



Article

Productivity Enhancement of Cucumber (*Cucumis sativus* L.) through Optimized Use of Poultry Manure and Mineral Fertilizers under Greenhouse Cultivation

Basheer Noman Sallam^{1,2,†}, Tao Lu^{1,†}, Hongjun Yu^{1,*}, Qiang Li^{1,†}, Zareen Sarfraz³, Muhammad Shahid Iqbal³ , Shumaila Khan¹, Heng Wang¹, Peng Liu¹ and Weijie Jiang^{1,*}

- ¹ Key Laboratory of Horticultural Crops Genetic Improvement (Ministry of Agriculture), Institute of Vegetables and Flowers, Chinese Academy of Agricultural Sciences, No.12 Zhongguancun, South Street, Haidian District, Beijing 100081, China; bns.alhakimi@gmail.com (B.N.S.); lutao@caas.cn (T.L.); liqiang05@caas.cn (Q.L.); shumaila.khan@kfueit.edu.pk (S.K.); 82101181122@caas.cn (H.W.); 82101179107@caas.cn (P.L.)
- ² Department of Horticulture and Its Technologies, Faculty of Agriculture, Foods and Environment, Sana'a University, Sana'a P.O. Box 1247, Yemen
- ³ Cotton Research Institute, Chinese Academy of Agricultural Sciences, Anyang 455000, China; zskpbg@gmail.com (Z.S.); shahidkoooria@gmail.com (M.S.I.)
- * Correspondence: yuhongjun@caas.cn (H.Y.); jiangweijie@caas.cn (W.J.); Tel.: +86-010-8210-8797 (W.J.)
- † These authors contributed equally to this work.



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Abstract: Cucumber, a widely cultivated vegetable, is mostly grown under greenhouse conditions. In recent years, the overuse of inorganic fertilizers for higher yield attainment adversely has affected human health and the environment. Therefore, a greenhouse experiment was designed to evaluate the effects of different nutrient sources (poultry manure (PM) and mineral fertilizer (MF)) on productivity-enhancing parameters of cucumber via univariate and multivariate analyses. Amounts of PM and MF (NPK15:15:15) were added to coco-peat per cubic meter by weight/volume (w/v) ratios as follows: T₁ (control), 60 kg PM; T₂, 30 kg PM + 3 kg MF; T₃, 30 kg PM + 5 kg MF, and T₄, 30 kg PM + 7 kg MF. The univariate analysis performed on the collected data illustrated the significant enhancement in growth and productivity for the integrated use of PM and MF. Multivariate analyses (correlation, clustering, and Principal Component Analysis) validated the results of univariate analysis by differentiating treatments into two groups. The three treatments obtained a distinguished group from T₁ (Control) and did not show significant differences among each other, with a maximum yield increase by T₂ (74.6%). According to these results, T₂ could improve cucumber productivity under greenhouse conditions. It can be taken as recommendations for better quality and yield enhancement in future improvement programs and cucumber-related farming communities.

Keywords: protected greenhouse; soilless culture; poultry manure; yield enhancement; cucumber; univariate analysis; multivariate analysis

1. Introduction

Cucumber (*Cucumis sativa* L.), a member of the family Cucurbitaceae, is regarded as an essential vegetable for fresh consumption crops worldwide and is a rich source of vitamins, minerals, and antioxidants [1,2]. Cucumber is a low-calorie food, consisting of 90% water, which is why it provides superior hydration. Its eminent texture and flavor are the main reasons for its use in salads in fresh form and pickles in the processed form [3]. Its medicinal value is another distinguished property, which includes its antioxidant ability, ability to lower glycemic and antimicrobial activity, etc. Its intake regularly helps to boost metabolism and improve immunity [3]. Due to its high yields and economic value, cucumber is extensively cultivated in greenhouses in China throughout the year. Its global production in 2019 was 87,805,086 tons on 2,231,402 hectares of cultivated area. It is ranked

10th among the most important vegetable crops worldwide. China shared 70,338,971 tons (80.11%) in global production in 2019 from 1,258,370 ha (56.39%) of cultivation area [4].

To cover rising demands, it is essential to produce a sufficient quantity of excellent-quality cucumber. Several cropping obstacles prevent productivity enhancement at the desired pace, and these are responsible for restricting the healthy development of industry [5]. Finding the possibilities and increasing the pool of knowledge regarding continuous cropping obstacles are among the possibilities to develop practical approaches to overcome the issues present in long-term intensive cucumber production [6]. Cucumber is assumed to perform better with enhanced productivity under early-season crop growing and during the summer [7,8]. The optimum growth occurs between 20 °C and 25 °C and with growth reduction below 16 °C or above 30 °C. Recently, cucumber cultivation in soilless mediums under controlled greenhouse conditions has become more developed and trendier around the globe than in the past [7–10]. Fertilization plays a vital role in improving soil fertility and crop yield [11,12]. Cucumber requires many nutrients for proper growth and yield.

