7f	627.6B
Mean	73.1C	96.5A	87.9B		9.2C	12.6A	11.6C		518.7C	703.4A	644.7B	
						2021						
VC+R	67.5j	91.3d	79.9g	79.5C	7.0d	12.1a	9.8b	9.6C	479.7l	684.7d	583.8k	582.7D
CO+R	76.3h	108.3a	101.1b	95.2A	9.8b	12.8a	12.2a	11.6A	551.7i	752.3a	733.8 b	679.3A
OM+R	70.8i	87.6e	82.2f	80.2C	8.1c	11.0b	10.0b	9.7C	503.4k	666.9e	613.1 f	594.5C
C	74.0h	96.0c	84.3f	84.8B	9.9b	11.6a	10.3b	10.6B	531.6j	704.4c	641.9l	626.0B
Mean	72.1C	95.8A	79.9B		8.7C	11.9A	10.6B		516.6C	702.1A	643.2B	

Irrigation level = IL, Organic fertilizer = OF, Vermicompost + rice straw = VC+R, Compost + Rice straw = CO+R, Organic manure + Rice straw = OM+R and Control (Soil) = C

Table 7. Effect of irrigation levels and organic fertilizers on no. of leaves, leaf area (cm2) and no. of branches in 2020 and 2021 seasons.

OF IL	No. of leaves / plant 70% ETo	85% ETo	100% ETo	Mean	Leaf area (cm^2) 70% ETo	85% ETo	100% ETo	Mean	No. of branches / plant 70% ETo	85% ETo	100% ETo	Mean
2020												
VC+R	232.2j	325.4d	265.8h	274.5C	133.2 l	155.3d	145.2h	144.6D	4.7e	8.7c	6.3d	6.6C
CO+R	253.1i	376.6a	354.1b	327.9A	141.0i	162.3a	159.8b	154.4A	5.7d	11.7a	10.7b	9.3A
OM+R	243.4i	304.4e	274.3g	274.0C	135.1k	152.9e	149.0g	145.7C	5.3d	8.3c	6.7d	6.8C
C	248.3i	347.1c	284.5f	293.3B	138.0j	158.0c	150.9f	148.9B	5.0d	9.7b	7.0c	7.2B
Mean	244.2C	338.4A	294.7B		136.8C	157.1A	151.2B		5.2C	9.6A	7.7B	
2021												
VC	231.1j	324.4d	264.5g	273.3C	131.4k	154.3d	143.8g	143.2D	4.3d	8.0b	6.3c	6.2C
CO	251.3h	375.6a	353.5b	326.8A	139.5h	161.4a	159.0b	153.3A	6.0c	10.7a	9.0b	8.6A
OM	242.2i	303.1e	272.9f	272.7C	134.1j	151.6e	148.0f	144.6C	5.3c	7.7b	6.7bc	6.6C
C	247.6h	345.8c	283.5e	292.3B	137.0i	156.6c	149.9f	147.8B	5.7c	8.3b	7.0b	7.0B
Mean	243.1C	337.2A	293.6B		135.5C	156.0A	150.2B		5.3C	8.7A	7.3B	

Irrigation level = IL, Organic fertilizer = OF, Vermicompost + rice straw = VC+R, Compost + Rice straw = CO+R, Organic manure + Rice straw = OM+R and Control (Soil) = C

Table 8. Effect of irrigation levels and organic fertilizers on leave nutrient content percentages of N, P and k in 2020 and 2021 seasons.

