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Effects of Addition of Humic and Fulvic Acids on Soil Properties and Germination Percentage of Cucurbit Plants (Zucchini and Cucumber)

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ABSTRACT

This research was conducted to study the effect of adding humic and fulvic acids to the irrigation water on soil properties and germination percentage of two cucurbit plants: zucchini and cucumber. The study was conducted in an open field in Sokhna District in the governorate of Zarqa (Jordan). The field soil was transported to calcareous sandy soil. In the beginning, the weeds and stones were removed, and the land was smoothed and plowed. Effort was made to control weeds and insects at all stages of plant growth. Then, an irrigation network was installed. The fulvic acid-humic acid (FA-HA) biostimulant mixture was incorporated with the irrigation water, and irrigation was practiced three days per week for four weeks. During this period, every irrigation round lasted for two to three hours. A mixture of humic acid (8.0%) and fulvic acid (8.0%) was added to the irrigation water. Three treatments were considered, corresponding to three acid mixture concentrations: 0.50 $mL.L^{-1}$, 1.00 $mL.L^{-1}$, and 1.50 $mL.L^{-1}$. The acid mixtures were added continuously at all stages of plant growth until plant maturity and harvest. Four replicates of the experiment were made. The plant growth variables of interest were germination percentage, number of leaves, date of fruition, size of fruit, and overall mass of fruits. Meanwhile, the soil parameters of interest were soil pH and soil salinity (electric conductivity (EC)) before and after adding the FA-HA mixture. The study found that the 0.5 $mL.L^{-1}$ acid mixture treatment led to the early growth of the zucchini plant seeds and that fruition took place 12 days after planting. In addition, the results showed an increase in plant germination under the 0.5 $mL.L^{-1}$ acid mixture treatment in light of the increase in the number of male and female plant flowers, with fruiting taking place on time. In conclusion, the relationship between zucchini growth and yield with FA-HA mixture concentration is non-linear. It is also concluded that the optimum acid mixture concentration and application rate are crop-specific. Hence, for each crop, the most appropriate acid mixture concentration should be determined first before the broad-scale application of amendments to the soil to ensure the contribution of this environmentally friendly practice to sustainable agriculture.

INTRODUCTION

Humic substances (e.g., humic acids (HAs) and fulvic acids (FAs)) are ubiquitous compounds that occur naturally in soils and waters. These complex superstructures are derived from the decomposition of dead plant and animal matter, and they are vital to soil health. They are heterogeneous in composition, which is specific to their site of origin, and they consist of weakly bound aggregates of small organic compounds that can sequester minerals and make them available for plants. As such, they may have nutritional value for humans. Extracts of fulvic and humic acids can be produced that can be suitable for such purposes (Murbach et al. 2020). In other respects, the HAs and FAs influence the fates and transport of various compounds in the soil (Makrigianni et al. 2022).

Canellasa et al. (2015) reviewed the use of humic substances as biostimulants in horticulture, with emphasis on (i) their effects on nutrient uptake and plant metabolism, (ii) the relationships between the chemical properties of humified matter and its bioactivity, with specific reference to the promotion of lateral root growth; and (iii) evaluation of the experimental data related to the overall effects of humic substances applied to horticultural crops.

Humic substances (HSs), which are friendly organic ligands, are vicariously introduced because they have positive effects on soil redox condition, plant properties, and metal speciation in soil. They are ubiquitously distributed in nature, and they mainly consist of HA, FA, and humus. The structures and characteristics of HA and FA vary broadly from one location to another, depending on many factors like their origin, environmental conditions, and age (Gao et al. 2022).

Murbach et al. (2020) clarified that "Historically, humic acids (HA; CAS no. 1415-93-6) have been defined as precipitates that form when basic extracts of humic matter are acidified while fulvic acids (FA; CAS no. 479-66-3) are those that remain in solution following this process." They further explained that HAs are soluble at alkaline pH while FAs exhibit pH-independent solubility. The solubility of FAs is imparted by hydrophilicity within the associations of small molecules due to an abundance of acidic functional groups, whereas the associations of molecules in the HAs are hydrophobic, which is a property that results in their stabilization at neutral pH and clumping at acidic pH (Murbach et al. 2020).

