Comparison between Organic and Mineral Fertilization for Soil Fertility Levels, Crop Macronutrient Concentrations, and Yield

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ABSTRACT

Interest in soil organic fertilization has grown appreciably in recent years; however, few studies have been performed in greenhouses. A comparative study of organic vs. mineral fertilization in a greenhouse has been conducted for 9 yr in a calcareous loamy soil classified as Xerofluvent in the Guadalquivir River Valley, Seville, Spain. The nutrient availability in the soil, macronutrient concentration in the edible part of the plants, and yield were examined. The organic fertilizer used was vegetal compost and green residue of previous crops that came from the experimental farm and did not depend on external inputs. The use of organic fertilizer resulted in higher soil organic matter, soil N content, and available P and K. However few differences were found in the macronutrient concentration in the edible part of the crops, independent of the type of fertilization. The nitrate concentration in the edible parts was significantly lower for the crops grown in the organically fertilized plots. Crop yield was not statistically different between fertilizer treatments. This study demonstrated that long-term use of organic compost in greenhouse soil improved soil fertility and produced similar yields and nutrient composition in the edible portion of crops compared with mineral fertilization.

Soil organic matter (SOM) is an important source of nutrients for plant growth that needs to be maintained for agricultural sustainability. Conventional farming often involves repeated tillage and large use of fertilizers and pesticides and can result in organic matter (OM) losses, and yield degradation in cultivated soils (Lampkin, 1998). Recently, the effect of organic matter amendments on soil properties has received renewed attention. Studies that compare organic and mineral fertilization in soils show higher SOM and total N for organic-amended soils (Bulluck et al., 2002; Ruiz, 2002; Warman, 2005). The amount of OM accumulated in soil can vary depending mainly on OM decomposition rate and type applied (Haynes and Naidu, 1998). Usually, the organic-amended soils showed significantly higher soil macronutrient content (Edmeades, 2003). However, other authors indicated lower macronutrient content for organically fertilized soils (Gosling and Shepherd, 2005).

The influence of soil fertilization on nutrient content in crops has been studied and different results have been recorded. Some authors show that the application of organic amendment improves soil nutrient content, but does not always increase plant nutrient concentration (Roe, 1998; Warman, 2005). Other studies show that the nutrient content in plants depends on crop type, nutrient type, climate type, and year of the study (Warman and Havard, 1997, 1998; Maqueda et al., 2001). Furthermore, much scientific literature shows that some of the comparisons are not experimentally valid due to variation in crop varieties, timing in fertilization, and handling and storage after harvesting (Warman and Havard, 1997). The results are too variable to make any definitive conclusion.

Nevertheless, there are reasonably consistent findings that show lower nitrate concentration in organic-amended vegetable crops (Vogtmann et al., 1993; Williams, 2002). Low nitrate content in the edible part of the plants is very important for human health, due to its potential transformation to nitrites, which have the highest possibility to interact with hemoglobin and affect blood oxygen transportation (Causeret, 1984). Bosch et al. (1991) reported that the use of organic amendment decreased the nitrate concentration in beet (*Beta vulgaris* L.) and lettuce (*Lactuca sativa* L.); however, no significant differences occurred in leek (*Allium ampeloprasum* L.), carrot (*Daucus carota* L.), and bean (*Phaseoulus vulgaris* L.).

Compared with mineral fertilizer, Vogtmann et al. (1993) indicated that compost application lowered vegetal yields the first 2 yr, but yields did not differ after the third year. Information from medium/long-term experiments are needed for predicting the impact of various soil fertilization schemes on macronutrient dynamics and their repercussion on crop quality and yield (Altieri, 1995). In addition, very few studies were performed in greenhouses, an important system of vegetable production with different climatic conditions as compared with the open-air system.

The objectives of this work were to determine in a 9-yr greenhouse experiment the influence of organic vs. mineral fertilization on (i) the nutrient availability in a calcareous soil of different fertilization regimes, (ii) the concentration of nutrients in the edible part of different crops and some quality parameter such as nitrate concentration, and (iii) crop yield.

