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Effects of Organic Fertilizer Supply on Soil Properties, Tomato Yield, and Fruit Quality: A Global Meta-Analysis

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Abstract: The increased use of chemical fertilizer input in agricultural production and the promotion of sustainable agriculture encourage researchers around the globe to undertake experiments regarding application of organic fertilizers on tomato production. This study aims to amalgamate the comprehensive effects of organic fertilizer application compared with the pure application of chemical fertilizers (100% CF) on soil properties, tomato yield, and fruit quality through meta-analysis. It helps to provide a certain reference for the sustainable development of circular agriculture systems in tomato planting. Articles related to the impact of organic fertilizers on tomato planting were searched on the Web of Science, Science direct, and Google Scholar. A total of 124 documents meeting the Meta-analysis criteria were screened out. A total of 2041 sets of data were screened for soil properties (electrical conductivity, pH, organic matter, total nitrogen, total phosphorus, total potassium, ammonium nitrogen, nitrate nitrogen, available phosphorus, available potassium, bacteria, fungi, urease, catalase) and tomato yield and quality (nitrate, sugar, lycopene, protein). The normal fitting of the response ratio of each data revealed that all of them satisfied the Gaussian curve, and there was no publication bias. The application of organic fertilizers (the total) compared with 100% CF can increase the yield by 3.48%, acidic soil by (pH < 6) 7.98%, neutral soil by (pH = 6~8) 3.35%, soil organic matter by 24.43%, total nitrogen by 32.79%, total phosphorus by 23.97%, total potassium by 44.91%, available phosphorus by 14.46%, available potassium by 16.21%, soil bacteria by 5.94%, urease by 22.32%, and catalase by 17.68%. The application of organic fertilizers (the total) had no significant effect on ammonium nitrogen, nitrate nitrogen, and soil fungi in the soil. After the subgroup analysis, bio-organic fertilizers (BF) can increase tomato yield by 14.15%, reduce soil electrical conductivity by 13.66%, and increase soil catalase activity by 24.55%. Ordinary organic fertilizer (OF) can improve tomato quality, reduce tomato nitrate by 13.02%, and increase sugar by 10.66%, lycopene by 10.78%, total nitrogen by 39.55%, total phosphorus by 29.11%, total potassium by 58.67%, soil bacteria by 6.54%, and urease by 25.41%. Both can increase tomato protein, soil pH, soil available phosphorus, and potassium, but neither can significantly affect the ammonium nitrogen, nitrate nitrogen, and soil fungi in the soil. Correlation analysis revealed a significant positive correlation of tomato yield with lycopene, soil electricity conductivity, organic matter, ammonium nitrogen, nitrate nitrogen, available phosphorus, and urease. The application of organic fertilizers can improve tomato yield and quality and soil properties more compared with 100% CF. BF have better effects on yield and soil electrical conductivity, whereas tomato quality and soil physical and chemical properties are more effected by OF. Hence, this study provides a pathway for the selection of organic fertilizer in tomato production.

Keywords: organic fertilizer; tomato; meta-analysis; yield; fruit quality; soil properties

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Citation: Fan, H.; Zhang, Y.; Li, J.; Jiang, J.; Waheed, A.; Wang, S.; Rasheed, S.M.; Zhang, L.; Zhang, R. Effects of Organic Fertilizer Supply on Soil Properties, Tomato Yield, and Fruit Quality: A Global Meta-Analysis. *Sustainability* **2023**, *15*, 2556. https://doi.org/10.3390/su15032556

Academic Editor: Monika Mierzwa-Hersztek

Received: 30 December 2022
Revised: 18 January 2023
Accepted: 22 January 2023
Published: 31 January 2023

1. Introduction

Tomato is the second largest vegetable crop in the human diet worldwide, after potato, with a very high nutritional and economic value [1,2]. In 2000, the total tomato production exceeded 100 million tons around the globe, and in 2021, the world's total tomato output was 182.05 million tons. The tomato planting area around the world also increased from 3.16 million hectares in 1994 to 5.055 million hectares in 2020 [3]. Tomatoes are an essential food for people and a valuable source of nourishment. Tomatoes are a source of high-quality vitamin C required by the human body [4]. Tomato and other vegetable crops have a large requirement for nitrogen. Driven by global demand and economic interests, farmers generally use excessive chemical fertilizers in order to pursue high yields [5]. The extensive application of chemical fertilizers can lead to a decrease in soil pH, which in turn leads to a decrease in the abundance of bacterial communities [6]. Moreover, intensive agriculture has also reduced soil biodiversity, increased the risk of soil-borne disease outbreaks, and seriously threatened the sustainable development of agriculture [7]. Similarly, over-manuring can also lead to many potential adverse factors, such as nitrate accumulation or leaching [8,9]. In addition, soil degradation such as acidification and salinization are common in vegetable fields [10]. The application of organic fertilizers has significantly improved the activity of microbial enzymes such as urease, catalase, and β-glucosidase, which are the biological indicators of the soil [11]. The main problems in the current vegetable system are reduced productivity, environmental degradation, and soil quality degradation [12,13]. Therefore, the application of organic fertilizers is an efficient and long-lasting solution. Previous studies have shown that the application of organic fertilizer is a sustainable vegetable planting strategy [14], it increases the yield of vegetables [15], reduces the loss of nutrients in the soil [16], reduces the greenhouse gas emission in agricultural production [17], controls the occurrence of vegetable diseases [18], and keeps the soil healthy enough for a long time [19]. The long-term application of organic fertilizers can improve the availability of soil phosphorus, which is affected by the comprehensive impact of organic fertilizer input, soil properties, and climatic conditions [20]. Bio-organic fertilizers usually combine the effects of microbial fertilizers and organic fertilizers with specialized functional microorganisms, manifold with harmless and decomposed organic materials and animal and plant residues as the source [21]. Compared with natural fermentation, bio-organic fertilizers are added with microbial agents to increase the beneficial bacteria in the fertilizer. In intensive vegetable cultivation, the use of microbial agents and compost to form bio-organic fertilizer is a win–win approach, which can increase yield and reduce nitrogen loss [22].

The Meta-analysis method is a statistical method which can comprehensively analyze the statistical results of several independent studies [23,24]. It was used to study the effects of different nitrogen fertilizer application rates on tomato yield, quality, and soils' physical and chemical properties [3]. Others used meta-analysis to investigate the effect of different microbial groups' biological control agents on tomato bacterial wilt [25,26]. The feasibility of using meta-analysis in tomato research is comprehensively explained. This study utilizes meta-analysis to explain the changes in properties of the soil and the yield and quality of the tomato after the application of different organic fertilizers (bio-organic fertilizers and ordinary organic fertilizers) compared with the pure application of chemical fertilizers (100% CF) and the correlation between yield, quality, and soil. The results of this study can provide a theoretical basis for the selection of organic fertilizers for different purposes in tomato planting and sustainable green agriculture.

2. Materials and Methods

2.1. Data Collection

Articles related to the impact of organic fertilizers on tomato planting were searched on the Web of Science website (www.webofscience.com, accessed on 30 June 2022), Science direct (www.sciencedirect.com, accessed on 30 June 2022), and Google Scholar (scholar.google.com, accessed on 30 June 2022). All the articles published from 2000 to 30 June 2022, were systematically reviewed. The relevant experiments on tomato yield, quality, and soil with organic fertilizers were included in the analysis. According to the requirements for data integration in meta-analysis and the purpose of this study, screening was carried out for: (1) The same study must include the treatment of organic fertilizer application and the control treatment of 100% CF. Organic fertilizer application was used in data processing. Fertilizer was used as the treatment group and chemical fertilizer only (100% CF) was used as the control group; (2) The article must have the mean of the relevant data, the standard deviation SD (can be converted by the standard error SE, SE = SD/$\sqrt{n}$), and the number of repetitions n. The data in the table can be directly extracted. The data in the figure were extracted by using the function of the image digitization tool in the tools in origin 2022. For data without standard deviation or standard error, we use 10% of its mean value (SD = mean $\times$ 10%) [27]; (3) Articles or data related to activated carbon was excluded from meta-analysis, since the literature revealed that activated carbon is a soil conditioner rather than an organic fertilizer and the fertility of activated carbon is difficult to release into the soil [28,29]; (4) Organic fertilizers are divided into two subgroups. The first type of bio-organic fertilizers are organic fertilizers with added microorganisms (*Bacillus*, *Trichoderma*, etc.), vermicompost (The studied literature has shown that vermicompost is a subdivided peat-like substance that biodegrades and stabilizes organic matter through the interaction between earthworms and microorganisms. It is produced through a non-thermophilic process [30], with more total microorganism and higher biological activity [31,32]). The second type of common organic fertilizer are commercial organic fertilizer, green manure, various manure, various straw compost, biogas residue, manure, etc.; (5) The basic information of test site, organic fertilizer type, and so on is relatively complete and reliable.

This research includes relevant test data from all around the world, including data from five continents, as shown in Figure 1, including 53 test points in Asia, 37 test points in Europe, 21 test points in North America, 4 test points in South America, and 9 test sites in Africa. The record included journal name, article title, test date, test location, test point coordinates (Table S1), and other information which were extracted from 124 documents. Screening revealed that yield was included in 373 groups; fruit data: nitrate in 48 groups, sugar in 85 groups, lycopene in 130 groups, protein in 30 groups; and soil data: electrical conductivity (Ec)in 115 groups, pH (<6, acid soil) in 119 groups, pH (6~8, neutral soil) in 101 groups, soil organic matter (SOM) in 173 groups, soil total nitrogen (TN) in 133 groups, total phosphorus (TP) in 57 groups, total potassium (TK) in 41 groups, ammonium nitrogen (NH_4^+-N) in 66 groups, nitrate nitrogen (NO_3^--N) in 80 groups, available phosphorus (AvP) in 168 groups, available potassium (AvK) in 145 groups, soil bacteria in 63 groups, soil fungi in 63 groups, soil urease in 30 groups, and soil catalase in 31 groups (Table S1). A total of 2041 groups of data.

