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Suitable Soil Conditions for Tomato Cultivation under an Organic Farming System

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Abstract

This study was conducted to determine the suitable soil conditions for tomato cultivation under an organic farming system. Tomatoes were cultivated in chemically and organically fertilized experimental fields from 2013 to 2015 in Moriyama City, Shiga prefecture, Japan. Organically and chemically fertilized soils had different total carbon (TC) and total nitrogen (TN) contents, and different carbon-to-nitrogen ratios (C/N ratios). The tomato yields varied from 1290 to 5960 kg/0.1ha in the organically fertilized fields. The organic soil conditions for the highest tomato yield showed a TC content of ~33,000 mg/kg, TN content of ~1600 mg/kg, and a C/N ratio of ~21. The yield was reproducible in the organic fields under similar values of TC, TN, and C/N ratio in the soil. Significantly higher nitrogen and phosphorus circulation activities were observed in the high-yielding fields. Appropriate control of TC, TN, and C/N ratio is necessary for the enhancement of both microbial activity and tomato yield. Values of the important tomato quality parameters (lycopene, glutamic acid, and acid content) were also increased in the high-yielding tomato fields. We therefore suggest that a suitable soil condition for improving both the yield and quality of tomatoes in an organic farming system is TC of 30,000 - 36,000 mg/kg, TN of 1600 - 1900 mg/kg, and a C/N ratio of 18 - 21.

Keywords

Tomato, Bacterial Biomass, Nitrogen Circulation Activity, Phosphorus Circulation Activity, SOFIX

1. Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most important vegetables globally and is cultivated in temperate to tropical regions. Recent world production of fresh tomato fruits was 165 million tons with a value of about 60 billion US dollars in 2013 [1].

Tomato fruits contain protein, fat, carbohydrate, minerals (such as calcium, phosphorus, and iron), carotene, thiamine, nicotinic acid, riboflavin, and ascorbic acid [2]. Tomato is also an important source for vitamins A and C, carotenoids, and lycopene [3]. Lycopene helps to reduce cancer risks [4] and protects the skin from ultraviolet radiation [5]. Carotenoids are useful against breast cancer and prostate cancer [6]. Tomato is ranked among the top five vegetables in terms of antioxidant activity [7].

Tomatoes are cultivated mainly by conventional methods using chemical fertilizers and agrochemicals. A recent report showed that only 1% of agricultural fields in the world are cultivated under organic farming systems [8]. Although the yield is relatively stable in conventional farming systems, excessive use of chemical fertilizers and agrochemicals can cause severe environmental, socio-economic, and human health problems. As a result, consumer awareness towards organic foods has been increasing recently.

Organic cultivation methods cause relatively lower environmental damage if compared with conventional farming and the organic crop product is considered tasty and healthy [9]. Studies on tomato have also shown that antioxidants, flavonoids, sugar, and vitamin C are generally higher in organically grown fruits than conventionally grown fruits [10] [11] [12]. However, the yield is more unstable and/or lower in organic farming systems than conventional systems [11] [13] [14] [15]. Therefore, an alternative organic agricultural system is required to ensure high yield and quality of agricultural products. In addition, the cultivation method must be efficient, reliable, reproducible, and simple.

Soil microorganisms play several beneficial roles such as decomposing organic materials, releasing nutrients to plants, and bioremediation of pesticide polluted soils [16] [17] [18]. Therefore, soil microorganisms are considered key players in maintaining soil fertility. A large and active microorganism community is needed for efficient nutrient cycling and steady supply of nutrients to the plants. Improving soil environment by controlling the organic matter level and nutrient ratio in the soil is important for soil microorganisms [13] [19].

In our previous study, we developed a soil fertility index, SOFIX, for the evaluation of soil fertility [20]. Analysis of the SOFIX data from several agricultural fields clearly showed that the number and activities of microorganisms can be significantly enhanced by controlling total carbon (TC) and total nitrogen (TN) contents, and carbon-to-nitrogen ratios (C/N ratios) at ≥25,000 mg/kg, ≥2500 mg/kg, and 10 - 25, respectively. However, the relationship between microbial activities and plant growth remains unknown. The objective of this study was to determine suitable soil conditions for improving the yield and quality of tomato under an organic farming system by enhancing the number and activities of soil microorganisms.

2. Materials and Methods

2.1. The Study Site

This study was carried out in agricultural fields located in Moriyama, Shiga prefecture, Japan (35˚5'33.85"N, 135˚58'28.57"E). The experiments were performed in three consecutive years from 2013 to 2015 to confirm the reproducibility under seasonal fluctuation. Moriyama has a humid temperate climate, where July is the warmest month and January is the coolest. Weather data of the nearest meteorological station (Hikone, Shiga, Japan) from the experimental field during the tomato growth period is shown in **Figure 1**. The initial physico-chemical properties of soil in the experimental field are shown in **Table 1**.