Nitrogen, phosphorous, and potassium (NPK) are the essential nutrients for plant growth when used in optimum amounts of 15:15:15, respectively [13]. However, the improper use of fertilizers is causing severe soil degradation and limited crop productivity. Poor management of fertilizers leads to the accumulation of salt in soil aquifers. Fertilizer management should be applied in an integrated manner according to soil type, climatic factors, and crop requirements [14,15]. The integrated utilization of mineral and organic fertilizers can enhance soil fertility. Previous studies have reported that the integration of mineral and organic fertilizers enhances plant growth, yield, and quality. It has been reported that both organic and mineral fertilizers, when used together, led to higher nutrient uptake and increased fruit production [16–18]. It is also reported that optimum poultry manure significantly influenced the growth, yield, and nutritional quality of lettuce [19].

Due to the higher cost of inputs, commercial vegetable production has become an expensive business. One prominent cause is the availability of arable land that is declining due to extensive urbanization. Furthermore, accelerated poverty and unemployment are faced mainly in all metropolitan cities across emerging nations, which can be prevented by opting for soilless culture to grow fresh vegetables in the adjoined outskirts. Soilless cultivation is defined as the technique of growing various crops in the absence of soil used as rooting media [20,21]. Numerous nations have extensively adopted it during the last five decades to sustain their crop production efficiently [22,23]. Several research reports have been published regarding cucumber cultivation in soilless media under greenhouse conditions [24–30]. The current climate change situation has accelerated interest in and choice of this approach, mainly due to environmental pollution, water shortage, abrupt changes in the surrounding environment, etc. Recently, China has widely adopted this technique as the eco-organic soilless culture at the commercial level, enabling organic manures as the substrate for plant production [31,32].

This economic technique has been recommended for developing countries due to its cost-effectiveness compared to mineral solution systems [21,33]. Usage of organic materials, such as crop residues, sewage sludge, compost, and poultry manure, is well recognized as beneficial in soil resumption [18,34–36]. Keeping in view the health benefits and nutritional significance, organically produced vegetables are in high demand these days. However, there is a lack of information regarding suitable proportions of mineral and organic fertilizers required for vegetable production: excessive nitrogen fertilizers in agriculture lead to the accumulation of nitrates in plants and groundwater [15,16,37–41], thus reducing chemical fertilizers required.

The assessment and description of trait variation are essential in selecting and devising best practices to achieve productivity and quality enhancement. Furthermore, studies on variation under safeguard and decision-making are valuable in performing efficient conservation phases and avoiding redundant practices that increase production [42]. Therefore, developing procedures for both characterizing variability and reducing data size to manageable and accessible levels is essential in such studies. It is critical for agronomic

characterization to be carried out using appropriate statistical methods. The widely used techniques include various univariate and multivariate methods such as ANOVA, mean comparison, regression, PCA, and AHC [43–45].

The main objective of the research was to assess and describe the impact of different ratios of PM and MF on the growth and productivity enhancement of cucumber crops by using univariate and multivariate analyses. The investigated fertilizer ratios or amounts can be recommended for better crop quality and yield attainment in future productivity enrichment programs and cucumber-related farming communities.

2. Materials and Methods

The experiment was conducted in a protected greenhouse at the Institute of Vegetables and Flowers (IVF), Soilless Culture Department, Chinese Academy of Agricultural Sciences (CAAS), during spring 2017 from February to the end of February May. The experiment followed a triplicated, completely randomized design CRD with four treatments with different substrate compositions as given Table 1. The experiment was conducted under a protected greenhouse using troughs built of red bricks. To execute the experiment, the sand, substrate (coco-peat), poultry manure, and MF were purchased from the Hebei Lingshousi County market to execute the experiment.

Table 1. Details of four investigated treatments with their respective substrate compositions.

Treatment	Substrate Composition
T ₁ (Control)	60 kg m ⁻³ PM
T ₂	30 kg m ⁻³ PM + 3 kg m ⁻³ MF
T ₃	30 kg m ⁻³ PM + 5 kg m ⁻³ MF
T ₄	30 kg m ⁻³ PM + 7 kg m ⁻³ MF

The treatments of the experiment were in each cubic substrate with 60 kg m⁻³ PM (T₁) used as a control, 30 kg m⁻³ PM plus 3 kg m⁻³ MF (T₂), 30 kg m⁻³ PM plus 5 kg m⁻³ MF (T₃), and 30 kg m⁻³ PM plus 7 kg MF (T₄).

The physicochemical properties of all substrates consisting of bulk density, air space, and porosity were evaluated according to [2,46]. The water-holding capacity (WHC), electrical conductivity (EC), and pH were measured carefully according to the methods of [47–49]. The aforementioned physico-chemical properties of sand and coco-peat utilized in this experiment are presented in Table 2.

Table 2. Some physicochemical characteristics of substrates.

Properties	Coco-Peat	Sand
Bulk Density (g cm ⁻³)	0.499	1.487
Air Space (%)	20.87	25.01
Water holding capacity (%)	75.7	27.14
Total Porosity (%)	94.9	51.99
Electrical Conductivity (dS m ⁻¹)	0.207	0.122
pH	7.3	7.9

The seedlings of cucumber (*Cucumis Sativus* L. cv Zhong Nong. No. 26. F1) were transplanted from the nursery to troughs at the four-leaf stage (45 days in age). Each treatment was replicated three times, and eight plants were grown as a plot. The irrigation practices were conducted daily, and fruit harvesting was carried out twice a week in the early morning. Sticky and yellow bands were used as insect control. The average relative humidity was maintained at 65%. However, the temperature was maintained on an average basis at 26 °C during daytime and 16 °C during nighttime. Cooling panels and fans were installed in the greenhouse at intervals working together to keep the temperature, and relative humidity maintained and kept the environment ventilated. An automatic photoperiod adjustment system was used to adjust the optimal amount of supplemental light needed to maintain plant growth. The system automatically directs LED lights to

be dim, brighten, and turn off throughout the day while targeting a specific daily light integral (DLI). In the current study, the photoperiod ranged between 10–12 h, and light intensity oscillated between 95–155 $W\ m^{-2}$. Irrigation water was scheduled every week as per requirements and when needed.

