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Eco-Physiological Properties of Open-Field Cucumbers Responded to Organic Liquid Fertilizers

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Abstract: This study was initiated to determine the effect of organic farm-derived liquid fertilizer (LF) on (1) the performance of open-field cucumbers (*Cucumis sativus* L.) and (2) the soil environment. Treatments included fertigation with a 0.2% solution of an equal T-N concentration on each LF, including long-term non-treatment (LNT, groundwater), non-treatment (NT, groundwater), oil cake (OC), bone meal + fish residue (BF), fish extract + active phosphoric acid (FP), sesame oil (SO), and starfish (SF). Electrical conductivity (EC) in LF was increased in the SF or BF, with high concentrations of T-C observed in the OC and BF and high P in the SO. LNT treatment decreased soil mineral nutrient concentrations and numbers of bacterial operational taxonomic units, invertebrates, and earthworms, significantly increasing infection of powdery mildew and downy mildew for the plants but reducing foliar concentrations of T-N, P, Ca, and SPAD values, and vegetative growth parameters. Soil bulk density decreased in the SF and SO plots. Total fruit yield and fruit yield efficiency were enhanced by BF, FP, SO, and SF treatments, with the highest top grade values observed on the FP- and SO-fruit. Overall, all the organic LF, in particular the SO treatment, would have improved eco-physiological sustainability and provided an alternative organic fertilizer for a short growing period.

Keywords: earthworms; fertigation; invertebrate; nutrient; pyrosequencing

1. Introduction

Cucumber (*Cucumis sativus* L.) is popular fin Korean side dishes raw, salted, or seasoned, and ranks in the top ten vegetables in terms of production and cultivation area [1]. Cucumber fruit contains a high amount of water, up to 95%, is low in calories as well as in mineral nutrients and vitamins, and has antioxidant and anti-inflammatory properties, attributed to cucurbitacin [2]. The production and cultivation area used for cucumber consistently decreased in the 30 years between 1985 and 2015 in S. Korea, in particular for open-field systems largely influenced by unpredictable climatic changes in recent years [1]. Although open-field remains an attractive cultivation method for people who create community gardens in suburbs or farm on a small scale or do organic farming, innovative cultivation technology has since developed for larger-scale farming.

Organic cucumber was reported as having the highest acceptability for consumers for the retention of the organoleptic properties compared to the conventional fruit in S. Korea [3]. Organic cultivation could be one of the most distinguishing strategies promoting the safety and quality of the fresh fruit products as well as conserving soil ecosystems [4]. Various organic materials from natural sources in plant and animal waste have been applied with liquid fertilizer (LF) in most organic farms as an additional fertilizer to increase solubility and promote plant productivity [5–9]. Different organic-based LF contained various concentrations of the mineral nutrients and solubilized at different rates of mineralization, presenting a difficulty in synchronizing the nutrient availability with crop demand in the open-field systems [5,10].

Drip irrigation systems in farms have been widely used for water management with fertigation [11]. Although farm-derived LF contained small amounts of actual mineral nutrients as an additional fertilizer, the application improved eco-physiological stability on the soil fauna and the crop productivity [7,10]. However, little has been studied about the effects of LF on chemical and bio-physical changes occurring in the soil during the cultivation of organic cucumber plants, thereby influencing the fruit productivity. This study was initiated to determine the effect of organic LF on the soil environment and on the performance of open-field cucumbers.

2. Materials and Methods

2.1. Field Condition

The experimental plots had been cultivated organically with lettuce, cabbage lettuce, carrot, and sweet potato from 2015 to 2018, annually fertilizing with 20,000 kg of manure compost (pig manure 30%, chicken manure 15%, cow manure 10%, rice bran 15%, saw dust 20%, bark 10% and organic matter (OM) 30%, Gyeongju, South Korea) per hectare as a basal fertilizer. In 2019, our previous study was conducted with fertigation of different organic LF as an additional fertilizer for cherry tomato plants without use of chemical soluble fertilizer, insecticide, or herbicide after planting [10], which repeated the trials in 2020, adding long-term non-treatment (LNT) plots over ten years. The soil type in the rooting zone between 0 and 20 cm depth was a sandy loam, comprising 57.4% of sand, 30.0% of silt, and 12.6% of clay. The weather data, temperature and rainfall, during the growing season in 2020 and in the last 30 years were obtained from the Korea Meteorological Administration [12].

'White Dadagi' cucumber seedlings (*Cucumis sativus* L.) with 5.4 cm in height and 4.9 mm in diameter were planted 40 cm apart with 90 cm between rows on a private fruit and vegetable farm in Gumi-si, South Korea (36° N, 128° E) on 30 April 2020. All plant shoots were minimally pruned and grown with a natural central leader shoot type. Vegetation around the cucumber plants was not mown to investigate its biological attributes during the growing season. Drip-irrigation was applied with two emitters per plant when precipitation was not received on the ground surface for three to four consecutive days during the season.

2.2. Treatments

In 2020, a half-amount of the manure compost was applied with a basal fertilizer in the experiment plot in Spring 2020 based on the recommendations for the mineral nutrients in the cucumber field [13], except for LNT plots. Treatments consisted of seven LF treatment plots, LNT, non-treatment (NT), oil cake (OC), bone meal + fish residue (BF), fish extract + active phosphoric acid (FP), sesame oil (SO), and starfish (SF), which had been applied with the previous experiment for cherry tomato plants in 2019. Pelletized OC contained 4.6% T-N, 1.4% P, 1.0% K, and OM 70% (Chamjoa, Farmhannong Co., Seoul, Korea). BF was made from 16.5% bone meal, 16.5% fish residue, 0.7% effective microorganisms (EM), 0.2% molasses, and 66.1% water with a three-month fermentation. FP included 2.0% fish extract, 2.0% molasses, 2.0% active phosphoric acid, and 94.0% water with six-month fermentation. SO included 32.7% sesame oil, 0.7% sea salt, 1.3% humus, and 65.3% water for three-months. SF contained 40.3% starfish, 10.1% seaweed, 3.4% molasses, 0.2% EM, 0.8% humus, and 45.2% of water with a three-year fermentation.

