Integrated Management of K-Additives to Improve the Productivity of Zucchini Plants Grown on a Poor Fertile Sandy Soil

Mona Tolba1,2*, Ihab M. Farid1; Hanan S. Siam2; Mohamed H.H. Abbas1*; Ibrahim Mohamed1; Safaa A. Mahmoud2; Abo El-Kair B. El-Sayed1

1Soils and Water Department, Faculty of Agriculture, Benha University, Egypt,
2Plant Nutrition Department, National Research Centre, Dokki, Giza, Egypt
3Algal Biotechnology Unit, Fertilization Technology Department, National Research Centre, Dokki-Cairo, Egypt

Abstract

Three eco-friendly approaches were investigated for their effects on improving K-uptake by zucchini plants; hence, increasing shoot growth and fruit productivity. These approaches were: (1) amending soil with biochar (0 and 5 g kg$^{-1}$), (2) spraying plants with Amphora extract (0 and 1 g L$^{-1}$) and (3) substituting inorganic-K fertilizers partially with organic ones. In this concern, five levels of compost (0, 1.5, 3, 4.5 and 6 g kg$^{-1}$) were applied to a poor fertile sandy soil (98.5% sand) in complementation with inorganic NPK-fertilizers to bring their concentrations, even in the control treatment, to the recommended levels. This investigation was conducted under the greenhouse conditions during the summer season of 2020. Results obtained herein reveal that application of either of biochar or Amphora extract exhibited positive effects on soil available-K (20 and 6.5% respectively), K-concentrations in fruits and total K-uptake by the aboveground plant parts. Furthermore, these two amendments raised considerably the dry weights of both zucchini shoots and fruits. On the other hand, compost could partially substitute inorganic-K fertilizers when it was applied at a rate not exceeding 3 g kg$^{-1}$, recording significant improvements in all the investigated parameters. Nevertheless, application of high compost doses reduced significantly fruit yield. Generally, there existed a highly significant linear relation between the total K-uptake by plants and fruit dry weights. Accordingly, treatments that improved considerably K-uptake by plants (the combination between foliar application of amphora extract + 5 g kg$^{-1}$ biochar + 0-3 g kg$^{-1}$ compost) recorded the highest improvements in productivity of zucchini plants.

Keywords: Potassium; Zucchini; Amphora extract; Biochar; Compost

1. Introduction

Zucchini (Cucurbita pepo L.) is a highly polymorphic vegetable crop (Kathiravan et al., 2006) that can be grown during the summer seasons (Shah et al., 2008). It is one of the most significant crops of the Cucurbitaceae family (Galal, 2016). The total cultivated area in Egypt was estimated by 24923 hectares in 2016, producing about 471,571.000 Ton (mega-grams) according to Ministry of Agriculture and Land Reclamation (2016). Fruits of this crop are suitable as a low-calorie diet (Verdone et al., 2018) beside their high contents of bioactive components including antioxidants, flavonoids, vitamins and minerals such as K, Mg, P, Ca and Fe (Tamer et al., 2010).