The total depth of the root zone (30 cm) was divided into three layers, and the thickness of each layer was 10 cm (Figure 1). The bottom layer was coco-peat, the top layer was sand, and the middle layer was used to treat the combination of coco-peat, MF, and PM (Table 1). The poultry manure and MF (N-P₂O₅-K₂O 15-15-15) were added well to the coco-peat based on the weight/volume (*w/v*).

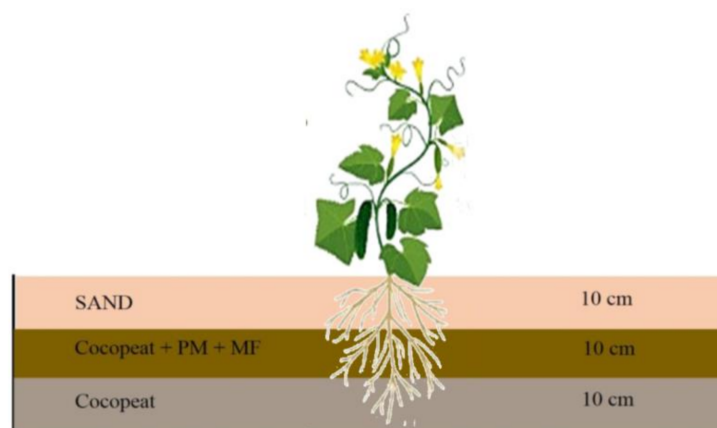


Figure 1. The schematic design three layers of the trough. The bottom layer contained coco-peat, the top layer contained sand, and the middle layer was used for different treatments of the combination of coco-peat, MF, and poultry manure (PM) except T1, which was used as control comprising only 60 kg of PM.

The reference level of the poultry manure (60 kg) was chosen based on the preliminary experiment investigating the effect of different manure levels 15, 30, 45, 60, and 75 $kg\ m^{-3}$ on the yield, quality, and some growth parameters of the cucumber. According to the nitrogen (N) content in the MF and PM, the concentration of N in 30 $kg\ m^{-3}$ of poultry manure was equivalent to its concentration in 5 kg MF. Accordingly, 5 kg of MF was chosen to be combined with 30 $kg\ m^{-3}$ PM to be similar to the control of nitrogen content and different fertilizer forms. In addition, ± 2 kg of MF were added to 5 $kg\ m^{-3}$ of MF and used in combination with PM.

Ten productivity-enhancing parameters were measured, including yield and quality parameters. Fruit yield per plant, fruit weight, leaf area, vine length, vine girth, and the number of leaves are yield traits, whereas dry matter, total soluble solids (TSS), leaf nitrogen contents, and fruit are quality traits. The data were collected from each plant in each replication, and then an average of eight plants per plot was considered for further analysis. The vine length was calculated starting from ground level until the tip of the vine with a measuring tape calibrated in centimeters, and the mean was determined for computational analysis. The vine girth was taken at 5 cm above the base on each sample plant using a Vernier caliper. The number of leaves from each plant was counted, and the mean value was estimated for further analysis. Leaf area was determined from three leaflets of each of the eight sampled plants based on the rectangular method. The leaflet's length and maximum width were determined from the plants' top, middle, and bottom portions.

The yield was calculated by weighing harvested fruits per plant. Fruit weight was measured at the end of experiments by analytical balance at a precision level of 0.001 (Mettler Toledo, LLC 1900 Polaris Parkway Columbus, OH 43240, USA). Dry matter and total soluble solids (TSS) were measured as indicators for fruit quality. Dry matter of the fruit (%) was obtained after the samples were dried at 60 °C until they had a constant weight. The TSS was measured by a refractometer.

Scored data were statistically analyzed for analysis of variance ANOVA to determine significant differences ($p < 0.05$) for traits under study. Treatment means were further compared using the Tuckey (HSD) test to determine the mean differences of different treatments.

A multivariate scatterplot matrix was constructed to determine correlation coefficients by Pearson's correlation method for all the productivity-enhancing traits and quality traits investigated under study. The multivariate analyses were performed, including basic statistics, correlation analysis, Principal Component Analysis (PCA), and two-way hierarchical clustering using Agglomerative Hierarchical Clustering (AHC) approach to figure out the Euclidean distance matrix for productivity-enhancing traits of cucumber under four treatments. All the analyses were carried out using the statistical software package SAS-JMP Pro 16 (SAS Institute Inc., Cary, NC, USA, 1989–2021).