Treatments were randomly assigned to three-plant plots with a Completely Randomized Block Design, and each treatment consisted of three plots (three replications). The plot size was 80 cm wide and 180 cm long, with 50 cm furrow between the plots. The experimental unit (data unit) was comprised of a single plant in the center of the triad and the others were guard plants to prevent nutrient contamination between the plots.

Approximately 100 mL of each LF on each plant was fertigated using a plastic cup for the first four weeks after 25-days transplanting twice per week, then fertigated with 330 mL of the LF for the rest of the growing season, and received approximately 5.45 L of each LF on each plant during the whole season. All three plants per treatment plot received the same amount of each LF during the growing season. Each amount of LF application was equated at rates equivalent to approximately 0.16 g of actual N per plant during the growing season, which is the typical amount of fertilizer additionally applied in the organic vegetable farming systems [13]. LNT and NT were applied with groundwater with the same amount of LF fertigated with the other organic LF.

2.3. Soil Chemical Analysis

Three soil samples per plant were randomly taken with a 2 cm-diameter soil probe at 60 days after fertigation (DAF), at the end of July, within 10 cm of the plant leader shoot at a depth of 0–20 cm. Each soil sample was then air-dried and passed through a 2-mm mesh sieve for soil nutrient analysis according to RDA protocols [14]. Soil pH and electrical conductivity (EC) were measured on the basis of a 1:5 (v/v) mix of soil:distilled water, using a pH meter (FIVEEAST FE20, Mettler Tonedo Co., Changzhou, China) and an EC meter (HI 2315 Conductivity Meter, Hanna Co., Seoul, Korea). Soil OM content was estimated by calculating the organic carbon (C) through OM oxidized by $K_2Cr_2O_7$ and followed by the Tyurin method. 5 g of each soil sample was used for soil T-N analysis using the Kjeldahl method, available P_2O_5 analysis using the Lancaster method, and exchangeable nutrient concentrations using an ICP-AES (Simultaneous ICP Spectrometer, SPECTRO Analytical Instruments GmbH Co., Baden-Württemberg, Germany).

2.4. Bio-Physical Analysis

Soil samples were also assessed for their bacterial community at the same time as the soil nutrient analysis described above occurred. The 16S rRNA gene fragments of the bacterial community sequencing data were analyzed using the Mothur software package to present operational taxonomic units (OTUs), good's non-parameter coverage, Chao1, Shannon, and inverse Simpson on each treatment plot [15].

A pit fall trap with a plastic circle cup (9.5 cm diameter and 7.5 cm length) was buried in the soil in the mid-point between plants at 46 DAF. Each trap was filled with a preservation solution consisting of a 1:1 mixture of ethyl-alcohol and ethyl-glycol to prevent spoilage of the collected invertebrates. Ground-dwelling invertebrates were captured two weeks after installation of the pit fall trap and visually evaluated for species in the lab.

Numbers of earthworms were visually counted at 67 DAF after excavating with a shovel 40 cm^3 of soil volume (width × depth), from the same location receiving the fertigation. Weed biomass with top and root was also collected from an area of 40 cm^2 around each cucumber plant, which was then placed in plastic bags, air-dried at 70 °C for seven days, and measured their dry weight (DW). Soils were additionally sampled for the soil bulk density at a depth of 0–10 cm under the mid-canopy of each plant using a 7.5-cm diameter cylindrical core (100 cm^3).

The most severe foliar diseases, powdery mildew (*Sphaerotheca fuliginea*) and downy mildew (*Pseudoperonospora cubensis*), at 60 DAF were visually detected on all the mature leaves on each plant. Any small regions observed in leaves were considered to be disease damage as they would grow out of the infected region, which was counted on per leaf basis and was estimated as a proportion of sample leaves infected.

2.5. Plant Nutrient Analysis

Five leaves per plant were randomly sampled at 60 DAF from the mid-point of each plant, air-dried, weighed with an electronic scale for the leaf DW, and ground in a blender with four mill blades (WDL-1, Wonder Blender Co., Tokyo, Japan) for macro-nutrient analyses [14]. Each of the dried plant material of 0.5 g was pre-digested with 10 mL HNO_3 and analyzed using the Kjeldahl method for

T-N concentration, the vanadate method for P concentration, and with atomic absorption spectrometry to measure concentrations of K, Ca, and Mg.

2.6. Plant Growth Measurement

Five leaves per plant at 45 and 60 DAF were taken to estimate foliar chlorophyll and T-N contents with a portable Soil Plant Analysis Development (SPAD) 502 meter (Minolta Co., Tokyo, Japan). The numbers of leaves were counted on each cucumber plant at 60 DAT. The leader shoot cross-sectional area (SCSA) of each plant from 5 cm above the ground was determined with a digital caliper (Mitutoyo Corp., Takatsu-ku, Japan). Whole three cucumber plants, including top and roots, on each treatment, were harvested at 60 DAF plant heights above and underground were measured. The whole plants were dried in the dry oven to measure the plant DW, which was then calculated for the SPW (specific plant weight) as the proportion of whole plant DW divided by SCSA.