Potassium (K) is one of the major macronutrients needed for crop development (Wang et al., 2019), achieving high yield, quality, and stress tolerance (Zörb et al., 2014). Its content varies significantly in crop tissues (0.4 to 4.3 %) according to the location, year, crop species and fertilizer application (Askegaard et al., 2004). Probably,
differences in root structure such as root density, rooting depth and root hair lengths might account for such variances (Nieves-Cordones et al., 2014). Generally, plants take up K via root hairs (Jungk, 2001) from (1) the water-soluble K in soil which is immediately accessible to plants and microorganisms; yet, this K-forms susceptible to leaching (Rosolem et al., 2018) and (2) the exchangeable K which is electrostatically attached to the surfaces of clay minerals and humic substances as an outer-sphere complex (Barré et al., 2008). It is worthy to mention that up to 98% of soil-K was found unavailable for plant uptake (Meena et al., 2016). Accordingly, farmers depend on commercial inorganic fertilizers to satisfy plant needs for K (Meena et al., 2016; Marzouk et al., 2020 and Elzemrany and Faiyad, 2021); however the efficiency of these fertilizers may increase when applied in combination with organic additives (Qaswar et al., 2020, Emam et al., 2020; Abdou Hussien et al., 2021) such as manure and compost (Sánchez et al., 2015). Moreover, organic additives may effectively substitute inorganic K-fertilizers (Jiang et al., 2019) to sustain soil and crop productivity (Meena et al., 2016). This is because some soil components such as clay content may fix K (Simonsson et al., 2009), especially within the arid zone (Najafi-Ghiri and Abtahi, 2013). On the other hand, K is not assimilated into organic matter (Ho and Tsay, 2010); thus organic applications may considerably enrich soils with available K to satisfy the nutritional needs of plant growth. In particular, compost is an eco-friendly approach to supply plants with K (Basak, 2018; Farid et al., 2018; Mohamed and Rashad, 2020). Also, biochar which is a carbon rich product produced via pyrolysis of organic wastes (Abdelhafez et al., 2014; Bassouny and Abbas, 2019; Abdelhafez et al., 2020 and 2021), can retain soil nutrients and reduce the need for artificial fertilizers (Ippolito et al., 2012; Lehmann and Joseph, 2015 and Rafique et al., 2020). Its application at a rate of 10% may cause major increases in K content in leaves, stem and root (Liu et al., 2015). Accordingly, the usage of organic additives is recommended for zucchini production under low-fertile soil conditions because these additives regulate soil physicochemical characteristics and nutrient availability (Alharbi et al., 2021).

The current study investigates to what extent organic additives (compost and/or biochar) can integrate with commercial inorganic K-fertilizers to increase zucchini productivity grown on a poor fertile sandy soil. In this concern, this soil type has a very limited capability to reserve exchangeable K (Meena et al., 2016); yet it is subjected to leaching from the top soil. Therefore, the colloidal particles amended via organic additives may effectively reserve exchangeable soil-K and consequently increase its availability in soil. Specifically, we anticipate that compost can partially substitute inorganic fertilizers in production of zucchini (hypothesis 1). Moreover, biochar application can raise the efficiency of this combined application under the conditions of light textured soils (hypothesis 2). It is worthy to mention that the algal extracts are rich in various elements (macro and micro) such as N, P, K, Ca, Cu, Fe, Mg, Mn and Zn which can play vital roles in plant physiological processes, inducing photosynthesis, cell divisions and cell elongation (Gollan and Wright, 2006). Diatoms such as Amphora coffeaeformis are thought to be a source of a variety of bioactive chemicals, namely carotenoids, sulfated polysaccharides, polyunsaturated fatty acids, vitamins C and E and β-glucans (El-Sayed et al., 2018). So, we assume that spraying plants with Amphora extract may have direct and indirect impacts on increasing plant capability to absorb and utilize soil-K; thus, increase its productivity (hypothesis 3).

2. Materials and Methods

Surface soil sample (0-30 cm) was collected from the experimental farm at the Research and Production Station EL-Nobaria, BeharaGovernorate, Egypt. This sample was air dried, crushed and sieved to pass through a 2-mm sieve; afterwards, soil was analysed for its physical and chemical characteristics as outlined by Klute (1986) and Sparks et al. (1996), respectively. Soils physical and chemical characteristics are presented in Table 1.

| TABLE 1. Physical and chemical properties of the investigated soil |
|------------------|------------------|------------------|
| Property          | Value            | Property          | Value            |
| Sand, %           | 98.5             | pH*              | 7.7              |
| Silt, %           | 1.0              | EC**, dS m⁻¹      | 0.6              |
| Clay, %           | 0.5              | Available-N, mg kg⁻¹ | 10.3            |
| Textural class    | Sand             | Available P, mg kg⁻¹ | 7.3              |
| Organic matter, g kg⁻¹ | 3.0              | Available-K, mg kg⁻¹ | 188              |

*pH was determined in 1:2.5 (soil:water) suspension, **EC was determined in soil paste extract, available NPK were extracted by K₂SO₄ (1%), NaHCO₃ (0.5N, pH 8.5) and ammonium acetate (1N, pH 7) methods, respectively.