3. Results

One-way ANOVA for different productivity-enhancing traits, including growth, yield, and quality parameters of cucumber under soilless culture, is shown in Table 3, depicting significant differences among them under different treatments. As shown in the table, the crop's fresh fruit yield per plant was significantly affected ($p < 0.05$) by all treatments. Comparisons for all pairs using Tukey–Kramer (HSD) method were carried out and are presented in Table 4. Application of MF at the ratio of 3 kg m^{-3} (T_2) showed the highest fruit yield per plant, which is (918.3 g) and the lowest (525.8 g) at T_1 (control), and there is a significant difference ($p < 0.05$) between them (Figure 2A). Similarly, as shown in Figure 2B, fruit weight was significantly affected ($p < 0.05$) by all treatments compared to control. The maximum average fruit weight (181.8 g) was recorded at T_3 , while the lowest average fruits weight (146.1 g) was at T_1 (control), and they differed significantly. In Figure 2C. Fertilizer application significantly affected ($p < 0.05$) leaf area. The maximum increase in leaf area was 658.9 cm^2 for T_2 . The vine length of cucumber was changed during plant growth under fertilizers treatments, as presented in Figure 2D. Significant differences ($p < 0.05$) of the treatments over the control were observed 27 days after transplant, attributed to fertilizer application. The highest increase in vine length was 202.8 cm for T_3 . Figure 2E revealed that the vine girth of the cucumber plant was changed during plant growth under fertilizers treatments.

Table 3. Mean Squares from One-way ANOVA for different productivity-enhancing traits of Cucumber under Soilless Culture.

Source of Variation	Treatment	Error	Pr (>F)
Degree of freedom	3	8	-
Fruit Yield Per Plant (g)	94,726.2 **	4802.60	0.0005
Fruit Weight (g)	871.007 **	18.9260	<0.0001
Leaf Area (cm^2)	62,614.9 **	1692.00	<0.0001
Vine Length (cm)	611.590 **	41.4210	0.0013
Vine Girth (mm)	0.66979 **	0.08351	0.0085
Number of Leaves	9.69972 **	0.61650	0.0010
Dry Matter (%)	1.13183 **	0.00631	<0.0001
Total Soluble Solids (%)	0.33155 **	0.01271	0.0002
N-Content (Leaf) (%)	6.99080 **	0.04253	<0.0001
N-Content (Fruit) (%)	1.33254 **	0.01317	<0.0001

** Highly significant ($p < 0.01$). N-Content: Nitrogen contents; Fruit Yield Per Plant, Fruit Weight, Leaf Area, Vine Length, Vine Girth, and Number of Leaves are yield traits; Dry Matter, TSS, N-Content (Leaf), and N-Content (Fruit) are quality traits.

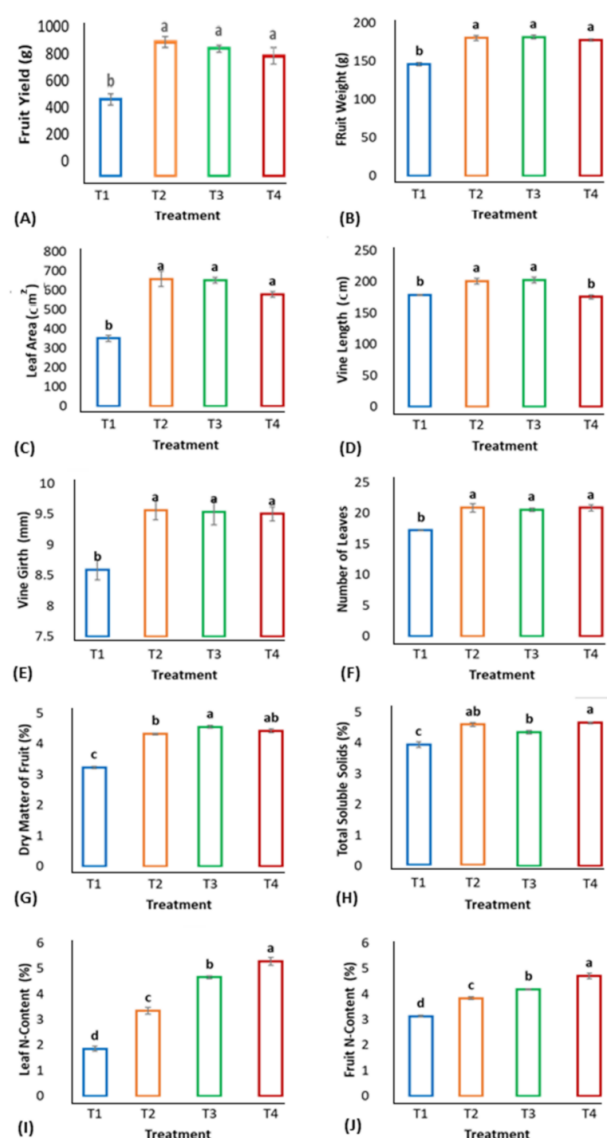


Figure 2. Graphical representation compares productivity-enhancing traits including Fruit Yield (A), Fruit Weight (B), Leaf Area (C), Vine Length (D), Vine Girth (E), Number of Leaves (F), Dry Matter (G), Total Soluble Solid (H), Leaf N-Content (I), and Fruit N-Content (J) in cucumber under soilless culture through Tukey–Kramer (HSD) test. Treatments sharing common letters revealed non-significant differences, and different letters depict significant differences ($p < 0.05$).

