horticulturae

MDPI

Article

Organic Amendment and Mulching Enhanced the Growth and Fruit Quality of Squash Plants (*Cucurbita pepo* L.) Grown on Silty Loam Soils

Mohamed Ahmed Youssef [1], Arwa Abdulkreem AL-Huqail [2,*], Esmat F. Ali [3] and Ali Majrashi [3]

[1] Department of Soils and Water Sciences, Faculty of Agriculture, Al-Azhar University, Assiut 71524, Egypt; dr_mayoussef@azhar.edu.eg
[2] Department of Biology, College of Science, Princess Nourah Bint Abdulrahman University, Riyadh 13324-8824, Saudi Arabia
[3] Department of Biology, College of Science, Taif University, P.O. Box 11099, Taif 21944, Saudi Arabia; a.esmat@tu.edu.sa (E.F.A.); aa.majrashi@tu.edu.sa (A.M.)
* Correspondence: aaalhuqail@pnu.edu.sa

Abstract: Adoption of suitable organic fertilizers and soil mulching are useful tools to enhance soil quality, which will inevitably lead to improved growth and yield of crops. Little is known about the soil organic amendments and Azolla (*Azolla pinnata*) under soil organic mulching on the growth and yield of squash plant (*Cucurbita pepo* L.). A comparative study mainly focused on the impacts of organic fertilizer treatments on soil fertility and squash growth under wheat straw mulch was conducted on wooden boxes filled with silty loam soil. Wheat straw, as an organic mulch, and five organic-fertilization treatments were added to the soil. Wheat straw with a size of <2 cm was added to the soil surface with a 2 cm thickness. The fertilization treatments were: control (CO), chemical fertilizer (CF), compost (CT), vermicompost (VC), and dry Azolla (DA). Wheat straw mulch had positive effects on the soil properties, growth, and yield. The maximum fruit yield was obtained from the soil fertilized with DA under wheat straw mulch, while the lowest one was found in the control without mulching. Azolla and organic fertilizers showed a remarkable superiority over the mineral fertilization in increasing the soil fertility as well as the growth and quality of squash fruits; this superiority increased under the wheat straw mulching system. The application of recommended mineral fertilization (CF), compost (CT), vermicompost (VC), and dry Azolla (DA) under wheat straw mulch increased the soil available-N by 2, 20, 12, and 29%, respectively, above the control (CO), while these organic fertilizers without mulching increased the soil available-N by 11, 32, 26, and 48%, respectively. The production of vegetable crops such as squash plants requires the addition of organic fertilizers and mulching to increase yield and quality of fruits.

Keywords: zucchini; dry Azolla; compost; vermicompost; wheat straw; fruit quality

Citation: Youssef, M.A.; AL-Huqail, A.A.; Ali, E.F.; Majrashi, A. Organic Amendment and Mulching Enhanced the Growth and Fruit Quality of Squash Plants (*Cucurbita Pepo* L.) Grown on Silty Loam Soils. *Horticulturae* **2021**, *7*, 269. https://doi.org/10.3390/horticulturae7090269

Academic Editor: Xun Li

Received: 10 July 2021
Accepted: 26 August 2021
Published: 28 August 2021

1. Introduction

Organic waste has been increased in recent years due to the increase in agricultural production and thus the environmental concerns have increased [1,2]. Recycling and converting of organic waste to organic fertilizers is an ideal solution to reduce environmental problems and increase soil fertility [3,4]. Furthermore, the use of organic amendments increases the soil quality and leads to enhancement of plant productivity [5,6]. The use of these organic materials as soil covers improves the physico-chemical properties of the soil and increases the activity of soil microorganisms and enzymes [7,8]. Therefore, it is of great significance to study the effect of organic mulching on soil nutrients and moisture status in arid and semi-arid areas for the sustainable development of regional agriculture. Organic mulching can not only provide a buffer against high and low temperature, but also enhance the water holding capacity of soil by improving the soil bulk density, porosity, and aggregate stability [9]. In arid and semi-arid areas, the soil moisture content of cultivated land is a key factor affecting crop yield [10]. The level of organic mulching application will directly affect the evaporation, infiltration, and runoff of soil water [11]. Nawaz et al. [12] found that soil evaporation decreased with mulching, thus it can increase the soil available water content. Organic mulching is a promising tool in increasing soil and plant productivity, thus, the use of different organic mulching systems should be investigated under different climate conditions. In today's era, intensive use of chemical fertilizer has been found to be obtain a better crop productivity and significantly enhance yield to various kinds of crop and efficient methods compared to organic manures [13,14]. However, the continuous application of chemical fertilizers has a negative impact on human health and several environment threats such as soil erosion, air and water pollution, water logging, and reduction in biodiversity [15–17]. The addition of high rates of chemical fertilizer adversely affects soil properties such as soil fertility, organic matter, biological activity, structure, water retention, salinity, and general soil quality [15–17]. Moreover, high rates of fertilization lead to the high cost of energy and crop production [15–17]. Therefore, organic waste must be recycled to become an alternative, even partially, to mineral fertilization. Different types of organic fertilizers are made from plant residues and animal manures (i.e., farm yard manure, compost, vermicompost, and green manure) [18,19]. Organic amendments have several beneficial effects such as improving the recovery of applied nutrients, water holding capacity, and minimizing ammonia volatilization [20,21]. According to Hu et al. [22] and Ali et al. [23], there are many benefits from the application of compost, vermicompost, and dry Azolla to soil. Besides, they can serve as good nutrient supplements to plants and microorganisms [24]. Therefore, the use of organic fertilization is very important in improving soil quality and supplying plants with nutrients, and improving plant growth without having any undesirable impacts on environmental systems [25].

Azolla is one of the great biological N fixation (30–100 kg N ha^{-1} $crop^{-1}$) and hence has particular value for organic agriculture production systems [16,20,26]. Azolla has been widely used as green amendments or bio-fertilizer, especially as it is a cheap source to supply plants with their N requirements [16,27,28]. Nitrogen is one of the elements necessary for plant growth [29]. Furthermore, the emission of nitrogen gases from agricultural soils is one of the most dangerous factors for the ecosystem [29]. Consequently, sustainable development to increase N use efficiency and reduce gas has become an important issue, especially, under climate changes [30,31]. The tissues of Azolla are an important source of N, as these tissues decompose within 8–10 days and then N releases to the soil solution and becomes available for plant uptake [27]. The addition of Azolla is a promising tool to increase N use efficiency and plant productivity [20,31].

Squash or zucchini plant (*Cucurbita pepo* L.) is one of the most important vegetable crops cultivated in Egypt for local market. Squash plants belong to the Cucurbitaceous family, which is a highly polymorphic vegetable plant and liked for human nutrition worldwide [32]. Squash fruit is rich with some essential nutrients (e.g., manganese, potassium, phosphorus, copper, and magnesium) [33]. Furthermore, it is rich in protein and bioactive compounds such as antioxidants, flavonoids, vitamins, and medicinal prospects [33]. Squash plants are widely cultivated in all soils [34], and can be planted in many temperature conditions (e.g., Mediterranean, tropical, and sub-tropical regions) [35]. Squash production in low fertility soils depends mainly on increasing the soil organic matter, which controls the soil physicochemical properties and nutrient availability [4]. Increasing the soil content of organic matter will lead to obtaining a safe product and savings in the consumption of mineral fertilizers in line with the principles of sustainable development [25].

There is little available information on the effect of compost, vermicompost, and Azolla under wheat straw mulching on squash growth, yield, and fruit quality. Therefore, the current study aims to improve the growth, yield, and fruit quality of squash by organic armaments and wheat straw mulching.