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Seeds of zucchini (Cucurbitapepo cultivar Jamila F1) were brought from HM. CLAUSE SAS Company, France. Amphora (Amphora coffeaeformis) extract was obtained from the Algae Biotechnology Unit, NRC, Cairo, Egypt. This extract contained (per liter) 54.1gN, 13.2gP, 6.3gK, 78.9gFe, 11gMn, 135gZn and 4.6 g Cu. Rice straw was collected from private fields at EL-DakahliaGovernorate, North Egypt. Half of these residues underwent pyrolysis under limited oxygen conditions for 5h using a traditional pyrolysis unit in New Borg El Arab City (SRTA-City, 21934), Alexandria while the other half underwent composting for 145 days until maturity in presence of 15% farmyard manure, 15kg NH₄SO₄ (20.6 g N kg⁻¹), 3 kg CaH₂PO₄ (6.7 g P kg⁻¹) and 15 kg calcium carbonate (CaCO₃) per mega-gram (ton). For preparation of co-composted biochar, extra 10% of biochar was added to the aforementioned additives while composting. Properties of the used organic additives are presented in Table 2.

**TABLE 2. Chemical properties of biochar and compost used in the study**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Compost</th>
<th>Biochar</th>
<th>Co-composted biochar</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH *</td>
<td>6.94</td>
<td>9.53</td>
<td>7.34</td>
</tr>
<tr>
<td>EC*</td>
<td>4.46</td>
<td>6.10</td>
<td>5.11</td>
</tr>
<tr>
<td>Total N (g kg⁻¹)</td>
<td>17.30</td>
<td>9.19</td>
<td>14.00</td>
</tr>
<tr>
<td>Total-P (g kg⁻¹)</td>
<td>9.10</td>
<td>5.20</td>
<td>5.90</td>
</tr>
<tr>
<td>Total-K (g kg⁻¹)</td>
<td>20.30</td>
<td>46.20</td>
<td>21.50</td>
</tr>
<tr>
<td>C/N ratio</td>
<td>11.38</td>
<td>48.30</td>
<td>12.20</td>
</tr>
</tbody>
</table>

*EC and pH were determined in 1:10 extract

2.2. Greenhouse experiment

A pot experiment was carried out under the greenhouse conditions (natural light and ambient temperature) at EL-DakahliaGovernment (31°15'38" N 31° 25' 44" E), North Egypt during the summer season of 2020, comprising three factors with three replicates each: (a) biochar at two different rates i.e., 0 and 5g kg⁻¹; (b) foliar application of Amphora extract at two different rates (0 and 1gL⁻¹); and (c) organic fertilization with compost at five rates of: 0 (K₀), 1.5 (K₁), 3.0(K₂), 4.5 (K₃) and 6.0 g kg⁻¹ (K₄). Supplementary doses of inorganic NPK fertilizers were added to all treatments, even to the control one, to standardize the level of NPK applications among treatments and raise NPK levels in soil to the optimum concentrations (0.27g kg⁻¹ ammonium nitrate (33.5% N), 0.15g kg⁻¹ calcium super phosphate(8.5 % P)and 0.35g kg⁻¹ potassium sulphate (40% K)). Twenty kilograms of air dried soil was uniformly packed in plastic pots (30 cm in diameter × 25 cm in depth) then planted with 6 seeds of zucchini (Cucurbitapepo) on the 15th of May, 2020. At the secondtrue-leaf stage, plants were thinned to two plants per pot and at the physiological maturity stage (80 days after planting), the aboveground plant parts were harvested, washed several times with tap water then distilled water. Plant materials were then oven dried at 70°C for 48 h and their weights were recorded. Soil samples were also collected from the rhizosphere of each treatment to determine their available contents of K.

2.3. Harvesting and measurement of K

Plant portions (equivalent to 0.4g) were acid digested using a mixture of H₂SO₄:HC1O₃ (4:1v/v) according to Cottenie et al. (1982) and the total contents of potassium in these extracts were determined by flame photometer (model Jenway PFP7). Available soil potassium was extracted by ammonium acetate method in 1:5 (soil: ammonium acetate, v/v) according to Hesse (1971) then shacked for 30 min and filtered. Afterwards, available potassium was determined in the filtrate using flame photometer.

2.4. Statistical analysis

Data were statistically analyzed using Costat software of variance and the mean values were compared using Duncan multiple range test at P≤0.05. Figures were plotted using SigmaPlot 10.