Cucumber fruit was weekly harvested at the light green color stage of fruit peel, counted, and weighed to determine the fruit yield from 11 DAF to 60 DAF. Fruit length and diameter were recorded with a digital caliper (Mitutoyo Corp., Takatsu-ku, Japan). The total fruit yield on each treatment was determined as the sum of all the harvested fruit from 11 DAF to 60 DAF and then dried in the dry oven at 70 °C for seven days to calculate the fruit yield efficiency, expressed as the percentage of fruit DW divided by whole plant DW. The middle point of the fruit was thinly peeled to measure the firmness using a hand-held penetrometer with 3.0 mm diameter tip (FR-5105, Lutron Electronic Enterprise Co., Ltd., Taipei, Taiwan) and to measure soluble solid contents (SSC) of fruit juice using a hand-held refractometer (GMK-706R, G-WON Hitech Co., Ltd., Seoul, Korea). Fruit surface color parameters, L* (from black to white), a* (from green to red), and b* (from blue to yellow), was assessed using a color difference meter (FR-5105, X-Rite, Inc., Grand Rapids, MI, USA) to measure the peel color. Top grade value of cucumber exhibited lengths between 260 and 280 mm and diameters between 30 and 50 mm.

2.7. Statistical Analysis

Data were subjected to an analysis of variance (ANOVA) to determine treatment differences with Duncan's multiple range test at $p < 0.05$. All statistical analyses were performed using the SAS statistical software package with Minitab Software Version 14.1 (Minitab, Inc., State College, PA, USA).

3. Results and Discussion

3.1. Soil Chemical Parameters

The total amount of precipitation and average temperatures during the growing season in 2020 were 67.4 mm and 19.1 °C in May, 198.1 mm and 24.1 °C in June, and 434.0 mm and 23.0 °C in July, with 77.0 mm and 18.0 °C in May, 130.3 mm and 22.1 °C in June, and 237.9 mm and 24.9 °C in July recorded over the last 30 years (data not presented).

The pH levels in all the LF solutions varied during the first eight weeks after storage (WAS), presumably due to the fluctuation of EC levels of each LF (Figure 1). The EC levels in LF declined on the NF (groundwater) but increased on the SF or BF. T-C concentration in the LF showed the highest values observed on the OC, followed by BF, SF, FP, SO, and NT, with an equal concentration of 0.2% T-N in those of LF (Table 1). P concentration in the LF was the lowest in the SF but the highest in the SO with high B. BF solution contained the highest concentrations of K and Ca with less heavy metals, Zn and Cu, inhibiting root respiration and biological activities before shoot growth [16].

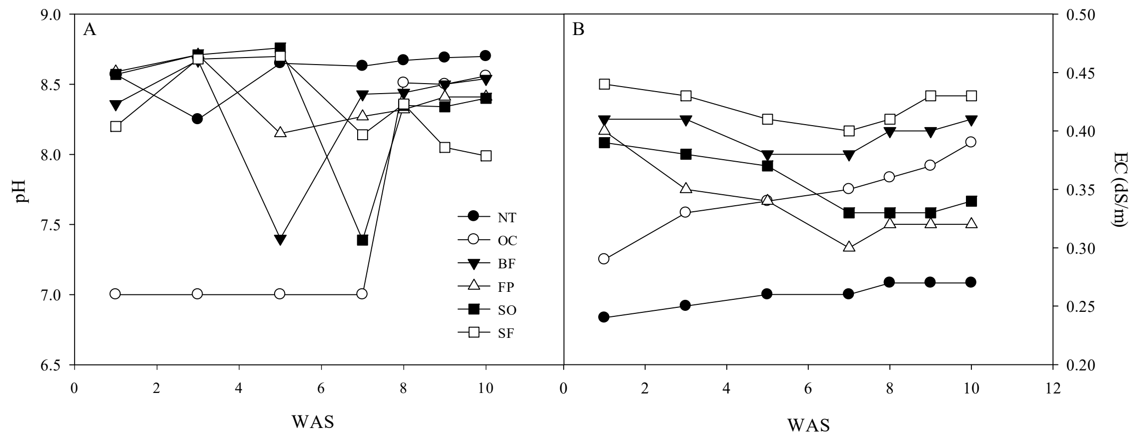

Figure 1. Variations of pH (**A**) and electrical conductivity (EC) (**B**) at weeks after storage (WAS) in liquid fertilizers with farm-derived renewable resources used in an experiment plot. NT: Non-treatment, OC: Oil cake, BF: Bone + fish meal, FP: Fish + phosphoric acid, SO: Sesame oil meal, SF: Starfish.

Table 1. Nutrient concentrations in liquid fertilizers (LF) with farm-derived renewable resources used in an experimental plot.

LF	T-C	T-N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
	(%)		(mg·L^{-1})								
NT	0.00	0.000	0.00	0.0	25.9	10.0	0.00	0.00	0.01	0.01	0.00
OC	1.77	0.200	3.28	6.4	33.9	16.0	0.07	0.00	0.04	0.06	0.19
BF	0.62	0.200	1.01	25.8	34.5	12.3	0.03	0.00	0.02	0.03	0.00
FP	0.40	0.200	0.62	7.0	30.8	12.6	0.02	0.00	0.01	0.07	0.00
SO	0.36	0.200	6.71	15.2	30.3	12.8	0.01	0.00	0.05	0.04	0.23
SF	0.44	0.200	0.24	12.2	31.1	14.2	0.03	0.00	0.02	0.04	0.02

NT: Non-treatment (groundwater), OC: Oil cake, BF: Bone + fish meal, FP: Fish + phosphoric acid, SO: Sesame oil meal, SF: Starfish.