2. Material and Methods

2.1. Experimental Design and Treatments

An experiment was conducted in wooden boxes under open field conditions in Assiut University, Assiut governorate, Egypt. The soil samples were collected from the surface soil layer (0–20 cm) from the Research Farm of Agriculture Faculty, Assiut University, Egypt. The soil samples were air-dried, then sieved using a 2 mm stainless steel sieve, and mixed thoroughly. Physicochemical properties of the studied soil were analyzed as described by Carter and Gregorich [36] and the results are shown in Table 1. The experiment was set up in wooden boxes (0.5 high and 1.5 × 0.70 m diameter) filled with the studied soil. The experiment contained two factors: (1) mulching (with or without) and (2) five fertilization treatments. The studied fertilization treatments were CO (control), CF (chemical fertilizer; full recommended NPK, 112 kg N ha^{-1}, 75 kg P_2O_5 ha^{-1}, and 75 kg K_2O ha^{-1}), CT (compost; 7.5 t ha^{-1}), VC (vermicompost; 7.5 t ha^{-1}), and DA (dry Azolla; 3.75 t ha^{-1}). Organic fertilizers were mixed with the soil before the sowing of squash seeds during soil preparation. The tested treatments were arranged in a random block design with two factors and three replications: two levels for the first factor (with or without muscling) and five levels for the second factor (CO, CF, CT, VC, DA). The total number of the experimental units was 30 boxes. Table 2 shows the main chemical composition of the studied organic fertilizers, which were carried according to the methods described by FAO [37]. Compost was obtained from the National Research Center Cairo, Egypt and consisted of animal manure and maize stover (1:5). Vermicompost, which was used in this study, is a commercial product manufactured by the National Research Center Cairo, Egypt. The vermicompost consisted of animal manure and maize Stover (1:5) and was digested by some worm species (e.g., Red Wiggler worms and Tiger worms). Dry Azolla (*Azolla pinnata*) was produced and then dried on the Laboratory of Soils and Water Department, Faculty of Agriculture, Al-Azhar University, Assiut, Egypt. Squash seeds (*Cucurbita pepo* L.) Hi-Tech cv. Eskandrani were sown in a 0.25 × 0.25 cm space on 14 October. After 15 days of germination, the plants were thinned to 12 plants per box. Wheat straw mulch (0.5–2 cm) was added to the surface of the boxes after 20 days of cultivation with a 2 cm thickness. All boxes were irrigated to 75% of soil field capacity.

Table 1. Basic soil properties.

Property	Unit	Value
Particle size distribution		
Sand	(g kg^{-1})	467 ± 15
Silt	(g kg^{-1})	327 ± 22
Clay	(g kg^{-1})	206 ± 21
Texture		Silty loam
Bulk density	(g cm^{-3})	1.45 ± 0.03
$CaCO_3$	(g kg^{-1})	33 ± 5
EC (1:2.5)	(dS m^{-1})	0.63 ± 0.10
pH (1:2.5)	—	7.91 ± 0.05
Organic matter	(g kg^{-1})	14.4 ± 2.0
Available–N	(mg kg^{-1})	52 ± 3
Available–P	(mg kg^{-1})	23 ± 4
Extractable–K	(mg kg^{-1})	422 ± 18

Each value represents a mean of three replicates. Data are means ± SE. EC: soil salinity as electrical conductivity (EC) unit.

Table 2. Chemical composition of organic amendments used in this study.

Characteristics	Unit	Compost	Vermicompost	Dry Azolla
EC (1:5) extract	(dSm^{-1})	5.47 ± 0.55	4.90 ± 0.45	2.15 ± 0.61
pH (1:5)	———	7.43 ± 0.08	7.60 ± 0.05	6.90 ± 0.08
Organic matter	(g kg^{-1})	332 ± 9	440 ± 27	673 ± 32
Total N	(g kg^{-1})	15.3 ± 1.3	15.6 ± 2.0	30.0 ± 2.5
Total P	(g kg^{-1})	6.3 ± 0.4	11. 7 ± 1.84	16.8 ± 1.9
Total K	(g kg^{-1})	12.7 ± 1.4	8.9 ± 0.69	29.0 ± 1.28
Total Fe	(mg kg^{-1})	220 ± 11	235 ± 12	250 ± 14
Total Mn	(mg kg^{-1})	120 ± 6	130 ± 7	140 ± 7
Total Zn	(mg kg^{-1})	128 ± 5	150 ± 6	125 ± 5
Total Cu	(mg kg^{-1})	36 ± 3	40 ± 2	38 ± 4

Each value represents a mean of three replicates. Data are means ± SE.

2.2. Plant Measurements and Crop Yield

Plant samples were taken after 45 days of sowing and the fresh biomass weight and dry biomass weight (g $plant^{-1}$) were recoded. Chlorophyll (SPAD value) in squash leaves was measured using the SPAD device (SPAD-502-m Konica Minolta, Inc., Tokyo, Japan). The following characters of fruit yield were recorded: fruit length (cm), diameter (cm), number of fruit $plant^{-1}$, and weight of fruit (g $fruit^{-1}$). The plant samples were oven-dried at 70 °C until constant weight to obtain the dry matter content and determined according to official methods of analysis [38]. Total soluble solid (T.S.S) of fruit juice was estimated by digital refractometer as Brix % (Hanna Instruments model HI 96801). The dried plant samples were ground and digested by a 2:1 mixture of H_2SO_4 and $HClO_4$. A total of 20 mL of the digestion mixture was added to 0.5 g of the plant sample with heating (100 °C) until the digestion process was complete. Nitrogen (N) in the extraction of plant samples was determined by using the Kjeldahl distillation method as described by the FAO [37]. Phosphorus (P) in the digested plant samples was measured by the ammonium molybdate method using a JENWAY 6305 UV/Visible Spectrophotometer at 643 nm, as described by Jackson (2005). Potassium (K) in the plant samples was determined by flamephotometer (BWB Model BWB-XP, 5 Channel) as described by Motsara and Roy [39]. Following the final harvest, soil samples (0–20 cm) were collected, air dried, and sieved through a 2 mm sieve, and prepared for chemical analyses. The soil samples were subjected to the following analyses: electrical conductivity (EC; dSm^{-1}), pH, organic matter (OM; g kg^{-1}), and available soil N, P, and K (mg kg^{-1}). The available forms of N, P, and K were extracted and measured by the standard procedures as described by Carter and Gregorich [36]. Nutrient use efficiency (NUE) was calculated according to the following equation: NUE = $(Y_t - Y_0)/N$, where Y_t is the yield of treatment (g); Y_0 is the yield of control; and N is the amount of added nutrients [40].

2.3. Statistical Analysis

The obtained results were checked for normality by Shapiro–Wilk. Moreover, homogeneity of variance was tested. The data were subjected to analysis of variance (two-way ANOVA) as described by Gomez and Gomez [41]. The differences between means were compared by Duncan's multiple range test at $p < 0.05$ levels of probability [42].

3. Results

3.1. Effect of Soil Mulching and Organic Amendments on Some Soil Chemical Properties

In the present study, the application of organic fertilizers and wheat straw mulch significantly affected ($p \leq 0.05$) soil salinity, pH, and organic matter (OM) (Table 3). The highest significant value of soil organic matter was obtained in the soil treated with Azolla and covered with wheat straw. The availability of N, P, and K in the studied soil under wheat straw mulch was significantly higher than the non-mulching treatments. The application of recommended mineral fertilization (CF), compost (CT), vermicompost (VC), and dry Azolla (DA) under wheat straw mulch increased the soil available-N by 2, 20, 12, and 29%, respectively, above the control (CO), while these organic fertilizers without mulching increased the soil available-N by 11, 32, 26, and 48%, respectively, above the control. In general, the concentrations of available soil N in the soil under the mulching treatments were higher than the non-mulching treatments. The behavior of P and K availability in the studied soil was similar to nitrogen in its effect by covering and organic fertilization. The highest significant values of available N, P, and K were recorded in the soil treated with Azolla and covered with wheat straw.

