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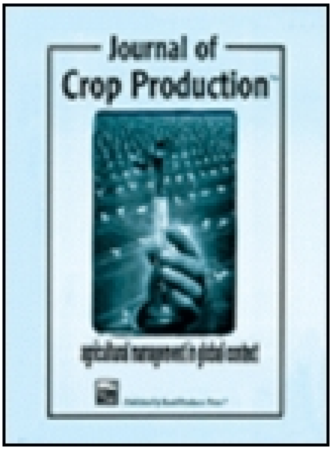

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Effects of Organic Fertilizers and a Microbial Inoculant on Leaf Photosynthesis and Fruit Yield and Quality of Tomato Plants

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Effects of Organic Fertilizers and a Microbial Inoculant on Leaf Photosynthesis and Fruit Yield and Quality of Tomato Plants

Hui-lian Xu
Ran Wang
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SUMMARY. An experiment was conducted to examine the effects of applications of an organic fertilizer (bokashi), and chicken manure as well as inoculation of a microbial inoculant (commercial name, EM) to bokashi and chicken manure on photosynthesis and fruit yield and quality of tomato plants. EM inoculation to both bokashi and chicken manure increased photosynthesis, fruit yield of tomato plants. Concentrations of sugars and organic acids were higher in fruit of plants fertilized with bokashi than in fruit of other treatments. Vitamin C concentration was higher in fruit from chicken manure and bokashi plots than in those from chemical fertilizer plots. EM inoculation increased vitamin C concentration in fruit from all fertilization treatments. It is concluded that both fruit quality and yield could be signifi-

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cantly increased by EM inoculation to the organic fertilizers and application directly to the soil. *[Article copies available for a fee from The Haworth Document Delivery Service: 1-800-342-9678. E-mail address: getinfo@haworthpressinc.com <Website: http://www.HaworthPress.com>]*

KEYWORDS. Effective microorganisms, EM, nature farming, organic farming, sugar, organic acid, tomato

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INTRODUCTION

Excessive use of chemical fertilizers has caused many problems in environmental pollution and soil degradation. With these concerns, many farmers in Japan have adopted nature farming practices. The concept and principles of nature farming were proposed by Mokichi Okada more than 60 years ago (Okada, 1993). Because chemical fertilizers and untreated animal products are not allowed in nature farming systems for crop and vegetable production, it is not easy to achieve yields equal to or higher than those obtained with chemical fertilizers. First, the growers must seek an alternative nutrient source. An organic fertilizer often used by farmers is called bokashi, which is a fermented mixture of oilseed cake, rice bran and fish-processing by-product (Yamada et al., 1996). A microbial culture called Effective Microorganisms or EM is often inoculated into bokashi before fermentation (Higa, 1994). This kind of organic fertilizer with EM inoculated is called EM bokashi. EM bokashi has been to be a useful nutrient source, but the other aspects of EM bokashi need to be elucidated. Therefore, a research project was initiated to examine the performance of EM bokashi in vegetable production. The first experiment was conducted to examine the effects of EM inoculation to bokashi and chicken manure on fruit yield and quality of tomato plants.

MATERIALS AND METHODS

Materials and Treatments

Tomato (*L. esculentum* L. cv. Momotaro T 96) seedlings with 5 leaves were transplanted into plastic pots each with a surface area of 0.02 m^2 and a height of 0.25 m. The pots were arranged randomly in a glasshouse. Six fertilization treatments each with 33 pots were as follows: (1) chicken manure; (2) chicken manure with EM (effective microorganisms, EM1) inoculated before fermentation; (3) anaerobic bokashi (anaerobically fermented organic materials such as rice bran, rapeseed mill cake and fish processing

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by-product); (4) anaerobic bokashi with EM inoculated before fermentation; (5) chemical fertilizer (ammonium sulfate 5.3 g, superphosphate 13 g and potassium sulfate 5 g per pot; and (6) the same amount of chemical fertilizer as in treatment (5) with 80 ml EM applied together. The amounts of N-P-K were adjusted to the same levels for all treatments.