MATERIALS AND METHODS

Field Experiment Design

A greenhouse study was performed on a loam soil classified as Xerofluvent (Soil Survey Staff, 1999), located in the Guadalquivir River Valley (SW Spain) at the CIFA "Las Torres-Tomejil" farm in Alcalá del Río (Seville, Spain). Textural and

Table 1. Physical and chemical characteristics of the soil at the beginning of the experiment in 1995 (mean ± SD).†

Sand	Silt	Clay	pH	EC‡	CEC§	$CaCO_3$	OM¶	Kjeldahl N	Available P	Available K
g kg^{-1}				dS m^{-1}	$cmol_c$ kg^{-1}	g kg^{-1}			mg kg^{-1}	
285 ±18	458 ±38	257 ±21	8.2 ±0.04	0.22 ±0.02	14.9 ±0.3	217.8 ±2.5	13.1 ±0.9	0.79 ±0.08	26.0 ±3.4	171.2 ±11.2

† Data are the means of 15 samples.
‡ EC, electrical conductivity.
§ CEC, cation exchange capacity.
¶ OM, organic matter.

chemical characteristics of the soil collected in 1995, before starting the experiment, are shown in Table 1.

A crop rotational system under organic [Regulation (EEC) No. 2092/91] and mineral soil fertilization was performed since 1995 in a greenhouse erected over the soil. Data reported in this study include results from 1999 to 2004. The greenhouse covered 25 × 14 m^2 of surface area and was divided into four different sectors, two devoted to organic and two devoted to mineral fertilization. Each of the four sectors was divided into three plots (G1, G2, and G3) and each plot was planted with a different crop to have biodiversity. Therefore, spatial and temporal crop variability were achieved, three crops simultaneously and seven throughout the experimentation period. Considering the marked uniformity of the soil (Table 1) and the operational restrictions imposed by crops management (Machado and Petrie, 2006) and the small greenhouse size, each 20 m^2 plot was divided into 20 subplots and four of them were selected at random where always samples were collected along the cultivation cycles. In addition, each soil sample was a composite taken by mixing three subsamples from three random points within each subplot.

Soil samples (0–15 cm deep) were taken for analysis at the beginning of each new crop. Soil samples were air-dried, sieved to 2 mm, and stored in plastic containers before analysis.

The crop cycles and rotations for the study period are shown in Table 2. There were two crop cycles per year, although some crops lasted more than one cycle. Beetroot and carrot were planted using seed with all other crops planted using nursery stock.

Composted vegetable residues and fresh residues of previous crops were used as organic amendments. The most relevant characteristics of the composts are shown in Table 3. Compost values are the means of 10 samples collected every spring and autumn during the study. Each sample is a composite of three subsamples taken from a pile of about 1 m deep at three depths, superficial, middle and bottom. Before planting, organic plots received different rates of either compost or previous crop residues, or both, depending on the amount of vegetal residues left and required fertilization; mineral plots received synthetic fertilizer applied according to literature values for a specific crop (Maroto, 1995). The organic amendment was spread onto the soil surface and the mineral fertilizer was applied through the drip irrigation system. The amounts of organic amendment and mineral fertilizer applied are shown in Table 4. From the nutrient contents of the compost and residues and the doses added to the soil, an estimate of the N, P, and K supplied to the organic plots was calculated and the data are shown in Table 5. There was no fertilization in certain cycles because they were continuation of the previous crops, and no soil samples were taken in these cases. Commercial pesticides were not used during this study on any of the experimental plots, and authorized products for organic agriculture were used for pest and disease control.

The organic residue was determined by the methods of M.A.P.A. (1994). Soil pH and electrical conductivity were determined using a 1:5 soil/water extract. Total N content was determined by Kjeldahl digestion and organic carbon (OC) by potassium dichromate oxidation, available-P using the Olsen et al. (1954) method, available K using extraction with ammonium acetate (M.A.P.A., 1994); cation exchange capacity (CEC) was determined using the method described by Tucker (1954). Particle size distribution was measured by the Boyoucos densimeter (M.A.P.A., 1994), and total carbonate content by the manometric method (M.A.P.A., 1994).