Table 3. Effects of organic amendments and mulching system on soil properties and nutrient availability.

Treatment		pH	EC (dSm^{-1})	O. M ($g\ kg^{-1}$)	Available ($mg\ kg^{-1}$)		
Mulching	Fertilizers				N	P	K
No-mulch	CO	7.81 ± 0.01^{abc}	0.344 ± 0.01^{c}	10.09 ± 0.63^{cd}	49.37 ± 0.31^{h}	20.77 ± 0.97^{d}	413 ± 5.51^{e}
	CF	7.83 ± 0.01^{a}	0.464 ± 0.02^{bc}	9.75 ± 0.97^{d}	54.53 ± 0.33^{g}	27.71 ± 0.57^{bcd}	552 ± 12.74^{cd}
	CT	7.71 ± 0.01^{e}	0.513 ± 0.03^{abc}	15.91 ± 0.37^{a}	65.11 ± 0.14^{d}	23.24 ± 1.18^{cd}	866 ± 20.84^{a}
	VC	7.77 ± 0.01^{dc}	0.410 ± 0.02^{c}	12.77 ± 1.14^{b}	62.41 ± 0.28^{e}	25.54 ± 1.21^{bcd}	530 ± 20.58^{cd}
	DA	7.78 ± 0.00^{abcd}	0.405 ± 0.02^{c}	12.39 ± 0.16^{bc}	72.85 ± 0.44^{b}	31.43 ± 0.90^{bc}	505 ± 9.43^{d}
Wheat straw mulch	CO	7.78 ± 0.01^{bcd}	0.412 ± 0.01^{c}	11.88 ± 0.92^{bcd}	60.24 ± 0.55^{f}	24.66 ± 2.58^{bcd}	430 ± 4.04^{e}
	CF	7.82 ± 0.01^{ab}	0.589 ± 0.11^{ab}	11.65 ± 0.18^{bcd}	61.55 ± 0.70^{ef}	33.14 ± 2.45^{ab}	781 ± 5.05^{b}
	CT	7.70 ± 0.01^{e}	0.648 ± 0.07^{a}	16.32 ± 0.33^{a}	72.35 ± 0.68^{b}	26.79 ± 1.79^{bcd}	572 ± 9.02^{c}
	VC	7.76 ± 0.02^{d}	0.480 ± 0.03^{bc}	14.23 ± 0.51^{ab}	67.44 ± 0.38^{c}	27.83 ± 1.87^{bcd}	775 ± 22.49 b
	DA	7.77 ± 0.00^{dc}	0.429 ± 0.05^{bc}	14.00 ± 0.60^{ab}	77.41 ± 0.33^{a}	40.24 ± 4.44^{a}	913 ± 1.68 a
Source of variance				(p-value)			
Mulching		ns	ns	*	**	**	*
Fertilizers		ns	*	*	**	**	*
Mulching × Fertilizers		*	*	**	**	**	**

CO = Control (without fertilization), CF = Recommended mineral fertilization (112 kg N ha^{-1} + 50 kg P_2O_5 + 75 kg K_2O ha^{-1}), CT = Compost (7.5 t ha^{-1}), VC = Vermicompost (7.5 t ha^{-1}), DA = Dry *Azolla pinnata* (3.75 t ha^{-1}). Different superscript letters in the same column indicate significant differences according to Duncan's multiple range test at $p \leq 0.05$. Data are means of three replicates ± SE. ns = not significant. * $p < 0.05$, ** $p < 0.01$, and ns indicates non-significant differences ($p \geq 0.05$).

3.2. Effect of Soil Mulching and Organic Amendments on the Growth of Squash Plants

Covering the soil with wheat straw mulch caused significant increases in the growth of squash plants (Figures 1 and 2). Squash plants grown under the wheat straw mulch had the highest chlorophyll (SPAD) and dry biomass weight. In most cases, the highest value of chlorophyll (SPAD)was observed with the application of DA and CF with and without wheat straw mulch. On the other hand, the lowest value of chlorophyll (SPAD) was recorded for CO with or without wheat straw mulch (Figure 1). The application of recommended mineral fertilization (CF), compost (CT), vermicompost (VC), and dry Azolla (DA) under the wheat straw mulch increased the dry biomass by 93, 141, 56, and 203%, respectively, above the control, while these organic fertilizers without mulching increased the dry biomass by 121, 151, 31, and 220%, respectively, above the control (Figure 2). The highest significant values of growth and chlorophyll (SPAD) were recorded in the soil treated with dry Azolla and covered with wheat straw.

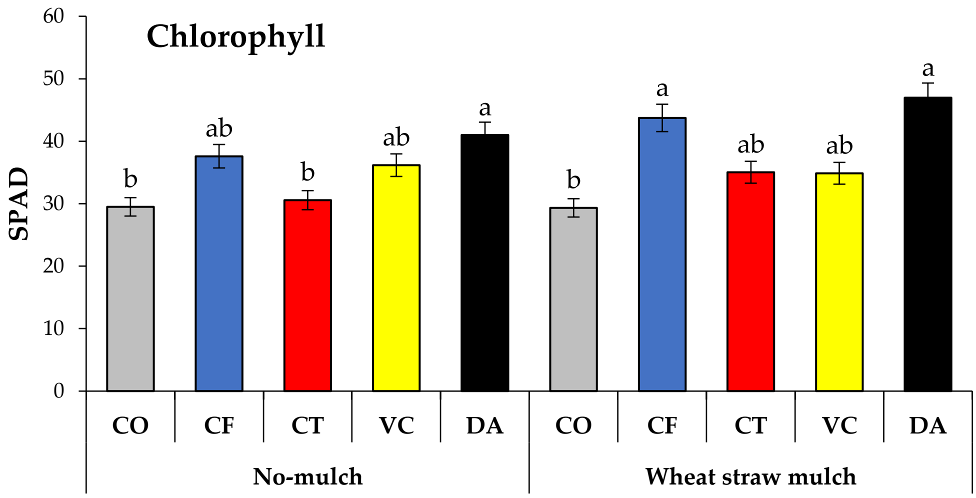

Figure 1. Effect of organic amendments and mulching system on chlorophyll (SPAD) in the leaves of squash plants. CO = Control (without fertilization), CF = Recommended mineral fertilization (112 kg N ha^{-1} + 50 kg P_2O_5 + 75 kg K_2O ha^{-1}), CT = Compost (7.5 t ha^{-1}), VC = Vermicompost (7.5 t ha^{-1}), DA = Dry *Azolla pinnata* (3.75 t ha^{-1}). Different letters indicate significant differences according to Duncan's multiple range test at $p \leq 0.05$. Data are means of three replicates ± SE.