Table 4. Mean comparison for different productivity-enhancing traits of cucumber for different treatments under soilless culture based on Tukey–Kramer (HSD) method.

Traits	T ₁ (Control)	T ₂	T ₃	T ₄
Fruit Yield Per Plant (g)	525.8 ± 35.73 b	918.3 ± 37.36 a	875.7 ± 24.3 a	824.7 ± 56.04 a
Fruit Weight (g)	146.13 ± 2.17 b	180.53 ± 3.32 a	181.85 ± 2.74 a	177.71 ± 1.41 a
Leaf Area (cm ²)	350.5 ± 14.95 b	658.8 ± 40.12 a	652.6 ± 14.25 a	579.3 ± 14.81 a
Vine Length (cm)	178.96 ± 1.02 b	201.13 ± 4.89 a	202.8 ± 4.2 a	175.77 ± 3.55 b
Vine Girth (mm)	8.59 ± 0.166 b	9.57 ± 0.158 a	9.54 ± 0.213 a	9.51 ± 0.117 a
Number of Leaves	17.21 ± 0.042 b	20.92 ± 0.686 a	20.58 ± 0.289 a	20.88 ± 0.516 a
Dry Matter (%)	3.23 ± 0.0382 c	4.33 ± 0.0313 b	4.56 ± 0.0441 a	4.43 ± 0.0635 ab
Total Soluble Solids (%)	3.912 ± 0.093 a	4.564 ± 0.065 ab	4.35 ± 0.056 b	4.66 ± 0.03 c
N-Content (Leaf) (%)	1.849 ± 0.098 d	3.344 ± 0.138 c	4.661 ± 0.061 b	5.296 ± 0.156 a
N-Content (Fruit) (%)	3.127 ± 0.033 d	3.84 ± 0.064 c	4.187 ± 0.023 b	4.717 ± 0.109 a

Values sharing the same letters in the same row are not significantly different at ($p < 0.05$). N-Content: Nitrogen contents; Fruit Yield Per Plant, Fruit Weight, Leaf Area, Vine Length, Vine Girth, and Number of Leaves are yield traits; Dry Matter, TSS, N-Content (Leaf), and N-Content (Fruit) are quality traits.

The highest increase in the ratio of the vine girth in comparison with the control was 9.57 cm for treatment (T₂). In Figure 2F, significant differences ($p < 0.05$) were observed for the number of leaves applying different fertilizer treatments over control. The maximum number of leaves was observed with T₂, i.e., 20.92 leaves. In Figure 2G, the dry matter of the fruit was significantly affected ($p < 0.05$) by all treatments compared with the control. The highest value of the dry matter, which was 4.56%, was obtained at T₃, while the lowest value (3.41%) was at T₁ (control), and all the treatments differed significantly from control. As shown in Figure 2H, all treatments showed a significant increase ($p < 0.05$) in the TSS of cucumber fruit over the control. The maximum increase in TSS observed was 4.66% with T₄. The total nitrogen contents were determined in leaves and fruits, as shown in Figure 2I,J. The results showed that all treatments were significantly different ($p < 0.05$) for the nitrogen contents over the control in both leaves and fruits. The highest value of N-contents in leaves and fruits, i.e., 5.296% and 4.72%, respectively, was achieved by T₄. The lowest values obtained for these nitrogen contents in leaves and fruits in control were 1.85% and 3.13%, respectively. The estimations depicted clear and significant differences between all the investigated traits under different treatments.

The correlation matrix of productivity-enhancing traits of cucumber is presented in Figure 3. All the traits depicted a positive trend in correlation with high significance with each other. Maximum values of positive correlation were observed for dry matter with fruit weight (0.97), fruit yield per plant (0.91), and leaf area (0.91). However, vine length revealed a minimum correlation with all the yield and quality traits. The rest of the parameters represented significant positive correlations among themselves.