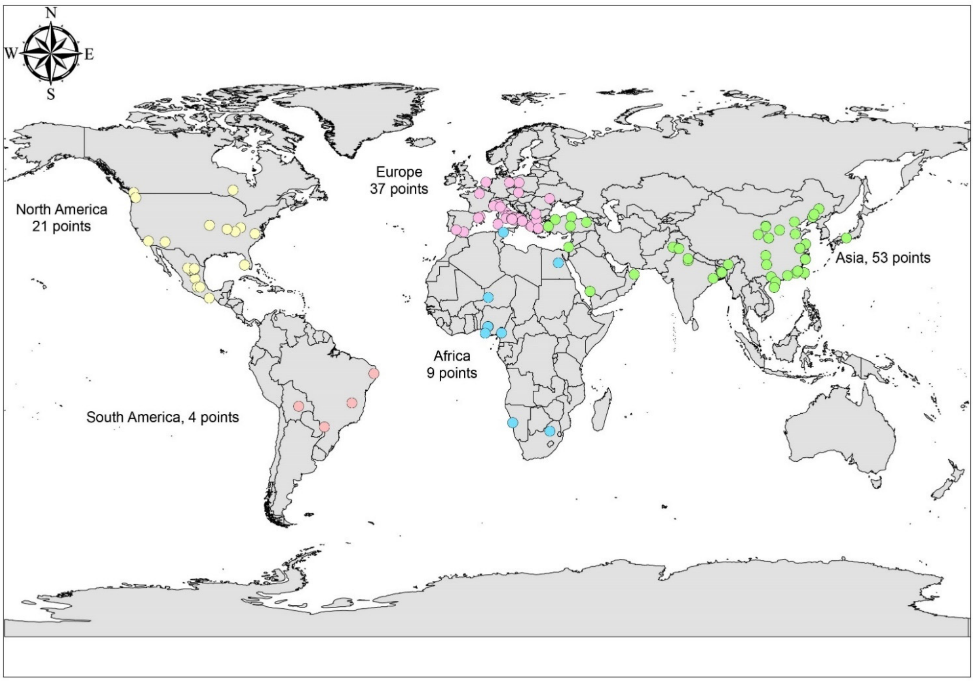

Figure 1. Trial sites for the application of organic fertilizers in global tomato cultivation (n = 124).

2.2. Meta-Analysis

Metawin 2.1 software was used for meta-analysis, the response ratio was selected as the effect ratio for different indicators. The formula for calculating the response ratio is [33]:

$$In(R) = In\left(\frac{X_t}{X_c}\right) = InX_t - InX_c \quad (1)$$

where X_t represents the average value of the treatment group (applied organic fertilizer), X_c represents the average value of the control group (100% CF). The variation coefficient *V(R)*, weight (W_{ij}), weighted effect ratio (R_{++}), standard error $S(R_{++})$, and 95% CI were calculated as follow [3]:

$$V(R) = \frac{S_t^2}{N_t X_t^2} + \frac{S_c^2}{N_c X_c^2} \quad (2)$$

$$W_{ij} = 1/V \quad (3)$$

$$R_{++} = \sum_{i=1}^{m}\sum_{j=1}^{ki} W_{ij}R_{ij} / \sum_{i=1}^{m}\sum_{j=1}^{ki} W_{ij} \quad (4)$$

$$S(R_{++}) = 1/\sqrt{\sum_{i=1}^{m}\sum_{j=1}^{ki} W_{ij}} \quad (5)$$

$$95\%CI = R_{++} \pm 1.96S(R_{++}) \quad (6)$$

The results of the studies were tested for heterogeneity prior to analysis. Fixed effect model (FEM) was used when probability value was $p > 0.1$, it is the indicator of heterogeneity of the data set. Random effect model (REM) was used when $p \leq 0.1$, indicated the data set is not heterogeneous [34]. The smaller the standard deviation of the effect size, the greater the weight assigned, the weighted effect ratio (RR_{++}) is the percentage of treatment relative to the control increase and decrease. If the 95% confidence interval (95%CI = ($e^{RR++} - 1) \times 100\%$) of a set of data does not coincide with 0, it is considered that the treatment has a significant impact on the target variable, and the interval < 0 has a negative effect, and > 0 has a positive effect [35].

2.3. Mapping Software and Correlation Analysis

Meta-analysis was conducted by Metawin 2.1 software, forest plot and regression analysis were carried by GraphPad Prism 8.0.2, Origin 2022 was utilized for normal distribution fitting and correlation analysis, tables were designed by excel 2007, and the world map was drawn by ArcMap 10.7 in ArcGIS.

3. Results

3.1. Heterogeneity Test and Analysis of Organic Fertilizer Application on Tomato Yield and Quality and Soil Properties

The Q test (the Q value represents the standardized sum of squares of the effect value, the larger the Q value, the greater the heterogeneity) and the I^2 test (the I^2 value represents the heterogeneity of individual effect values to the total effect value, the larger the I^2 value, the greater the heterogeneity) were carried out for meta-analysis. The heterogeneity analysis of tomato yield and quality and soil physical and chemical properties after the application of organic fertilizers was shown in Table 1. The results showed that, except for Soil urease ($p < 0.1$), all our indexes met $p < 0.01$. The cut-off values for high, medium, and low heterogeneity were 75%, 50%, and 25%, respectively [36]. The I^2 values of Soil SOM, Soil TN, Soil TK, Soil AvP, Soil bacteria, and Soil fungi were in the range of 81.16%–97.35%, hence belonging to high heterogeneity. Yield, Sugar of tomato fruit, Protein of tomato fruit, Soil pH (<6), Soil TP, Soil AvK, and Soil catalase I^2 values lies within 51.12~72.40%, thus revealing medium heterogeneity. The I^2 values of Nitrate of tomato fruit, Lycopene of tomato fruit, Soil Ec, Soil pH (6~8), Soil NO_3^--N, Soil NH_4^+-N, and Soil urease belonged to low heterogeneity within 38.29%~49.22%. All the indicators were heterogeneous; therefore, the random effect model (REM) was selected to conduct meta-analysis.

Table 1. Heterogeneity test of different indicators and analysis of differences between the groups.

Different Indicators	*n*	Heterogeneity			Between
		P_Q	Q	I^2 (%)	
Soil Ec	115	0.00000	200.05	43.01	0.00701
Soil pH (<6)	119	0.00000	253.17	53.39	0.38239
Soil pH (6~8)	101	0.00000	186.34	46.34	0.92011
Soil SOM	173	0.00000	913.15	81.16	0.01363
Soil TN	133	0.00000	2287.66	94.23	0.00000
Soil TP	57	0.00001	114.58	51.12	0.14923
Soil TK	41	0.00000	226.46	82.34	0.00002
Soil NH_4^+-N	66	0.00030	111.56	41.74	0.83171
Soil NO_3^--N	80	0.00000	148.09	46.65	0.67503
Soil AvP	168	0.00000	2460.97	93.21	0.99625
Soil AvK	145	0.00000	345.67	58.34	0.79134
Soil bacteria	63	0.00000	2336.25	97.35	0.00000
Soil fungi	63	0.00000	463.93	86.64	0.26200
Soil urease	18	0.05051	27.55	38.29	0.39877
Soil catalase	27	0.00000	94.22	72.40	0.00554
Yield	379	0.00000	1104.63	65.78	0.00002
Nitrate of tomato fruit	48	0.00014	90.60	48.12	0.92353
Sugar of tomato fruit	85	0.00000	280.61	70.06	0.00000
Lycopene of tomato fruit	130	0.00000	254.03	49.22	0.00000
Protein of tomato fruit	30	0.00000	82.64	64.91	0.18312

3.2. Meta-Analysis of Organic Fertilizer Application on Soil Properties

3.2.1. Meta-Analysis of Organic Fertilizer Application on Soil Electrical Conductivity and pH

Since there is a difference between field and potted production data, in order to reduce this difference, the effect ratio InR_{++} is used as the observed value, and origin 2023 is used for frequency statistics, and the number of frequencies is used as the vertical axis to make a histogram. Curve fitting is performed using the GaussAmp function, and the processing of the following data is similar. According to the classification of soil pH, pH < 6 is classified as acidic soil, pH 6~8 is classified as neutral soil, and pH > 8 is classified as alkaline soil and the research objects were all classified by pH under 100% CF. Since the data sets of alkaline soils are few and did not pass the heterogeneity test during data extraction, thus alkaline soils are not specifically studied. The normal distribution was fitted to the observed values of meta-analysis (Figure 2).

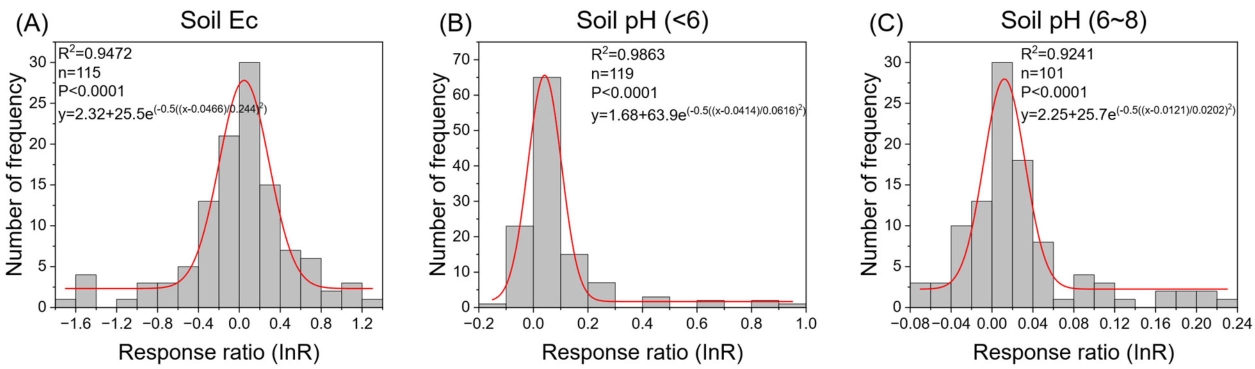

Figure 2. Soil conductivity and pH sample distribution number map, the red curve is the normal distribution fitting curve.

When organic fertilizers (the total) were applied, compared with the 100% CF (Figure 3), Soil Ec was not significantly reduced (its 95% CI passed through the zero line), however bio-organic fertilizer (BF) could significantly reduce Ec by 13.66% (95% CI, −25.22% −2.09%), similarly, ordinary organic fertilizer (OF) could not significantly improve Soil Ec. When the pH < 6, the application of organic fertilizers can increase the soil pH, the total can significantly increase the soil pH by 7.98% (95% CI, +5.82% +10.13%), BF can increase the pH by 6.32% (95% CI, +1.86% +10.77%) whereas OF could significantly increase the pH by 8.52% (95% CI, +6.03% +11.01%), although the difference between groups was not significant ($p = 0.38$, Table 1). When the pH was 6–8, the application of organic fertilizers could still increase the pH, but the increase was smaller compared with pH < 6. The increase in the pH due to the total was 3.35% (95% CI, +2.36% +4.33%), BF can significantly increase the pH by 3.42% (95% CI, +1.56% +5.28%), whereas OF can significantly increase the pH by 3.31% (95% CI, +2.12% +4.50%), the difference between groups was not significant ($p = 0.92$). The results of the meta-analysis showed that bio-organic fertilizer could significantly reduce Soil Ec compared with the 100% CF. In acidic soils, organic fertilizers could increase Soil pH. In neutral soils, organic fertilizers could still increase pH, but the increase was small.