OF IL	N% 70% ETo	85% ETo	100% ETo	Mean	P% 70% ETo	85% ETo	100% ETo	Mean	K% 70% ETo	85% ETo	100% ETo	Mean
2020												
VC+R	2.8b	3.9ab	2.23c	3.0D	0.36i	0.60c	0.459f	0.47D	1.70g	2.79a	2.12d	2.20C
CO+R	3.1b	4.61a	4.35a	4.0A	0.45f	0.71a	0.660b	0.61A	1.98d	3.12a	2.94a	2.68A
OM+R	2.8b	3.7b	3.34b	3.3C	0.39h	0.56d	0.488f	0.48C	1.78f	2.60ab	2.17c	2.18D
C	2.53c	4.1a	3.53b	3.4B	0.43g	0.62c	0.522e	0.52B	1.85e	2.80a	2.38c	2.34B
Mean	2.8C	4.1A	3.4B		0.41C	0.62A	0.53B		1.83C	2.83A	2.40B	
2021												
VC+R	2.6c	3.9b	2.75e	3.1D	0.35j	0.59c	0.45g	0.46D	1.63d	2.74b	2.05b	2.14B
CO+R	3.1d	4.41a	4.26b	3.9A	0.44g	0.71a	0.65b	0.60A	1.92c	3.20a	2.76b	2.63A
OM+R	2.8e	3.6c	3.27c	3.2C	0.39i	0.55d	0.48f	0.48C	1.64d	2.30b	2.02b	1.99C
C	2.51e	4.0b	3.49c	3.3B	0.42h	0.61c	0.51e	0.51B	1.74c	2.45b	2.12b	2.10B
Mean	2.8C	4.0A	3.4B		0.40C	0.62B	0.52A		1.73C	2.67A	2.24B	

Irrigation level = IL, Organic fertilizer = OF, Vermicompost + rice straw = VC+R, Compost + Rice straw = CO+R, Organic manure + Rice straw = OM+R and Control (Soil) = C

Chemical composition

Some chemical parameters for pepper plants were measured and data are showen in Table (9). The dry matter of plants were increased by using irrigation level at 85% ETo in the rice straw medium, followed by using 85% of irrigation level in the clay soil. On the contrary, the dry matter of plant was decreased by using 70% ETo irrigation level in the two seasons. Dry matter also enhanced by using compost fertilizer in rice straw medium compared with other organic fertilizers. The use of vermicompost in the rice straw resulted the lowest amount of dry matter in the two seasons. Thus, using 85% of irrigation level combined with compost in rice straw gave the highest amount of dry matter for pepper plant compared with the other treatments. Chlorophyll reading (SPAD) for plant leaves was enhanced when the 85% irrigation level was applied and decreased by reducing irrigation level up to 70% ETo. Besides, the compost application with rice straw was the best treatment, which resulted in the highest chlorophyll reading. The interaction between 85% irrigation level and compost application was the best treatment for chlorophyll content. Vitamin C, ascorbic acid is a quality parameter in pepper fruits. Data in Table 9 clears that irrigation level 85% ETo enhanced the content of vitamin C in pepper fruits, while 70% irrigation level decreased the content of vitamin C, in both growing seasons. Application of compost in rice straw as well as cultivation in soil gave the highest values of vitamin C, respectively. The lowest values of vitamin C were obtained using vermicompost in rice straw, as well as the lowest irrigation level of 70% ETo in the two seasons.

Table 9. Effect of irrigation levels and organic fertilizers on leaves dry weight (g), chlorophyll SPAD and vitamin C (mg / 100 g F.W) in 2020 and 2021 seasons.

OF IL	Plant dry matter (g / plant) 70% ETo	85% ETo	100% ETo	Mean	Chlorophyll SPAD 70% ETo	85% ETo	100% ETo	Mean	Vitamin C mg / 100g 70% ETo	85% ETo	100% ETo	Mean
2020												
VC+R	55.0i	88.8c	77.4ef	73.7C	58.53f	67.40b	64.27c	63.40D	137.1f	147.1b	142.2d	142.7C
CO+R	65.0g	110.6a	105.2b	93.6A	62.51d	70.50a	70.13a	67.72A	141.1d	152.1a	148.7b	147.3A
OM+R	56.7i	86.4c	77.5e	73.5C	59.10f	67.50b	66.23b	64.28C	139.1e	144.9c	143.8c	142.6C
C	60.5h	108.0a	81.2d	83.3B	60.43e	69.40a	66.70b	65.51B	141.1d	147.5b	144.2c	144.3B
Mean	59.3C	98.4A	85.3B		60.15C	68.70A	66.83B		137.1f	147.1b	142.2d	142.7C
2021												
VC+R	54.1g	88.4d	76.7g	73.1C	58.27e	66.53b	63.67c	62.82D	133.00f	145.77b	141.50d	140.09D
CO+R	63.9h	109.5a	103.2c	92.2A	61.37d	69.97a	69.40a	66.91A	140.43d	150.63a	147.77b	146.28A
OM+R	56.1g	86.1e	76.7g	73.0C	58.67e	67.03b	65.53b	63.74C	137.73e	143.53c	142.93c	141.40C
C	61.7h	105.7b	81.1f	82.8B	59.74e	68.47a	65.87b	64.69B	141.43d	146.60b	143.20c	143.74B
Mean	59.0C	97.4A	84.4B		59.51C	68.00A	66.12B		133.0C	145.8A	143.9B	