Recently, attention has grown to the use of HAs and FAs in agricultural production. For example, Bayat et al. (2021) investigated the comparative effects of HA and FA on growth, antioxidant activity, and nutrient content of the Eurasian plant (yarrow). The experimental treatments corresponded to additions of HA and FA to soil at concentrations of 5, 10, 15, and 20 $kg.ha^{-1}$. The results showed that the application of HA and FA to soil improved the growth of yarrow and the amounts of photosynthetic pigments and antioxidants in it. The results also indicated that the highest shoot dry weight in the field-grown plants was associated with the 15 $kg.ha^{-1}$ addition of HA, while in the greenhouse experiment, the highest shoot dry weight was concomitant to the 20 $kg.ha^{-1}$ FA treatment. These researchers, accordingly, concluded that the application of HA or FA to soil has positive effects on the growth and antioxidant activity of yarrow, especially under field conditions.

Ran et al. (2022) conducted pot experiments to investigate the influence of extracts of FA and HA on methylation and bioaccumulation of mercury (Hg) in paddy soil. They found that the FA and HA extracts largely increased the abundance of Hg-methylating microbes and low molecular weight organic matter (e.g., cysteine) in the paddy soil. Furthermore, the results showed that all the FA treatments increased the mobility and methylation of Hg in the soil and its absorption by plant roots.

Gao et al. (2022) studied the mechanism of heavy metal activation or passivation and the plant response that is triggered by FA and HA addition to soil. They examined the Cd activation effect of FAs and HAs derived from pig, goat, and duck manure composts, straw compost, and commercial materials (i.e., PC, GC, DC, SC, and CM). Moreover, they looked into the roles of these materials in plant growth promotion and Cd uptake. The results pointed out that due to the reduction of soil pH by FA and HA and the multiple functional groups of the various FA-and HA-containing materials that were added to soil, the concentration of available Cd increased by 4.3–4.8% and 3.6–6.3% when FA and HA from the various sources, respectively, were applied to soil for 30 days. Slight inhibitory effects of plant growth and Cd uptake were observed, which led to a reduction of Cd accumulation with DHA, SHA, and CHA treatments. The corresponding soil Cd removal efficiencies of PFA and PHA were 43.5% and 34.6%, respectively, which have abundant O- and N-containing functional groups.

In Jordan, there is a lack of studies on the impacts of the addition of FA and HA to soil on its properties and plant germination and growth parameters of both the cucurbit plants and other plants. This research addresses this knowledge gap. It examines the effects of FA and HA addition to soil on its properties and on the germination and growth of two cucurbit plants: zucchini and cucumber.

MATERIALS AND METHODS

This research was conducted in an open field in Sokhna District in the governorate of Zarqa, Jordan. The field soil was transported to calcareous sandy soil. In the beginning, the weeds and stones were removed from the field. Then, the land was smoothed and plowed. After that, an irrigation network was installed and tested. After that, the two cucurbit plants under study, namely, zucchini and cucumber, were planted in furrows with suitable distances between plants and rows. Rows were separated from one another by a distance of 120 cm. In the meantime, the distances between plants were 40 cm in the case of cucumber and 80 cm in the case of zucchini. Plant irrigation was performed using a drip irrigation system with an FA-HA mixture added to the irrigation water at a concentration of 8.0% each. Drip irrigation was practiced three days per week for four weeks, and each irrigation round lasted from two to three hours. Effort was made to control weeds and insects at all stages of plant growth. For example, insect traps were employed to control the whiteflies.

An aqueous mixture of 8.0% HA and 8.0% FA (Humilic 8-8 (JISA, Jordan)) was added to the irrigation water. The acids were added simultaneously and continuously at all stages of plant growth until plant maturity and harvest. Three treatments were considered, corresponding to the acid mixture concentrations of 0.50 $mL.L^{-1}$, 1.00 $mL.L^{-1}$, and 1.50 $mL.L^{-1}$. Accordingly, the experiment had a completely randomized experimental design with three treatments and four replicates. As such, besides the control block (T_0), the experiment included three treatment blocks: T_1 (acid mixture application at a concentration of 0.50 $mL.L^{-1}$), T_2 (acid mixture application at a concentration of 1.00 $mL.L^{-1}$), and T_3 (acid mixture concentration at a rate of 1.50 $mL.L^{-1}$).

The irrigation water parameters of concern were pH and electric conductivity (EC), while the soil parameters of interest were soil pH and soil salinity in terms of EC. Meanwhile, the plant growth variables of interest were germination percentage, number of leaves, date of fruition, size of fruit, and overall mass of fruits.