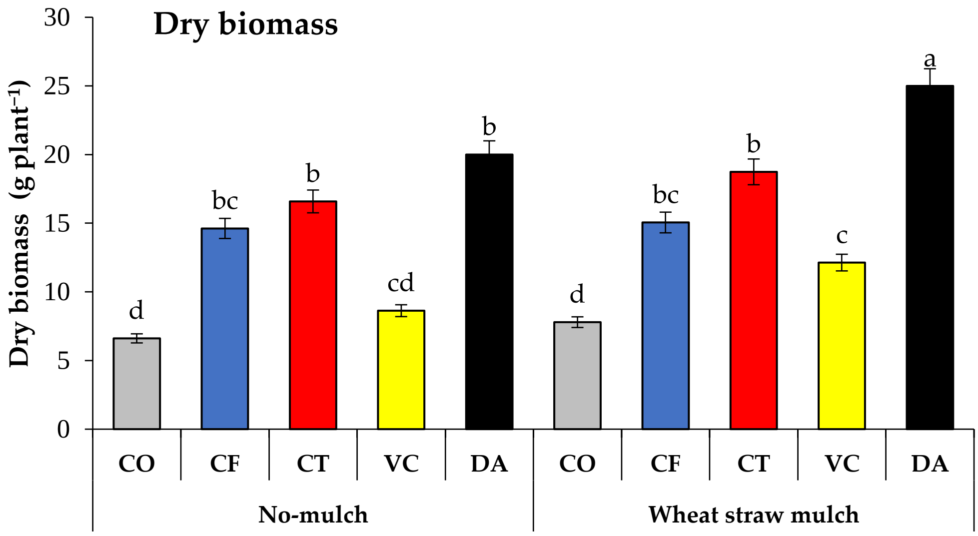

Figure 2. Effect of organic amendments and mulching system on the growth of squash plants. CO = Control (without fertilization), CF = Recommended mineral fertilization (112 kg N ha^{-1} + 50 kg P_2O_5 + 75 kg K_2O ha^{-1}), CT = Compost (7.5 t ha^{-1}), VC = Vermicompost (7.5 t ha^{-1}), DA = Dry *Azolla pinnata* (3.75 t ha^{-1}). Different letters indicate significant differences according to Duncan's multiple range test at $p \leq 0.05$. Data are means of three replicates ± SE.

3.3. Effect of Soil Mulching and Organic Amendments on Nutrient Use Efficiencies

Nutrient use efficiencies significantly affected by the application of the fertilization treatments and wheat straw mulching are shown in Figure 3. The highest significant values of N, P, and K use efficiencies were recorded in the plants amended with DA under wheat straw mulching, while the lowest values were found in the VC under no mulching treatment. Nitrogen, phosphorus, and potassium were used efficiently when dry Azolla was added under wheat straw mulching.

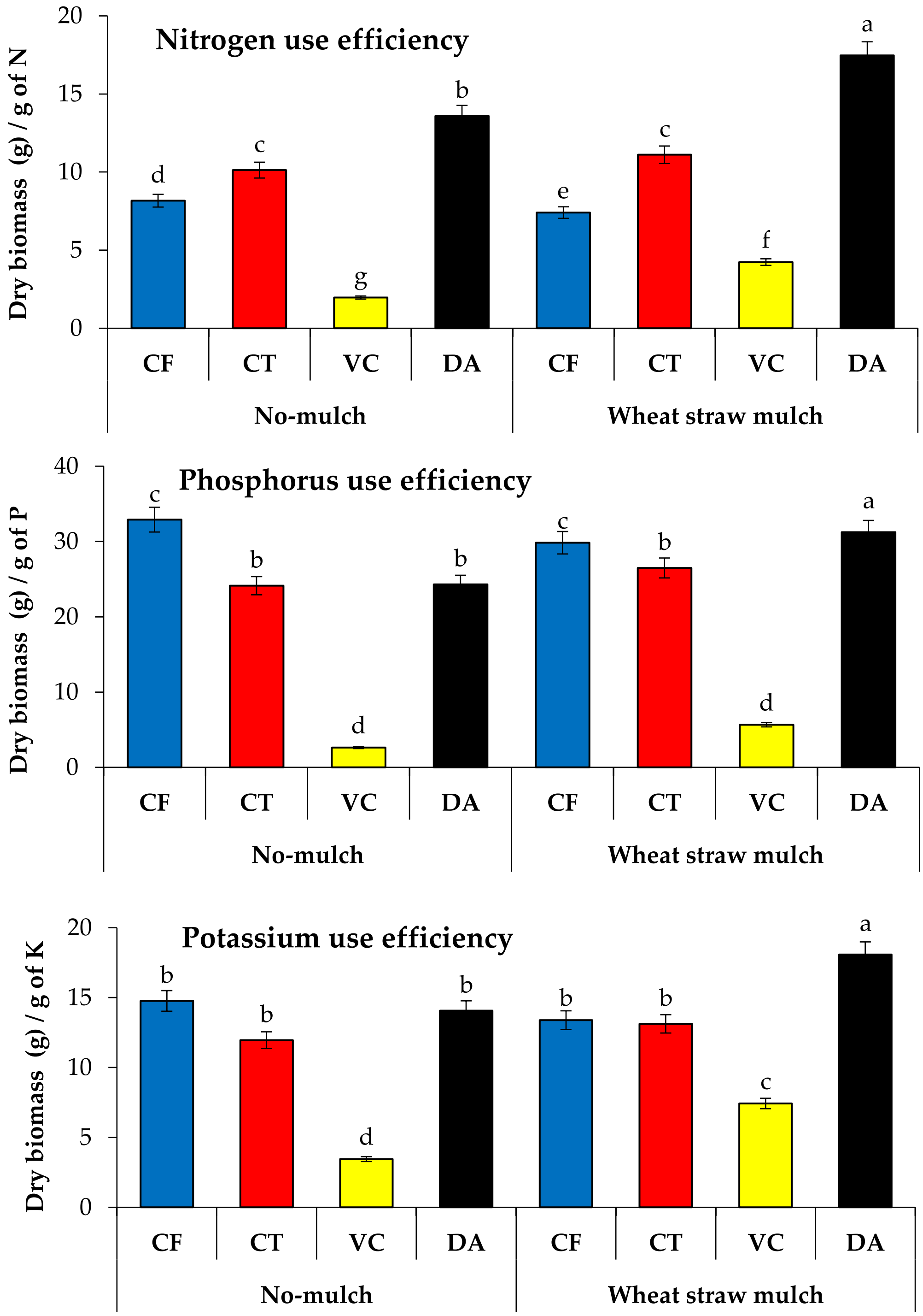

Figure 3. Effect of organic amendments and mulching system on nutrient use efficiency. CO = Control (without fertilization), CF = Recommended mineral fertilization (112 kg N ha^{-1} + 50 kg P_2O_5 + 75 kg K_2O ha^{-1}), CT = Compost (7.5 t ha^{-1}), VC = Vermicompost (7.5 t ha^{-1}), DA = Dry *Azolla pinnata* (3.75 t ha^{-1}). Different letters indicate significant differences according to Duncan's multiple range test at $p \leq 0.05$. Data are means of three replicates ± SE.

3.4. Effect of Soil Mulching and Organic Amendments on Fruit Yield Quality

The fruit length, diameter, number of fruit, and weight of fruit were significantly affected ($p \leq 0.05$) by mulching treatments and organic amendments (Table 4). The wheat straw mulching increased the fruit yield compared to the non-mulching treatments. The application of CF, CT, VC, and DA under mulching treatment increased the fruit length by 23, 14, 11, and 23%, respectively, above the control, while these increases were 26, 13, 9, and 25%, respectively, above the control under the non-mulching treatments. In most cases, the highest significant value of the fruit weight was observed by applying DA under the wheat straw mulch. The maximum fruit number and weight was obtained from the soil covered by wheat straw and treated with dry Azolla.

Table 4. Effects of different organic fertilizers and mulching system on squash yield and its components.