2.2. Cultivation of Tomato in the Fields under Chemical and Organic Farming Systems

In our previous study, we found that microorganisms and nutrient cycling activities in the soil are highly enhanced at TC ≥ 25,000 mg/kg and C/N ratios from 10 to 25 in soil [20]. In this study, the soil conditions suitable for enhancing the activity of microorganisms were examined for tomato cultivation. Seven organic and two chemical experimental conditions were prepared by using 3 field compartments in 2013 to 2015 (**Table 2**). Organic experimental fields were prepared with TC from 27,500 to 58,000 mg/kg, TN from 1000 to 4300 mg/kg, and C/N ratio from 13 to 30 (Fields A and B in 2013, Fields C and D in 2014, and Fields G, H, and I in 2015). To provide different TC, TN, and C/N ratio in the organic fields, cow manure, chicken manure, and soybean meal were used. The nutrient contents in the organic fertilizers are shown in **Table 3**.

In 2013 and 2014, a control experiment was simultaneously carried out using the chemical fertilization plan recommended for tomato by Shiga prefecture, Japan (200:180:250 kg N:P_2O_5:K_2O per ha) (Field E in 2013 and Field F in 2014). A half dose of N and full doses of P and K were applied on the day of transplanting and the remaining half dose of N was top dressed after one month. Following chemical fertilizers were used: ammonium sulfate (21% N), single super phosphate (17.5% P_2O_5), and potassium sulfate (50% K_2O). The differences in TC, TN, and C/N ratio between the two chemical fields was due to the seasonal effect.

Each field was 24 m^2 (6 m × 4 m) and had 6 plant rows with 60 plants (10 plants per row). Fields were 1 m apart to prevent interaction between the treatments. One-month old seedlings of tomato (cv. Momotaro) were transplanted in May. The seedlings were purchased from TAKII & Co. Ltd., Kyoto, Japan. No pesticides were used in both chemical and organic fields. Black plastic mulch was used to control weeds and conserve the soil moisture.

2.3. Harvesting and Yield Measurement

Tomatoes were harvested once the fruits turned light red. In all years, harvesting began at the end of June and lasted until the beginning of August. The fresh