3. Results and Discussion

3.1. Soil available potassium

Application of biochar raised significantly the available content of K in the sandy soil by 20% versus the non-amended one. These results are in agreement with the findings of Gao et al. (2017) who recorded significant increases in soil available K owing to application of biochar. Maybe, biochar stimulated the activities of K-dissolving bacteria (Zhang et al., 2020). Likewise, spraying plants with Amphora extract led to significant increases in soil available K by 6.5%. Probably, these extracts induced root growth (Suprja et al., 2020), which in turn increased the root exudates (Neumann, 2007). These exudates took part in increasing the availability of soil-K (Wang et al., 2011 and Zörb et al., 2014). Amending soils with compost (up to 3 g kg⁻¹) raised significantly available potassium in soil, while higher application rates lessened this content in soil. In this concern, the rate K₃ recorded the highest avail- K content (208.5mgkg⁻¹), followed by the rate K₂ (193mgkg⁻¹) while the rate K₀ (155.1 mgkg⁻¹) recorded the least available K value. Compost may increase P availability in soil (Litaor et al., 2017) by enhancing plant roots to secret more exudates (Sun et al., 2020) and also stimulate the activities of in-situ K-dissolving bacteria (Sahoo et al., 2013). Concerning the combination between the foliar application of amphora, biochar and organic vs inorganic fertilizer treatments, K₃ recorded the highest values of available potassium in soil when combined with soil application of biochar and the foliar spray of Amphora extract (Table 3).
3.2. The above-ground biomass of zucchini plants

Dry weights of zucchini shoot and fruits increased significantly owing to the application of biochar (Fig 1). These results agree with the findings of Amin and Eissa (2017) who attributed such increases to the concurrent improvements in nutrient use efficiencies by plants grown on a soil amended with biochar. Also, foliar application of amphora extract increased plant shoot and fruit dry weights by 16.3 and 43.5%, respectively. This extract probably played significant roles in increasing plant height, number of leaves (per plant), leaf area and chlorophyll a&b (Mogazy et al., 2020). Regarding the effect of organic and inorganic fertilizers on leaves and fruit dry weights, it was found that compost applied at a rate of K5 record the highest significant increases (72.6g plant\(^{-1}\) in shoot dry weights while the rate K1 (58g plant\(^{-1}\)) recorded the highest significant increases in fruit dry weights. The significant role of compost treatments on enhancing the growth characteristics of plants such as dragonhead is well known and these results may be attributed to the role of macro- and micro-nutrients provided by compost as well as the improvements in soil conditions, beside of stimulating metabolic processes, encouraging growth and increasing the synthesis and accumulation of more metabolites in plant tissues (Wahby et al., 2006).

![Fig 1. Grand means of shoot and fruit dry weights of zucchini plants grown on a poor fertile light textured soil as affected by biochar application, algal extract foliar application and organic fertilizers (compost), either solely or in combinations. For treatments from K1 to K5: see footnote of Table 3. Similar letters indicate no significant variations among treatments](image-url)
Yet, application of high dose of compost might not be a suitable option to attain high fruit productivity because high doses of compost led to concurrent significant reductions in shoot and fruit yields. In this concern, the application of compost at a rate of 3 g kg\(^{-1}\) seemed to be acceptable to attain the highest increases in plant growth and fruit yield.

Concerning the interactions among the three factors under investigation, it was found that the highest increases in shoot and fruit dry weights were recorded for either of K\(_1\) or K\(_3\) treatments in presence of biochar +Amphora foliar spray, with no significant variations between these two treatments (Fig 2). In soil amended with higher rates of organic additives (6 g kg\(^{-1}\) compost and 5 g kg\(^{-1}\) biochar), shoot and fruit dry weights seemed to be relatively low, especially for plants not sprayed with Amphora extract.