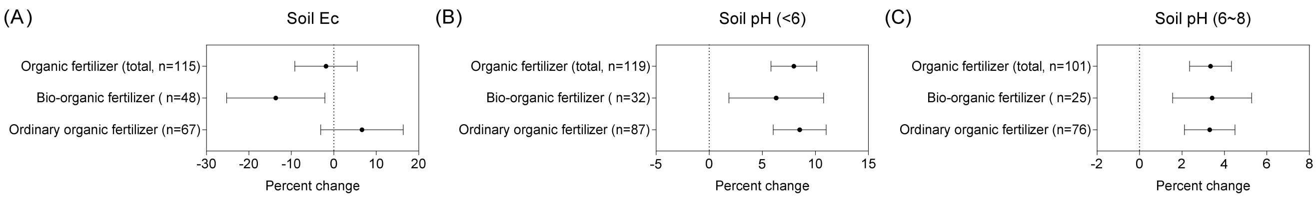

Figure 3. Global effects of organic fertilizer application on soil electrical conductivity and pH.

3.2.2. Meta-Analysis of Organic Fertilizer Application on Soil Nutrient Index

The application of organic fertilizer significantly manipulates the nutrient index of the soil, and this change can be traced. Frequency statistics were performed on the response ratio (InR) of the soil's SOM, TN, TP, TK, NH_4^+-N, NO_3^--N, AvP, and AvK, and fitted in the normal distribution. The fitting results are shown in Figure 4, whose R^2 values are 0.8966, 0.8492, 0.9577, 0.9678, 0.9185, 0.9415, 0.9481, 0.9067, and their P values are all <0.001. The fitting results were significant and have certain research significance.

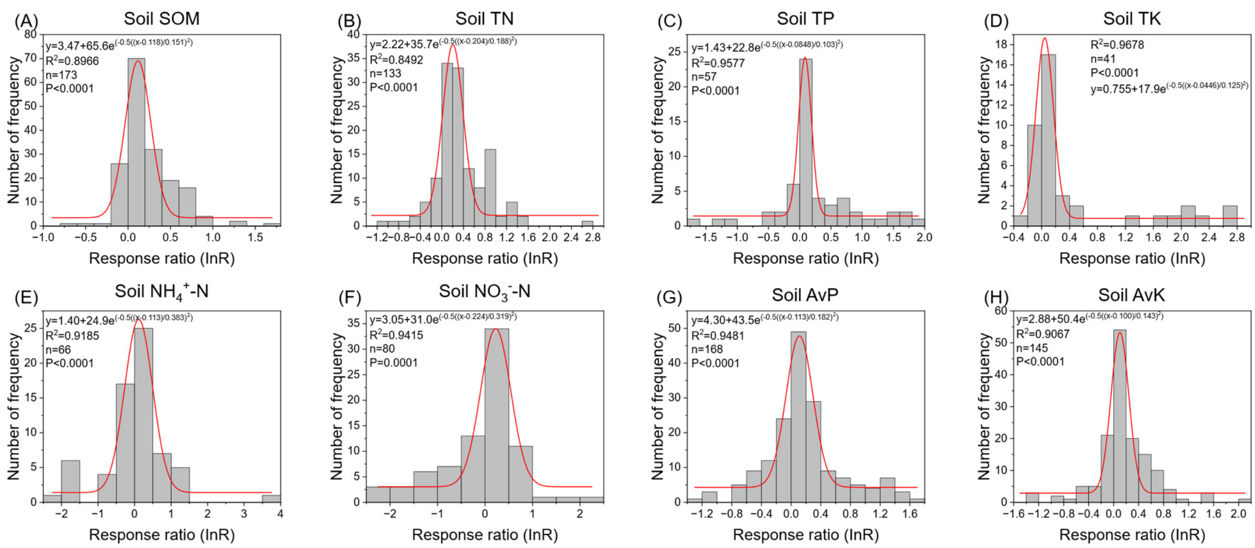

Figure 4. Soil nutrient index sample distribution quantity map, the red curve is the normal distribution fitting curve.

Compared with 100% CF, the application of organic fertilizers (the total) can significantly increase Soil SOM by 24.43% (95% CI, +22.42% +26.44%), and bio-organic fertilizer (BF) can significantly increase SOM by 19.70% (95% CI, +15.29% +24.10%) (Figure 5). The highest increase of 25.76% (95% CI, +23.48% +28.04%) in SOM was recorded by ordinary organic fertilizer (OF). There is a significant difference between OF and BF ($p < 0.05$), the difference between the groups is shown in Table 1. The increase in total nutrients in the soil, i.e., TN 32.79% (95% CI, +30.77% +34.80%), TP 23.97% (95% CI, + 11.56% +36.37%), and TK 44.91% (95% CI, +33.63% +56.19%), was significant after the application of organic fertilizers (the total). However, the application of organic fertilizers (the total) had the highest effect on TK. After subgroup analysis, BF and OF significantly improved Soil TN by 11.00% (95% CI, +6.67% +15.33%) and 39.55% (95% CI, +37.24% +41.86%), respectively, with significant differences between the groups ($p < 0.001$). BF crossed the zero line in both TP and TK, neither of which could significantly improve this metric. OF significantly increased TP and TK by 29.11% (95% CI, +14.68% +43.53%) and 58.67% (95% CI, +45.52% +71.82%), respectively. The difference among BF and OF in TP was not significant ($p = 0.15$), however a significant difference ($p < 0.001$) among BF and OF was recorded for TK (Table 1).

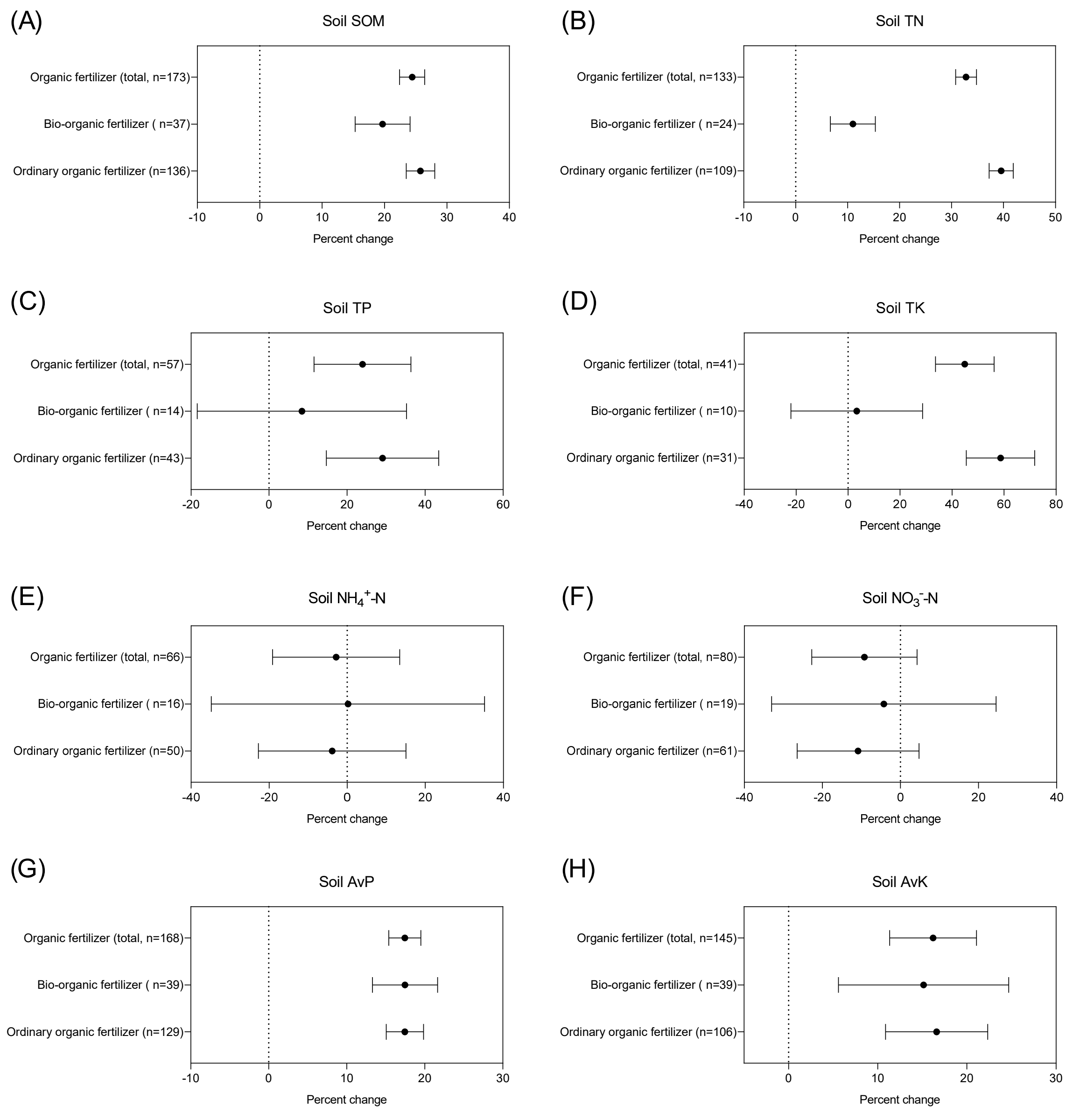

Figure 5. Global effects of organic fertilizer application on soil nutrient index.

The available nutrients in the soil are also very important, and this part of the nutrient crops can be directly absorbed and utilized. The NH_4^+-N and NO_3^--N in the soil have no significant impact after the application of organic fertilizers, and both have passed the zero line. Soil AvP and AvK after the application of organic fertilizers significantly improved. In total, OF and BF significantly increased AvP by 14.46% (95% CI, +15.40% +19.51%), 14.47% (95% CI, +13.29% +21.64%), and 17.45% (95% CI, +15.06% +19.84%), respectively. In total, BF and OF significantly increased AvK by 16.21% (95% CI, +11.34% +21.08%), 15.15% (95% CI, +5.60% +24.70%), 16.61% (95% CI, +10.88% +22.34%), respectively, although the difference between the groups was not significant for soil AvP (p = 0.996) and AvK (p = 0.791) (Table 1). The results of the meta-analysis showed that the application of organic fertilizer can increase SOM, TN, TP, TK, AvP, and AvK in soil, but it has no significant effect on NH_4^+-N and NO_3^--N in soil. Similarly, OF can increase SOM, TN, TP, and TK significantly compared with BF. There is no significant difference between OF and BF in the promotion effect of AvP and AvK.

3.2.3. Meta-Analysis of Organic Fertilizer Application on Soil Microbial Quantity and Enzyme Activity

The application of organic fertilizer has a certain impact on the microbial and enzyme activities in the soil, and the frequency of its response ratio (InR) has been fitted with a normal distribution. The results are shown in Figure 6. Soil bacteria, fungi, urease, catalase whose R^2 = 0.9147, 0.9943, 0.8805, 0.9523, respectively, have p values < 0.0001. The fitting results are satisfactory, which has certain research significance. The total compared with the 100% CF significantly increased Soil bacteria by 5.94% (95% CI, +5.73% +6.15%), and BF and OF were significantly increased by 4.86% (95%CI, +4.49% +5.23%) and 6.54% (95% CI, +6.27% +6.80%), respectively. The difference between the groups was significant (Table 1). However, Soil fungi passed the zero line, and the total and OF could not be significantly reduced, and BF could not be significantly increased.