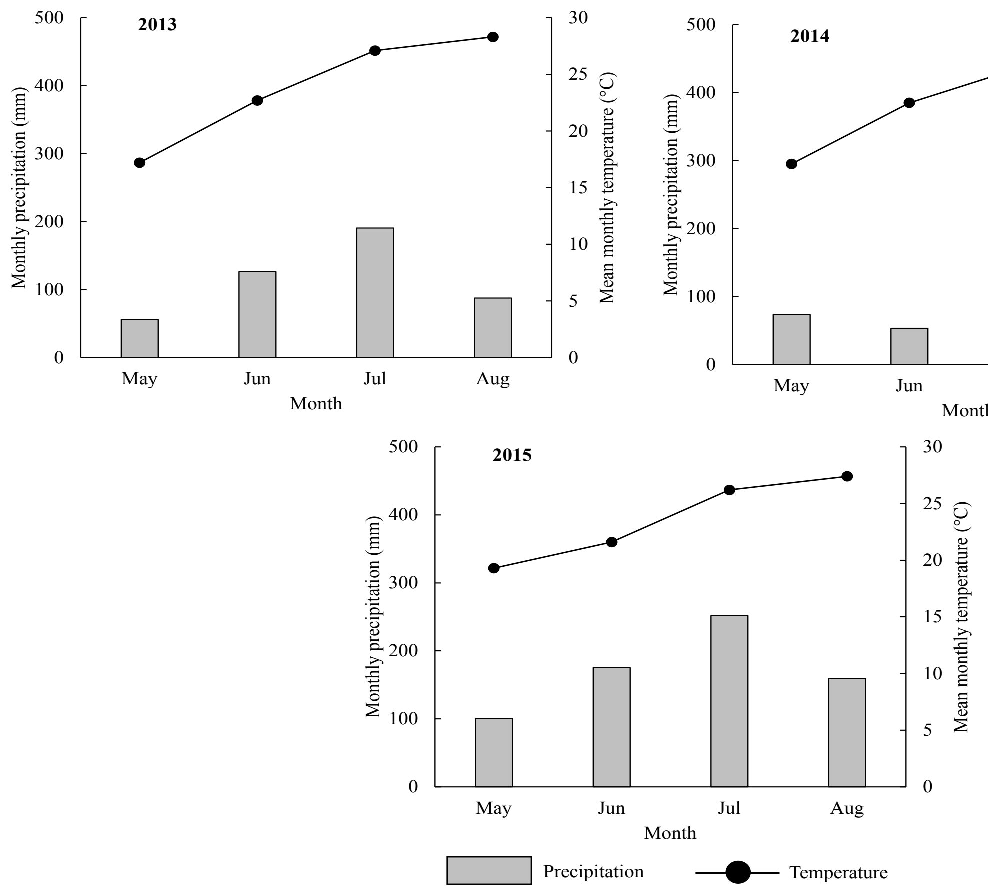

Figure 1. Weather data of the nearest meteorological station from the experimental field (Hikone, Shiga) during tomato growing months in 2013 to 2015. Precipitation (mm) (▭) and mean monthly temperature (˚C) (—●—) from May to August are shown. (Source: Japan Meteorological Agency (http://www.data.jma.go.jp)).

Table 1. Initial physico-chemical properties of soil of the experimental field.

Soil property	Value or type
Texture	Sandy loam
pH (1:2.5; soil-to-water, w/v)	5.5 (±0.10)
Bulk density (dry) (g/cm^3)	1.53 (±0.04)
TC (mg/kg)	20,000 (±1730)
TN (mg/kg)	900 (±130)
C/N ratio	22 (±4)
TP (mg/kg)	1090 (±66)
TK (mg/kg)	3330 (±210)

Value in parenthesis followed by ± is standard deviation (n = 3).

weight of the harvested tomato was recorded. On the last day, all remaining fruits were also picked for weighing.

2.4. Analysis of Soil Properties

Soil analysis was done using a composite sample taken from 5 randomly selected points in a field. The following soil properties were analyzed: TC, TN, total

Table 2. Farming system and soil condition in this study.

Year	Experimental field	Farming system	TC (mg/kg)	TN (mg/kg)	C/N ratio
2013	A	Organic	57,000^{a} (±2650)	2800^{b} (±170)	20^{bc} (±2.1)
	B	Organic	58,000^{a} (±2000)	4300^{a} (±270)	13^{d} (±0.4)
	C	Chemical	20,000^{d} (±1730)	900^{e} (±130)	22^{b} (±3.2)
2014	D	Organic	27,500^{c} (±1320)	1400^{d} (±100)	20^{bc} (±0.6)
	E	Organic	36,000^{b} (±1730)	1900^{c} (±170)	19^{bc} (±2.4)
	F	Chemical	16,000^{d} (±1730)	1000^{e} (±120)	16^{cd} (±3.5)
2015	G	Organic	31,000^{bc} (±2000)	1000^{e} (±170)	30^{a} (±4.2)
	H	Organic	33,000^{bc} (±1730)	1600^{cd} (±100)	21^{bc} (±1.6)
	I	Organic	30,000^{bc} (±1730)	1700^{cd} (±87)	18^{bc} (±1.9)

Means followed by same letter do not significantly differ ($p < 0.05$, Tukey's test). Value in parenthesis followed by ± is standard deviation ($n = 3$).

Table 3. The nutrient contents in the organic fertilizersused in this study.

Organic fertilizer	TC (mg/kg)	TN (mg/kg)	C/N ratio
Cow manure	199,500^{b} (±20,560)	11,580^{c} (±940)	17^{a} (±0.5)
Chicken manure	240,900^{b} (±19,300)	35,410^{b} (±2630)	7^{b} (±0.1)
Soybean meal	446,800^{a} (±12,870)	76,970^{a} (±1490)	6^{b} (±0.2)

Means followed by same letter do not significantly differ ($p < 0.05$, Tukey's test). Value in parenthesis followed by ± is standard deviation ($n = 3$).

phosphorus (TP), total potassium (TK), total bacterial biomass, N circulation activity, and P circulation activity. The TC was analyzed using a TOC analyzer (Model: SSM-5000A, Shimadzu, Kyoto, Japan). The TN, TP, and TK were analyzed by extracting soil samples using the Kjeldahl digestion method followed by analysis using the indophenol blue method, molybdenum blue method, and atomic absorption spectrophotometry, respectively [20].

The total bacterial biomass in soil was estimated by quantification of environmental DNA (eDNA) extracted by using the slow-stirring method [21]. The extracted eDNA was quantified based on the intensity of the eDNA bands after electrophoresis on agarose gel using Kodak 1D 3.6 Image Analysis Software (Kodak, CT, USA). The bacterial biomass in the soil was estimated by using the equation $Y = 1.70 \times 10^{8} X$ ($r^2 = 0.96$), where Y and X are the bacterial biomass g^{-1} soil and the amount of eDNA, respectively.