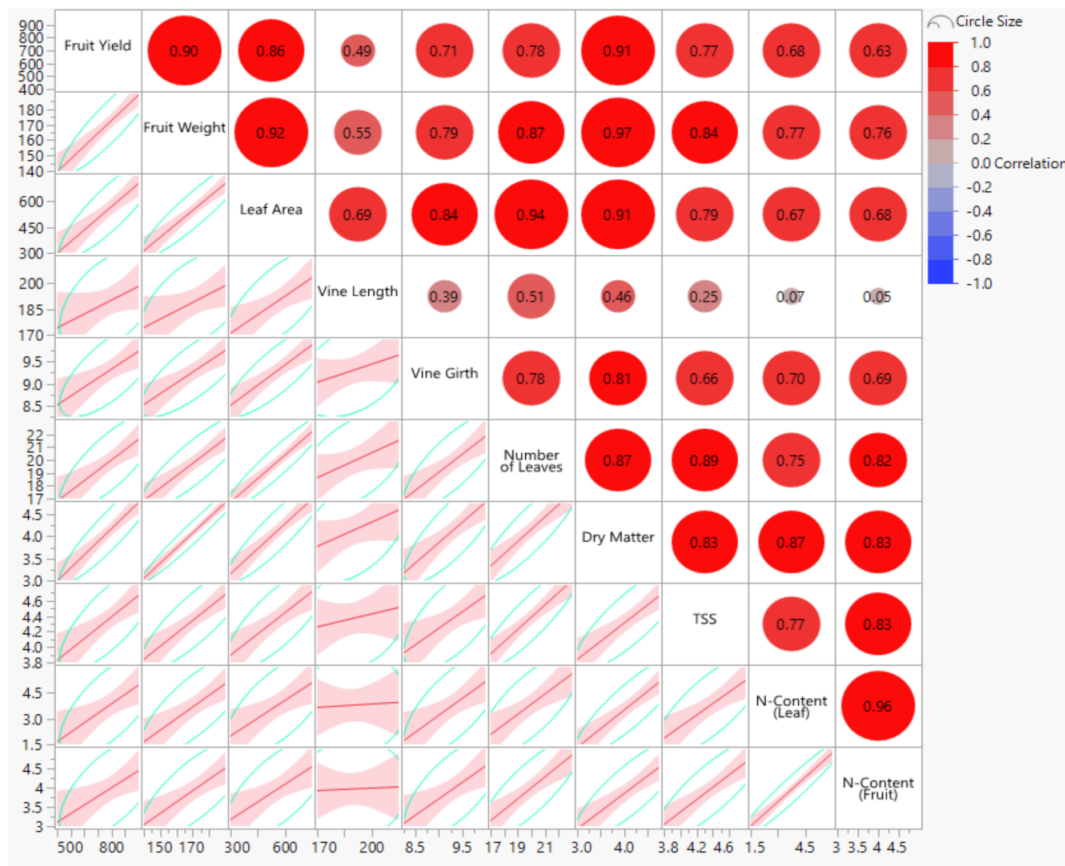


Figure 3. Scatterplot matrix for productivity—enhancing traits of cucumber under 4 treatments. The biplots of each trait with other traits showing significant relationships are presented at the lower side of the diagonal, while on the upper side, the correlation among traits under different treatments is displayed. Different shades of colors show different levels of correlation values and sizes of circles to represent the extent of correlation among these traits under treatments.

Multivariate analysis was performed to further validate the outcome obtained from the univariate method used to distinguish the augmented treatments from conventional ones. The clustering of traits was done based on the discrimination among four treatments depicted in the form of a heat map in Figure 4. The hierarchical clustering was operated using morphological traits data from different treatments via the agglomerative approach. This approach was based on squared Euclidean distance between treatments using Ward's method. This heat plot discriminates the control T_1 from the rest of the augmented treatments T_2 , T_3 , and T_4 , forming two clusters. The two treatments T_2 and T_3 depicted productivity and quality-enhancing outcomes, respectively.

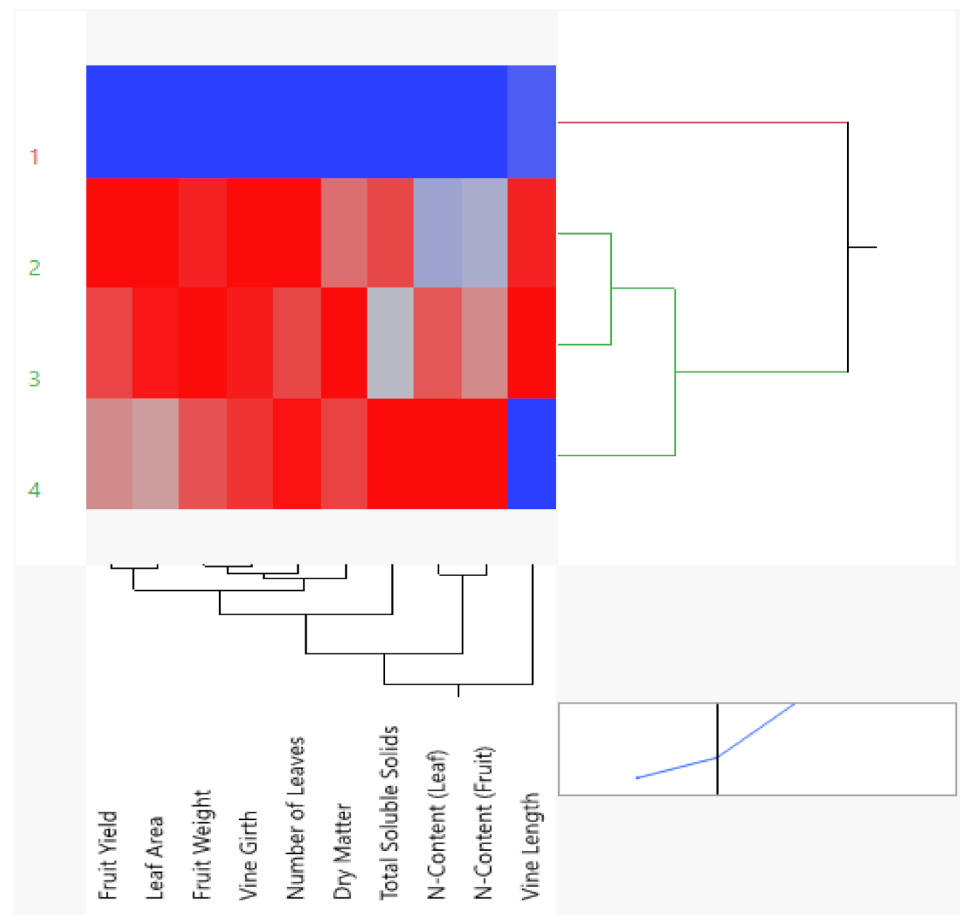


Figure 4. Two-way hierarchical clustering using Agglomerative Hierarchical Clustering (AHC) approach to figure out the Euclidean distance matrix for productivity-enhancing traits of cucumber under 4 treatments. The heat plot was assembled in JMP pro. Based on Ward's minimum variance method, V. 16 (SAS Institute Inc., Cary, NC, USA). Both the vertical and horizontal axes represent clades formation based on division related to traits under different treatments.