The field and laboratory data were compiled and analyzed statistically. Comparisons were held between the control group and the treatment groups, as well as between the treatment groups, in the study variables using One-Way Analysis of Variance (ANOVA). When this test revealed significant differences between the compared groups, pairwise comparisons were made between the groups using Fisher's Least-Significant Difference (LSD) *post hoc* test to identify the similar groups. All statistical tests were performed in XLSTAT (v. 2019.2.2.59614) at the 0.05 level of statistical significance (α).

RESULTS AND DISCUSSION

Effect of Acid Mixture Addition on Irrigation Water

This study examined the effect of the addition of FA and HA to irrigation water on its pH and salinity in terms of electric conductivity (EC). The mean water pH values of the various treatments and four replicates are listed in Table 1. It is seen that the original irrigation water had a pH value of 9.00. The addition of the 1:1 FA-HA mixture increased the water pH. The new pH values associated with the 0.5, 1.0, and 1.50 mL.L acid mixture concentrations were 9.90, 9.50, and 10.70, respectively. It is found that the higher the concentration of the acid mixture, the higher the increase in the pH value of the irrigation water.

One-Way Analysis of Variance (ANOVA) unclosed significant differences in the pH values between the treated water and the blank water. Fisher's LSD *post hoc* test unveiled that the irrigation water treated with FA-HA mixture at the concentration of 1.50 $mL.L^{-1}$ had a significantly higher pH value than the control water and the other two treatments. Meanwhile, the differences in mean pH values between the control water and the water treated with 0.50 $mL.L^{-1}$ and 1.0 $mL.L^{-1}$ acid mixture are statistically insignificant. The 1.50 $mL.L^{-1}$ acid mixture treatment increased the water pH value to significantly higher values than those of the blank and the other treatments (0.5 and 1.0 $mL.L^{-1}$).

The mean electric conductivity (EC) values of the irrigation water before FA-HA mixture addition and under the different treatments are provided in Table 2. The initial or original irrigation water is non-saline (freshwater). It had an EC value of 592.0 $\mu S.cm^{-1}$. The results demonstrate that the 0.50 $mL.L^{-1}$ treatment reduced the EC of the irrigation

Table 1: Effect of addition of fulvic acid-humic acid mixture to irrigation water on its pH.

Plant	Week	pH			
		Acid Concentration			
		Blank	0.5 $mL.L^{-1}$	1.0 $mL.L^{-1}$	1.5 $mL.L^{-1}$
Zucchini	1	9.00^{b}	9.50^{b}	9.90^{ab}	10.70^{a}
	2	9.00^{b}	9.50^{b}	9.90^{ab}	10.70^{a}
	3	9.00^{b}	9.50^{b}	9.90^{ab}	10.70^{a}
	4	9.00^{b}	9.50^{b}	9.90^{ab}	10.70^{a}
	5	9.00^{b}	9.50^{b}	9.90^{ab}	10.70^{a}
Cucumber	1	9.00^{b}	9.50^{b}	9.90^{ab}	10.70^{a}
	2	8.80^{b}	9.50^{b}	9.90^{ab}	10.70^{a}
	3	9.00^{b}	9.50^{b}	9.90^{ab}	10.70^{a}
	4	9.00^{b}	9.50^{b}	9.90^{ab}	10.70^{a}
	5	9.00^{b}	9.50^{b}	9.90^{ab}	10.70^{a}

Table 2: Effect of addition of fulvic acid-humic acid mixture to irrigation water on its electric conductivity.

Plant	Week	Electric Conductivity (EC [µS.cm^{-1}])			
		Acid Concentration			
		Blank	0.5 mL.L^{-1}	1.0 mL.L^{-1}	1.5 mL.L^{-1}
Zucchini	1	592.00 ^{a}	405.00 ^{a}	422.00 ^{a}	448.00 ^{a}
	2	592.00 ^{a}	405.00 ^{a}	422.00 ^{a}	448.00 ^{a}
	3	592.00 ^{a}	405.00 ^{a}	555.33 ^{a}	448.00 ^{a}
	4	592.00 ^{a}	405.67 ^{a}	422.00 ^{a}	431.33 ^{a}
	5	592.00 ^{a}	405.00 ^{a}	422.00 ^{a}	448.00 ^{a}
Cucumber	1	592.00 ^{a}	405.00 ^{b}	422.00 ^{b}	448.00 ^{ab}
	2	592.00 ^{a}	405.00 ^{b}	422.00 ^{b}	448.00 ^{ab}
	3	592.00 ^{a}	405.00 ^{b}	422.00 ^{b}	448.00 ^{ab}
	4	592.67 ^{a}	405.33 ^{b}	422.00 ^{b}	448.00 ^{ab}
	5	592.67 ^{a}	438.33 ^{b}	422.00 ^{b}	448.00 ^{ab}

Table 3: Effect of addition of fulvic acid-humic acid mixture to irrigation water on soil solution pH.