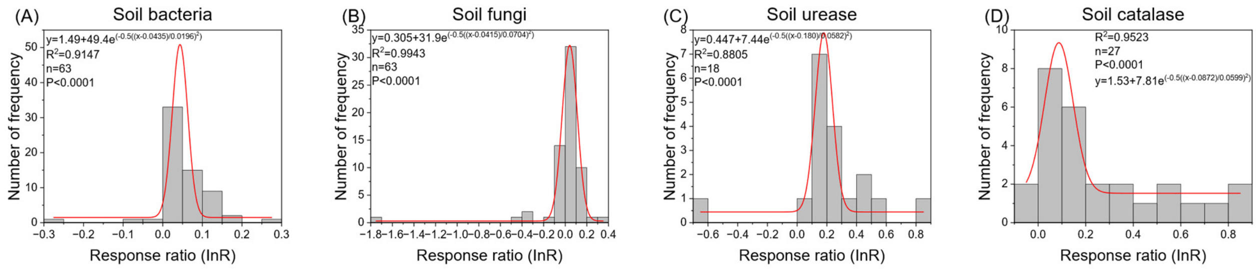

Figure 6. The number of soil microorganisms and the distribution of enzyme activity samples, the red curve is the normal distribution fitting curve.

Soil urease is related to the nitrogen cycle in soil, and soil catalase activity is related to soil detoxification ability. Applying organic fertilizer (the total) can significantly increase soil urease by 22.32% (95%CI, +11.28% +33.35%), BF cannot be significantly increased after the zero line, and OF can be significantly increased by 25.41% (95%CI, +11.35% +39.47%) (Figure 7). Through the application of organic fertilizers, the total, BF, and OF could significantly increase soil catalase activity by 17.68% (95% CI, +13.17% 22.18%), 24.55% (95% CI, +16.92% 32.18%), and 12.31% (95% CI, +6.14% 18.47%), respectively. The results of the meta-analysis showed that the application of organic fertilizers can increase soil bacteria, and also that BF has a better effect than OF, whereas no significant effect was revealed on soil fungi. The application of organic fertilizer can increase the activity of soil urease, whereas BF showed no significant effect. The effect of BF is better than that of OF as it can increase the activity of soil catalase.

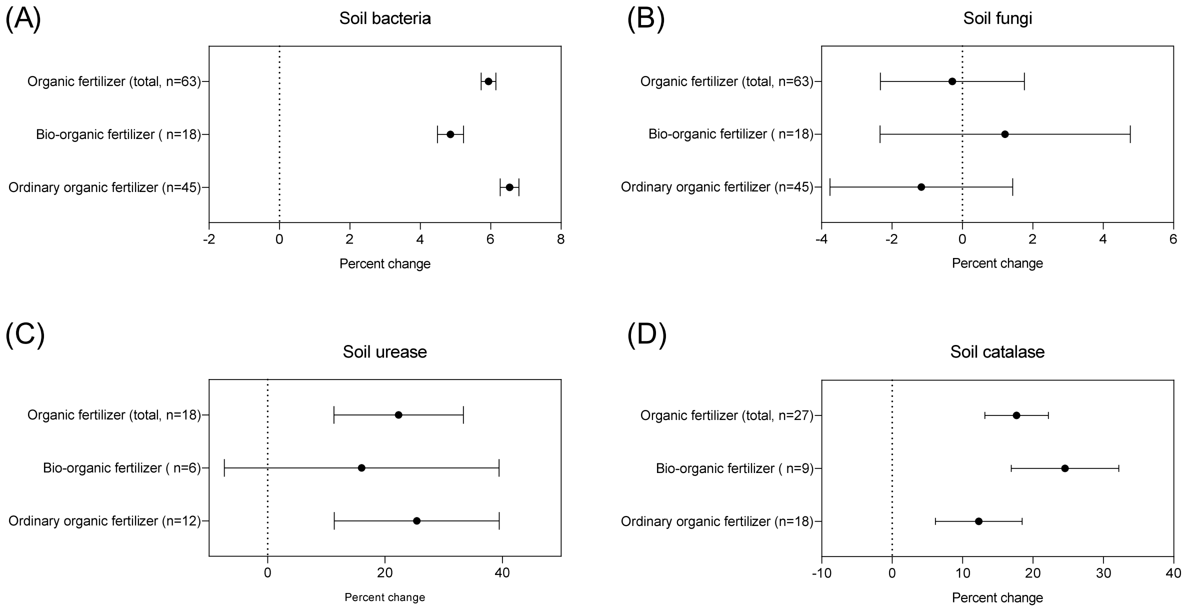

Figure 7. Global effects of organic fertilizer application on soil microbial quantity and enzyme activity.

3.3. Meta-Analysis of Organic Fertilizer Application on Tomato Yield and Quality

The fitting results of the yield data are shown in Figure 8A, the data collected for the study satisfies the normal distribution, which has a good research value. The application of organic fertilizers (the total) increased the yield by 3.48% (95% CI, +0.28% +6.67%) compared with 100% CF. The yield of bio-organic fertilizer (BF) was increased by 14.15% (95% CI, +8.28% +20.02%). Since the confidence interval of Ordinary organic fertilizer (OF) (95% CI, −4.91% +2.72%) passed through zero, the effect of organic fertilizer on the yield was not significant, and the difference between groups was $p < 0.001$ (Table 1). The results of the meta-analysis showed that compared with the total, BF significantly increased the yield, while OF had no significant effect.

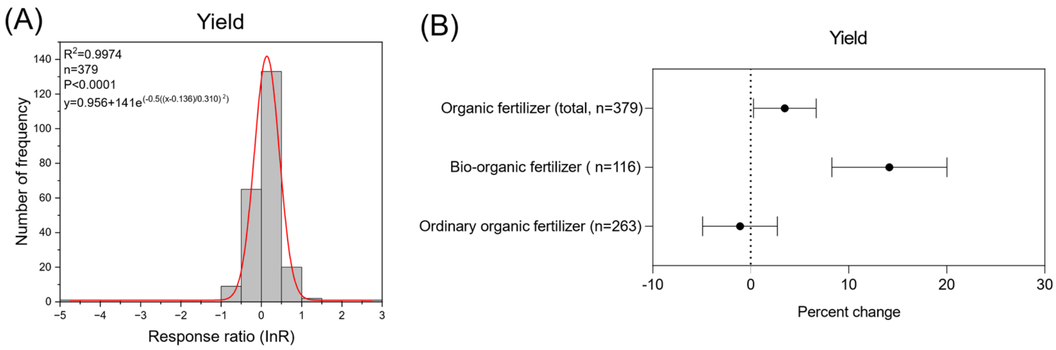

Figure 8. The number of tomato yield samples and global effects of organic fertilizer application on tomato yield.

The fitting of the normal distribution was carried out during the data processing. The data for the meta-analysis revealed the normal distribution, which is of research significance (Figure 9). The application of organic fertilizers can significantly reduce the nitrate content of tomato fruit by 12.66% (95% CI, −21.81% −3.50%) compared with the 100% CF. BF cannot significantly reduce tomato nitrate, whereas OF can significantly reduce tomato nitrate by 13.02% (95% CI, −25.20% −0.84%) (Figure 10). The application of organic fertilizers (the total) can significantly increase the tomato sugar content by 4.79% (95% CI, +2.41% +7.17%) compared with 100% CF. BF cannot significantly reduce the tomato sugar content after passing through the zero line, and OF can significantly increase the tomato sugar content by 10.66% (95% CI, +7.50% +13.82%). The application of the total can significantly increase the lycopene content of tomato fruit by 4.80% (95% CI, +2.01% +7.58%), and BF cannot significantly reduce the fruit lycopene content after passing through the zero line. Ordinary organic fertilizer could significantly increase the lycopene content by 10.78% (95% CI, +7.04% +14.52%). The protein content of tomato significantly increased by 13.82% (95% CI, +7.56% +20.08%) after the application of organic fertilizer (the total), whereas BF significantly increased the protein content by 10.12% (95% CI, +1.30% +18.93%) and OF significantly increased the protein of tomato fruit by 18.30% (95% CI, +8.47% +28.13%). There was no significant difference between the groups (p = 0.18, Table 1). The meta-analysis revealed that OF can significantly improve tomato fruit quality compared with BF.

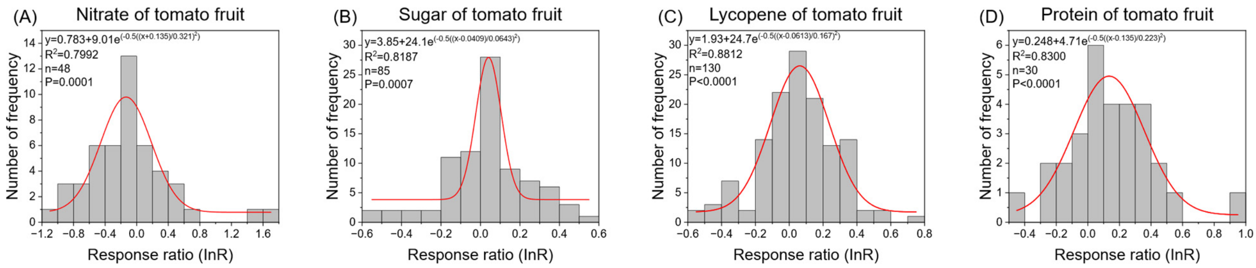

Figure 9. The distribution quantity map of tomato quality index samples, the red curve is the normal distribution fitting curve.