Treatment		Fruit Number (Fruit Plant^{-1})	Fruit Length (cm)	Fruit Diameter (cm)	Fruit Weight (g Fruit^{-1})
Mulching	**Fertilizers**				
No-mulch	CO	6.67 ± 0.27 ^{b}	8.37 ± 0.18 ^{d}	2.57 ± 0.03 ^{d}	35.60 ± 1.60 ^{a}
	CF	7.67 ± 0.27 ^{ab}	10.50 ± 0.54 ^{ab}	2.83 ± 0.03 ^{cd}	35.81 ± 1.45 ^{a}
	CT	8.33 ± 0.26 ^{ab}	9.43 ± 0.72 ^{abcd}	2.70 ± 0.08 ^{cd}	36.72 ± 1.02 ^{a}
	VC	7.33 ± 0.26 ^{ab}	9.10 ± 0.19 ^{bcd}	2.63 ± 0.03 ^{cd}	35.68 ± 1.25 ^{a}
	DA	8.00 ± 0.82 ^{ab}	10.47 ± 0.53 ^{ab}	2.80 ± 0.19 ^{cd}	37.14 ± 2.04 ^{a}
Wheat straw mulch	CO	7.00 ± 0.82 ^{b}	8.87 ± 0.35 ^{cd}	2.77 ± 0.17 ^{cd}	36.69 ± 5.16 ^{a}
	CF	9.00 ± 0.82 ^{ab}	10.93 ± 0.47 ^{a}	3.63 ± 0.07 ^{a}	37.24 ± 3.00 ^{a}
	CT	9.33 ± 1.09 ^{ab}	10.10 ± 0.36 ^{abc}	3.17 ± 0.19 ^{abc}	41.16 ± 5.04 ^{a}
	VC	7.67 ± 0.27 ^{ab}	9.80 ± 0.33 ^{abcd}	3.00 ± 0.17 ^{bcd}	40.01 ± 1.39 ^{a}
	DA	10.33 ± 1.52 ^{a}	10.90 ± 0.46 ^{a}	3.50 ± 0.17 ^{ab}	43.39 ± 4.48 ^{a}
Source of variance		(*p*-value)			
Mulching		*	**	*	*
Fertilizers		*	**	*	**
Mulching × Fertilizers		*	*	**	**

CO = Control (without fertilization), CF = Recommended mineral fertilization (112 kg N ha^{-1} + 50 kg P_2O_5 + 75 kg K_2O ha^{-1}), CT = Compost (7.5 t ha^{-1}), VC = Vermicompost (7.5 t ha^{-1}), DA = Dry *Azolla pinnata* (3.75 t ha^{-1}). Different letters in the same column indicate significant differences according to Duncan's multiple range test at $p \leq 0.05$. Data are means of three replicates ± SE. ns = not significant. * $p < 0.05$, ** $p < 0.01$, and ns indicates non-significant differences ($p \geq 0.05$).

The quality of squash fruit was evaluated and the data are shown in Figure 4. The highest total soluble solid (4.17 Birx) was found in the case of DA without mulching, while the lowest was found in the control with mulching. N content in the fruit reached the highest (29.05 g kg^{-1} DW) value with DA and mulching, while the lowest (11.03 g kg^{-1} DW) was found in the case of the control without mulching. The highest K content in the fruit (20.45 g kg^{-1} DW) was found with CF and mulching, while the lowest (13.56 g kg^{-1} DW) with the control without mulching.

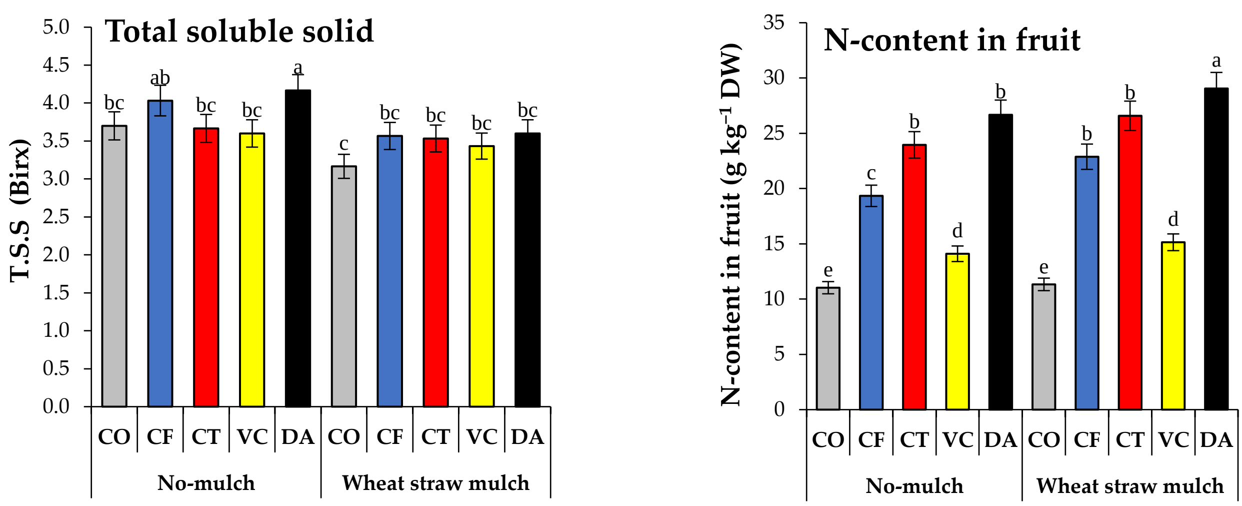

Figure 4. *Cont.*

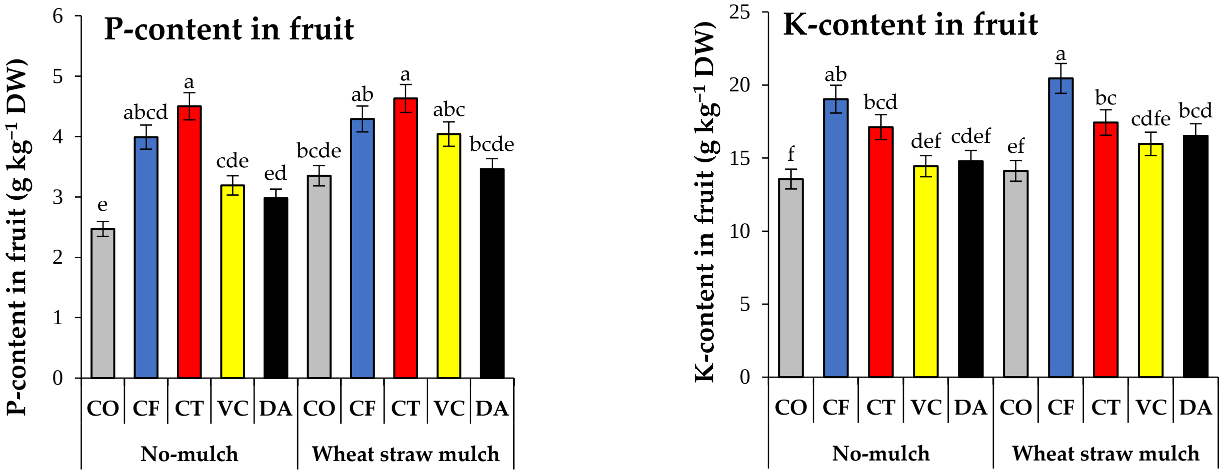

Figure 4. Effect of organic amendments and mulching system on squash fruits. CO = Control (without fertilization), CF = Recommended mineral fertilization (112 kg N ha^{-1} + 50 kg P_2O_5 + 75 kg K_2O ha^{-1}), CT = Compost (7.5 t ha^{-1}), VC = Vermicompost (7.5 t ha^{-1}), DA = Dry *Azolla pinnata* (3.75 t ha^{-1}). Different letters indicate significant differences according to Duncan's multiple range test at $p \leq 0.05$. Data are means of three replicates ± SE.