Plant	Week	pH			
		Acid Concentration			
		Control	0.5 mL.L^{-1}	1.0 mL.L^{-1}	1.5 mL.L^{-1}
Zucchini	1	8.50^{a}	8.70^{a}	8.30^{a}	8.50^{a}
	2	8.50^{a}	9.30^{a}	9.20^{a}	9.20^{a}
	3	8.50^{a}	8.80^{a}	9.10^{a}	8.60^{a}
	4	8.50^{a}	8.80^{a}	9.10^{a}	8.60^{a}
	5	8.50^{a}	8.80^{a}	9.00^{a}	8.50^{a}
Cucumber	1	8.40 ^{a}	8.70 ^{a}	8.30 ^{a}	8.70 ^{a}
	2	8.50 ^{a}	9.30 ^{a}	9.20 ^{a}	9.20 ^{a}
	3	8.50 ^{a}	8.80 ^{a}	9.10 ^{a}	8.60 ^{a}
	4	8.50 ^{a}	8.80 ^{a}	9.10 ^{a}	8.60 ^{a}
	5	8.40 ^{a}	8.80 ^{a}	9.00 ^{a}	8.50 ^{a}

water from 592.0 µS.cm^{-1} to 405.0 µS.cm^{-1}. The other two acid mixture treatments also reduced the EC of the irrigation water, however, to somewhat lower extents. Specifically, the 1.0 mL.L^{-1} treatment decreased the mean EC of the irrigation water from 592.0 µS.cm^{-1} to 422.0 µS.cm$^{-1,}$ while the 1.5 mL.L^{-1} treatment reduced it to 448.0 µS.cm^{-1}. So, the highest decrease in salinity of the irrigation water was associated with the lowest acid mixture concentration (0.50 mL.L^{-1} (Table 2)). This indicates that the higher the FA-HA mixture concentration, the lower the reduction in irrigation water EC.

One-way analysis of Variance (ANOVA) brought to notice that the differences in the mean EC values between the treated water and the blank water are statistically significant, while differences between the mean EC values of the treated water are statistically insignificant. In other words, analysis supports that there are no statistically significant differences in the mean EC values between the three irrigation water treatments (405.0-448.0 µS.cm^{-1}). However, the mean EC values of the treated water are significantly lower than the mean EC of the control (original) water. Thereupon, it is concluded that FA-HA mixture treatment of the irrigation water reduces its salinity noticeably.

Effect of Acid Addition on Soil

This study investigated the impact of the addition of FA-HA biostimulant mixture to irrigation water on the pH and EC of the soil solution. The results (Table 3) point out that the control soil had alkaline pH, ranging from 8.40 to 8.50. In general, the addition of the FA-HA mixture to the soil via the irrigation water increased the soil solution pH. However, the changes in soil pH varied with treatment. For example, under the 0.50 mL.L^{-1} acid mixture treatment, the mean soil pH increased slightly in the first week from 8.50 to 8.70, then it jumped to 9.30 in the second week and stabilized later to 8.80 (Table 3). Comparable results were recorded under the 1.5 mL.L^{-1} acid mixture treatment. In the case of the 1.0 $mL.L^{-1}$ acid mixture treatment, however, the mean soil pH dropped slightly in the first week from 8.50 to 8.30. It increased to 9.20 in the second week and almost stabilized at 9.10 afterward. So, the soil solution pH keeps changing during the first three weeks of the acid mixture addition and stabilizes at a higher than the original pH value afterward.

One-way analysis of Variance (ANOVA) revealed that the reported differences in the mean soil solution pH values between the control and the treated soils are statistically insignificant. So are the differences between the three treated soils. Stated otherwise, statistical testing supports that there are no statistically significant differences in the mean pH values between the control soil and the treated soils or between the three soils under the different FA-HA mixture treatments during the study period. Generally, the increases in mean soil solution pH by the effect of the acid mixture treatment were the highest during the second week of the growing season. In view of the study results (Table 3), the researchers conclude that, in general, FA-HA treatment of the soil leads to an increase in soil solution pH, however, insignificantly. In this respect, it should be recalled that the addition of acids, even if weak and at low concentrations, to alkaline soil reduces its pH.