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**Fig 2.** Shoot and fruit dry weights of zucchini grown on a poor fertile light textured soil as affected by biochar application, algal extract and compost, either solely or in different combinations. For treatments from K\(_1\) to K\(_5\); see footnote of Table 3. Similar letters indicate no significant variations among treatments

3.3. Potassium concentrations and uptake in the aboveground plant tissues

Application of either biochar or Amphora extract raised significantly K-content in fruits as well as the total K uptake by the above ground parts; yet K-content in shoots did not vary significantly owing to the these two amendments (Table 3). In this concern, amending soils with biochar or spraying plants with the algal extract...
recorded 16.7 and 36.4% increases, respectively, in total K-uptake by the aboveground plant parts while the corresponding increase was only 5.6% corresponding to K-content in fruits. Probably, K in biochar (Elshony et al., 2019) and algal extract took part in plant nutrition (Mutale-Joan et al., 2020). Relating to the effect of organic (compost) vs inorganic fertilizers on the concentration and uptake of K by plants, K$_4$ and to some extent K$_3$, was the most effective treatment that increased potassium concentration and uptake by plants while K$_3$ seemed to be the least effective one.

**TABLE 4.** K content within shoots and fruits of zucchini plants grown on a light textured soil as affected by biochar application, algal extract and compost, either solely or in different combinations

<table>
<thead>
<tr>
<th>Concentration of K in shoot, g kg$^{-1}$</th>
<th>K$_1$</th>
<th>K$_2$</th>
<th>K$_3$</th>
<th>K$_4$</th>
<th>K$_5$</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>-Biochar</td>
<td>18.7</td>
<td>19.4bc</td>
<td>20.8a-c</td>
<td>23.8ab</td>
<td>21.7a-c</td>
<td>20.9AB</td>
</tr>
<tr>
<td>+Alga</td>
<td>22.6a-c</td>
<td>21.0a-c</td>
<td>22.6a-c</td>
<td>23.6ab</td>
<td>22.3a-c</td>
<td>22.4A</td>
</tr>
<tr>
<td>Mean</td>
<td>20.7A-C</td>
<td>20.2BC</td>
<td>21.6A-C</td>
<td>23.7A</td>
<td>22.0A-C</td>
<td>21.6A</td>
</tr>
<tr>
<td>+Biochar</td>
<td>23.8ab</td>
<td>20.8a-c</td>
<td>22.4a-c</td>
<td>22.7a-c</td>
<td>21.4a-c</td>
<td>22.2A</td>
</tr>
<tr>
<td>+Alga</td>
<td>14.8d</td>
<td>18.4cd</td>
<td>20.0a-c</td>
<td>22.1a-c</td>
<td>24.5a-c</td>
<td>19.9B</td>
</tr>
<tr>
<td>Mean</td>
<td>19.3C</td>
<td>19.6C</td>
<td>21.2A-C</td>
<td>22.4A-C</td>
<td>23.0AB</td>
<td>21.1A</td>
</tr>
<tr>
<td>Grand means</td>
<td>20.0B</td>
<td>19.9B</td>
<td>21.4AB</td>
<td>23.0 A</td>
<td>22.5A</td>
<td></td>
</tr>
</tbody>
</table>

**Main effects of algal inoculation**

<table>
<thead>
<tr>
<th>Concentration of K in fruit, g kg$^{-1}$</th>
<th>K$_1$</th>
<th>K$_2$</th>
<th>K$_3$</th>
<th>K$_4$</th>
<th>K$_5$</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>-Biochar</td>
<td>55.1c-e</td>
<td>54.7c-f</td>
<td>54.1d-f</td>
<td>52.1ef</td>
<td>50.0f</td>
<td>53.2C</td>
</tr>
<tr>
<td>+Alga</td>
<td>56.5a-e</td>
<td>58.6a-d</td>
<td>60.3ab</td>
<td>53.7d-f</td>
<td>55.3b-e</td>
<td>56.9B</td>
</tr>
<tr>
<td>Mean</td>
<td>55.8 BC</td>
<td>56.6 AB</td>
<td>57.2 AB</td>
<td>52.9 C</td>
<td>52.6 C</td>
<td>55.0B</td>
</tr>
<tr>
<td>+Biochar</td>
<td>55.7b-e</td>
<td>58.3a-d</td>
<td>57.4a-d</td>
<td>59.6a-c</td>
<td>53.9d-f</td>
<td>57.0B</td>
</tr>
<tr>
<td>+Alga</td>
<td>59.2a-c</td>
<td>60.2ab</td>
<td>61.1a</td>
<td>59.3a-c</td>
<td>56.7a-e</td>
<td>59.3A</td>
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<tr>
<td>Mean</td>
<td>57.4AB</td>
<td>59.2A</td>
<td>59.3A</td>
<td>59.4A</td>
<td>55.3B C</td>
<td>58.1A</td>
</tr>
<tr>
<td>Grand means</td>
<td>56.6AB</td>
<td>57.9A</td>
<td>58.2A</td>
<td>56.1AB</td>
<td>53.9B</td>
<td></td>
</tr>
</tbody>
</table>