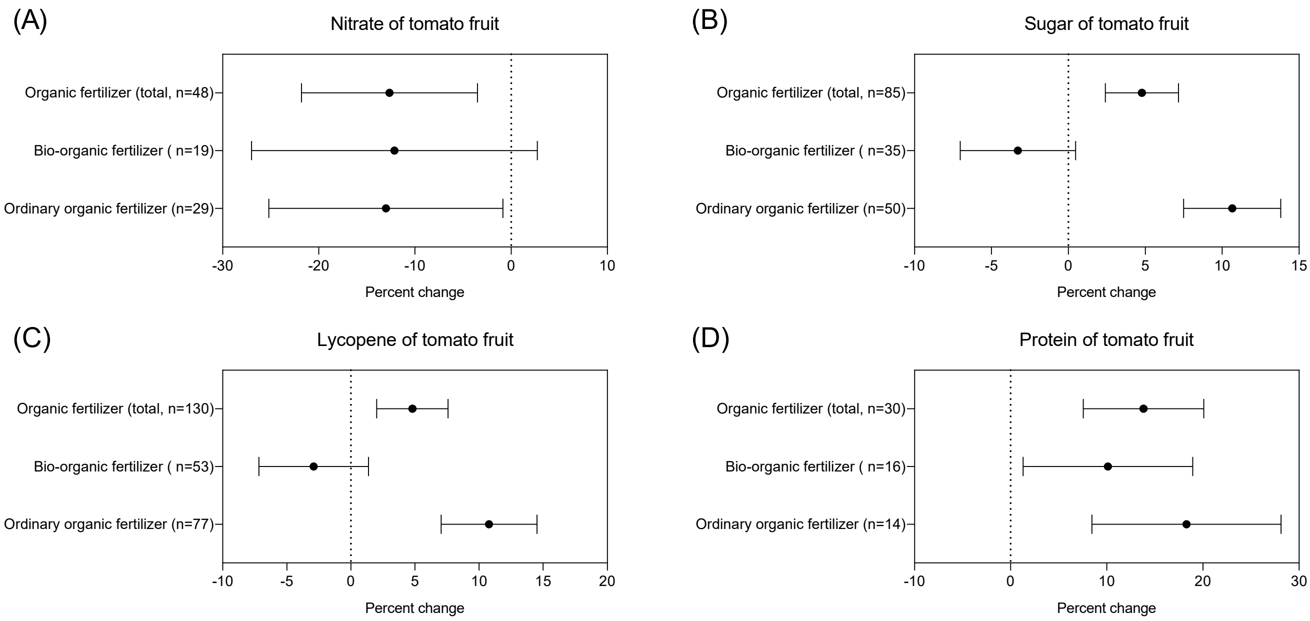

Figure 10. Global effects of organic fertilizer application on tomato quality.

3.4. Regression Analysis of Yield after Organic Fertilizer Application

The yield index is particularly important in actual production, so we specially analyzed it in the regression analysis. Due to the differences between potted plants and fields, and the differences between measurement methods, to eliminate this difference, response ratio (InR) was used as the observed value when performing regression analysis, the regression analysis was performed after one-to-one correspondence. This correlation represents the increase or decrease in output which is related to the increase or decrease of a certain indicator (i.e., InR = 0.1, indicated the increase is 10.52%). When this range is correlated, the same indicator itself is also relevant. In terms of quality indicators, yield is positively correlated with lycopene. Among the soil indicators, yield is significantly positively correlated with soil Ec. When the pH of the 100% CF is less than 6, there is a significant positive correlation between yield and pH. Similarly, there is a significant positive correlation between yield and pH when pH = 6~8, and the slopes of the two are similar (the slope of Figure 11C is 2.46, and the slope of Figure 11D is 2.79).

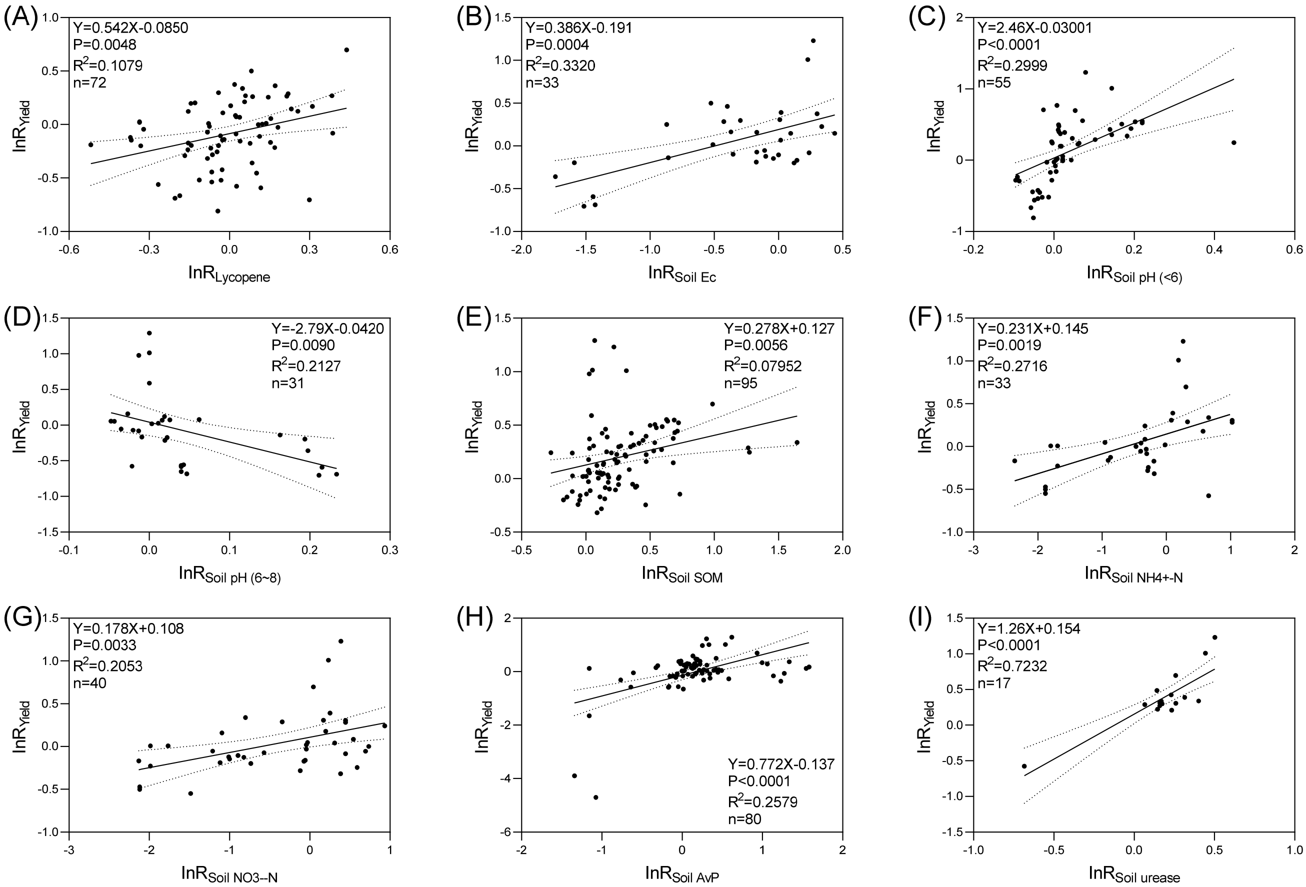

Figure 11. Regression analysis of yield after applying organic fertilizer, the straight line represents the fitting curve after one regression, and the dotted line is the 95% confidence interval.

The results of the regression analysis showed that when the pH was slightly acidic, the increase in yield was the highest. The results revealed that the application of organic fertilizers has a significant positive correlation with SOM. The slope of SOM is 0.278. Similarly, the application of organic fertilizers cannot significantly increase or decrease soil ammoniacal nitrogen and nitrate nitrogen, and the slope of NH_4^+-N (0.231) is greater than the slope of NO_3^--N (0.178), indicating that the yield increases with the increase of NH_4^+-N is greater than NO_3^--N. Among the nutrient indicators, yield has no significant correlation with total nutrients, but it is significantly positively correlated with AvP, and its slope is the highest (0.772). In addition, yield is also significantly positively correlated with soil urease (slope is 1.26). The regression analysis results showed that yield has a strong correlation with lycopene in the quality index, also when the soil electrical conductivity and AvP increases, the yield increases. Tomato yields are higher when the soil is slightly acidic. Its yield has a strong correlation with soil nitrogen-related indicators (NH_4^+-N, NO_3^--N, urease).

3.5. Correlation Analysis of Soil Properties and Tomato Yield, Fruit Quality after Application of Organic Fertilizer

Similarly, we used the response ratio (InR) of all indicators as the observed value and used the Correlation Plot in origin 2022's Apps to conduct a correlation analysis. The Correlation Type was selected as Pearson, and the significance level was selected as 0.05.

As shown in Figure 12, the correlation of output is consistent with the regression analysis results in Figure 11. Fruit nitrate was significantly positively correlated with lycopene, soil pH (<6), pH (6~8), and TK, and significantly negatively correlated with fruit sugar and soil TN. Fruit sugar was significantly positively correlated with fruit protein, soil Ec, TN, NO_3^--N, and bacteria, and significantly negatively correlated with soil NH_4^+-N. Lycopene was significantly positively correlated with soil SOM, TN, NO_3^--N, and AvK, and was significantly negatively correlated with soil NH_4^+-N. Protein was significantly positively correlated with soil SOM, and negatively correlated with Soil pH (6–8) and Soil nitrate nitrogen. Soil Ec was significantly positively correlated with Soil pH (<6), TN, TP, TK, NO_3^--N, AvP, AvK, and urease, and significantly negatively correlated with Soil pH (6~8). pH (<6) was significantly positively correlated with Soil TN, TP, TK, and NH_4^+-N, and significantly negatively correlated with soil fungi and catalase. Soil pH (6~8) was significantly negatively correlated with soil SOM and AvP. Soil SOM was significantly positively correlated with Soil TN, AvP, AvK, and bacteria, and significantly negatively correlated with soil catalase. Soil TN was significantly negatively correlated with soil TP, TK, AvP, AvK, Bacteria, and Soil catalase. Soil TP was significantly positively correlated with Soil TK, AvP, and AvK. Soil TK was significantly positively correlated with Soil NO_3^--N and fungi. Soil NH_4^+-N was significantly positively correlated with soil NO_3^--N, and significantly negatively correlated with Soil fungi. Soil NO_3^--N was significantly positively correlated with Soil AvK. Soil AvP was significantly positively correlated with Soil AvK. Soil AvK was significantly positively correlated with Soil catalase. Soil urease was significantly positively correlated with Soil catalase.