The influence of FA-HA mixture addition to the soil via the irrigation water on the EC of the soil solution was analyzed in the present study. Table 4 presents the weakly mean soil solution EC values during the growing season pooled over replicates. The measurements spotlight that the field soil originally had a mean EC value of 349.0 $\mu S.cm^{-1}$ and that EC generally increased from one week to another in the growing season. The highest increase in the mean EC was 296 $\mu S.cm^{-1}$, an increase from 349 to 745 $\mu S.cm^{-1}$. It was reported in the second week of the growing season (Table 4). After that, the soil solution EC dropped profoundly but remained still higher than the original, or starting, EC (349 $\mu S.cm^{-1}$). In all cases, a slight drop in EC took place in the fifth week of the growing season.

Table 4 shows that the mean weak EC values of the soils planted with Zucchini were about the same as those planted with cucumber. Further, the study results disclose that the FA-HA mixture treatments affected soil solution EC by increasing them in the first growing week and reducing them in the subsequent weeks (Table 4).

Statistically significant differences in soil solution EC were detected. However, the differences varied from growing week to another. As an example, in the first growing week, the treated soils had significantly higher mean EC values (619.0-671.0 $\mu S.cm^{-1}$) than the control soil (349.0 $\mu S.cm^{-1}$), and there were no statistically significant differences in EC values between the soils under the three treatments (Table 4). In the second growing week, the treated soils had significantly lower EC values than the control soil. There were no significant differences in EC values between the soils under the three treatments, both those planted with Zucchini and those planted with cucumber, except in the first week in the case of cucumber, in which the 1.50 $mL.L^{-1}$ acid mixture treatment resulted in an EC value comparable to that of the control soil, which is significantly lower than the mean EC values associated with the other treatments (Table 4).

During the third, fourth, and fifth growing weeks, the treated soils had significantly lower EC values than the control soil. Additionally, the soil treated with 1.50 $mL.L^{-1}$ FA-HA mixture generally had a significantly lower EC value than that treated with 1.0 $mL.L^{-1}$ acid mixture. Also, the soils treated with 0.50 $mL.L^{-1}$ acid mixture had significantly higher EC values than the soils receiving the aforementioned two treatments. These general trends were nearly the same in the soils, irrespective of whether they were planted with

Table 4: Effect of addition of fulvic acid-humic acid mixture to irrigation water on the soil solution electric conductivity.

Plant	Week	Electric Conductivity (EC [$\mu S.cm^{-1}$])			
		Acid Concentration			
		Control	0.5 $mL.L^{-1}$	1.0 $mL.L^{-1}$	1.5 $mL.L^{-1}$
Zucchini	1	349.00 ^{e}	654.00 ^{ab}	671.00 ^{ab}	619.00 ^{ab}
	2	745.00 ^{a}	376.00 ^{e}	335.00 ^{e}	384.00 ^{e}
	3	678.00 ^{ab}	584.00 ^{abc}	422.00 ^{cde}	386.00 ^{e}
	4	687.00 ^{ab}	584.00 ^{abc}	422.00 ^{cde}	386.00 ^{e}
	5	675.00 ^{ab}	580.00 ^{bcd}	420.00 ^{de}	376.00 ^{e}
Cucumber	1	348.00 ^{d}	694.00 ^{ab}	678.00 ^{ab}	269.00 ^{d}
	2	749.00 ^{a}	379.00 ^{d}	338.00 ^{d}	384.00 ^{d}
	3	678.00 ^{ab}	585.00 ^{bc}	428.00 ^{cd}	396.00 ^{d}
	4	659.00 ^{ab}	594.00 ^{ab}	428.00 ^{cd}	398.00 ^{d}
	5	680.00 ^{ab}	575.00 ^{bc}	427.00 ^{cd}	367.00 ^{d}

Zucchini or cucumber. Accordingly, it may be stated that, in general, the highest reduction in the soil EC is concomitant to the 1.50 $mL.L^{-1}$ acid mixture treatment. In other words, the higher the FA-HA mixture, the lower the soil solution EC.