Photosynthetic Measurement

Photosynthesis was measured using Li-6400 Portable Photosynthesis System (LI-COR Inc. Lincoln, Nebraska, USA) at 50 and 90 days after tomato plants were transplanted. The 5th leaf from the top was used for measurements for each sampled plant. The maximum gross photosynthetic capacity (P_C), the quantum yield ($Y_Q = KP_C$) and dark respiration rate (R_D) were analyzed from a light response curve modeled using an exponential equation, $P_N = P_C\,(1 - e^{-KI}) - R_D$, where K is a constant and I is the photosynthetic photon flux (Xu et al., 1995).

Preparation of Plant, Soil and Fruit Samples

The whole plant was sampled with leaves and stem separated on the 50 and 90 days after tomato plants were transplanted. The samples were dried in an oven at 105°C for 2 h and under 85°C over 24 h. Dry mass of a whole plant was recorded and the dry material was ground with a vibrating sample mill. A prepared sample of 5 g was used for measurements of mineral salts and other nutrients. The tomato fruits were picked once a week when tomato fruits began to ripen 2.5 months after being transplanted. The fruit yield, the crack rate and single fruit mass were calculated. A slice representing the whole fruit was used for fruit quality analysis. The duration involved in fruit development from pollination to maturity were divided into 4 stages as (1) 15 days after pollination with small size and green color; (2) fruit begin to turn color from green to white; (3) fruit in orange color; and (4) fruit in red color. The soil samples were taken at the same time as the plant samples.

Mineral Analyses of Soil and Plant Samples

Concentrations of K, Mg and Ca in plant and fruits were determined with an atomic absorption spectrophotometer (180-30, HITACHI, Japan); concentrations of total N and C were measured by MT-700 CN CORDER (Yanaco, Japan); and concentrations of nitrate-N and phosphorus were determined by colorimetry.

Analysis of Fruit Quality

Fresh fruit tissue was homogenized with distilled water in a ratio of 1:4. The homogenate was centrifuged at 8000 × g for 15 min at 4°C and the supernatant passed through 0.45-μm filter. Sugars were measured by HPLC (Jasco) with RI-930 Detector and a column of Shodex SC1011) at a column temperature of 80°C and a flow rate of 1 ml min^{-1}. Organic acids were measured by HPLC (Jasco) with UV-970 Detector and column of Shodex RSPark KC-811 at a column temperature of 40°C and a flow rate of 0.75 ml min^{-1}. Vitamin C was determined by a reflectometer (RQflex, Merck).

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RESULTS AND DISCUSSION

Plant Growth and Fruit Yield

Organic Fertilization. At the early growth stage, plant growth or fruit yield was lower in the bokashi plots but turned higher at later growth stages, compared with the chemical-fertilized plants (Figure 1, Table 1). This might be due to the low nutrient availability at the beginning, which limited the plant growth. In the present study, the organic fertilizer is an anaerobically fermented mixture of organic materials. Nutrients, especially nitrogen, are not mineralized immediately after fermentation. The mineralization of the nutrients takes a period of time even when applied to the soil. That is why the plants fertilized with organic materials grew more slowly than those fertilized with chemical fertilizers at earlier stages. Therefore, the growers should take some measures to make the nutrients in organic materials available before plants begin their rapid growth. Nutrients in chemical fertilizers are immediately available when applied to the soil but the sustainability is low. As shown in Table 2, 50 days after the seedlings were transplanted, nitrate and available

FIGURE 1. Fruit yield at different stages of tomato plants with different fertilization treatments.