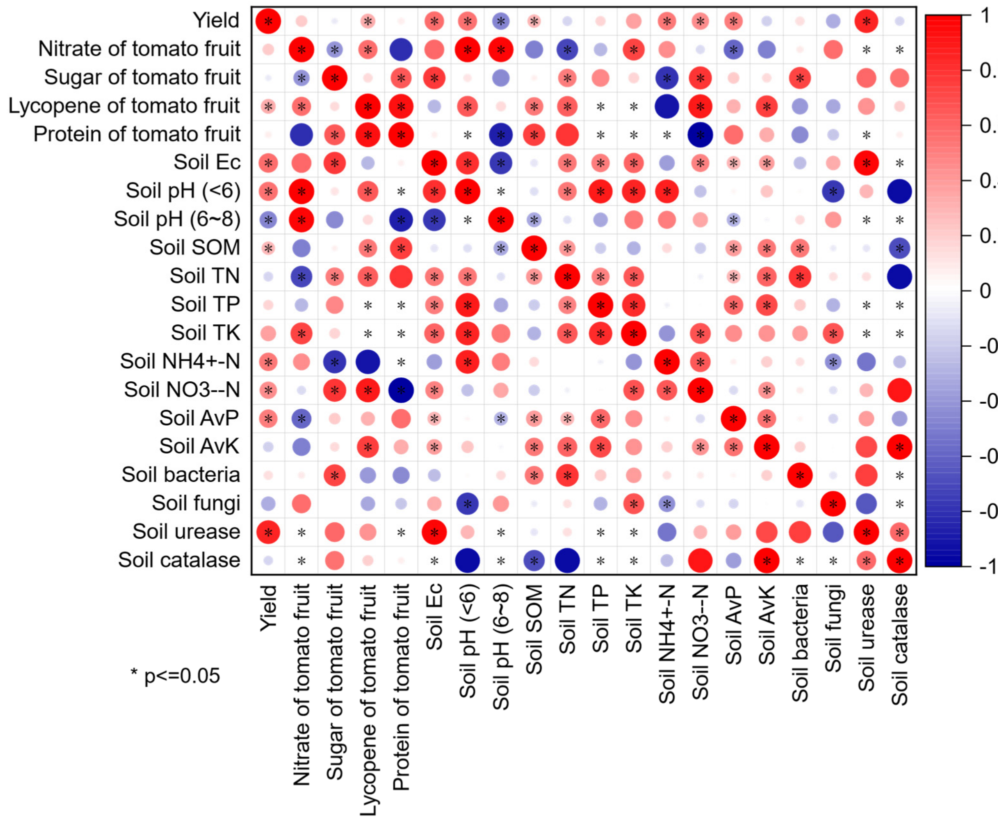

Figure 12. Correlation analysis of soil properties and tomato yield, fruit quality after application of organic fertilizer. Red indicates positive correlation, blue indicates negative correlation, darker color indicates stronger correlation, if the point is white and marked with *, it means that there is no overlap between the two datasets.

4. Discussion

4.1. Effects of Organic Fertilizer Application on Soil Properties

In our study, a meta-analysis study showed that only bio-organic fertilizers (BF) significantly reduced soil Ec by 13.66%, while ordinary organic fertilizers (OF) did not (Figure 3). Both kinds of organic fertilizers could significantly increase soil pH (acid soil, <6 and neutral soil, 6~8). In fact, the application of organic fertilizers can provide long-term fertility for agricultural production [37]. It is speculated that long term fertility is closely related to the improvement of soil conductivity through the input of organic fertilizer to avoid or reduce the risk brought by inorganic fertilizer [38]. Vermicomposting (BF) has the lowest electrical conductivity compared with other organic fertilizers [39]. Some studies have suggested that the excessive application of a certain compost (OF) in tomato planting will lead to the excessive concentration of certain ions, which ultimately leads to the death of tomatoes [40], hence indicating that some organic fertilizers do not reduce Ec but rather increase Ec. Organic fertilizers can activate soil nutrients, and thus improve soil fertility [41,42]. The biodegradation and transformation of organic matter in organic fertilizers can significantly increase the metabolic activity of microorganisms, activate soil nutrients, and promote the absorption of nutrients by crops [43]. It is evident from the meta-analysis that the application of organic fertilizers can significantly increase soil SOM, TN, TP, TK, AvP, and AvK compared with 100% CF, but it has no significant effect on NH_4^+-N and NO_3^-N (Figure 5). The effect of BF was not as good as OF on total nutrients. However, the effects of AvP and AvK were equivalent. Studies have proposed that BF can improve AvP better than OF [44]. Compared with conventional fertilization, the contents of AvN, AvP, and AvK in soil treated with organic fertilizer and microbial preparation were increased by 27.7%, 12.3%, and 133.7% [45], respectively, which fully indicated the characteristics of 100% CF leaching easily. Studies have shown that the combined application of organic fertilizers and microbial preparations can significantly increase soil pH and increase SOM, soil TN, AvN, AvP, and AvK [46,47]. The long-term application of organic fertilizers can increase microbial biomass and enzyme activity, and improve the quantity and quality of SOM [48]. Adding *Bacillus* and *Pseudomonas* to organic fertilizer can further improve soil enzyme activity and nutrient content [49]. The improvement of soil fertility is due to the propagation of microorganisms in organic fertilizers, which can regulate the accumulation and circulation of soil nutrients [50]. Organic fertilizer can improve different crops and different soils to some extent. The improvement of total soil nutrients by BF is not as good as that by OF, which may be due to the reproduction and fixation of microorganisms in BF which consume part of the organic matter and the nitrogen, phosphorus, and potassium. The increasing effect of BF in soil fertility due to AvP and AvK is equivalent to that of OF, and microorganisms play a very important role. Soil enzyme activity is very important, and this indicator contributes to revealing the mechanism of disease suppression after soil improvement with organic fertilizers [51]. Organic fertilizers can improve the number of soil microorganisms and the availability of nutrients so that crops can be better absorbed [52]. Many studies have manifested that the application of organic fertilizers can increase soil enzyme activity and soil microbial functional diversity [48,53]. Meta-analysis indicated that the application of organic fertilizers could significantly increase soil bacteria by 5.94% compared with 100% CF, however the effect on soil fungi was not significant. The application of organic fertilizers can significantly increase soil urease by 22.32% compared with 100% CF (BF is not significant), and soil catalase by 17.68% (where BF is better than OF) (Figure 7). Studies have shown that in cotton drip irrigation systems, the combined application of organic and inorganic fertilizers has the best effect on the total scale of microbial communities, whereas organic fertilizers have the greatest impact on soil enzyme activities [54]. Verstraete and Voets [55] showed that the application of animal manure plus green manure over a 7-year period substantially increased diphosphatase, urease, saccharase, and b-glucosidase activities. Compared with conventional fertilization, organic fertilizers and microbial preparations treated soil increased urease, phosphatase, sucrase and catalase activities by 86.3, 85.1, 46.6, and 33.5%, respectively. Furthermore, the number of bacteria and actinomycetes increased by 89.9 and 183.4%, respectively [45]. The effect of BF on improving soil bacteria is not as good as that of OF, which is consistent with the result that the soil SOM of BF is not as good as that of BF because the reproduction and survival of microorganisms require certain nutrients provided by organic matter in the soil. In general, all kinds of organic fertilizers improved the physicochemical and biological properties of soil. The catalase and pH of BF were better than that of OF, while the Ec, bacteria, urease, and total nutrients were lower than that of OF. This may be related to the structure and quantity of microbial communities in BF, and the specific reasons need further study.

4.2. Effects of Organic Fertilizer Application on Tomato Yield

The results of the meta-analysis revealed that the application of organic fertilizers can increase the yield by 3.48% compared with 100% CF. BF can increase the yield by 14.15%, whereas OF have no significant effect on yield (Figure 8). Studies have shown that organic fertilizers can change soil microbial community structure after fumigation. Chemical fertilizers increased strawberry yield, and increased *Fusarium* and *Phytophthora* pathogen mortality. A significant increase in strawberry yield was positively correlated with increases in beneficial microorganisms such as *Gemmatimonadetes*, *Firmicutes*, *Bacillus*, and *Flavisolibacter*. Organic fertilizers can activate beneficial microorganisms in the soil after fumigation, promote soil health, and increase fruit yield [56]. The significant impact of bio-organic fertilizers and chemical fertilizers on soil lies in the structure of soil microbial communities. Studies have shown that the application of organic fertilizers increases *Ascomycota*, which can promote the absorption of nutrient elements by plant roots and promote plant growth and development [57]. Some studies have shown that fresh chicken manure can significantly improve soil microbial substrate-induced respiration and shorten the recovery time of soil beneficial microorganisms and increase taxonomic diversity [58]. Studies have revealed that vermicomposting can produce more stable yields compared with chemical fertilizers. This can be attributed to the high proportion of degraded organic matter in vermicomposting, thus resulting in higher nutrient utilization compared with other organic amendments. Vermicomposting also contains humic acid, which can promote the release of cations and promote plant growth [59]. Vermicomposting resulted in an increase in the concentration of nitrogen-fixing microorganisms in the soil, hence the increased N availability [30]. In the production of pak choi, a combination of biological organic fertilizer and chemical fertilizer was used. The application of organic fertilizer could increase the yield, and the diversity and richness of the microorganisms were increased [60]. Organic fertilizer application increased the soil microbial community's resistance to disturbance compared with chemical fertilization or no fertilization [61–63]. This revealed that bio-organic fertilizers and common organic fertilizers have changed the community structure of soil microorganisms. The improvement methods of different organic fertilizers were different, and the community structure was related to the yield. Then soil microbial community structure interacts with crops, which affects the yield. The specific reasons for the impact need further mechanistic research.

4.3. Effects of Organic Fertilizer Application on Tomato Quality

The results of the meta-analysis showed that the application of organic fertilizers could significantly reduce fruit nitrate by 12.66%, and significantly increase fruit sugar by 4.79%, fruit lycopene by 4.80%, and fruit protein by 13.82% (Figure 10). OF showed significant effects on nitrate, sugar, lycopene, and protein, while BF only showed significant effects on protein. BF could not significantly improve the fruit quality, and it was speculated that it was related to significantly increasing the yield. In this case, the nutrient supply required by the crop was not sufficient, resulting in a lower quality than with OF. Studies have revealed that in bread wheat, grain yield is negatively correlated with its grain protein content. Quantitative trait locus (QTL) is intended to alleviate this relationship in genetic breeding [64]. A higher 1000 grain weight was negatively correlated with quality characteristics [65]. The meta-analysis revealed that the bio-organic fertilizer had significantly increased the tomato yield, but the effect was non-significant on its quality. It is evident from a study that the total contents of flavonoids, anthocyanin, and oxalic acid in strawberry fruits was higher for OF than for those in BF [66]. The application of cattle manure (OF) on dragon's head (*Lallemantia iberica* (M. Bieb.) Fisch. and C. A. Mey), produced a higher quality essential oil content than vermicomposting (BF) [67]. Similarly, the application of ordinary organic fertilizer increased total phenol, flavonoids, and DPPH antioxidant activity in Syrian cephalaria (*Cephalaria syriaca* L.), more than bio-organic fertilizer [68]. It is evident from the previous studies that bio-organic fertilizers are not as good as organic fertilizers in improving the fruit quality of different crops, but this conclusion is not universal and varied accordingly, and was thus related to the type of crops and the quality of organic fertilizers. Moreover, there is a negative correlation between the yield and quality of different crops, but this negative correlation is not certain. The effect of BF on quality improvement is not as good as that OF, and the reasons need to be further studied.