Irrigation level = IL, Organic fertilizer = OF, Vermicompost + rice straw = VC+R, Compost + Rice straw = CO+R, Organic manure + Rice straw = OM+R and Control (Soil) = C

Fruit yield

Data in Figure (3) present the effect of irrigation levels, organic fertilizers and their interactions on pepper fruit yields. Generally, irrigation level of 85% ETo increased total yield / m2, whereas, fruit yields decreased when using 70% ETo irrigation level, in both growing seasons. Regarding the effect of organic fertilizers, using compost with rice straw cultivated medium gave the highest yield followed by cultivation in the clay soil (control), whereas, the lowest yield was obtained from using vermicompost in rice straw medium during both growing seasons. The highest yield obtained using 85% ETo, with compost, as an organic fertilizer. On the contrary, yield was decreased when 70% ETo irrigation level was combined with vermicompost in both seasons.

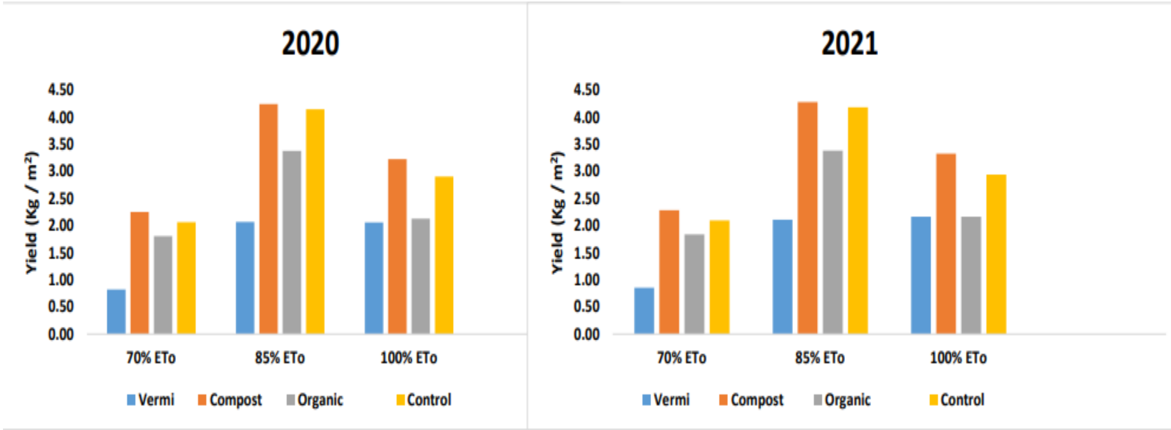


Figure 3. Effect of different irrigation levels and organic fertilizers on total fruit yield (Kg / m^2) in 2020 and 2022 seasons

Water use efficiency (WUE)

Water use efficiency (WUE) affected by different irrigation levels as well as by organic fertilizers, as shown in Figure (4). In the 2020 and 2021 growing seasons, 85% ETo improved WUE for pepper planted in rice straw as well as clay soil. On the contrary, irrigation at 100% ETo level decreased the value of WUE, while irrigation level of 70% ETo presented the worst values of WUE, in the both seasons. Regarding organic fertilizers, compost was the best treatment which gave the highest value of WUE followed by cultivation in clay soil. Whereas, using vermicompost led to decrease WUE in all treatments, during 2020 and 2021 growing seasons. Concerning the interaction between irrigation and organic fertilization, the best value of WUE obtained by using 85% ETo level, when combined with compost application in the rice straw medium. In contrast, using 70% ETo combined with vermicompost application resulted in the lowest WUE values in both seasons.