At harvest, the edible portion of each crop was sampled for analysis. The samples were carefully removed, washed with tap water to remove any attached soil particles, rinsed twice with distilled water, and then dried at 60°C. Afterward, dried samples were passed through 40-mesh screens and stored in plastic containers. Plant Kjeldahl N was determined by acid-digestion and posterior determination by autoanalyzer (BRAN+LUEBBE, method G-188-97, BRAN+LUEBBE, Norderstedt, Germany). For P and K, the samples were analyzed by dry-ashing and the ash treated with hot concentrated HCl, and the element concentration determined by inductive coupled plasma (ICP). Plant nitrate concentration was determined using the hydrazine reduction method in 2% acetic acid plant extract and analyzed using an autoanalyzer (Kampshake et al., 1967).

Statistical analysis was performed using SPSS 11.0 for Windows (SPSS, 2001). The results were expressed as mean values. Significant statistical differences of all variables between the different treatments were established by the students *t* test at $p < 0.05$. Data of soil characteristics, nutrient content, and yield from east and west plots were grouped since no statistically significant differences were observed by section location.

RESULTS AND DISCUSSION

The soil was classified as a loam soil with high carbonate content. The soil was very uniform in physical and

Table 2. Crop rotations (1999–2004) used in the three plots (G1, G2, G3) in the greenhouse.†

	Cultivation cycle‡									
	1999	2000		2001		2002		2003		2004
Plots	A	S	A	S	A	S	A	S	A	S
G1	MA	MA c	BE	TO	CH	CH c	MA	TO	F	BE
G2	BE	BE c	CH	CH c	TO	TO c	BE	BR	F	TO
G3	CH	CH c	TO	CA	BE	BE c	TO	PE	F	MA

† BE, bean; BR, beetroot; CA, carrot; CH, chard; F, fallow; MA, marrow; PE, pepper; TO, tomato.
‡ Letter is crop cycle (A, autumn; S, spring), and number is year of cycle. The letter c after crop indicates continuation of previous crop.

Table 3. Elemental analysis of the vegetal compost (dry wt. basis†) added to the organic plots (mean ± SD)‡.

pH	EC§	C¶	N	P	K	Ca	Mg	Na	Fe	Mn	Cu	Zn
	dS m^{-1}	g kg^{-1}								mg kg^{-1}		
7.7 ±0.2	2.56 ±1.3	183.2 ±32	9.0 ±1.3	5.8 ±1.4	3.6 ±1.2	118.2 ±22	5.9 ±2.3	1.0 ±0.3	8.4 ±1.3	270 ±40	18.7 ±2.3	55.5 ±5.3

† The humidity is 26 ± 3%.
‡ Data are the means of 10 samples.
§ EC, electrical conductivity.
¶ C, organic carbon.

chemical characteristics (Table 1), implying any crop and soil differences experienced during the project may be attributed to the treatment and not to soil heterogeneity.

Organic Carbon

Soil organic carbon content was found to be considerably greater in organic plots compared with those receiving mineral fertilizer (Fig. 1). Gaps in plots G2 (Fig. 1–6) are because no soil samples were taken, since they were continuation of the previous crops. Values for the organic treatment ranged between 10.3 and 18.5 g kg^{-1}, while the mineral treatment values ranged between 5.4 and 10.3 g kg^{-1}. Since the first year of this study (1999), the difference of OC between organic and mineral plots was evident, due to the addition of organic amendments during the previous 4 yr (1995–1999).

The addition of organic amendment in continuous cycles increases slightly the OC content in the soil. On the contrary, the continuation of previous crop in some cycles (i.e., no new fertilization, for example, the spring 2000), showed a decrease of OC in samples taken in the next season. However, the absence of a new crop in autumn 2003 showed an increase of OC in spring 2004. It could be due to the type of organic amendment used in the two previous cycles (autumn 2002, spring 2003) that was exclusively the residues of previous crops with the exception of plot G1 in spring 2003. The plant residues were applied on the soil surface retarding the raise of the OC until spring 2004. The continuous addition of organic matter is important to maintain the yield and content of SOM, which can be easily oxidized under the climatic conditions of our soils, located in the Mediterranean region, and especially the greenhouse conditions (high humidity and temperature). This is also important because the "young" SOM is the most biologically active OM fraction, and therefore more susceptible to be influenced by agricultural management (Wander et al., 1994). It is important to emphasize that the type and amount of organic amendment used is suitable to maintain an adequate level of OC in this soil, as shown in Fig. 1. In a short-term study, Bulluck et al. (2002) found that SOM and total C were higher in plots with organic amendment compared with synthetic fertilizer. Andrews et al. (2002) reported that the application of 11.2 to 22.5 Mg ha^{-1} yr^{-1} of different composts increased OC by 8% compared with conventional fertilized sites in the first 2 yr. In the third year there was a 16% increase in OC in the organic sites compared with conventional fertilized sites.