A review of the literature shows that few studies examined the impacts of the application of HA and/or FA to soil on its physico-chemical characteristics. In one of these studies, Khalil et al. (2011) reported that separate applications of FA and HA to soil at the concentrations of 5, 10, 15, and 20 $L.acre^{-1}$, each decreased soil pH and EC and that these acids resulted in almost equal reductions in soil pH and EC that increase with acid concentration. Stated otherwise, the higher the concentration of the acid added to the soil, the relatively higher the drop in soil pH and EC. Though the acids were added separately to the soil, nearly the same changes (reductions) in soil pH and EC were induced by the similar concentrations of the two acids. Gao et al. (2022) also reported that FA and HA addition to soil reduced its pH.

Effect of Acid Addition on Cucurbit Plants

Effects of the addition of FA-HA mixture to irrigation water on cucumber and zucchini germination and growth were investigated. The investigation encompassed the germination percentage, number of leaves, fruit size, and overall fruit mass. The main findings are given and discussed in the following two sub-sections.

Zucchini (*Cucurbita pepo*)

Zucchini had higher mean germination percentages, in general, than cucumber. Table 5 spotlights that the mean germination percentage of Zucchini was 99.67% in the control plot. The addition of the FA-HA mixture at the concentration of 0.50 $mL.L^{-1}$ resulted in 100.0% germination. Meanwhile, the FA-HA mixture concentration of 1.0 $mL.L^{-1}$ did not produce a change in the average germination percentage, which was equivalent to that of the control plants (99.67% (Table 5)). The acid mixture concentration of 1.50 $mL.L^{-1}$ led to 100.0% germination of Zucchini. In addition, the ANOVA uncovers that the differences between the control and the treatments, as well as between the treatments themselves, in the mean germination percentage are not significant statistically (Table 5).

As to the mean number of leaves, the study results (Table 5) demonstrate that they were almost the same, both in the control plot and under the different acid-mixture treatments; they ranged from 9 to 11 leaves. Statistical testing revealed that there are no statistically significant differences in these numbers between the control and treatments or among treatments. So, differences in the average numbers of zucchini leaves between the control and treatments, as well as between the treatments, are statistically insignificant.

Comparison of the findings of this study with those of previous studies indicates similarities and differences. For example, El-Masry et al. (2012) reported that the application of HA to soil significantly increased the vegetative growth of squash (*Cucurbita pepo* L.), including the stem length, the number of leaves per plant, the leaf area, the total leaf area per plant, and the dry weights of stems and leaves. Meantime, the average fruit weight increased only slightly. Omar et al. (2020) obtained some similar results. They found that foliar application of potassium fulvate (6, 9, and 12 $kg.acre^{-1}$) to squash (*Curcurbita pepo* L.) resulted in improved growth and yield. Potassium fulvate application produced profound increases in plant length, leaf fresh weight, leaf dry weight, total leaf area per plant, fruit length, fruit diameter, fruit mass, and total yield. However, the best growth results were produced by the 6.0 $kg.acre^{-1}$ treatment after the first 40 days of planting and by the 9.0 $kg.acre^{-1}$ after 70 days of planting. This suggests that the relationship between squash growth and yield with concentration of potassium fulvate is not linear and that it is time-dependent; higher concentrations of this biostimulant are needed with time within the same growing season. Consequently, the best yield parameters were associated with the 9.0 $kg.acre^{-1}$ treatment.

Table 5: Effect of addition of fulvic acid-humic acid mixture to irrigation water on plant germination and growth.

Plant	Acid Mixture Concentration	Germination Percentage	No. of Leaves	Fruit Shape	Fruit Mass
Zucchini	0	99.67 ^{a}	10.00 ^{a}	0.00 ^{b}	0.00 ^{b}
	0.5	100.00 ^{a}	11.00 ^{a}	4.76 ^{a}	1383.33 ^{a}
	1.0	99.67 ^{a}	10.33 ^{a}	0.00 ^{b}	0.00 ^{b}
	1.50	100.00 ^{a}	9.00 ^{a}	0.00 ^{b}	0.00 ^{b}
Cucumber	0	70.00 ^{c}	4.00 ^{b}	0.00 ^{b}	0.00 ^{b}
	0.5	90.00 ^{a}	7.00 ^{a}	2.00 ^{a}	250.00 ^{a}
	1.0	80.00 ^{b}	5.00 ^{b}	0.00 ^{b}	0.00 ^{b}
	1.50	90.00 ^{a}	4.00 ^{b}	0.00 ^{b}	0.00 ^{b}