Soil pH, EC, OM, and concentrations of T-N, P_2O_5, K_2O, CaO, and MgO were reduced in the LNT plots (Table 2). Soil pH results were slightly alkaline for all plots, containing in some parts calcareous soils. These would have reduced concentrations of soil K_2O due to increased competition with Ca and K_2O for a spot on the cation exchange capacity [17]. All plots showed soil OM as 35 g/kg above the desired levels [13] and may have increased concentrations of soil EC.

Table 2. Soil chemical properties of the cucumber field in this study as affected by liquid fertilizers (LF).

LF	pH (1:5)	EC (dS·m^{-1})	OM (g·kg^{-1})	Total T-N (%)	P_2O_5 (mg·kg^{-1})	ExCation (cmolc·kg^{-1})		
						K_2O	CaO	MgO
Pre application								
All plots	7.0	0.21	12.9	0.06	243	0.33	12.9	3.8
After application								
LNT	7.4 b	0.16 b	36.3 c	0.06 b	232 c	0.30 a	12.3 b	3.1 a
NT	7.7 a	0.37 a	51.9 abc	0.16 a	661 ab	0.24 a	17.3 a	2.6 ab
OC	7.8 a	0.40 a	47.2 bc	0.15 a	626 b	0.33 a	18.1 a	2.4 b
BF	7.8 a	0.39 a	52.8 a	0.16 a	701 ab	0.34 a	17.2 a	2.5 b
FP	7.8 a	0.39 a	46.7 bc	0.15 a	740 a	0.31 a	18.3 a	2.6 ab
SO	7.8 a	0.38 a	48.6 abc	0.15 a	681 ab	0.25 a	17.9 a	2.4 b
SF	7.8 a	0.36 a	45.4 bc	0.14 a	669 ab	0.22 a	17.7 a	2.7 ab
Desired level	6.0–7.0	0.00–0.20	25–35	–	400–500	0.70–0.80	5.0–6.0	1.5–2.5

Desired levels adopted from RDA [13]. Mean values (n = 3) in each column followed by the same lower-case letters were not significantly different according to Duncan's multiple range test at $p \leq 0.05$. LNT: Long-term non-treatment, NT: Non-treatment, OC: Oil cake, BF: Bone + fish meal, FP: Fish + phosphoric acid, SO: Sesame oil meal, SF: Starfish.

3.2. Soil Bio-Physical Parameters

LNT plots showed decreasing numbers of OTUs and a richness estimator of Chao1 with respect to the bacterial community, although the Good's coverage and diversity were similar in all treatment plots (Table 3). The 69.5% of phylum were Proteobacteria, Actinobacteria, and Acidobacteria of the 16S rRNA gene sequence obtained from all the soil samples (Figure 2), which are the common phyla observed in the arable land [10,18,19]. Low nutrient accumulation and low soil pH increased Actinobacteria with relatively low competitiveness but reduced Proteobacteria [10,19–21], which was observed on the LNT treatment plots.

Table 3. Soil bacterial community as affected by liquid fertilizers (LF).

LF	Number of OTUs	Good's Coverage	Richness Estimator (Chao1)	Diversity Index	
				Shannon	Inverse Simpson
LNT	886 b	0.99 a	1047 a	7.74 a	0.98 a
NT	1140 a	0.99 a	1371 a	7.91 a	0.98 a
OC	1193 a	0.99a	1445 a	8.10 a	0.99 a
BF	1180 a	0.99 a	1394 a	8.00 a	0.98 a
FP	1153 a	0.99 a	1354 a	8.04 a	0.99 a
SO	1131 a	0.99 a	1375 a	7.54 a	0.97 a
SF	1164 a	0.99 a	1365 a	8.04 a	0.99 a

Mean values (n = 3) in each column followed by the same lower-case letters were not significantly different according to Duncan's multiple range test at $p \leq 0.05$. LNT: Long-term non-treatment, NT: Non-treatment, OC: Oil cake, BF: Bone + fish meal, FP: Fish + phosphoric acid, SO: Sesame oil meal, SF: Starfish. OTUs: Operational taxonomic units.