The N circulation activity was analyzed based on the values of ammonium oxidation activity, nitrite oxidation activity, and the total bacterial biomass [20]. The bacterial biomass of 6.0×10^{8} cells·g^{-1} was defined as 100 points. Using the scores of bacterial biomass, ammonium oxidation rate, and nitrite oxidation rate, a radar chart was constructed, and the relative area of the inner triangle was expressed as the N circulation activity.

The area of the triangle in the radar chart was calculated as follows:

$$\text{Area} = \frac{(a \times b) + (b \times c) + (c \times a)}{4} \times \frac{\sqrt{3}}{100}$$

where, *a*, *b*, and *c* denote scores of bacterial biomass, ammonium oxidation rate, and nitrite oxidation rate, respectively. The area of the outer triangle was calculated by the maximum values and the inner one was by the measured scores.

Nitrogen circulation activity was analyzed by calculating the relative area of inner triangle as follows:

$$N \text{ circulation activity} = \frac{\text{Area of the inner triangle}}{\text{Area of the outer triangle}} \times 100$$

Similarly, the *P* circulation activity was estimated using the methods of Horii *et al.* [22] by analyzing the rate of mineralization of organic P from the substrate (sodium phytate) during an incubation period of 3 days at 25˚C.

Soil texture was analyzed with the hydrometer method [23] using a Bouyoucos Hydrometer (type 152H). The pH and electrical conductivity (EC) were analyzed using a pH meter (LAQUA F-72, Horiba, Kyoto, Japan) and an EC meter (5LE1-408, Kenis, Hyogo, Japan), respectively, in a 1:2.5 soil-to-water suspension (w/v).

2.5. Analysis of Tomato Fruit Quality

A composite sample of at least three tomato fruits from each treatment were mixed using a grinder. The fruit suspension was kept in a freezer (−20˚C) until lycopene, glutamic acid, antioxidants, sugar, and acid analysis.

2.5.1. Lycopene Analysis

Lycopene in tomato was estimated following the procedures of Fish *et al.* [24]. A tomato fruit suspension (about 0.5 g) was placed in a 50-mL brown glass vial. Subsequently, 5 mL of 0.05% but ylated hydroxytoluene (w/v in acetone), 5 mL of 95% ethanol and 10 mL of hexane were added to the vial. The vial was shaken reciprocally at 150 rpm for 15 min under cool conditions. After shaking, the mixture was allowed to stand for 5 min at room temperature. The upper layer (hexane layer) was taken for spectrophotometric analysis (503 nm). The lycopene concentration in the fruit suspension was calculated as follows based on the sample weight:

$$\text{Lycopene concentration}\left(\text{mg/100 g}\right) = \frac{\text{Absorbance at 503 nm} \times 536.9}{17.2 \times 10 \times \text{sample weight}\left(\text{g}\right)}$$

where, 17.2 is molar extinction coefficient of lycopene in hexane and 536.9 is molecular weight of lycopene.

2.5.2. Glutamic Acid Content and Polygalacturonase Activity

Glutamic acid in tomato fruit suspension was determined using a Yamasa L-glutamic acid measurement kit II (Cosmo Bio Co. Ltd., Tokyo, Japan) according to the manufacturer's instructions. Polygalacturonase activity was analyzed according to the procedures of [25] [26].

2.5.3. Water-Soluble Antioxidants Concentration

The water-soluble antioxidants concentration was estimated spectrophotometrically using the molybdenum blue method. The diluted tomato fruit suspension was combined with 1 mL of ammonium molybdate solution (0.6 M sulfuric acid, 30 mM disodium phosphate, and 4 m Mhexaammoniumheptamolybdate, in water) and incubated at 90˚C for 1 h. The absorbance of the solution was then measured at 695 nm. A standard curve was prepared against the known concentrations of ascorbic acid.

2.5.4. Sugar and Acid Contents

The sugar content (Brix) was analyzed using a DBX-55 refractometer (Atago, Tokyo, Japan). The acid content was determined by titrating the fruit extract with 0.1 M sodium hydroxide until pH 4.1 was reached based on pH meter readings (LAQUA F-72, Horiba, Kyoto, Japan). Since about 80% of the total organic acid is citric acid in tomato [27], acid content was calculated in terms of citric acid following the procedures of Garner *et al.* [28].

2.6. Statistical Analysis

All analyses were carried out in 3 replicates. Statistically significant differences were identified using ANOVA/Tukey's test. Temporal differences in bacterial biomass, N circulation activity, and P circulation activity in 2015 experiment were compared using t-test.