4. Discussion

Agricultural waste has increased dramatically in recent years due to the increase in agricultural production and thus the burden has increased on environmental scientists to devise innovative methods to recycle the agricultural waste [1,2]. Converting the agricultural waste into organic fertilizers is an ideal solution to reduce environmental problems and at the same time increase the soil fertility [3,4]. In the current study, wheat straw was used to cover the soil to increase the productivity of squash with the use of organic fertilizers instead of the chemical ones. The application of compost, vermicompost, and dry Azolla to the soil increased the growth and yield of squash plants. Moreover, the results of the yield and fruit quality were also controversially close to those obtained from the mineral fertilization. The use of Azolla to fertilize the soil and wheat straw mulch led to obtain the best results in yield, growth, and quality. The studied organic fertilizers were able to significantly increase the availability and uptake of the essential plant nutrients, which led to an increase in photosynthesis and thus increased the growth of squash plants. These results regarding the improvement in soil quality as a result of organic fertilization are consistent with those obtained from the studies of Alharbi et al. [4] and Rekaby et al. [43]. Organic fertilizers increase the organic matter content and nutrient availability in soil [43,44]. Moreover, organic fertilizers play important roles in balancing plant nutrition by improving soil properties such as soil structure, soil organic matter, cation exchange capacity, and soil microbial activity [44–47].

Covering the soil surface has many benefits that lead to a noticeable improvement in soil quality and thus increase plant production [12,46–48]. In this study, wheat straw was used as mulch. The results of the current study showed the superiority of covering the soil with wheat straw and increasing the growth of squash plants growing in the soil covered with wheat straw. It was revealed that the use of mulching improved the soil quality, soil moisture content, and microbial activities [29]. Improving the quality of the soil enables the plant to absorb its nutrient requirements from the soil and provides better growth and development of roots, which ultimately increases the number of roots [1–4,29]. The findings of the current study are in agreement with those of Sun [6,8,46]. Effects of organic mulching include an increase in specific mineral elements in the soil as the organic compounds decompose and improve the nutrient availability and soil quality [8,9,46]. Different mulches with different compositions will affect a growing medium differently [6,7,12,46]. Soil moisture is higher under a mulched area than a non-mulched area and the mulch caused less fluctuation in soil moisture compared to in the non-mulched areas [12,47]. Mulching is an important factor for successful crop yield. It absorbs the heat from the solar radiation, increases the soil temperature, and helps to increase the crop production [7,8]. Additionally, it reduces the cost through reducing the weed infestation in the field and moisture conservation [46]. The use of organic mulches has several benefits including soil moisture retention, reduction of soil temperatures, enhancing plant growth, and nutrient availability [47–52].

The addition of dry Azolla (*Azolla pinnata*) in the current study showed a remarkable superiority over compost and vermicompost in increasing the growth and productivity of squash plants. The dry Azolla added to the soil contained 30, 16.8, and 29 g kg^{-1} of N, P, and K (dry weight basis). Moreover, Azolla contained 673 g kg^{-1} of organic matter (Table 2). Azolla's high content of nutrients and organic matter improved its ability to enhance the soil quality and nutrient availability, and consequently caused significant increases in the growth and quality of squash fruits. These findings are in agreement with those of El Husieny et al. [16]. The addition of Azolla to soil has several advantages such as improving soil physico-chemical properties, improving soil organic matter, enhancing nutrient availability, and reducing the ammonia loss [16,20,26]. The addition of Azolla to soil minimizes the negative effects of soil salinity, reduces the soil pH, increases the nitrogen use efficiency, and promotes plant growth [16,28]. Nitrogen is one of the necessary elements for plant growth, and is one of the elements that plants consume in large quantities [29]. Furthermore, the emission of nitrogen gases from agricultural soils is one of the most dangerous effect for environmental ecosystems [29]. Consequently, research dealing with how to increase the efficiency of nitrogen fertilizers and reduce the emission of gases has become important matters for those working in plant nutrition, especially under climate changes and the increase in demand for food [30]. The current research paper confirmed the ability of Azolla (*Azolla pinnata*) in increasing the availability and uptake of N over the other organic and inorganic fertilization treatments. The tissues of Azolla are important sources of N, as these tissues decompose within 8–10 days and then N releases to the soil solution and becomes available for plant uptake [27]. Dry Azolla addition increased the nutrient use efficiencies of N, P, and K compared to other fertilization treatments. The superiority of Azolla in increasing the efficiency of the use of nutrients was clearly shown under the straw mulching system. Increasing the nutrient use efficiency is the result of increasing the availability of these elements in the soil, which facilitates their absorption by the plant and increases the production of dry matter for plants [53–61].

5. Conclusions

Developing growth of squash (*Cucurbita pepo* L.) plants generally reflected the positive effects of organic fertilization and mulching. The mulching of soil with wheat straw improved the growth and yield, enhanced the soil fertility, and increased the nutritive value of fruit. Moreover, the better plant development of squash was recorded under dry Azolla treatment with wheat straw mulching, followed by seam treatment without wheat straw mulching. It was concluded from this study that organic fertilization under an organic mulching system of soil showed a positive increase in the growth characteristics, fruit yield, and all the soil studied traits compared to the chemical fertilization without mulching.

Author Contributions: Conceptualization M.A.Y.; Methodology, E.F.A.; Software, M.A.Y.; Validation, M.A.Y. and E.F.A.; Data curation, M.A.Y., A.A.A.-H. and E.F.A.; Writing—original draft preparation, M.A.Y. and E.F.A.; Writing—review and editing, M.A.Y., E.F.A. and A.M.; Visualization, A.A.A.-H., M.A.Y. and E.F.A.; Supervision, E.F.A.; Project administration M.A.Y. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Deanship of Scientific Research at Princess Nourah Bint Abdulrahman University, Saudi Arabia through the Fast-track Research Funding Program. The authors are also grateful to Taif University Researchers Supporting Project number (TURSP-2020/110), Taif University, Saudi Arabia for the financial support and research facilities.