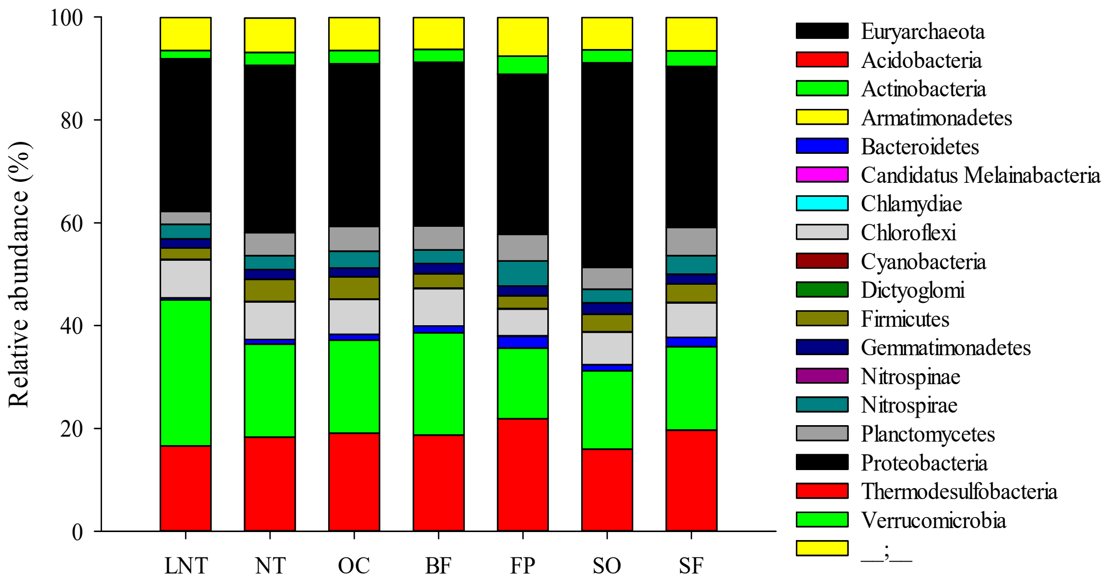

Figure 2. Relative abundance of the dominant bacterial phyla as affected by liquid fertilizers. LNT: Long-term non-treatment, NT: Non-treatment, OC: Oil cake, BF: Bone + fish meal, FP: Fish + phosphoric acid, SO: Sesame oil meal, SF: Starfish.

The number of invertebrates increased in the BF and SF treatment plots but decreased in LNT plots (Figure 3A),which was likely associated with the concentration of T-C and EC observed in the LF solutions. High levels of fertilization increased populations of invertebrate herbivores living on plants in relation to the nutrient availability in the invertebrates or in the stressed plants [10,22]. *Entomobryidae* were observed the most in all the plots (Figure 3B), and are known as the primary decomposer and one of the most abundant invertebrates in S. Korea [22,23] and the most numerous meso-invertebrates in the forest floor [24–26]. Eco-friendly farm land provided alternative prey and shelters for insects of *Trachelipodidae* and *Labiduridae* [10] which were also observed in high numbers in all the plots.

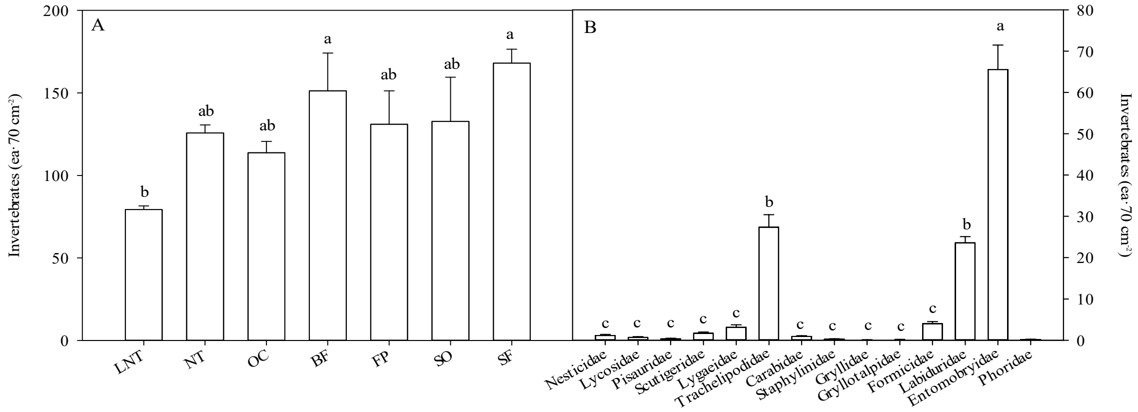

Figure 3. Total number of invertebrates (**A**) and species of invertebrates (**B**) as affected by liquid fertilizers. LNT: Long-term non-treatment, NT: Non-treatment, OC: Oil cake, BF: Bone + fish meal, FP: Fish + phosphoric acid, SO: Sesame oil meal, SF: Starfish. Different lower-case letters on each datum point for each phase indicate significant differences as determined by Duncan's multiple range test at $p \leq 0.05$. Bars represent error of the means.

Amount of vegetation biomass increased in SF plots (Figure 4A), probably due to receiving greater mineral nutrients compared to the LF plots (Figure 1B), as observed on the previous our experiment plots [10]. Numbers of earthworms significantly increased in BF treatment plots, receiving high C and low Cu and Zn in the LF compared to the values observed on the LNT and NT plots (Figure 4B). Earthworm biomass, an important sustainability bioindicator, was enriched by the application of organic manure with vegetation cultivation than those of chemical fertilizers containing high Cu and Zn concentrations, though susceptible to soil fauna [27,28]. Soil bulk density most significantly decreased with SF treatment, followed by SO treatment (Figure 4C). SF treatment containing high EC increased the biomass of vegetation, invertebrates, and earthworms, which would have promoted soil aeration and soil bulk density, being conducive to the healthy growth of the cucumber plants with a shallow root system [29].

Leaf width regions with powdery mildew and downy mildew were highly infected for the LNT and NT plants (Figure 5). Parasitic fungi and bacteria stimulated the activity of polygalactronase in the plant tissue, which dissolved the middle lamella in the cells to facilitate the infection process [30]. The polygalactronase activity of *Botrytis cinera* Pars. in lettuce decreased with increasing Ca concentrations, which was also confirmed in positive relationships between Ca concentrations and infection rates with powdery mildew ($r^2 = 0.426$; data not presented) and with downy mildew ($r^2 = 0.498$). Moreover, an increase of P concentrations in cucumber plants treated with phosphate salts as foliar fertilizers induced systemic protection to powdery mildew in the leaves [31], which was observed on all the plants treated with organic LF.