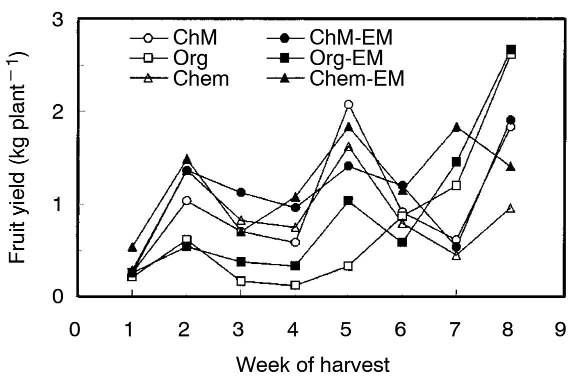

TABLE 1. Fruit yield and number, abnormal and green fruit and fruit size as well as photosynthetic capacity (P_C), respiration (R_D) and quantum yield (Y_Q) at later growth stage of tomato plants under different fertilizations.

Treatment	Fruit characteristics					Photosynthetic parameter		
	Yield (g plt^{-1})	Numb. (plt^{-1})	Abnormal (%)	Green (%)	Size (g)	P_C	R_D (μmol m^{-2} s^{-1})	Y_Q (mmol mol^{-1})
ChM	823 ±32	8.0 ±0.4	9.8 ±3.4	8.1 ±1.7	94.5 ±2.5	17.6 ±1.2	1.02 ±0.02	19.5 ±2.7
ChM + EM	935 ±63	8.8 ±0.6	9.5 ±2.0	5.9 ±1.3	100.4 ±3.0	19.3 ±1.7	1.31 ±0.02	24.3 ±2.9
Org	622 ±36	6.2 ±0.4	17.3 ±2.8	20.0 ±3.9	81.1 ±3.9	20.4 ±2.1	1.05 ±0.01	31.2 ±3.4
Org + EM	723 ±59	7.3 ±0.7	17.2 ±3.9	18.5 ±2.7	81.6 ±2.5	23.1 ±1.6	1.84 ±0.02	34.4 ±1.8
Che	818 ±21	7.1 ±0.2	12.4 ±3.5	11.4 ±2.9	102.4 ±2.5	18.4 ±1.3	1.12 ±0.03	30.7 ±2.5
Che + EM	1012 ±30	10.1 ±0.3	8.7 ±1.8	9.4 ±1.8	91.2 ±2.8	20.2 ±0.9	1.65 ±0.02	34.5 ±2.9

Data showing means ± SE (n = 9). ChM = chicken manure; Org = bokashi; Che = chemical fertilizer.

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phosphorus concentrations were higher with bokashi and chicken manure treatments than for the chemical fertilizer treatment. The nutrients in the chemical treatment might be lost by leaching from the soil-root zone in irrigation water at the early growth stages. On the contrary, organic materials could sustain the nutrients for a longer time than chemical fertilizers. Moreover, organic materials also contain micronutrients in addition to the macronutrients that are available in chemical fertilizers. Some macronutrients such as calcium and magnesium were included in organic fertilizers but not chemical fertilizers and consequently were more in soils fertilized with bokashi and chicken manure than soils treated with chemical fertilizer (Table 2). Therefore, at the later growth stages, plants fertilized with organic materials grew better than those fertilized with chemical fertilizers. The chicken manure used in the present study was aerobically treated before application and no growth limitation was observed at the early stages. However, the nutrients could not be sustained at the later growth stage of plants with either chicken manure or chemical fertilizer treatment, compared with bokashi.

Effects of EM Inoculation. EM inoculation increased plant growth and fruit yield in all treatments. EM was inoculated to the organic materials or chicken manure before anaerobic fermentation. The microorganisms were reproduced and changed the properties of the organic materials. Some microorganisms produce plant growth regulators (Arshad and Frankenberger Jr.,

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TABLE 2. The concentration (mg kg^{-1}) of mineral salts and C:N in soil in 50 days and 90 days after tomato seedlings were transplanted.