5. Conclusions

Organic fertilizers can improve soil properties, tomato yield, and fruit quality. Bio-organic fertilizers have better effects on tomato yield, soil electrical conductivity, and soil catalase activity. Common ordinary organic fertilizers have better effects on tomato quality (nitrate, sugar, tomato red element) and soil total nitrogen, phosphorus, and potassium, and soil bacteria. Both bio-organic and ordinary organic fertilizer can improve the protein content of tomato and the pH of acidic and neutral soil, and increase soil organic matter and available phosphorus and potassium, but have no significant effect on soil ammonium nitrogen, nitrate nitrogen, and soil fungi. However, the mechanism of these effects needs to be further investigated.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su15032556/s1, Table S1: The relevant test data from all around the world.

Author Contributions: Data collection and collation, H.F., Y.Z., J.L. and J.J.; Fund support and pilot guidance, L.Z. and R.Z.; Responsible for manuscript writing and chart making, H.F. and S.W.; Responsible for language polish and text modification A.W. and S.M.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by [Hainan Chengmai County 2022 high standard farmland construction project agricultural measures soil testing and fertilizer formula technical services] grant number [HD-KYH-2022079] and Priming Scientific Research Foundation of Hainan University 456 (KYQD(ZR)1987). The APC was funded by [HD-KYH-2022079].

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available upon request.

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

References

1. Barros, L.; Dueñas, M.; Pinela, J.; Carvalho, A.M.; Buelga, C.S.; Ferreira, I.C.F.R. Characterization and Quantification of Phenolic Compounds in Four Tomato (*Lycopersicon esculentum* L.) Farmers' Varieties in Northeastern Portugal Homegardens. *Plant Foods Hum. Nutr.* **2012**, *67*, 229–234. [CrossRef] [PubMed]
2. Toor, R.K.; Savage, G.P.; Heeb, A. Influence of different types of fertilisers on the major antioxidant components of tomatoes. *J. Food Compos. Anal.* **2006**, *19*, 20–27. [CrossRef]
3. FAO. *Crop Data*; Food and Agriculture Organization of the United Nations (FAO): Roma, Italy, 2018; Available online: http://www.fao.org/faostat/en/#data/QC (accessed on 25 August 2022).
4. Huo, J.; Liu, J.; Feng, H.; Wang, Y. Research progress on flavor quality of tomato fruit. *J. Chin. Veg.* **2005**, *2005*, 38–40.

5. Thompson, R.B.; Martínez-Gaitan, C.; Gallardo, M.; Giménez, C.; Fernández, M.D. Identification of irrigation and N management practices that contribute to nitrate leaching loss from an intensive vegetable production system by use of a comprehensive survey. *Agric. Water Manag.* **2007**, *89*, 261–274. [CrossRef]
6. Carrara, J.E.; Walter, C.A.; Hawkins, J.S.; Peterjohn, W.T.; Averill, C.; Brzostek, E.R. Interactions among plants, bacteria, and fungi reduce extracellular enzyme activities under long-term N fertilization. *Glob. Chang. Biol.* **2018**, *24*, 2721–2734. [CrossRef] [PubMed]
7. Wang, J.; Lu, X.; Zhang, J.; Wei, H.; Li, M.; Lan, N.; Luo, H. Intercropping perennial aquatic plants with rice improved paddy field soil microbial biomass, biomass carbon and biomass nitrogen to facilitate soil sustainability. *Soil Tillage Res.* **2021**, *208*, 104908. [CrossRef]
8. Min, J.; Zhang, H.; Shi, W. Optimizing nitrogen input to reduce nitrate leaching loss in greenhouse vegetable production. *Agric. Water Manag.* **2012**, *111*, 53–59. [CrossRef]
9. Thompson, R.B.; Incrocci, L.; van Ruijven, J.; Massa, D. Reducing contamination of water bodies from European vegetable production systems. *Agric. Water Manag.* **2020**, *240*, 106258. [CrossRef]
10. Guo, J.H.; Liu, X.J.; Zhang, Y.; Shen, J.L.; Han, W.X.; Zhang, W.F.; Christie, P.; Goulding, K.W.T.; Vitousek, P.M.; Zhang, F.S. Significant Acidification in Major Chinese Croplands. *Science* **2010**, *327*, 1008–1010. [CrossRef]
11. Tejada, M.; Garcia, C.; Gonzalez, J.L.; Hernandez, M.T. Use of organic amendment as a strategy for saline soil remediation: Influence on the physical, chemical and biological properties of soil. *Soil Biol. Biochem.* **2006**, *38*, 1413–1421. [CrossRef]
12. Liang, L.Z.; Zhao, X.Q.; Yi, X.Y.; Chen, Z.C.; Dong, X.Y.; Chen, R.F.; Shen, R.F. Excessive application of nitrogen and phosphorus fertilizers induces soil acidification and phosphorus enrichment during vegetable production in Yangtze River Delta, China. *Soil Use Manag.* **2013**, *29*, 161–168. [CrossRef]
13. Qiu, S.J.; Ju, X.T.; Ingwersen, J.; Qin, Z.C.; Li, L.; Streck, T.; Christie, P.; Zhang, F.S. Changes in soil carbon and nitrogen pools after shifting from conventional cereal to greenhouse vegetable production. *Soil Tillage Res.* **2010**, *107*, 80–87. [CrossRef]
14. Yi, X.; Yu, L.; Chang, S.-H.; Yin, C.; Wang, H.; Zhang, Z. The effects of China's Organic-Substitute-Chemical-Fertilizer (OSCF) policy on greenhouse vegetable farmers. *J. Clean. Prod.* **2021**, *297*, 126677. [CrossRef]
15. Zhou, J.; Li, B.; Xia, L.; Fan, C.; Xiong, Z. Organic-substitute strategies reduced carbon and reactive nitrogen footprints and gained net ecosystem economic benefit for intensive vegetable production. *J. Clean. Prod.* **2019**, *225*, 984–994. [CrossRef]
16. Xu, Y.; Ma, Y.; Cayuela, M.L.; Sánchez-Monedero, M.A.; Wang, Q. Compost biochemical quality mediates nitrogen leaching loss in a greenhouse soil under vegetable cultivation. *Geoderma* **2020**, *358*, 113984. [CrossRef]
17. Gruda, N.; Bisbis, M.; Tanny, J. Impacts of protected vegetable cultivation on climate change and adaptation strategies for cleaner production—A review. *J. Clean. Prod.* **2019**, *225*, 324–339. [CrossRef]
18. van Bruggen, A.H.C.; Sharma, K.; Kaku, E.; Karfopoulos, S.; Zelenev, V.V.; Blok, W.J. Soil health indicators and Fusarium wilt suppression in organically and conventionally managed greenhouse soils. *Appl. Soil Ecol.* **2015**, *86*, 192–201. [CrossRef]
19. Luan, H.; Gao, W.; Huang, S.; Tang, J.; Li, M.; Zhang, H.; Chen, X. Partial substitution of chemical fertilizer with organic amendments affects soil organic carbon composition and stability in a greenhouse vegetable production system. *Soil Tillage Res.* **2019**, *191*, 185–196. [CrossRef]
20. Kang, J.; Amoozegar, A.; Hesterberg, D.; Osmond, D.L. Phosphorus leaching in a sandy soil as affected by organic and inorganic fertilizer sources. *Geoderma* **2011**, *161*, 194–201. [CrossRef]
21. Kiruba, N.J.M.; Saeid, A. An Insight into Microbial Inoculants for Bioconversion of Waste Biomass into Sustainable "Bio-Organic" Fertilizers: A Bibliometric Analysis and Systematic Literature Review. *Int. J. Mol. Sci.* **2022**, *23*, 13049. [CrossRef]
22. Geng, Y.; Wang, J.; Sun, Z.; Ji, C.; Huang, M.; Zhang, Y.; Xu, P.; Li, S.; Pawlett, M.; Zou, J. Soil N-oxide emissions decrease from intensive greenhouse vegetable fields by substituting synthetic N fertilizer with organic and bio-organic fertilizers. *Geoderma* **2021**, *383*, 114730. [CrossRef]
23. Bender, D.J.; Contreras, T.A.; Fahrig, L. Habitat loss and population decline: A meta-analysis of the patch size effect. *Ecology* **1998**, *79*, 517–533. [CrossRef]
24. Ellenberg, S.S. Meta-analysis: The quantitative approach to research review. *Semin. Oncol.* **1988**, *15*, 472–481.
25. Liu, B.; Wang, X.; Ma, L.; Chadwick, D.; Chen, X. Combined applications of organic and synthetic nitrogen fertilizers for improving crop yield and reducing reactive nitrogen losses from China's vegetable systems: A meta-analysis. *Environ. Pollut.* **2021**, *269*, 116143. [CrossRef]
26. Chandrasekaran, M.; Subramanian, D.; Yoon, E.; Kwon, T.; Chun, S.-C. Meta-analysis Reveals That the Genus *Pseudomonas* Can Be a Better Choice of Biological Control Agent against Bacterial Wilt Disease Caused by *Ralstonia solanacearum*. *Plant Pathol. J.* **2016**, *32*, 216–227. [CrossRef] [PubMed]
27. Gattinger, A.; Muller, A.; Haeni, M.; Skinner, C.; Fliessbach, A.; Buchmann, N.; Mäder, P.; Stolze, M.; Smith, P.; Scialabba, N.E.-H.; et al. Enhanced top soil carbon stocks under organic farming. *Proc. Natl. Acad. Sci. USA* **2012**, *109*, 18226–18231. [CrossRef]
28. Ahmed, A.; Kurian, J.; Raghavan, V. Biochar influences on agricultural soils, crop production, and the environment: A review. *Environ. Rev.* **2016**, *24*, 495–502. [CrossRef]
29. He, M.; Xiong, X.; Wang, L.; Hou, D.; Bolan, N.S.; Ok, Y.S.; Rinklebe, J.; Tsang, D.C.W. A critical review on performance indicators for evaluating soil biota and soil health of biochar-amended soils. *J. Hazard. Mater.* **2021**, *414*, 125378. [CrossRef]
30. Wang, X.-X.; Zhao, F.; Zhang, G.; Zhang, Y.; Yang, L. Vermicompost Improves Tomato Yield and Quality and the Biochemical Properties of Soils with Different Tomato Planting History in a Greenhouse Study. *Front. Plant Sci.* **2017**, *8*, 1978. [CrossRef]