According to PCA, 97.5% of the total variation was covered by the first two PCs. The Scree plot demonstrates the first two PCs with maximum coverage of 97.5% of total variation explained (Figure 5a). It was further elaborated by a factor map of squared cosines/coordinates representing long bars for variables' contribution to total variation (Figure 5b). This map chart is also validating the higher contribution of PC1 and PC2. Moreover, the distribution details related to traits and treatments covered by the first two PCs were revealed in the Biplot matrix (Figure 6). It validates clear discrimination of Control T_1 from the rest of the augmented treatments T_2 , T_3 , and T_4 .

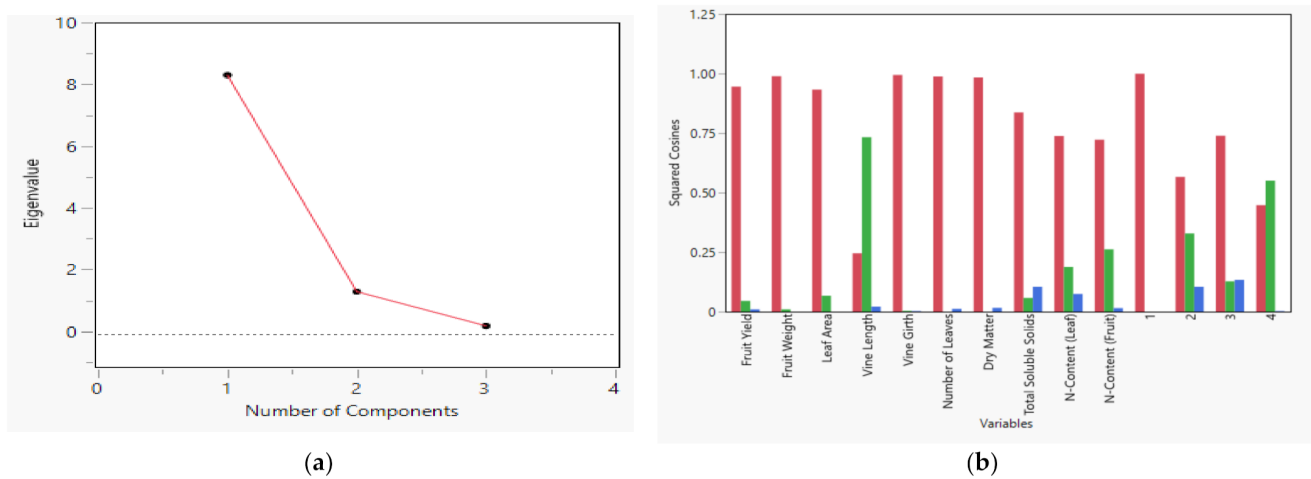


Figure 5. (a) Scree plot reveals the number of components covering sufficient variation related to treatments used for investigated traits. (b) Squared cosines associated with the principal components for ten investigated traits and four treatments.