Treat.	T-C	T-N	C:N	NH_4^+	NO_3^-	Av.-P	K_2O	CaO	MgO
	50 days after transplanting								
ChM	58.5 ±1.36	4.5 ±0.01	12.9	8.2 ±0.41	174.2 ±30.36	517.9 ±7.67	939 ±111.5	4367 ±419.2	960 ±67.2
ChM + EM	58.0 ±1.36	4.6 ±0.07	12.6	8.2 ±1.22	175.7 ±12.22	573.5 ±83.73	880 ±35.3	4879 ±262	1020 ±37.2
Org	60.2 ±0.82	5.0 ±0.07	12.0	11.4 ±3.04	367.0 ±154.1	318.0 ±35.12	630 ±194.0	4030 ±41.9	1161 ±13.8
Org + EM	60.3 ±0.88	5.0 ±0.18	12.0	10.2 ±2.75	279.0 ±163.8	356.7 ±43.33	358 ±97.4	3720 ±149.1	1070 ±87.9
Che	54.9 ±0.96	4.2 ±0.03	13.1	32.6 ±10.75	152.3 ±17.60	209.8 ±28.48	327 ±10.8	5110 ±282.0	825 ±34.5
Che + EM	55.7 ±0.50	4.3 ±0.03	13.1	35.53 ±9.77	115.6 ±34.48	271.1 ±8.82	288 ±22.5	5112 ±319.0	761 ±64.5
	90 days after transplanting								
ChM	57.1 ±0.93	4.7 ±0.04	12.0	10.1 ±0.88	21.2 ±2.91	726.8 ±75.35	601 ±91.5	5481 ±44.4	1034 ±22.9
ChM + EM	58.1 ±0.59	4.7 ±0.03	12.3	10.5 ±0.70	20.89 ±1.62	674.8 ±63.60	511 ±74.6	5233 ±155.4	1010 ±29.6
Org	58.8 ±1.10	4.86 ±0.0	12.3	16.8 ±1.49	75.5 ±4.3	370.8 ±24.93	252 ±33.59	3356 ±201.2	953 ±33.5
Org + EM	58.6 ±0.53	4.8 ±0.06	12.2	23.6 ±0.82	51.8 ±2.12	365.8 ±16.67	141 ±1.63	3351 ±193.2	883 ±51.5
Che	54.0 ±0.70	4.2 ±0.03	13.1	33.0 ±4.46	30.5 ±3.51	287.8 ±15.28	204 ±38.6	4907 ±110.1	690 ±22.1
Che + EM	53.9 ±0.36	4.1 ±0.04	13.1	44.3 ±2.77	16.7 ±1.35	312.8 ±8.82	163 ±23.7	4642 ±130.1	634 ±10.74

Data showing means ± SE (n = 9). ChM = chicken manure; Org = bokashi; Che = chemical fertilizer.

1992). In this study, available phosphorus concentration on 50 days after transplanting were higher in EM treated soils than untreated soils. This might be associated with the activities of the EM microbes. However, on 90 days after planting, the nitrogen and available phosphorus concentrations were lower in EM-treated soils. This might be associated with more absorption of the nutrients by the plants that showed faster growth and higher fruit yield in EM-treated plots than untreated plots. Even if the EM liquid was directly applied to soil at the same time with chemical fertilizers, it also showed growth promotion and yield increasing effects.

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Photosynthetic Activity

Effect of Fertilization. Photosynthetic capacity (P_C) and dark respiration were maintained higher at the later growth stage in plants of the bokashi treatment than in those of chemical and chicken manure treatments. This result was visible from the plant appearance at the later growth stage. Plants of bokashi treatment maintained more active young leaves and developed more young fruit than plants in other two treatments. This was due to more nutrients sustained in the soil of bokashi treatment than in soils of other treatments (Table 2). Quantum yield was higher in plants of bokashi and fertilizer treatments than plants of chicken manure treatment. The reason for this result is not clear.