Cucumber (*Cucumis sativus*)

Cucumber plants that received FA-HA mixture treatment generally had higher mean germination percentages than the control plants. Table 5 shows that the mean germination percentage of cucumber was 70.0% in the control plot. The FA-HA mixture concentrations of 0.50 $mL.L^{-1}$ and 1.50 $mL.L^{-1}$ did, each increased this percentage to 90.0%. Meanwhile, the FA-HA mixture concentrations of 1.0 $mL.L^{-1}$ increased the average germination percentage to 80.0%. This means that the concentrations of 0.50 $mL.L^{-1}$ and 1.50 $mL.L^{-1}$ have better effects on cucumber germination than the 1.0 $mL.L^{-1}$ concentration. These differences are statistically significant. That is treatment results in significantly higher germination percentages (80.0-90.0%) than the percentages obtained with no FA-HA mixture treatment (70.0%). In addition, the results (Table 5) indicate that the FA-HA mixture treatments have higher positive germination effects on Zucchini (99.67-100.0%) than on cucumber (80.0-90.0%).

Regarding the mean number of leaves of cucumber, the experimental results (Table 5) demonstrate that the mean numbers of leaves were very close in the control plot and under the 1.0 $mL.L^{-1}$ and 1.50 $mL.L^{-1}$ acid mixture concentration treatments. The mean number of leaves under the treatment of 0.50 $mL.L^{-1}$ acid mixture concentration was significantly higher (7) than the mean numbers of leaves of cucumber in the control plot (4) and under the other two treatments (5 and 4).

The foregoing findings were compared with the findings of previous studies. Hamail et al. (2014) found that foliar application of HA (20 $mL.L^{-1}$) to cucumber plants resulted in early fruit setting, reduced number of male flowers, an increased number of female flowers and fruits per plant, and a higher total yield. Foliar application of FA (20 $mL.L^{-1}$) gave comparable results. However, in comparison with HA, it led to earlier fruit setting, a higher reduction in the number of male flowers, higher increases in the numbers of female flowers and fruits per plant, and a higher total yield.

These results have some similarities with the results of previous studies. For example, El-Nemr et al. (2012) found that all growth parameters of cucumber (*Cucumis sativus* L.) increased by foliar application of HA (1.0, 2.0, and 3.0 $g.L^{-1}$) to this plant and that the higher the employed acid concentration, the higher the positive effects. The parameters included plant height, number of stems per plant, number of leaves per plant, fresh weights of leaves, number of fruits per plant, fruit mass, and plant yield. In addition, all treatments resulted in an earlier-than-usual fruit setting. Identical results were reported by Shafeek et al. (2016). However, the HA treatments in Shafeek et al. (2016) work corresponded to the application of acid solutions to the soil at concentrations of 3.0, 6.0, and 9.0 $L.acre^{-1}$. However, responses of all the aforementioned growth and yield parameters to the HA applications were identical in El-Nemr et al. (2012) and Shafeek et al. (2016) work, despite differences in the acid concentrations applied and the application methods.

CONCLUSIONS

Conclusions were drawn from the research results. One of these conclusions is that aqueous solutions of FA-HA mixture can be promising soil amendment and plant growth biostimulant that increases plant growth and yield and reduces plant stress. Another conclusion is that the addition of this acid mixture to water has noticeable effects on its pH and EC, as well as on those of the receiving soil. A conclusion, too, is that the FA-HA mixture treatments have higher positive effects on germination and growth (e.g., number of leaves) of zucchini than on cucumber. This suggests that zucchini responds better to the FA-HA mixture additions than cucumber. In other words, applying this acid mixture treatment to zucchini is more cost-effective than applying it to cucumber, which may need higher concentrations of this acid mixture or different combinations of the two acids to produce similar germination and growth to those of zucchini.

The researchers also conclude that FA-HA mixture application to soil has positive effects on plant growth until a certain concentration (0.50 $mL.L^{-1}$ in the present study), above which deleterious effects on plant growth are observed. This leads to the conclusion that the relationship between zucchini growth and yield with FA-HA mixture concentration is non-linear. The same applies to cucumber. It is also concluded that the optimum acid mixture concentration and application rate are crop-specific. Hence, for each crop, the most appropriate acid mixture concentration should be determined first before the broad-scale application of amendments to the soil to ensure the contribution of this environmentally friendly practice to sustainable agriculture.

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