Acknowledgments: This research was funded by the Deanship of Scientific Research at Princess Nourah Bint Abdulrahman University, Saudi Arabia through the Fast-track Research Funding Program. The authors are also grateful to Taif University Researchers Supporting Project number (TURSP-2020/110), Taif University, Saudi Arabia for the financial support and research facilities.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Gomah, H.H.; Ahmed, M.M.; Abdalla, R.M.; Farghly, K.A.; Eissa, M.A. Utilization of some organic wastes as growing media for lettuce (*Lactuca sativa* L.) plants. *J. Plant. Nutr.* **2020**, *43*, 2092–2105. [CrossRef]
2. Farghly, K.A.; Gomah, H.H.; Ahmed, M.M.; Abdalla, R.M.; Eissa, M.A. Corn wastes and peanut shell as growing media for production of red radish plants in soilless system. *Commun. Soil Sci. Plant Anal.* **2020**, *51*, 1799–1810. [CrossRef]
3. Kheir, A.M.; Ali, E.F.; Ahmed, M.; Eissa, M.A.; Majrashi, A.; Ali, O.A. Biochar blended humate and vermicompost enhanced immobilization of heavy metals, improved wheat productivity, and minimized human health risks in different contaminated environments. *J. Environ. Chem. Eng.* **2021**, *9*, 105700. [CrossRef]
4. Alharbi, S.; Majrashi, A.; Ghoneim, A.M.; Ali, E.F.; Modahish, A.S.; Hassan, F.A.; Eissa, M.A. A new method to recycle dairy waste for the nutrition of wheat plants. *Agronomy* **2021**, *11*, 840. [CrossRef]
5. Kader, M.A.; Senge, M.; Mojid, M.A.; Ito, K. Recent advances in mulching materials and methods for modifying soil environment. *Soil Till. Res.* **2017**, *168*, 155–166. [CrossRef]
6. Sun, X.; Wang, G.; Ye, Y.; Ma, Q.; Guan, Q.; Jones, D.L. Response of nitrogen fractions in the rhizosphere and bulk soil to organic mulching in an urban forest plantation. *J. For. Res.* **2021**, 1–12. [CrossRef]
7. Dietrich, G.; Recous, S.; Pinheiro, P.L.; Weiler, D.A.; Schu, A.L.; Rambo, M.R.L.; Giacomini, S.J. Gradient of decomposition in sugarcane mulches of various thicknesses. *Soil Till. Res.* **2019**, 66–75. [CrossRef]
8. Sun, X.; Ye, Y.; Ma, Q.; Guan, Q.; Jones, D.L. Variation in enzyme activities involved in carbon and nitrogen cycling in rhizosphere and bulk soil after organic mulching. *Rhizosphere* **2021**, *19*, 100376. [CrossRef]
9. Kader, M.A.; Singha, A.; Begum, M.A.; Jewel, A.; Khan, F.H.; Khan, N.I. Mulching as water-saving technique in dryland agriculture: Review article. *Bull. Natl. Res. Cent.* **2019**, *43*, 147. [CrossRef]
10. Eissa, M.A.; Rekaby, S.A.; Hegab, S.A.; Ragheb, H.M. Effect of deficit irrigation on drip-irrigated wheat grown in semi-arid conditions of Upper Egypt. *J. Plant Nutr.* **2018**, *41*, 1576–1586. [CrossRef]
11. Ranaivoson, L.; Naudin, K.; Ripoche, A.; Affholder, F.; Rabeharisoa, L.; Corbeels, M. Agro-ecological functions of crop residues under conservation agriculture. A review. *Agron. Sustain. Dev.* **2017**, *37*, 26. [CrossRef]
12. Nawaz, A.; Lal, R.; Shrestha, R.K.; Farooq, M. Mulching affects soil properties and greenhouse gas emissions under long-term no-till and plough-till systems in alfisol of Central Ohio. *Land Degrad. Develop.* **2017**, *28*, 673–681. [CrossRef]
13. Subedi, P.; Shrestha, J. Improving soil fertility through Azolla application in low land rice: A review. *Azarian J. Agric.* **2015**, *2*, 35–39.
14. Subhan, A.; Khan, Q.U.; Mansoor, M.; Khan, M.J. Effect of organic and inorganic fertilizer on the water use efficiency and yield attributes of wheat under heavy textured soil. *Sarhad J. Agric.* **2017**, *33*, 582–590. [CrossRef]
15. Abd El-Latif, K.M.; Poraas, M.E.A.; Aboul El-Defan, T.A. Assessment of role of some compost and their residual effects on plants grown in sandy and/or calcareous soil. *J. Soil Sci. Agric. Eng.* **2010**, *1*, 65–76. [CrossRef]
16. El Husieny, A.A.; Ahmed, B.M.; Elbaalawy, A.M. Efficiency of Azolla and biochar application on Rice (*Oryza sativa* L.) productivity in salt-affected soil. Egypt. *J. Soil Sci.* **2020**, *60*, 277–288. [CrossRef]
17. Singh, T.B.; Ali, A.; Prasad, M.; Yadav, A.; Shrivastav, P.; Goyal, D.; Dantu, P.K. *Role of Organic Fertilizers in Improving Soil Fertility*; Naeem, M., Ansari, A., Gill, S., Eds.; Contaminants in Agriculture; Springer: Cham, Switzerland, 2020; pp. 61–77.
18. Srivastava, P.K.; Singh, P.C.; Gupta, M.; Sinha, A.; Vaish, A.; Shukla, A.; Singh, N.; Tewari, S.K. Influence of earthworm culture on fertilization potential and biolog- ical activities of vermicomposts prepared from different plant wastes. *J. Plant Nutr. Soil Sci.* **2011**, *174*, 420–429. [CrossRef]
19. El-Gizawy, E.S.A.; Atwa, A.A.I.; Talha, N.I.; Mostafa, R.A.I. Effect of compost and compost tea application on faba bean crop and some soil biological and chemical properties. *J. Soil Sci. Agric. Eng. Mansoura Univ.* **2013**, *4*, 863–874. [CrossRef]
20. Awodun, M.A. Effect of Azolla (Azolla species) on physiomineral properties of the soil. *World J. Agric. Sci.* **2008**, *4*, 157–160.
21. Wang, X.; Jia, Z.; Liang, L.; Yang, B.; Ding, R.; Nie, J.; Wang, J. Impacts of manure application on soil environment, rainfall use efficiency and crop biomass under dry land farming. *Sci. Rep.* **2016**, *6*, 20994. [CrossRef] [PubMed]
22. Hu, Y.; Sun, Z.; Wang, D.; Sun, Y. Analysis of antagomistic microorganism in vermicompost. *Chin. J. Appl. Environ. Biol.* **2004**, *10*, 99–103.
23. Ali, M.; Hossain, M.; Rahman, M.; Islam, M. Effect of vermicompost on growth, yield, chemical composition and oil content of rapeseed (var. SAU SHARISHA^{-1}). *J. Expt. Biosci.* **2012**, *3*, 91–963.
24. Demir, Z. Effects of vermicompost on soil physicochemical properties and Lettuce (*Lactuca sativa* Var. *Crispa*) yield in greenhouse under different soil water regimes. *Commun. Soil Sci. Plant Anal.* **2019**, *17*, 2151–2168. [CrossRef]
25. Fawzy, Z.F.; El-Bassiony, A.M.; Marzouk, N.M.; Zaki, M.F. Comparison of nitrogen fertilizer sources and rates on growth and productivity of squash plants. *Inter. J. Pharm. Tech. Res.* **2016**, *9*, 51–57.