3. Results

3.1. Effect of Soil Conditions on Growth and Yield of Tomato

To investigate suitable organic soil conditions for tomato cultivation, the effects of soil conditions on tomato growth and yield were investigated. Soil conditions (TC, TN, and C/N ratio), microbial biomass in soil, and tomato yield in organic (Fields A, B, D, and E) and chemical fields (Fields C and F) are shown in **Table 4**. The average tomato yields in organic fields ranged between 1290 to 5380 kg/0.1 ha. Among the four organic fields, the yields in Fields A and B were significantly lower than those in Fields D and E. Compared with the average tomato yield cultivated in Shiga prefecture, Japan (2470 kg/0.1 ha), the yields in the organic fields (Fields A and B) in 2013 were 48% to 36% lower, whereas yield of tomatoes cultivated in the Fields D and E in 2014 were 118 and 45% higher, respectively. The bacterial biomass in organic fields was $\geq 10.2 \times 10^8$ cells/g.

Although the environmental condition is an important factor for plant growth, microbial biomass and nutrient cycling activities are mainly affected by TC, TN, and C/N ratio [20]. The role of microorganisms and nutrient cycling activity are crucial for the plant growth in organic farming systems. Therefore,

Table 4. Bacterial biomass and tomato yield in the experimental fields of 2013 and 2014. Bacterial biomass was analyzed one week after fertilizer application.

Year	Experimental field	Bacterial biomass ($\times10^8$ cells/g)	Yield (kg/0.1 ha)	*Relative yield (%)
2013	A	10.2^{bc} (±0.36)	1580^{de} (±62)	64
	B	11.5^{b} (±0.87)	1290^{e} (±110)	52
	C	7.4^{c} (±0.30)	1750^{d} (±56)	71
2014	D	15.3^{a} (±2.07)	3580^{b} (±130)	145
	E	12.6^{ab} (±2.14)	5380^{a} (±160)	218
	F	13.7^{ab} (±0.98)	2500^{c} (±69)	101

Means followed by same letter do not significantly differ ($p < 0.05$, Tukey's test). Value in parenthesis followed by ± is standard deviation (n = 3). *Relative yield in each field was calculated with reference to the average tomato yield of 2470 kg/0.1ha in Shiga prefecture from 2009 to 2013 (source: database of Ministry of Agriculture, Forestry and Fisheries, Japan (available at: http://www.maff.go.jp)).

we analyzed the yield of tomato grown in 2 years in relation to TC, TN, and C/N ratio.

The tomato yield was highly affected by the soil conditions (TC, TN, and C/N ratio) in the organic fields. The yield was significantly highest in Field E having TC 36,000 mg/kg, TN 1900 mg/kg, and C/N ratio 19, but significantly low yield was observed in the fields A and B having high levels TC (57,000 to 58,000 mg/kg) and TN (2800 to 4300 mg/kg). Although the tomato yields were low in Fields A and B, the shoot yields (stem and leaf, without fruits) were higher than those in the chemically fertilized field (data not shown). These results suggest that TN contents in Fields A and B were too high for tomato cultivation. From these cultivation results, TC around 36,000 mg/kg, TN around 1900 mg/kg, and C/N ratio about 20 seem to be suitable organic soil conditions for high tomato yield.

3.2. Reproducibility of Soil Conditions for Tomato Cultivation

To examine the reproducibility of the most suitable soil conditions for tomato cultivation observed in the previous experiment (*i.e.*, TC 36,000 mg/kg and C/N ratio 20), three organic fields with similar TC but different C/N ratio were prepared. The bacterial biomass and tomato yield in the three organic fields (Fields G, H, and I) are shown in **Table 5**. In the fields, bacterial biomass was $\geq 9.0 \times 10^8$ cells/g. The tomato yields were significantly higher in Field H (5960 kg/0.1 ha) and Field I (5540 kg/0.1ha) compared to that in Field G (3170 kg/0.1ha), but the yield in Field G was still higher than the regional average yield (2470 kg/0.1 ha). In addition, the values of TC, TN, and C/N ratio in Fields H and I were similar to those in the high yielding field (Field E) of previous experiment (**Table 2**). These results confirm that a high tomato yield can be achieved by maintaining the soil conditions similar to those of Fields H and I.

Table 5. Bacterial biomass and yield of tomato in the experimental fields of 2015. Bacterial biomass was analyzed one week after organic fertilizer application.

Year	Experimental field	Bacterial biomass ($\times 10^8$ cells/g)	Yield (kg/0.1 ha)	*Relative yield (%)
2015	G	11.0^{ab} (±0.44)	3170^{b} (±210)	128
	H	9.0^{b} (±1.10)	5960^{a} (±390)	241
	I	12.0^{a} (±0.92)	5540^{a} (±430)	224

Means followed by same letter do not significantly differ ($p < 0.05$, Tukey's test). Value in parenthesis followed by ± is standard deviation ($n = 3$). *Relative yield in each field was calculated with reference to the average tomato yield of 2470 kg/0.1 ha in Shiga prefecture from 2009 to 2013 (source: database of Ministry of Agriculture, Forestry and Fisheries, Japan (available at: http://www.maff.go.jp)).