3.3. Plant Nutrition and Growth

Plants grown in LNT showed low foliar concentrations of T-N, P, and Ca, with no significant difference observed for K and Mg among the treatment plants (Table 4). Foliar concentrations of K, Ca, and Mg from all plants were over the desired levels for growth of cucumber plants [13]. This would have been caused by improved availability of basic cations under the alkaline soil pH, which was between 7.4 and 7.8 in all the plots [17]. Low foliar P concentration resulted in the FP plants with increased soil P_2O_5, whereas highest foliar P was observed in SF plants. Movement of phosphate ions from soil to plants are improved by a symbiotic mycorrhizal fungi and phosphate-solubilizing bacteria, Actinobacteria and Firmicutes [21,32], which may have affected low absorbing phosphate ions in the FP plots, which showed a low bacterial soil colonization of 16.2% (Figure 2).

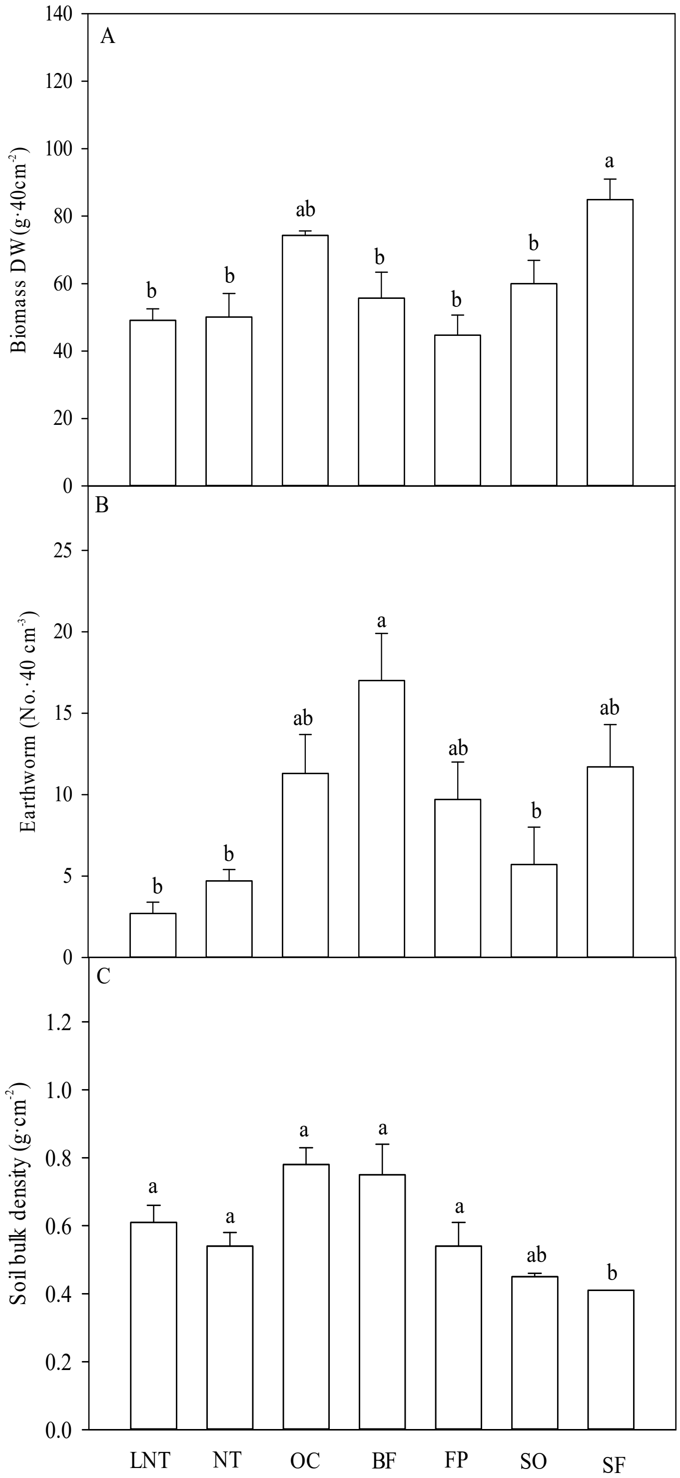

Figure 4. Biomass accumulation (**A**), number of earthworms (**B**), and soil bulk density (**C**) as affected by liquid fertilizers. LNT: Long-term non-treatment, NT: Non-treatment, OC: Oil cake, BF: Bone + fish meal, FP: Fish + phosphoric acid, SO: Sesame oil meal, SF: Starfish. Different lower-case letters on each datum point for each phase indicate significant differences as determined by Duncan's multiple range test at $p \leq 0.05$. Bars represent error of the means.