Effect of EM Inoculation. EM inoculated to bokashi and chicken manure and directly applied to soil together with chemical fertilizer increased photosynthetic activity, dark respiration and quantum yield. This result was consistent with plant growth, plants appearance and fruit yield at the later growth stages.

Sugars, Organic Acids and Vitamin C

Effects of Fertilizations. The sugars in tomato fruit are mainly glucose, fructose and sucrose. The concentration of sugars in fruit varied with the fertilizers. As shown in Table 3, the fruit in plots fertilized with chicken manure contained the highest concentration of sugars and those in chemical fertilizer plots had the lowest concentrations of sugars. Compared with the chemical fertilization treatment, the organic acid concentration of fruit in bokashi-fertilized plot was high, followed by the treatment with chicken manure. The ratio of sugars to organic acids was higher in fruit with the chicken manure treatment, resulting in a sweeter taste of fruit. The ratio of sugars to organic acids in the bokashi treatment was similar to that in the chemical fertilizer treatment, but the fruit grown with bokashi-fertilizer was more tasteful since both the sugars and organic acids were higher. As shown in Table 3, vitamin C (ascorbic acid) concentration was lower for the chemical fertilizer treatment than for the two organic fertilizer treatments. The results suggested clearly that organic fertilization improved fruit quality shown by sugar, organic acid and vitamin C concentrations. The bokashi and chicken manure contain not only nutrients but also organic matter required for plants. Organic matter plays important roles in plant growth and development by releasing nutrients, improving soil physical and chemical properties and promoting root activity. The nutrients released from the organic materials are in balance with various elements. Some physiologically active substances released from organic matter can increase root activity (Yamada, 1997). Tomato plants with a high root activity can penetrate more deeply in the soil

TABLE 3. Sugars and organic acids in the ripe tomato fruit from different fertilization treatments

Treatment	Sugars ($g\ kg^{-1}$)				Organic acids ($g\ kg^{-1}$)				Sugars/acids
	Sucrose	Glucose	Fructose	Total	Citric	Malic	Total	Ascorbic	
ChM	1.01 ±0.62	33.4 ±1.8	29.8 ±1.0	64.2	6.32 ±0.42	1.80 ±0.42	8.12	0.16 ±0.019	7.91
ChM + EM	0.68 ±0.45	33.0 ±0.4	30.7 ±0.5	64.4	6.41 ±0.09	1.99 ±0.28	8.40	0.19 ±0.010	7.66
Org	1.43 ±0.21	30.7 ±4.3	27.0 ±1.5	59.1	6.98 ±1.22	1.85 ±0.85	8.83	0.12 ±0.0004	6.70
Org + EM	1.70 ±0.55	29.5 ±1.8	29.1 ±1.1	60.3	6.96 ±1.35	1.69 ±0.03	8.65	0.14 ±0.007	6.97
Che	0.24 ±0.11	25.1 ±3.7	25.2 ±2.1	50.5	6.57 ±1.06	1.48 ±0.25	8.05	0.11 ±0.004	6.28
Che + EM	0.64 ±0.17	26.6 ±4.2	26.9 ±1.9	54.1	6.69 ±0.78	1.24 ±0.18	7.93	0.12 ±0.009	6.78

Data showing means ± SE (n = 9). ChM = chicken manure; Org = bokashi; Che = chemical fertilizer.

with improved physical and chemical properties. This enable tomato plant to absorb water in deep soil layers an irrigation is reduced. Reduced irrigation or low water management can increase sugar concentration of fruit (Yamada, 1997).