Scow et al. (1994) reported that OM increased after alternate application of compost (0.6–1.2 Mg ha^{-1}) and cover crop over 4 yr. However, Gosling and Shepherd (2005) did not show differences in SOM of soil with different type of fertilization, but it is not surprising due to different soil composition, climate, and rate and composition of organic amendments.

Soil Nitrogen

In all cases, significant increases in Kjeldahl N content was observed in the organically amended plots compared with the mineral plots (Fig. 2). For the organic treatment, the Kjeldahl N content values ranged between 1.4 and 2.5 g kg^{-1}, while the mineral plots values ranged between 0.8 and 1.2 g kg^{-1} (Fig. 2). The N content of organic plots is about twice the N content of the mineral fertilized plots. In the organic-amended soils, a strong relationship between the content of N and OM was found, in agreement with other authors (Drinkwater

Table 4. Crop rotation, organic and mineral fertilization applied to plots during the study, 1999–2004.

Plot		G1				G2					G3				
Fertilization		OF† Mg ha^{-1}	MF kg ha^{-1}				OF† Mg ha^{-1}	MF kg ha^{-1}				OF† Mg ha^{-1}	MF kg ha^{-1}		
Cycle (year)‡	Crop§		N	P_2O_5	K_2O	Crop		N	P_2O_5	K_2O	Crop		N	P_2O_5	K_2O
A (1999)	MA	10.5R¶	200	100	200	BE	9.3R	50	100	200	CH	30°C	150	100	150
S (2000)	MAc	–	–	–	–	BEc	–	–	–	–	CHc	–	–	–	–
A (2000)	BE	50C + 2.5R	25	50	50	CH	50°C + 2.9R	200	100	200	TO	50°C	250	125	400
S (2001)	TO	50C + 3.8R	400	200	400	CHc	20°C	200	100	200	CA	3.6R	150	100	200
A (2001)	CH	11.2R	200	100	200	TO	30°C	400	200	400	BE	50°C + 4.2R	50	100	200
S (2002)	CHc	–	–	–	–	TOc	–	–	–	–	BEc	–	–	–	–
A (2002)	MA	5R	400	200	400	BE	11.2R	50	100	200	TO	13.2R	400	200	400
S (2003)	TO	20C + 8R	400	200	400	BR	13.5R	100	50	100	PE	14.1R	350	100	650
A (2003)	F	–	–	–	–	F	–	–	–	–	F	–	–	–	–
S (2004)	BE	11R	50	100	200	TO	50°C	400	200	400	MA	50°C + 8.9R	400	200	400

† OF, organic fertilization included Mg ha^{-1} added with compost (C) and with residues from previous crops (R). MF, mineral fertilization.
‡ Letter is crop cycle (A, autumn; S, spring), and number is year of cycle.
§ BE, bean; BR, beetroot; CA, carrot; CH, chard; F, fallow; MA, marrow; PE, pepper; TO, tomato; c, continuation previous crop.
¶ R, residues from previous crop.

Table 5. Crops rotation and N, P, K applied to plots with organic and mineral fertilization during the study, 1999–2004.