**Main effects of algal inoculation**

<table>
<thead>
<tr>
<th>Uptake of K by the aboveground plant parts, g plant$^{-1}$</th>
<th>K$_1$</th>
<th>K$_2$</th>
<th>K$_3$</th>
<th>K$_4$</th>
<th>K$_5$</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>-Biochar</td>
<td>3.8f</td>
<td>3.4gh</td>
<td>3.8f</td>
<td>2.3jk</td>
<td>2.1 k</td>
<td>3.1D</td>
</tr>
<tr>
<td>+Alga</td>
<td>4.8cd</td>
<td>4.4c-e</td>
<td>5.1 bc</td>
<td>3.8fg</td>
<td>2.5jk</td>
<td>4.1B</td>
</tr>
<tr>
<td>Mean</td>
<td>4.3C</td>
<td>3.9D</td>
<td>4.4BC</td>
<td>3.1E</td>
<td>2.3F</td>
<td>3.6B</td>
</tr>
<tr>
<td>+Biochar</td>
<td>4.2ef</td>
<td>4.1ef</td>
<td>4.3d-f</td>
<td>2.8ij</td>
<td>2.1 k</td>
<td>3.5C</td>
</tr>
<tr>
<td>+Alga</td>
<td>5.5ab</td>
<td>5.4ab</td>
<td>5.9a</td>
<td>4.5c-e</td>
<td>3.2hi</td>
<td>4.9A</td>
</tr>
<tr>
<td>Mean</td>
<td>4.9A</td>
<td>4.8AB</td>
<td>5.1A</td>
<td>3.6D</td>
<td>2.6F</td>
<td>4.2A</td>
</tr>
<tr>
<td>Grand means</td>
<td>4.6AB</td>
<td>4.3B</td>
<td>4.8A</td>
<td>3.3C</td>
<td>2.6D</td>
<td></td>
</tr>
</tbody>
</table>

For treatments from K$_1$ to K$_5$; see footnote of Table 3. Similar letters indicate no significant variations among treatments. **Bold letters are the grand means.**

Based on the aforementioned results, compost can partially substitute inorganic K fertilizers to satisfy K-needs for zucchini, only when it is applied at relatively low rates (≤3 g kg$^{-1}$); consequently, it improves plant growth and productivity. Higher application doses of compost are not guaranteed to attain high crop production. These findings confirmed partially the first hypothesis. On the other hand, the combination between biochar and high doses of compost led to significant reductions in K availability and uptake by plants; subsequently lenessed dry weights of both shoots and fruits. These results, of course, did not support the second hypothesis. It is worth mentioning that spraying plants with *Amphora* extract increased plant capability to absorb and utilize soil-K; thus improved plant growth and productivity. Therefore, we accept

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the third hypothesis. In this concern, algal extract foliar applications is recommended for inducing plant growth under drastic stress conditions (Abdel-Maguid et al., 2004; 2005; Shabaan et al., 2010; Tarraf et al., 2015; Enan et al., 2016; El-Sayed et al., 2018b; Anter and El-Sayed, 2020 and Reda et al., 2020) which may exists in sandy soils subjected to prolong irrigations.