31. Patra, R.K.; Behera, D.; Mohapatra, K.K.; Sethi, D.; Mandal, M.; Patra, A.K.; Ravindran, B. Juxtaposing the quality of compost and vermicompost produced from organic wastes amended with cow dung. *Environ. Res.* **2022**, *214*, 114119. [CrossRef]
32. Zhou, Y.; Li, H.; Guo, W.; Liu, H.; Cai, M. The synergistic effect between biofertility properties and biological activities in vermicomposting: A comparable study of pig manure. *J. Environ. Manag.* **2022**, *324*, 116280. [CrossRef]
33. Hedges, L.V.; Gurevitch, J.; Curtis, P.S. the meta-analysis of response ratios in experimental ecology. *Ecology* **1999**, *80*, 1150–1156. [CrossRef]
34. Xiao, J.; Wang, C.; Huang, M.; Sun, N.; Zhang, W.; Xu, M. Integrated analysis of the effects of biochar on soil properties and fruit and vegetable yields in facility greenhouses. *J. Plant Nutr. Fertil.* **2018**, *24*, 228–236.
35. Jeffery, S.; Verheijen, F.G.A.; van der Velde, M.; Bastos, A.C. A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. *Agric. Ecosyst. Environ.* **2011**, *144*, 175–187. [CrossRef]
36. Higgins, J.P.T.; Thompson, S.G.; Deeks, J.J.; Altman, D.G. Measuring inconsistency in meta-analyses. *BMJ* **2003**, *327*, 557–560. [CrossRef]
37. Viator, R.P.; Kovar, J.L.; Hallmark, W.B. Gypsum and Compost Effects on Sugarcane Root Growth, Yield, and Plant Nutrients. *Agron. J.* **2002**, *94*, 1332–1336. [CrossRef]
38. Bhardwaj, D.; Ansari, M.W.; Sahoo, R.K.; Tuteja, N. Biofertilizers function as key player in sustainable agriculture by improving soil fertility, plant tolerance and crop productivity. *Microb. Cell Factories* **2014**, *13*, 66. [CrossRef]
39. Hashemimajd, K.; Kalbasi, M.; Golchin, A.; Shariatmadari, H. Comparison of Vermicompost and Composts as Potting Media for Growth of Tomatoes. *J. Plant Nutr.* **2004**, *27*, 1107–1123. [CrossRef]
40. Lazcano, C.; Arnold, J.; Tato, A.; Zaller, J.G.; Domínguez, J. Compost and vermicompost as nursery pot components: Effects on tomato plant growth and morphology. *Span. J. Agric. Res.* **2009**, *7*, 944–951. [CrossRef]
41. Wang, L.G.; Li, W.J.; Qiu, J.J.; Ma, Y.L.; Wang, Y.C. Effect of biological organic fertilizer on crops growth, soil fertility and yield. *Soils Fertil.* **2004**, *5*, 12–16.
42. Shi, H.; Tan, J.; Qin, X.; Wang, R.J. Effects of Different Bio-organic Fertilizers on Growth and Development, Yield and Quality of Flue-cured Tobacco. *China Tob. Sci.* **2014**, *2*, 74–78.
43. Nagaraju, A.; Sudisha, J.; Murthy, S.M.; Ito, S.-I. Seed priming with *Trichoderma harzianum* isolates enhances plant growth and induces resistance against *Plasmopara halstedii*, an incitant of sunflower downy mildew disease. *Australas. Plant Pathol.* **2012**, *41*, 609–620. [CrossRef]
44. Li, R.; Tao, R.; Ling, N.; Chu, G. Chemical, organic and bio-fertilizer management practices effect on soil physicochemical property and antagonistic bacteria abundance of a cotton field: Implications for soil biological quality. *Soil Tillage Res.* **2017**, *167*, 30–38. [CrossRef]
45. Zhai, Z.G.; Hu, Q.L.; Chen, J.R.; Liu, C.X.; Guo, S.; Huang, S.Q.; Zeng, W.A. Effects of combined application of organic fertilizer and microbial agents on tobacco soil and tobacco agronomic traits. In Proceedings of the 6th International Conference on Agricultural and Biological Sciences (ABS), Online, 23–26 August 2020.
46. Liu, F.; Han, D.; Zhao, M.; Xiaoyong, L.; Guan, C. Effects of application of microbial agents along with humic acid potassium on tobacco-planted soil and economic benefit of flue-cured tobacco. *Acta Agric. Zhejiangensis* **2017**, *29*, 1064–1069.
47. Li, L.I.; Han, Z.; Zhang, Y.; Yan, X.M.; Zhang, G.C.; Gao, X.D.; Zhang, Y.N.; Chao, Y.E.; Shao-Bo, L.I. Effects of Reducing Nitrogen Fertilizer Combined with Microbial Agents on Rice Root Growth and Soil Enzyme Activities. *J. Chin. Soil. Sci.* **2019**, *50*, 932–939.
48. Bending, G.D.; Turner, M.K.; Rayns, F.; Marx, M.-C.; Wood, M. Microbial and biochemical soil quality indicators and their potential for differentiating areas under contrasting agricultural management regimes. *Soil Biol. Biochem.* **2004**, *36*, 1785–1792. [CrossRef]
49. Li, B.; Guo, L.; Wang, H.; Li, Y.; Lai, H.; Wang, X.; Wei, X. Bio-Organic Fertilizers Manipulate Abundance Patterns of Rhizosphere Soil Microbial Community Structure To Improve Tomato Productivity. *Res. Sq.* **2021**, *1*, 852188. [CrossRef]
50. Ingram, L.J.; Schuman, G.E.; Stahl, P.D.; Spackman, L.K. Microbial Respiration and Organic Carbon Indicate Nutrient Cycling Recovery in Reclaimed Soils. *Soil Sci. Soc. Am. J.* **2005**, *69*, 1737–1745. [CrossRef]
51. Bonilla, N.; Gutiérrez-Barranquero, J.A.; De Vicente, A.; Cazorla, F.M. Enhancing Soil Quality and Plant Health through Suppressive Organic Amendments. *Diversity* **2012**, *4*, 475–491. [CrossRef]
52. Khan, M.S.; Zaidi, A.; Wani, P.A.; Oves, M. Role of plant growth promoting rhizobacteria in the remediation of metal contaminated soils. *Environ. Chem. Lett.* **2009**, *7*, 1–19. [CrossRef]
53. Marinari, S.; Masciandaro, G.; Ceccanti, B.; Grego, S. Influence of organic and mineral fertilisers on soil biological and physical properties. *Bioresour. Technol.* **2000**, *72*, 9–17. [CrossRef]
54. Tao, R.; Liang, Y.; Wakelin, S.A.; Chu, G. Supplementing chemical fertilizer with an organic component increases soil biological function and quality. *Appl. Soil Ecol.* **2015**, *96*, 42–51. [CrossRef]
55. Verstraete, W.; Voets, J.P. Soil microbial and biochemical characteristics in relation to soil management and fertility. *Soil Biol. Biochem.* **1977**, *9*, 253–258. [CrossRef]
56. Li, Q.; Zhang, D.; Song, Z.; Ren, L.; Jin, X.; Fang, W.; Yan, D.; Li, Y.; Wang, Q.; Cao, A. Organic fertilizer activates soil beneficial microorganisms to promote strawberry growth and soil health after fumigation. *Environ. Pollut.* **2022**, *295*, 118653. [CrossRef]
57. Toffa, J.; Loko, Y.L.E.; Kpindou, O.K.D.; Zanzana, K.; Adikpeto, J.; Gbenontin, Y.; Koudamiloro, A.; Adandonon, A. Endophytic colonization of tomato plants by *Beauveria bassiana* Vuillemin (Ascomycota: Hypocreales) and leaf damage in *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) larvae. *Egypt. J. Biol. Pest Control* **2021**, *31*, 82. [CrossRef]

58. Zhang, D.; Cheng, H.; Hao, B.; Li, Q.; Wu, J.; Zhang, Y.; Fang, W.; Yan, D.; Li, Y.; Wang, Q.; et al. Fresh chicken manure fumigation reduces the inhibition time of chloropicrin on soil bacteria and fungi and increases beneficial microorganisms. *Environ. Pollut.* **2021**, *286*, 117460. [CrossRef]
59. Carricondo-Martínez, I.; Berti, F.; Salas-Sanjuán, M.D.C. Different Organic Fertilisation Systems Modify Tomato Quality: An Opportunity for Circular Fertilisation in Intensive Horticulture. *Agronomy* **2022**, *12*, 174. [CrossRef]
60. Jin, L.; Jin, N.; Wang, S.; Li, J.; Meng, X.; Xie, Y.; Wu, Y.; Luo, S.; Lyu, J.; Yu, J. Changes in the Microbial Structure of the Root Soil and the Yield of Chinese Baby Cabbage by Chemical Fertilizer Reduction with Bio-Organic Fertilizer Application. *Microbiol. Spectr.* **2022**, *10*, e01215-22. [CrossRef]
61. Cui, X.; Zhang, Y.; Gao, J.; Peng, F.; Gao, P. Long-term combined application of manure and chemical fertilizer sustained higher nutrient status and rhizospheric bacterial diversity in reddish paddy soil of Central South China. *Sci. Rep.* **2018**, *8*, 16554. [CrossRef]
62. Francioli, D.; Schulz, E.; Lentendu, G.; Wubet, T.; Buscot, F.; Reitz, T. Mineral vs. Organic Amendments: Microbial Community Structure, Activity and Abundance of Agriculturally Relevant Microbes Are Driven by Long-Term Fertilization Strategies. *Front. Microbiol.* **2016**, *7*, 1446. [CrossRef]
63. Legrand, F.; Picot, A.; Cobo-Díaz, J.F.; Carof, M.; Chen, W.; Le Floch, G. Effect of tillage and static abiotic soil properties on microbial diversity. *Appl. Soil Ecol.* **2018**, *132*, 135–145. [CrossRef]
64. Geyer, M.; Mohler, V.; Hartl, L. Genetics of the Inverse Relationship between Grain Yield and Grain Protein Content in Common Wheat. *Plants* **2022**, *11*, 2146. [CrossRef] [PubMed]
65. Xu, Q.; Chen, W.; Xu, Z. Relationship between grain yield and quality in rice germplasms grown across different growing areas. *Breed. Sci.* **2015**, *65*, 226–232. [CrossRef]
66. Ali, Q.; Kurubas, M.S.; Ustun, H.; Balkhi, M.; Erkan, M. Evaluation of Foliar Organic Fertilizer, Biofertilizer and Biological Fungicide on the Antioxidant Compounds and Postharvest Quality Attributes of Strawberry Fruit. *Erwerbs-Obstbau* **2022**, *64*, 365–376. [CrossRef]
67. Maddahi, S.; Rahimi, A.; Moghaddam, S.S.; Pourakbar, L.; Popović-Djordjević, J. Effects of Sowing Time and Chemical, Organic, and Biological Fertilizer Sources on Yield Components and Antioxidant Properties of Dragon's Head (*Lallemantia iberica* (M. Bieb.) Fisch. & C. A. Mey). *J. Plant Growth Regul.* **2022**, *41*, 1276–1290. [CrossRef]
68. Rahimi, A.; Amirnia, R.; Moghaddam, S.S.; El Enshasy, H.A.; Hanapi, S.Z.; Sayyed, R.Z. Effect of Different Biological and Organic Fertilizer Sources on the Quantitative and Qualitative Traits of *Cephalaria syriaca*. *Horticulturae* **2021**, *7*, 397. [CrossRef]