Plot		G1			G2			G3	
Fertilization		OF† kg ha^{-1}	MF‡ kg ha^{-1}		OF† kg ha^{-1}	MF‡ kg ha^{-1}		OF† kg ha^{-1}	MF‡ kg ha^{-1}
Cycle (year)§	Crop¶	N–P–K	N–P–K	Crop	N–P–K	N–P–K	Crop	N–P–K	N–P–K
A (1999)	MA	39.7–7.6–70 (R)	200–43.7–166	BE	51.1–4.1–40.9 (R)	50–43.7–166	CH	205–102–85 (C)	150–43.7–124.5
S (2000)	MAc	–	–	BEc	–	–	CHc	–	–
A (2000)	BE	332–214–133 (C) 13–1.1–11 (R)	25–22–41.5	CH	317–160–102 (C) 18–1.8–10 (R)	200–43.7–166	TO	342–175–148 (C)	250–54.6–332
S (2001)	TO	385–185–128 (C) 23–2.3–13 (R)	400–87.4–332	CHc	167–90.1–74 (C)	200–43.7–166	CA	13.6–2.6–24 (C)	150–43.7–166
A (2001)	CH	42–8–75 (R)	200–43.7–166	TO	216–139.2–86.4(C)	400–87.4–332	BE	304–187–120 (C) 9.2–1.9–15 (R)	50–43.7–166
S (2002)	CHc	–	–	TOc	–	–	BEc	–	–
A (2002)	MA	8.5–1.7–13.75 (R)	400–87.4–332	BE	44.6–8.5–78.7 (R)	50–43.7–166	TO	84–8.3–47.1 (C)	400–87.4–332
S (2003)	TO	132.6–85.5–53 (C) 44–3.5–35.2 (R)	400–87.4–332	BR	84–9.3–45.4 (R)	100–21.9–83	PE	54–10.2–95 (C)	350–43.7–539.5
A (2003)	F	–	–	F	–	–	F	–	–
S (2004)	BE	23.5–2.9–17.4 (R)	50–43.7–166	TO	314–190–183 (C)	400–87.4–332	MA	340–190–170 (C) 16.6–3.3–27 (R)	400–87.4–332

† OF, organic fertilization included N, P, K added by compost (C) and with residues previous crops (R).
‡ MF, N, P, K added by mineral fertilization.
§ Letter is crop cycle (A, autumn; S, spring), and number is year of cycle.
¶ BE, bean; BR, beetroot; CA, carrot; CH, chard; F, fallow; MA, marrow; PE, pepper; TO, tomato; c, continuation previous crop.

et al., 1995). Other authors also found higher N content in soil amended with organic residues than with mineral fertilizer soils (Scheller and Raupp, 2005; Warman, 2005). It is necessary to indicate that the N applied through the organic amendment is not immediately available for plant use and must be mineralized. Soil organic N content may increase slightly because the N in organic amendment will not fully decompose in one single year (Sims, 1995). Therefore, the higher N contents in organic plots could be due in part to the nutrient supply with the composts (Tables 3–5). Organic soils are characterized by higher levels of microbial activity compared with mineral soils (Melero et al., 2006), and the N mineralization in soil is closely linked to labile soil OM pools and is largely mediated by soil microorganisms (Scheller and Vogtmann, 1995).

Soil Phosphorus

The available P content in the organically fertilized plots was significantly higher compared with the mineral ones, on the order of 2 to 4 times (Fig. 3). Levels of P in the organic plot showed greater fluctuations, compared with mineral plots, which reflect the absence of organic fertilization in some cycles and/or the plant uptake exceeded the supply P fertilizer. The absence of fertilization cycles in spring 2000 produced a clear decrease in available P in organic plots. The absence of cycle in autumn 2003 resulted in a decrease in P in the next cycle, except in the plot G1, because of the previous high fertilization in spring 2003 in this plot (Table 4). In a 3-yr study, Gliessman et al. (1996) found higher P content in organic plots after the second year following annual applications of 18.5 and 37 Mg ha^{-1} yr^{-1} of compost. Clark et al. (1998) and Edmeades (2003) showed similar results in a review of long-term studies.

There is considerable evidence in the literature to suggest that the application of organic material to soil may increase P solubility (Sanyal and De Datta, 1991). There are various mechanisms to explain the increase of available P in our experiments: (i) the use of organic amendments with a higher P content than those used in mineral fertilization (Table 5), and (ii) the decomposition of organic amendments could have resulted in concentrations of organic acids that effectively reduced P sorption to the soil and increase P availability (Laboski and Lamb, 2003). Ruiz (2002) in a previous study in our plots showed that the OM added increased the availability of P in calcareous soils, suggesting that it is due to the increase of microbial biomass in organic plots. Microbial biomass increases when organic matter is added to the soil, increasing CO_2 release, which forms H_2CO_3 in the soil solution, resulting in the dissolution of primary P-containing minerals and therefore increasing available P content (Tisdale et al., 1985). On the other hand, Tan (1998) indicated that P can be fixed in calcareous soils by forming $Ca_3(PO_4)_2$ with Ca from $CaCO_3$; however, the organic anions from organic amendments decrease the fixation of P.