3.4. Correlation coefficients between zucchini fruit and shoot dry weights in relation with K-availability and uptake by plants

All calculated correlation coefficient values amongst the studied traits were significant and positive (Table 5). In this concern, K-uptake was correlated significantly and positively with K-availability in soil \( (R^2=0.634) \). Likewise, K content in both shoots and fruits were correlated significantly and positively with K-uptake by the aboveground plantparts. Moreover, shoot and root dry weights were correlated positively and significantly with K-content in these plant parts. Results obtained herein highlighted the presence of very high correlations between fruit yield and shoot biomass \( (R^2=1)\)

| TABLE 5. Correlation coefficients between zucchini fruit and shoot dry weights in relation with K-availability and uptake by plants |
|---|---|---|---|---|---|---|
| Shoot dry weight | Fruit dry weight | Available-K | K in shoot | K in fruits | Total K uptake |
| Shoot dry weight |  | 0.707** | 0.585** | 0.577** | 0.999** | 0.974** | 0.815** | 0.0907 | -1.8596 | 0.0648 | 0.9762 | 0.949 | 1.9016 | 58.333 |
| Fruit dry weight | 0.707** | 0.585** | 0.577** | 0.999** | 0.974** | 0.815** | 0.0907 | -1.8596 | 0.0648 | 0.9762 | 0.949 | 1.9016 | 58.333 |
| Available-K content in soil | 0.585** | 0.577** | 0.999** | 0.680** | 0.668** | 0.815** | 0.0907 | -1.8596 | 0.0648 | 0.9762 | 0.949 | 1.9016 | 58.333 |
| K in shoot | 0.585** | 0.577** | 0.999** | 0.680** | 0.668** | 0.815** | 0.0907 | -1.8596 | 0.0648 | 0.9762 | 0.949 | 1.9016 | 58.333 |
| K in fruit | 0.668** | 0.680** | 0.668** | 0.620** | 0.3432 | 0.634** | 0.0648 | 0.9762 | 0.3331 |
| Total K-uptake in the aboveground plant part | 0.815** | 0.974** | 0.815** | 0.634** | 0.3432 | 0.762** | 0.0648 | 0.9762 |

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

It seems that the fruit yields of zucchini plants were highly correlated with total K uptake by plants. Therefore, a regression function was conducted between these two parameters (Fig 3A) to estimate the coefficient of determination \( (R^2=0.949) \), which was high enough to indicates the presence of a linear relationship between zucchini fruit yield and the increase in total K-uptake by plants. A linear function was not applicable for the relation between the increases that occurred in total K-uptake by plants and zucchini shoot biomass \( (R^2=0.666, \text{Fig 3B}) \). The regression relations between total zucchini shoot and fruit yields with available potassium content in soil were also not significant \( (R^2=0.334 \text{ and } 0.333, \text{respectively, Figs C and D}) \), and this probably indicates that there were many other soil factors that affect the availability of soil-K, hence limit its uptake by plants, e.g. the release-fixation process of interlayer K. (Barrê et al., 2008).

Fig 3. Regression relations between zucchini shoot and fruit dry weights in relation to total K-uptake by plants (A, B) and K-available content in soil (C, D)
Conclusion

Three eco-friendly approaches were investigated for their impacts on improving K-uptake by zucchini plants and consequently increasing their growth and productivity. These approaches were: (1) amending soil with biochar, (2) spraying plants with *Amphora* extract and (3) substituting partially inorganic K-fertilizers with an organic one (compost). The first two approaches seemed to be appropriate for improving total K-uptake by the aboveground plant parts; hence increasing shoot and fruit dry weights. Furthermore, the combinations between these two approaches were superior to each one when applied solely. On the other hand, compost could partially substitute inorganic K-fertilizers; yet its application at a rate exceeding 3 g kg⁻¹ may considerably lessen available-K content and uptake by plants. This might take place via temporarily bio-immobilization in soils as a result of induction of soil microbial growth and activity through organic additives. In this concern, there existed a highly significant linear relationship between total K-uptake and fruit dry weights. Accordingly the application of high rates of compost to substitute partially inorganic fertilizers might not be the suitable choice to increase zucchini productivity.

Author Contributions: Conceptualization, All authors; methodology, Mona Tolba, Hanan S. Siam, Safaa A. Mohamed and Abo El-Kair B. El-Sayed; formal analysis, all authors; resources and writing—original draft preparation, all authors; writing—review and editing, all authors.

Conflicts of interest

There are no conflicts to declare.

Formatting of funding sources

There is no fund.

Acknowledgments

Deep thanks to Prof. Dr. Hassan H. Abbas, Soils and Water Department, Benha University for his help and valuable advices during the course of this study.

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Egypt. J. Soil Sci.61, No. 3 (2021)