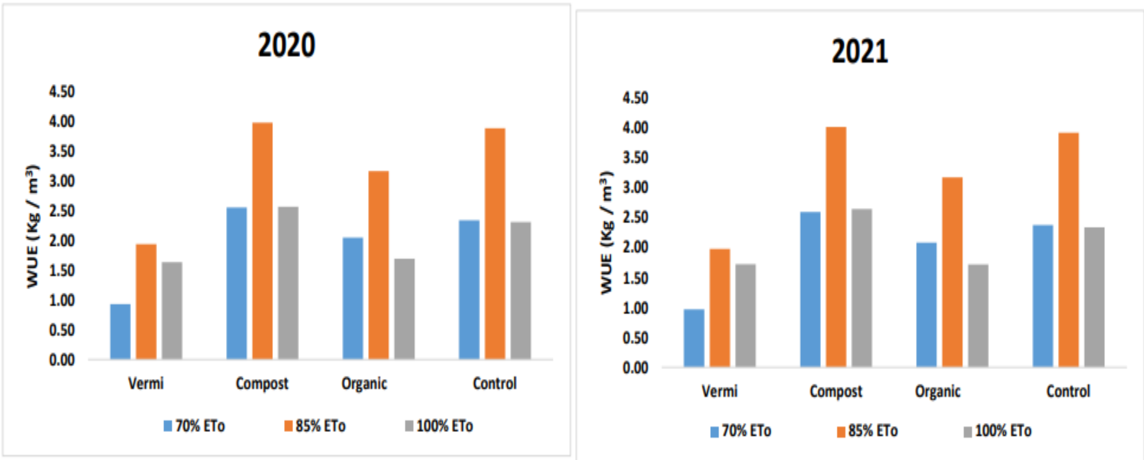


Figure 4. Effect of different irrigation levels and organic fertilizers on water use efficiency (WUE) (Kg / m^3) in 2020 and 2021 seasons

Discussion

Currently, affordable sustainable agriculture methods, using domestic residues of agricultural sector, became a necessary target for the improvement of agricultural crop production. In addition, rationalizing water consumption, for alternative cultivation medium, should reduce both water and nutrients leaching, which may lead to the reduction of the negative impacts of future climate change on the environment. Temperature and soil moisture depend on soil properties, as well as the amount of water applied. In this regard, rice straw as a cultivation medium led to the decrease of soil temperature and soil moisture, compared to clay soil. However, clay soil is rich in microorganism and organic matter, when compared to rice straws. Therefore, the enrichment of rice straw, by some organic fertilizers, in this study, led to the increase in medium temperature and moisture. On the other hand, using adequate amount of water led to enhanced both soil moisture and temperature. These results are matched with those of Abdel – Sattar, (2004 & 2005); Stahl & Ramadan, (2007); Chen, et al., (2019) and Haq, et al., (2021).

The Enhancement of vegetative growth parameters was due to the improvement in soil properties, such as water holding capacity and soil temperature, through the use of both suitable organic fertilizers and suitable irrigation levels, which led to the creation of a suitable conditions surrounding the root zone of pepper plants (Choe et al., 1991; Abdel–Sattar, 2004 & 2005 and Bhanwaria et al., 2022).

Increasing nutrient and chemical components in pepper plants were due to the suitable conditions around the root zone that enhanced absorption and accumulation of these components in plant parts (Ou-Zine et al., 2021; Piñar et al., 2021 and Cano-Ortiz et al., 2021).