Numerous studies have shown that the over-application of P in the organic form is largely responsible for soil P accumulation, at values often above crop requirements (Edmeades, 2003). That is why it is necessary to control the addition of organic amendment. However, our data indicate that in calcareous soils it seems to be more advantageous to apply these organic amendment rather than mineral fertilizer to improve the availability of P to plants, due to the high retention of P in this soil type.

Soil Potassium

The values of available K in the organic plots were higher than those of the mineral plots (Fig. 4). The available K in organic plots doubled when compared with mineral plots. The values in G1 show a continuous decrease throughout the study. This result could be due to lower fertilization in the last years (absence of crop cycles and fertilization that mostly consisted of previous crop residues without organic amendments from external sources, and the higher productivity (Tables 4, 5, and 7). It is interesting to denote that although the sup-

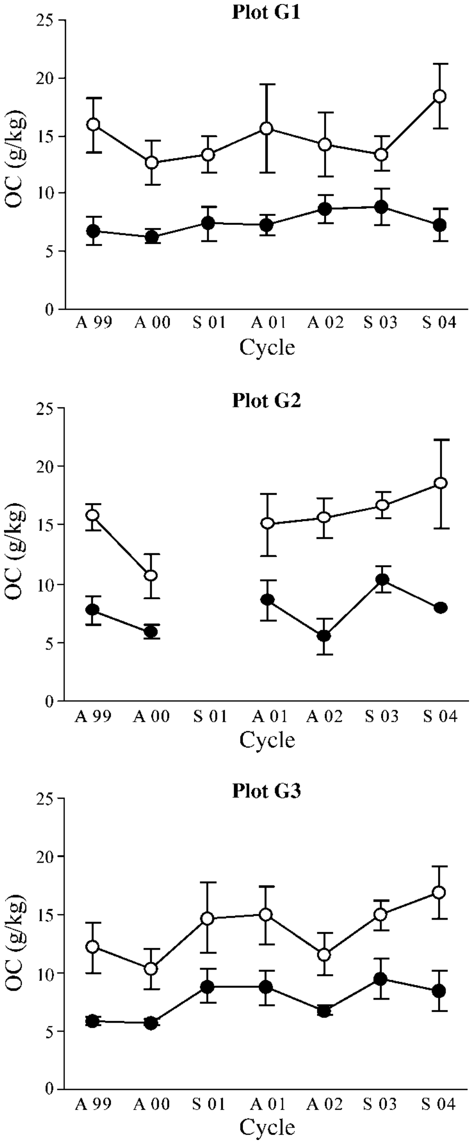

Fig. 1. Values of organic carbon (OC) in the three greenhouse plots (G1, G2, G3) across different cultivation cycles ranging from autumn (A) 1999 through spring (S) 2004. Mineral plots (closed circle); organic plots (open circle). Error bars indicate standard deviations of means (n = 8).