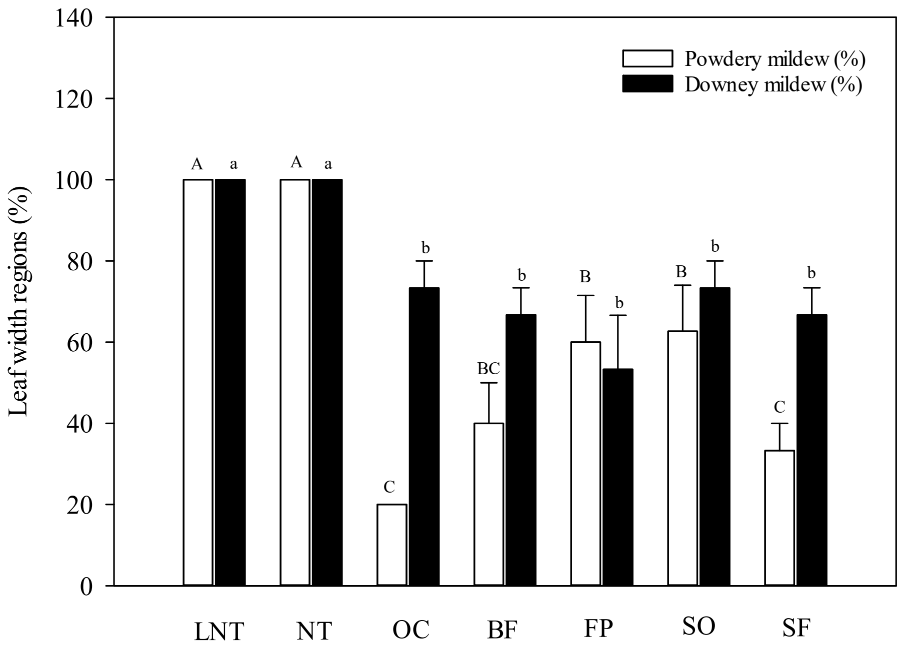

Figure 5. Foliar disease as affected by liquid fertilizers. LNT: Long-term non-treatment, NT: Non-treatment, OC: Oil cake, BF: Bone + fish meal, FP: Fish + phosphoric acid, SO: Sesame oil meal, SF: Starfish. Different lower-case letters on each datum point for each phase indicate significant differences as determined by Duncan's multiple range test at $p \leq 0.05$. Bars represent error of the means.

Table 4. Leaf macro-nutrient concentration of cucumber plants as affected by liquid fertilizers (LF).

LF	**Nutrient Concentration (%)**				
	Total N	**P**	**K**	**Ca**	**Mg**
LNT	1.6 c	0.05 c	1.12 a	3.4 c	0.65 a
NT	2.3 ab	0.13 bc	0.90 a	4.4 bc	0.65 a
OC	2.7 a	0.21 b	1.06 a	6.1 a	0.72 a
BF	2.1 b	0.21 b	0.95 a	5.1 ab	0.62 a
FP	2.2 b	0.13 bc	1.06 a	5.7 a	0.65 a
SO	2.3 ab	0.21 b	0.94 a	5.7 a	0.71 a
SF	2.1 b	0.44 a	1.02 a	5.1 ab	0.61 a
Desired level	1.8–2.3	0.1–0.4	0.4–0.6	0.4–0.8	0.1–0.3

Desired levels adopted from RDA [13]. Mean values (n = 3) in each column followed by the same lower-case letters were not significantly different according to Duncan's multiple range test at $p \leq 0.05$. LNT: Long-term non-treatment, NT: Non-treatment, OC: Oil cake, BF: Bone + fish meal, FP: Fish + phosphoric acid, SO: Sesame oil meal, SF: Starfish.

The LNT plants had decreased foliar SPAD values at first (45 DAT) and second stages (60 DAT) as well as decreased leaf number and area, leaf DW, plant height, SCSA, and plant DW (Table 5). SF treatment containing high EC significantly increased SCSA and plant DW, which was similarly obtained for cucumber plants with organic and inorganic fertilizers [33]. SO treatment increased SPW, the ratio of plant dry matter to area, and is an indicator of the accumulation of high-density substances in cells [34], which was but reduced by the LNT, NT, FP, and OC treatments.

3.4. Fruit Productivity

LNT and NT plants reduced weekly fruit yield from 32 DAF to 49 DAF (Figure 6). Total fruit yield was significantly increased by BF, FP, SO, and SF treatments, improving the fruit yield efficiency (Table 6). LNT and NT plants resulted in low fruit length and diameter, FW, SSC, firmness, hunter b*, and top grade of fruit, with a high portion of 30% in top grade observed on the FP- and SO-treated fruit. OC treatment enhanced fruit FW, SSC, firmness, and hunter b value, presumably due to the dilution effect of fruiting associated with the reduced fruit yield compared to the other organic LF. Although each of the organic LF treatments was given the same concentration of T-N in the cucumber field, the application made a difference to soil chemical and bio-physical parameters and cucumber productivity due to supplements from different amounts of mineral nutrients as well as physiological substrates, such as auxin, cytokinin, and organic acids, through degradation of the fermentation process [35].

Table 5. Growth of cucumber plants as affected by liquid fertilizers (LF).

LF	Leaf					Plant Height (cm)			SCSA (cm^2)	Plant DW (g)	SPW ($g{\cdot}cm^{-2}$)
	1st SPAD	2nd SPAD	No.	Area (cm^2)	DW (g)	Under	Above	Total			
LNT	33.5 b	30.7 b	21.7 b	313.2 c	8.0 b	16.0 b	173.7 c	189.7 c	41.8 c	28.2 c	0.67 c
NT	54.4 a	43.3 a	36.7 a	602.4 ab	16.1 a	21.3 ab	269.7 b	291.0 b	102.0 ab	109.9 b	1.08 b
OC	53.2 a	39.2 a	38.7 a	561.0 b	15.6 a	25.0 a	322.3 a	347.3 a	95.0 ab	106.7 b	1.12 b
BF	49.8 a	39.5 a	38.0 a	616.9 ab	18.9 a	28.0 a	317.7 a	345.7 a	102.0 ab	132.9 ab	1.30 ab
FP	50.9 a	42.8 a	38.0 a	677.2 a	19.3 a	25.0 a	312.3 a	337.3 a	113.0 a	116.9 b	1.03 b
SO	53.0 a	42.0 a	38.7 a	621.1 ab	18.8 a	26.7 a	319.0 a	345.7 a	83.3 b	125.1 ab	1.50 a
SF	51.3 a	44.8 a	40.0 a	642.7 ab	19.2 a	27.7 a	338.0 a	365.7 a	116.8 a	145.7 a	1.25 ab

Mean values (n = 3) in each column followed by the same lower-case letters were not significantly different according to Duncan's multiple range test at $p \leq 0.05$. LNT: Long-term non-treatment, NT: Non-treatment, OC: Oil cake, BF: Bone + fish meal, FP: Fish + phosphoric acid, SO: Sesame oil meal, SF: Starfish. DW: Dry weight. SCSA: Leader shoot cross sectional area, SPW: Specific plant weight.