Water use efficiency (WUE) is an indicator of irrigation water productivity. It is a ratio between how much water were used in irrigation and the quantity of produced yield. So, the more irrigation water applied, the more WUE values decreased. Thus, the application of adequate amount of irrigation water increases water productivity. On the other hand, the soil conditioner material, such as organic fertilizers, enhanced soil properties and led to increasing WUE in the organic manure, compost and vermicompost treatments medium irrigation level. Opposite results were obtained when using either high or low amount of irrigation water and gave lower value of WUE. These results are in agreement with those of Salama & Mohammedien, (1996).

Crop yield is the net output of crop production and considered to be the final response of plant growth, nutrients content and different biological processes in plant. Thus, the enhancement of different plant growth characteristics reflexing to the increasing of total yield of plant (Adhikari et al., 2016 & Khandekar et al., 2017). Therefore, this study recommended that the yield of pepper fruits were increased when an adequate level of irrigation water (85%) was combined with application of compost in the rice straw medium, due to the enhancement of all previous studied characteristics

CONCLUSION

Sustainability is maximizing the utilization of available natural resources. Sustainable agricultural production may be achieved by reusing and recycling some of agricultural residues as well as reducing the use of synthetic fertilizers. Therefore, using organic fertilizers, instead of chemical fertilizers, reduce harm impacts of emissions on the environment. This study has investigated the effect of using one of the biggest crop residues in Egypt, rice straw, as a cultivation medium, with organic fertilizers i.e., organic manure, compost and vermicompost; to enhance the properties of this medium. On the other hands, irrigation management and rationalization of water use in agriculture became an urgent necessity because of the water scarcity conditions in the world. According to the study, using rice straws with compost as organic fertilizer, combined with the appropriate amount of irrigation water, resulted in the highest pepper yield as well as the highest water use efficiency for pepper production under greenhouse conditions.

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التقنيات الزراعية المستدامة لإنتاج الفلفل تحت ظروف الصوب الزراعية

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الملخص

إجريت تجربة حقلية خلال موسمي2019- 2020 و 2020- 2021 على نباتات الفلفل (*Capsicum annuum L*) في ظروف صوبة زراعية مغطاة. تمت دراسة عاملين ، (أ) الأسمدة العضوية و (ب) مستويات الري. كانت معاملات التسميد: تطبيق نصف الكمية من الأسمدة المعدنية مع أنواع مختلفة من الأسمدة العضوية مثل السماد العضوي الحيوانى والسماد الفيرميكومبست والسماد االكمبوست مع بيئة قش الأرز بالمقارنة بالتربة الطينية. كانت معاملات الري: ثلاثة مستويات للري 70 و 85 و 100٪ على أساس البخرنتح المرجعي (ETo). تم توزيع كلا العاملين (أ و ب) في تصميم قطاعات كامل العشوائية بثلاث مكررات. أشارت النتائج إلى أن درجة حرارة التربة والرطوبة كانت أكثر ملاءمة لنمو النبات في قش الأرز بإضافة الكمبوست تحت مستوى رى 85٪. تم تحسين النمو (طول النبات ، عدد الأوراق ، مساحة الورقة ، عدد الأفرع ، أقطار الساق والوزن الرطب والجاف للنباتات) باستخدام السماد الكمبوست تحت مستوى الري 85٪. تم الحصول على نفس الاتجاه في المحتوى الكيميائي لنباتات الفلفل للكلوروفيل ، N، P، K وفيتامين C في الثمار. زيادة طفيفة في محصول الثمار في معاملة قش الأرز بمستوى ري 85٪ مع السماد العضوي مقارنة بالتربة الطينية (الكنترول). تمت زيادة إنتاجية المياه ، والتي تعتبر كفاءة استخدام المياه (WUE) ، في قش الأرز المروي ، مع السماد الكمبوست ، بنسبة 85 ٪ من ETo. أوضحت الدراسة أن استخدام مخلفات المحاصيل الزراعية ذات التكلفة المعقولة كوسيلة للزراعة بالإضافة إلى الأسمدة العضوية بدلاً من الأسمدة المعدنية ، حقق إنتاجًا مستدامًا أعلى من الفلفل الأخضر.

الكلمات الدالة: الزراعة المستدامة ، الفلفل الأخضر ، قش الأرز ، مستويات الري ، الأسمدة العضوية