3.3. Relationship among Yield and Quality of Tomato and Nutrient Circulation Activities in Soil

The quality of tomato was also analyzed in the three organic fields in 2015 (Fields G, H, and I) and compared with the yield (**Figure 2**). Lycopene and glutamic acid contents in Fields H and I (soil TN 1600 mg/kg and 1700 mg/kg) were significantly higher than those in Field H (soil TN 1000 mg/kg). In contrast, no significant differences in antioxidant content, polygalacturonase activity, and sugar content were observed among the three fields, but the acid content in Field G was slightly lower than in Field I. Therefore, the soil conditions of Fields H and I would improve both yield and quality in tomato cultivation.

Bacterial biomass and nutrient circulation activities were examined in the three organic fields of 2015 (**Figure 3**). The bacterial biomass in the fields ranged from 9.0×10^8 to 1.4×10^9 cells/g-soil. No relationship between bacterial biomass and tomato yield was observed, but the N and P circulation activities were significantly higher in Fields H and I (higher tomato yields) than those in Field G (lower tomato yield). The results suggest that high levels of N and P circulation activities in soil contributes for the enhancement of tomato yield and quality.

3.4. Analysis of Suitable Soil Conditions for Tomato Cultivation under an Organic Farming System

To find the suitable soil conditions for tomato cultivation under an organic farming system, soil properties in the three experimental fields of 2015 (Fields G, H, and I) were analyzed (**Table 6**). In the high-yielding fields (Fields H and I), available nitrogen (ammonium and nitrate) and electrical conductivity (EC) were significantly higher than those in the low yielding field (Field G). The tomato quality parameters (lycopene, glutamic acid, and acid contents) were also higher in Fields H and I. Based on a series of the experiments, for tomato cultivation in the organic farming system, TC and TN in soil should be enhanced by organic materials but higher C/N ratio seems to reduce the tomato yield. Therefore, the following soil properties were identified as suitable conditions for tomato cultivation under an organic farming system: TC of 30,000 - 36,000 mg/kg, TN of 1600 to 1900 mg/kg, C/N ratio of 18-21, TP of 1000 - 1500 mg/kg, and TK of 3000 - 4000 mg/kg.