Effects of EM Inoculation

EM inoculated to the organic materials or applied directly to the soil with chemical fertilizers did not have a significant effect on fruit sugar and organic acid concentrations per unit of dry mass. However, the EM treatment increased fruit yield. Moreover, increasing the fresh yield might also dilute the active substances such as sugars and organic acids. If the fruit sugar and organic acid concentrations are calculated on per plant, the effect of EM in increasing sugar concentration becomes apparent. As shown in Table 3, EM did increase the fruit vitamin C concentration. In all the treatments of organic and chemical fertilizer, EM inoculation increased vitamin C concentration in tomato fruit, although the mechanism for this effect of EM is not clear.

Dynamic Changes in Sugars and Organic Acids in Developing Fruit. The changes in concentrations of sugars during fruit development in different treatments showed the same trend, as in Figure 2. The concentrations of sugars increased steadily from stage 1 (green fruit) to stage 4 (ripe fruit), but the increasing extent was lower before stage 2 than thereafter. This suggested that different kinds of fertilizers affected the fruit sugar concentration mainly

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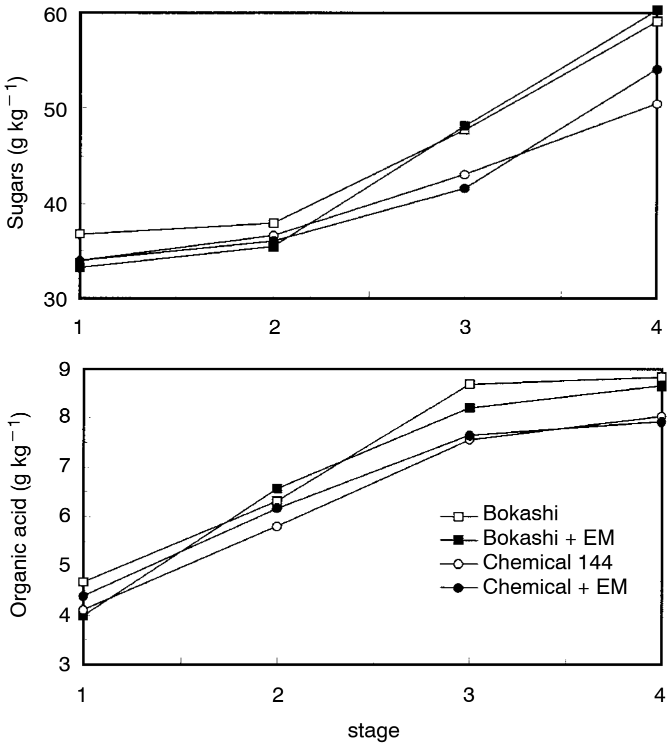
FIGURE 2. Dynamic changes in sugar and organic acid concentrations of tomato plants fertilized with bokashi and chemical fertilizers.



at the later development stage. Though the organic acid in all treatments steadily increased from beginning to the end, there was very little increment after Stage 3. This suggested that the effect of different fertilizers on organic acids were mainly at early stages of fruit development.

The integrated results showed that if the nutrients in organic materials were available at the early growth stages, both chicken manure and bokashi could be used as substitute for chemical fertilizer with a comparable yield and higher quality. Both quality and yield increasing effects could be expected from EM inoculation to the organic fertilizers and application to the soil directly.

CONCLUSIONS

Plant growth and fruit yield were low in the bokashi-applied plots at earlier growth stages but were higher at later growth stage because of the low

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nutrient availability at the beginning and high nutrient sustainability at the later stage. Concentrations of sugars were highest in fruit of plants fertilized with chicken manure and lowest in fruit of plants with chemical fertilizers. Organic acid concentration was higher in fruit of bokashi-fertilized plants than in fruit of other plots. Vitamin C (ascorbic acid) concentration was higher in fruit of plants fertilized with chicken manure and bokashi than in those fertilized with chemical fertilizer. EM inoculation increased fruit yield and vitamin C concentration. If the nutrients in organic materials were available, both chicken manure and bokashi could be used as substitutes for chemical fertilizer with a comparable yield and higher quality. Increased yields and improved quality could be expected from EM inoculation either to the organic materials or to the soil directly.

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