26. Kassem, A.H.M.; Abd El-Aal, A.M. Minimizing the effect of soil salinity on fennel plant using cyanobacteria and compost. *J. Product. Dev.* **2016**, *21*, 153–178.
27. Yadav, R.K.; Abraham, G.; Singh, Y.V.; Singh, P.K. Advancements in the utilization of Azolla-Anabaena system in relation to sustainable agricultural practices. *Proc. Indian Nan. Sci. Acad.* **2014**, *80*, 301–316. [CrossRef]
28. Asghar, W.; Iftikhar, F.; Latif, A.; Khan, I.A. Azolla bacteria promoting rice growth under saline condition. *Agric. Res. Tech. J.* **2018**, *18*, 556048.
29. Ding, Z.; Zhou, Z.; Lin, X.; Zhao, F.; Wang, B.; Lin, F.; Ge, Y.; Eissa, M.A. Biochar impacts on NH_3-volatilization kinetics and growth of sweet basil (*Ocimum basilicum* L.) under saline conditions. *Ind. Crop. Prod.* **2020**, *157*, 11290–12903. [CrossRef]
30. Fixen, P.; Brentrup, F.; Bruulsema, T.; Garcia, F.; Norton, R.; Zingore, S. Nutrient/fertilizer use efficiency: Measurement, current situation and trends. In *Managing Water and Fertilizer for Sustainable Agricultural Intensification*; IFA, IWMI, IPNI and IPI: Paris, France, 2015; p. 270.
31. Yao, Y.; Zhang, M.; Tian, Y.; Zhao, M.; Zeng, K.; Zhang, B.; Zhao, M.; Yin, B. Azolla biofertilizer for improving low nitrogen use efficiency in an intensive rice cropping system. *Field Crop. Res.* **2018**, *216*, 158–164. [CrossRef]
32. Abd El-All, H.M.; Ali, S.M.; Shahin, S.M. Improvement growth, yield and quality of squash (*Cucurbita pepo* L.) plant under salinity conditions by magnetized water, amino acids and selenium. *J. Appl. Sci. Res.* **2013**, *9*, 937–944.
33. Tamer, C.E.; İncedayi, B.; Parseker, A.S.; Yonak, S.; Copur, O.U. Evaluation of several quality criteria of low calorie pumpkin dessert. *Not. Bot. Horti. Agrobot. Cluj-Napoca* **2010**, *38*, 76–80. [CrossRef]
34. Kumar, G.; Purty, R.S.; Sharma, M.P.S.; Singla-Pareek, L.; Pareek, A. Physiological responses among brassica species under salinity stress show strong correlation with transcript abundance for SOS pathway-related genes. *J. Plant Physiol.* **2009**, *166*, 507–520. [CrossRef] [PubMed]
35. Abd El-Mageeda, T.A.; Semida, W.M.; Abd El-Wahed, M.H. Effect of mulching on plant water status, soil salinity and yield of squash under summer-fall deficit irrigation in salt affected soil. *Agric. Water Manag.* **2016**, *173*, 1–12. [CrossRef]
36. Carter, M.R.; Gregorich, E.G. *Soil Sampling and Methods of Analysis*, 2nd ed.; CRC Press: Boca Raton, FL, USA, 2007; pp. 427–444.
37. FAO. Guide to laboratory establishment for plant nutrient analysis. In *Fertilizer and Plant Nutrition Bulletin*; FAO: Rome, Italy, 2008; Volume 19.
38. A.O.A.C. *Official Methods of Analysis*, 14th ed.; Association of Official Analytical Chemists: Washington, DC, USA, 1984.
39. Motsara, M.; Roy, R.N. *Guide to Laboratory Establishment for Plant Nutrient Analysis*; Food and Agriculture Organization of the United Nations Rome: Rome, Italy, 2009.
40. Eissa, M.A. Efficiency of P fertigation for drip-irrigated potato grown on calcareous sandy soils. *Potato Res.* **2019**, *62*, 97–108. [CrossRef]
41. Gomez, K.A.; Gomez, A.A. *Statistical Procedures for Agricultural Research*, 2nd ed.; John Wiley and Sons: New York, NY, USA, 1984; p. 680.
42. Steel, R.G.D.; Torrie, J.H.; Dicky, D.A. *Principles and Procedures of Statistics, a Biometrical Approach*, 3rd ed.; McGraw Hill, Inc. Book Co.: New York, NY, USA, 1997; pp. 352–358.
43. Rekaby, S.A.; Awad, M.Y.; Hegab, S.A.; Eissa, M.A. Effect of some organic amendments on barley plants under saline condition. *J. Plant Nutr.* **2020**, *43*, 1840–1851. [CrossRef]
44. Eissa, M.A.; Nasralla, N.N.; Gomah, N.H.; Osman, D.M.; El-Derwy, Y.M. Evaluation of natural fertilizer extracted from expired dairy products as a soil amendment. *J. Soil Sci. Plant Nutr.* **2018**, *18*, 694–704. [CrossRef]
45. Eissa, M.A.; Almaroai, Y.A. Phytoremediation capacity of some forage plants grown on a metals-contaminated soil. *Soil Sediment. Contam.* **2019**, *28*, 569–581. [CrossRef]
46. Ali, E.F.; Al-Yasi, H.M.; Kheir, A.M.; Eissa, M.A. Effect of Biochar on CO_2 Sequestration and productivity of pearl millet plants grown in saline sodic soils. *J. Soil Sci. Plant Nutr.* **2021**, *2*, 897–907. [CrossRef]
47. Abeed, A.H.; Eissa, M.A.; Abdel-Wahab, D.A. Effect of exogenously applied jasmonic acid and kinetin on drought tolerance of wheat cultivars based on morpho-physiological evaluation. *J. Soil Sci. Plant Nutr.* **2021**, *21*, 131–144. [CrossRef]
48. Tian, C.; Zhou, X.; Ding, Z.; Liu, Q.; Xie, G.; Peng, J.; Rong, X.; Zhang, Y.; Yang, Y.; Eissa, M.A. Controlled-release N fertilizer to mitigate ammonia volatilization from double-cropping rice. *Nut. Cycl. Agroecosyst.* **2021**, *119*, 123–137. [CrossRef]
49. Meena, R.S.; Gogaoi, N.; Kumar, S. Alarming issues on agricultural crop production and environmental stresses. *J. Clean. Prod.* **2017**, *142*, 3357–3359. [CrossRef]
50. Yousef, A.F.; Youssef, M.A.; Ali, M.M.; Ibrahim, M.M.; Xu, Y.; Mauro, R.P. Improved growth and yield response of Jew's Mallow (*Corchorus olitorius* L.) plants through biofertilization under semi-arid climate conditions in Egypt. *Agronomy* **2020**, *10*, 1801. [CrossRef]
51. De, P.; Chakravarti, A.K.; Chakraborty, P.K.; Chakraborty, A. Study on the efficacy of some bio resources as mulch for soil moisture conservation and yield of rain fed groundnut (*Arachis hypogaea*). *Arch. Agron. Soil Sci.* **2005**, *51*, 247–252. [CrossRef]
52. Teame, G.; Tsegay, A.; Abrha, B. Effect of organic mulching on soil moisture, yield, and yield contributing components of sesame (*Sesamum indicum* L.). *Int. J. Agron.* **2017**, 4767509. [CrossRef]
53. Liu, D.; Ding, Z.; Ali, E.F.; Kheir, A.M.; Eissa, M.A.; Ibrahim, O.H. Biochar and compost enhance soil quality and growth of roselle (*Hibiscus sabdariffa* L.) under saline conditions. *Sci. Rep.* **2021**, *11*, 1–11.
54. Abou-Zaid, E.A.; Eissa, M.A. Thompson seedless grapevines growth and quality as affected by glutamic acid, vitamin b, and algae. *J. Soil Sci. Plant Nutr.* **2019**, *19*, 725–733. [CrossRef]

55. Ali, A.M.; Awad, M.Y.; Hegab, S.A.; Gawad, A.M.A.E.; Eissa, M.A. Effect of potassium solubilizing bacteria (*Bacillus cereus*) on growth and yield of potato. *J. Plant Nutr.* **2021**, *44*, 411–420. [CrossRef]
56. Eissa, M.A. Effect of compost and biochar on heavy metals phytostabilization by the halophytic plant old man saltbush [*Atriplex nummularia* Lindl]. *Soil Sediment Contam. Int. J.* **2019**, *28*, 135–147. [CrossRef]
57. Eissa, M.A.; Abeed, A.H. Growth and biochemical changes in quail bush (*Atriplex lentiformis* (Torr.) S.Wats) under Cd stress. *Environ. Sci. Pollut. Res.* **2019**, *26*, 628–635. [CrossRef]
58. Al-Sayed, H.; Hegab, S.A.; Youssef, M.; Khalafalla, M.; Almaroai, Y.A.; Ding, Z.; Eissa, M.A. Evaluation of quality and growth of roselle (*Hibiscus sabdariffa* L.) as affected by bio-fertilizers. *J. Plant Nutr.* **2020**, *43*, 1025–1035. [CrossRef]
59. Eissa, M.A. Phytoextraction of nickel, lead and cadmium from metal contaminated soils using different field. *World Appl. Sci. J.* **2014**, *32*, 1045–1052. [CrossRef]
60. Eissa, M.A.; Nafady, M.; Ragheb, H.; Attia, K. Effect of soil moisture and forms of phosphorus fertilizers on corn production under sandy calcareous soil. *World Appl. Sci. J.* **2013**, *26*, 540–547. [CrossRef]
61. Eissa, M.A. Performance of river saltbush (*Atriplex amnicola*) grown on contaminated soils as affected by organic fertilization. *World Appl. Sci. J.* **2014**, *30*, 1877–1881.