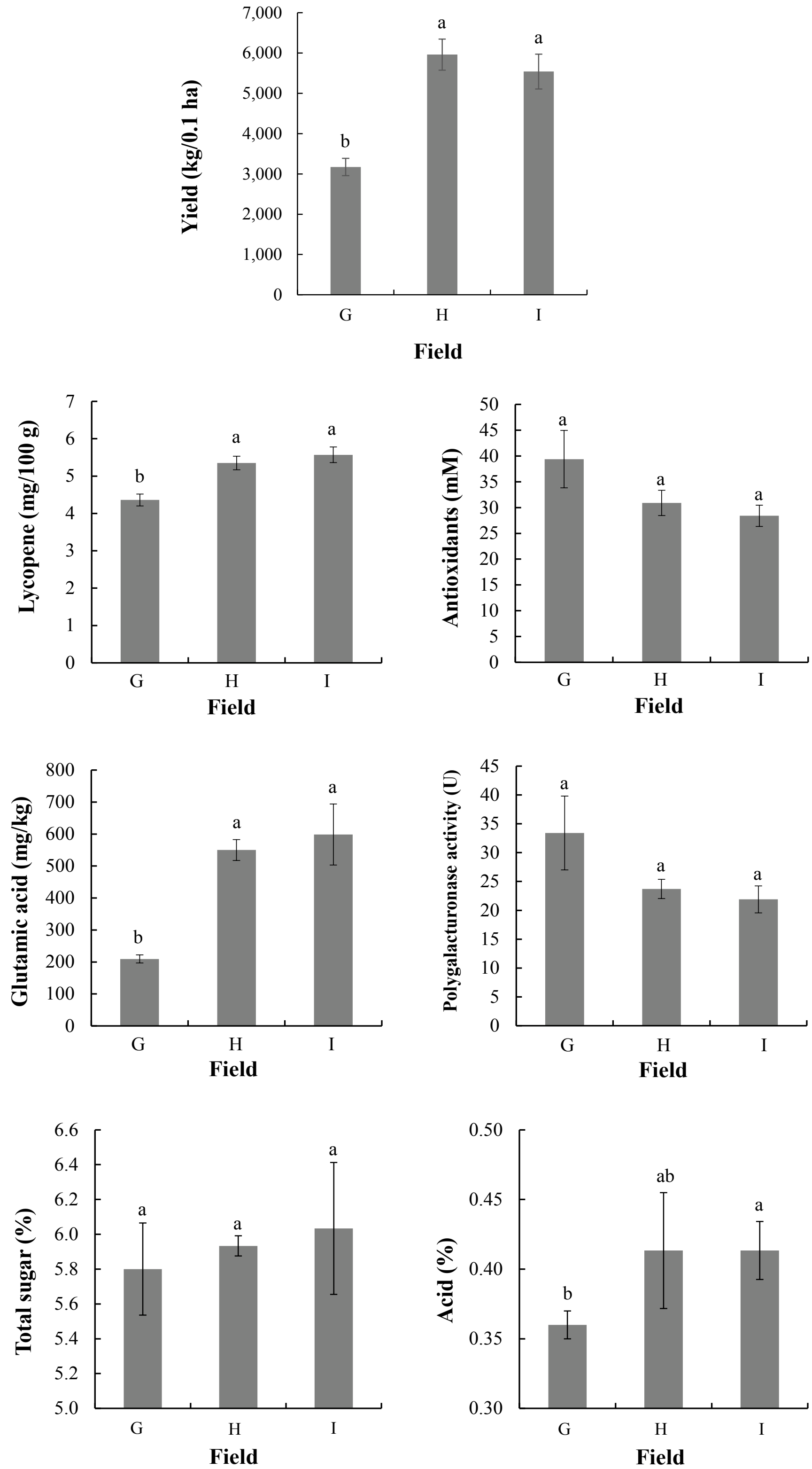

Figure 2. Yield and quality of tomato in the three experimental fields of 2015. Yield (kg/0.1 ha), lycopene (mg/100 g), antioxidants (mM), glutamic acid (mg/kg), polygalacturonase activity (U), total sugar (%), and acid (%) of Fields G, H, and I are shown. Each value is an average of three replications. Error bars denote the standard deviation. Values with same letter do not significantly differ ($p < 0.05$, Tukey's test).

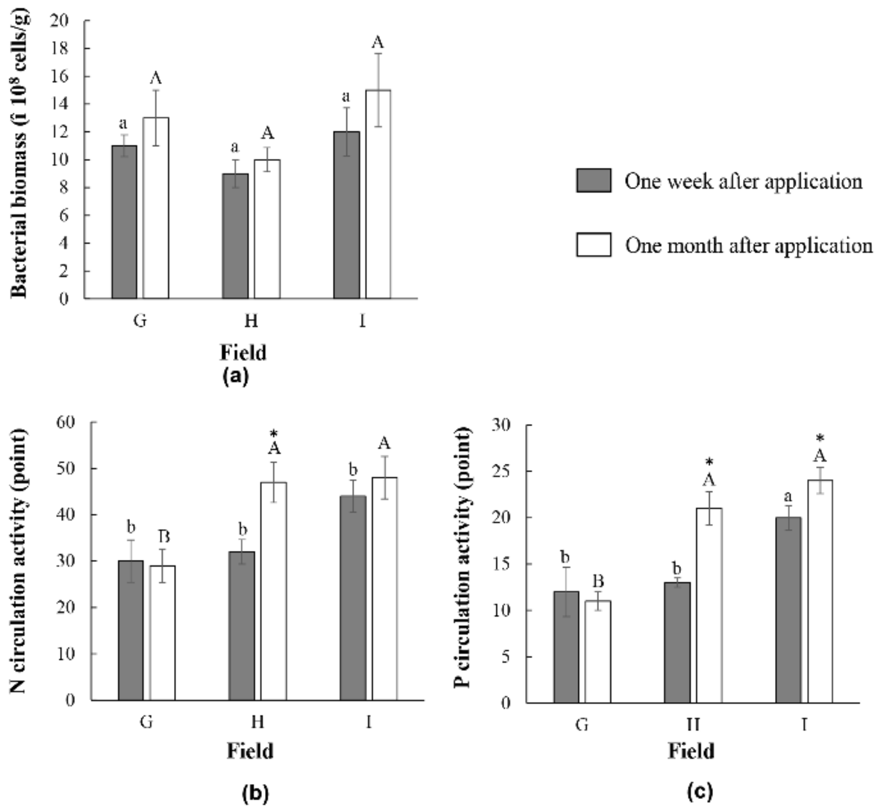

Figure 3. Microbiological properties of soil in three experimental fields of 2015. Bacterial biomass ($\times 10^8$ cells/g) (a), N circulation activity (point) (b), and P circulation activity (point) (c) of Fields G, H, and I are shown. Bars filled with solid gray ( ) and with horizontal lines ( ) indicate the values at one week and one month after organic fertilizer application, respectively. Values with same letter in an observation period (lowercase for one week and uppercase for one month) do not significantly differ ($p < 0.05$, Tukey's test). Asterisk (*) indicates significant difference between two observation periods in the same field ($p < 0.05$, t-test).