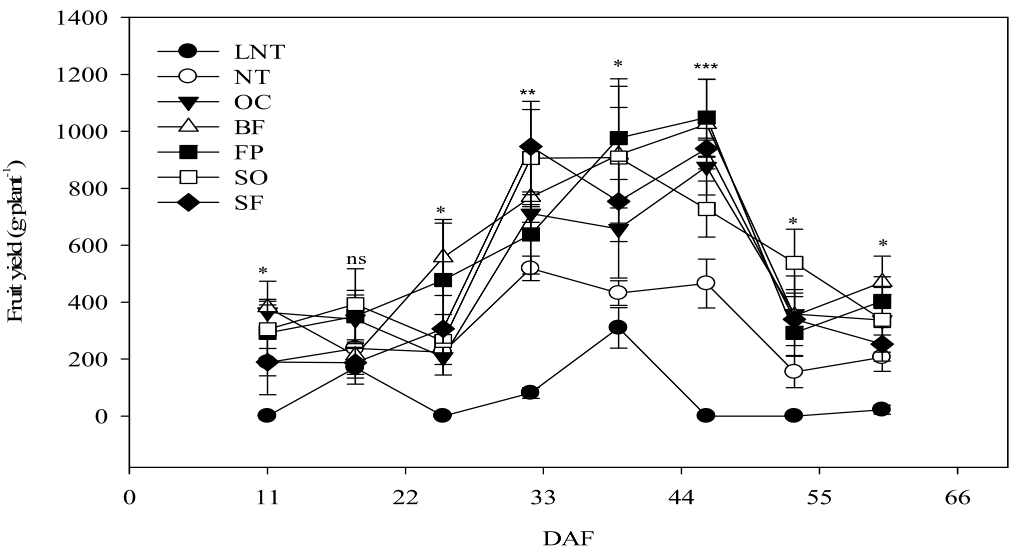

Figure 6. Weekly fruit yield from 11 to 60 days after fertigation (DAF) of liquid fertilizers. LNT: long-term non-treatment, NT: Non-treatment, OC: Oil cake, BF: Bone + fish meal, FP: Fish + phosphoric acid, SO: Sesame oil meal, SF: Starfish. *, **, *** adjacent to each datum point for each sampling time indicate significant differences as determined by Duncan's multiple range test at $p \leq 0.05$, 0.01 or 0.001, respectively; ns, not significantly different.

Table 6. Fruit characteristics as affected by liquid fertilizers (LF).

LF	Total Fruit Yield (kg·plant^{-1})	Fruit Yield Efficiency (%)	Length (mm)	Diameter (mm)	Avg. FW (g)	SSC (°Brix)	Firmness (N)	Hunter	Top Grade (%)		
									L*	a*	b*
LNT	0.6 d	76.5 ab	161.7 b	25.2 c	102.1 c	2.1 c	11.3 d	53.0 a	−8.0 a	32.4 c	0.0 c
NT	2.5 c	81.4 ab	230.3 a	33.5 b	182.9 b	2.8 b	12.7 c	54.7 a	−9.8 bc	34.1 bc	6.7 c
OC	3.0 bc	71.5 b	244.0 a	35.6 ab	216.8 a	3.4 a	14.2 a	54.8 a	−10.6 c	37.8 a	20.0 ab
BF	4.8 a	86.8 a	234.0 a	36.8 a	201.6 ab	3.2 ab	13.7 ab	55.8 a	−10.0 bc	35.6 ab	10.0 bc
FP	4.5 a	88.7 a	243.7 a	35.0 ab	224.8 a	3.5 a	12.9 c	56.3 a	−9.6 bc	34.6 bc	30.0 a
SO	4.6 a	86.8 a	242.0 a	36.1 ab	225.8 a	3.3 a	13.4 bc	55.7 a	−9.8 bc	36.4 ab	30.0 a
SF	3.9 ab	84.6 a	239.7 a	36.0 ab	215.0 a	3.3 a	13.3 bc	56.9 a	−9.4 b	35.2 abc	10.0 bc

Mean values (n = 3) in each column followed by the same lower-case letters were not significantly different according to Duncan's multiple range test at $p \leq 0.05$. LNT: Long-term non-treatment, NT: Non-treatment, OC: Oil cake, BF: Bone + fish meal, FP: Fish + phosphoric acid, SO: Sesame oil meal, SF: Starfish. L*, a*, and b* indicate lightness, proportion of redness, and proportion of yellowness of fruit surface color, respectively.

4. Conclusions

All the organic LF, in particular for SO treatment, partially contained mineral nutrients with high concentrations of P and B, contributed to the improved fruit productivity in a short growing period, providing to be valid alternative organic fertilizers. However, high amount of precipitation in July of 2020 may have reduced the treatment effects on the soil chemical and biological parameters compared to those of values observed in 2019, previously conducted with cherry tomato plants in the same plots. Long-term studies are further required to evaluate the optimum amount of organic feeding levels to reduce nutrient surplus and maintain soil sustainability in the open-field system.

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