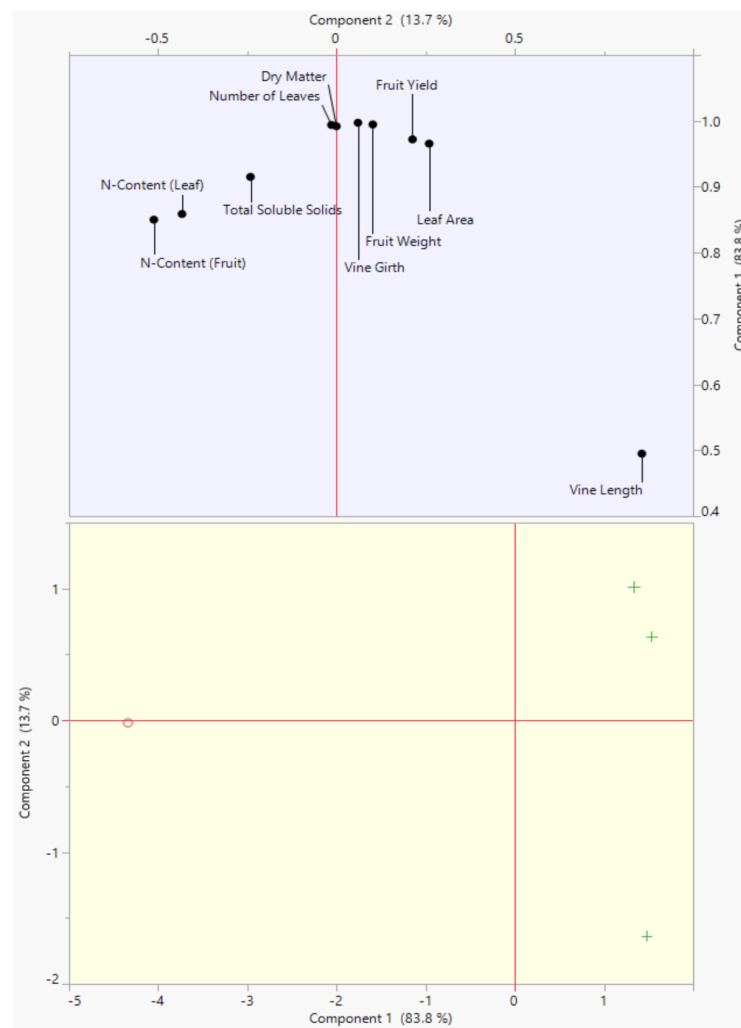


Figure 6. Biplot matrix for principal component analysis revealing the distribution of traits in question under treatments. The upper half of the matrix represents traits, while the lower half depicts treatments placed at different places of the scatterplot.

4. Discussion

Findings of the current study, which was executed to examine the effects of different fertilizer treatments as compared to conventional application of fertilizers under soilless culture, have demonstrated that application of PM combined with MF had a significant effect on the cucumber production by the increase in yield and vegetative growth [50]. It is also evident that we can benefit from poultry manure application, especially improvement in fruit quality resulting from nutrient uptake, increasing organic matter content, and enhancing the activity of microorganisms [51–54]. These nutrients increase vegetative growth and form a robust radical total, thus increasing the number of leaves and vine length. These results agree with previous studies. Increasing amounts of manures in treatments have positively influenced all the traits. Such findings were previously reported by Hamma et al. [55] and Law-Ogbowo [56]. Compared to untreated (control) ones, the highest number of leaves observed for treated cucumber plants, compared to untreated (control) ones, indicated higher nutrient uptake, which ultimately gave rise to a higher leaf area. Higher leaf area was an apparent cause of maximum light interception. Wider leaf area is necessary for maximum light interception for increased photosynthesis and transpiration [57], leading to improved production/yield due to higher translocation of assimilates to the storage organ, i.e., fruit [56].

The application of MF and PM improved the cucumber's growth characteristics, which triggered an increase in the average weight of fruit and net yield. This result agrees with previous works [16,18,21,58–60]. The quality of cucumber fruits was enhanced by mineral contents, dry matter, and total soluble solids. The improvement in the fruit quality of cucumber could mainly be attributed to the combined use of organic and MF. Furthermore, the improved growth of plants under study positively responds to the balanced discharge of additional nutrient elements through moisture made available by applying PM and coco-peat. These findings were also confirmed by previous studies [33,51,55,58].

Among the treatments where poultry manure at 30 kg m^{-3} was combined with MF, the results showed no significant differences. The application of MF was found to increase the growth and yield parameters significantly over the control. However, only minor variations were observed among these treatments. The possible reason could be the slight variation in the dosage of MF, where 3, 5, and 7 kg m^{-3} NPK were applied to T₂, T₃, and T₄, respectively. It is also likely that the crop met the nutrient requirement from the poultry manure combined with the lowest level of NPK. Therefore, more applications of MF might not have significant effects on the measured parameters. Sometimes the overdose of fertilizer negatively affects some parameters [12,61]. For instance, the overdose of nitrogen could prolong the growth stage and delay the fruiting stage. As shown in Figure 2, the total yield among T₂, T₃, and T₄ has slightly decreased as a function of NPK increase. Although the decrease in yield was insignificant, it indicates the negative effect of the overuse of MF on the crop. Our findings are consistent with the previously reported studies [15,56,61–64].

The correlation of parameters investigated with each other represented in Figure 3 depicts a significant positive correlation. All the traits except vine length significantly depend on each other for better performance [65]. All the quality parameters positively correlate with yield parameters and ultimately increase the net yield [66,67]. Maximum correlations were observed for dry matter with fruit yield per plant, fruit weight, and leaf area. This indicates the interdependence of dry fruit matter on traits under study contributing to yield. Our findings follow those of previous studies [42,65,68–71].

Both PCA and AHC multivariate methods are widely adopted today to cluster and represent closeness or distances between variables in the dataset [72]. The visual display of variables data is plotted as factors acquired through the PCA approach [73]. In this study, the first two PCs represented maximum coverage of variation. The AHC method divided the treatments into two distinct clusters, revealing control T₁ as discriminant from the rest. The two clusters formation confirms different effects of conventional amount of manure used from augmented amounts used in the study. It was observed that the

augmented amounts have a better impact on the productivity and quality of the fruit traits. The T2 improved the productivity traits, while T3 helped to enhance quality traits more. Both univariate and multivariate analysis methods provided the grounds to support the hypothesis that the treatments used on traits were sufficient to cover maximum variation. Similar findings are reported in the study [43].

5. Conclusions

Presently, production of cucumber is dependent mainly on chemical fertilizers which have adverse effects on human health and surrounding environments. This study demonstrated the better and safe use of PM and MF at various combination ratios on cucumber crop. The vegetative growth and yield productivity of the crop were significantly enhanced with organic fertilizer application. The results did not show significant differences between the three experimental mineral fertilizer ratios combined with poultry manure. Hence, the lowest ratio could be recommended as best to achieve better quality and growth. The obtained results can be used as future recommendations in crop cultivation programs focusing on productivity and quality enhancement and the global farming community under soilless cultures of cucumber.

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