4. Discussion

Recent reports show that only 1% of agricultural fields in the world are cultivated under an organic farming system [8]. This is typically because the yields under organic farming are unstable or because a successful organic cultivation requires several years of experience [11] [13] [14] [15]. In the current study, we investigated the suitable soil conditions for tomato cultivation under an organic farming system.

Soil microorganisms play several beneficial roles in cultivated land such as decomposition of organic materials, nitrification, and P mineralization. Therefore, microorganisms are important parameters for soil fertility. In our previous study, we showed that TC, TN, and C/N ratio are closely related to the bacterial biomass and nutrient cycling activities in soil [20] [29] Enhancement of microorganisms and their activities are more important under organic systems than under conventional systems, because microorganisms help to supply nutrients to plants by decomposing the added organic materials. Properly controlled TC, TN

Table 6. Relationship between soil properties and tomato yield in the experimental fields of 2015. Soil properties analyzed after one week of organic fertilizer application are shown.

Soil property and tomato yield	Field G	Field H	Field I
Total nutrient amount and ratio			
TC (mg/kg)	31,000^a (±2000)	33,000^a (±1730)	30,000^a (±1730)
TN (mg/kg)	1000^b (±170)	1600^a (±100)	1700^a (±87)
C/N ratio	31^a (±4.2)	21^b (±1.6)	18^b (±1.9)
TP (mg/kg)	900^b (±36)	1100^b (±44)	1400^a (±140)
TK (mg/kg)	3450^a (±53)	3500^a (±92)	3700^a (±230)
Soluble nutrient			
NH_4^+-N (mg/kg)	45^b (±6.6)	83^a (±8.2)	63^{ab} (±7.0)
NO_3^--N (mg/kg)	8^c (±2.0)	41^b (±4.4)	60^a (±6.6)
Soluble P (mg/kg)	14^a (±3.6)	21^a (±6.6)	23^a (±4.6)
Soluble K (mg/kg)	46^a (±4.7)	46^a (±8.5)	29^b (±6.2)
pH and EC			
pH (1:2.5 soil-water; w/v)	5.9^a (±0.15)	5.8^a (±0.05)	5.7^a (±0.10)
EC (ds/m)	0.1^b (±0.02)	0.4^a (±0.10)	0.4^a (±0.04)
Tomato yield (kg/0.1 ha)	3170^b (±240)	5960^a (±390)	5540^a (±430)

Means followed by same letter do not significantly differ ($p < 0.05$, Tukey's test). Value in parenthesis followed by ± is standard deviation ($n = 3$).

and C/N ratios result in a high level bacterial biomass and enhanced N and P circulation activities.

Generally, the yields under organic systems are either unstable or lower compared to those in the conventional systems [11] [13] [14] [15]. Nitrogen availability is the most important in limiting yield of tomato under organic farming systems [30]. A previous study demonstrated that high level of tomato yields under organic farming systems than that under conventional systems was associated to the high nitrogen mineralization rate and higher microbial diversity in soils under organic systems [31]. In this study, we found that properly controlled TC, TN, and C/N ratio and high levels of N circulation activity and P circulation activity resulted into higher tomato yield in the organic fields compared to the chemically fertilized fields. Therefore, enhancement of the number and activities of microorganisms by maintenance of the soil condition (especially TC, TN, and C/N ratio) seem necessary for achieving high yield of tomato from organic farming systems.

Organic crop products are typically considered to be of high quality [9] [32]. In general, quality and quantity are oppositely related in crop products obtained under conventional farming systems [33]. In this study, lycopene, glutamic acid, and acid contents in tomato fruit seemed to be enhanced in the high-yielding organic fields. Lycopene is a major antioxidant component [34], and glutamic acid, sugar, and acidity are the major taste indicators in tomato [35]. Enhancement of sugar and organic acid contents in organically produced tomatoes have also been reported previously [36]. Therefore, appropriate soil conditions in organic systems not only enhance the yield of tomato but also can improve the quality.

A suitable organic soil condition of tomato would be also effective for other vegetable fruits. In this point, the amount of TN and the balance of C/N in soil are most important, because higher C/N ratio inhibits reproduction and enhances vegetative growth (**Table 4**). However, crop production could be increased only after the organic soil enhances activities of microorganisms maintaining appropriate nutrients for plants.

5. Conclusion

In this experiment, a suitable soil condition for increasing the yield of tomatoes in an organic farming system was determined as TC of 30,000 - 36,000 mg/kg, TN of 1600 - 1900 mg/kg, and a C/N ratio of 18 - 21. The quality of tomato also seems to be changed by soil environmental condition.

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Conflict of Interest

The authors declare no conflicts of interest in this paper.

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