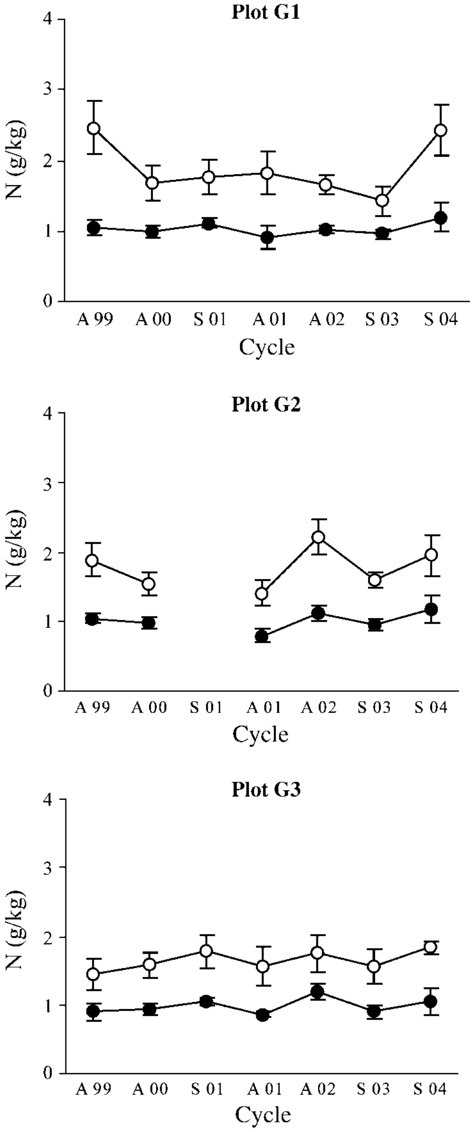

Fig. 2. Values of Kjeldahl N (N) in the three greenhouse plots (G1, G2, G3) across different cultivation cycles ranging from autumn (A) 1999 through spring (S) 2004. Mineral plots (closed circle); organic plots (open circle). Error bars indicate standard deviations of means (n = 8).

ply of K is lower with organic fertilization (Table 5), K availability in the soil organically fertilized is higher. The results obtained indicate that the increase of available K comes both from the K released from organic amendment and increasing of K availability after addition of this organic amendment.

Some authors have also shown an increase in available K after organic amendment (Gliessman et al., 1996; Bulluck et al., 2002; Edmeades, 2003). In a 3-yr study, Andrews et al. (2002) found higher K in organic systems, 11 and 20% higher in Years 1 and 3 after treatment, respectively, following applications of 11 to 23 Mg ha^{-1} yr^{-1} of compost. They attributed the result to the high K content of the compost and the increase of exchange sites due to organic matter added, which do not fix K strongly. On the contrary, illite-type clay minerals, dominant in our soil (data not shown), fix K strongly, and may be the reason for the lower K availability observed in the mineral plots compared with the organic plots.

pH Values

The values of pH did not generally show significant differences between the organic and mineral fertilization, but the pH trend seems to be toward lower values for organic plots compared with mineral plots (Fig. 5). Clark et al. (1998) showed that the soil pH increased from 6.9 to 7.4 after 4 yr of organic fertilization. These authors indicated that the reduction in ammonium fertilizer is one of the reasons for the increase in pH. Bulluck et al. (2002) showed an increase in pH in soils amended organically due to the complexation of Al and increases of basic cation in the soil solution. All these

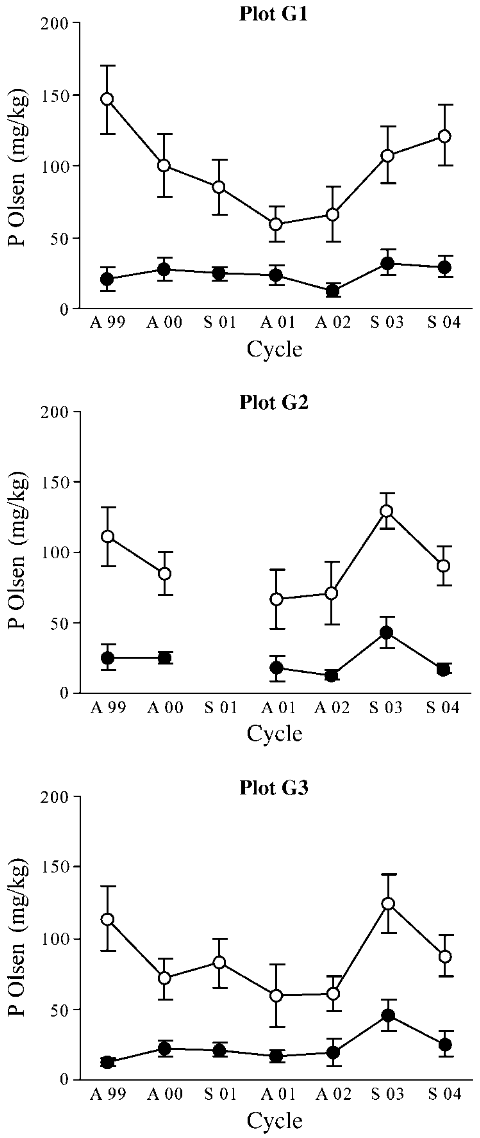

Fig. 3. Values of P Olsen in the three greenhouse plots (G1, G2, G3) across different cultivation cycles ranging from autumn (A) 1999 through spring (S) 2004. Mineral plots (closed circle); organic plots (open circle). Error bars indicate standard deviations of means (n = 8).

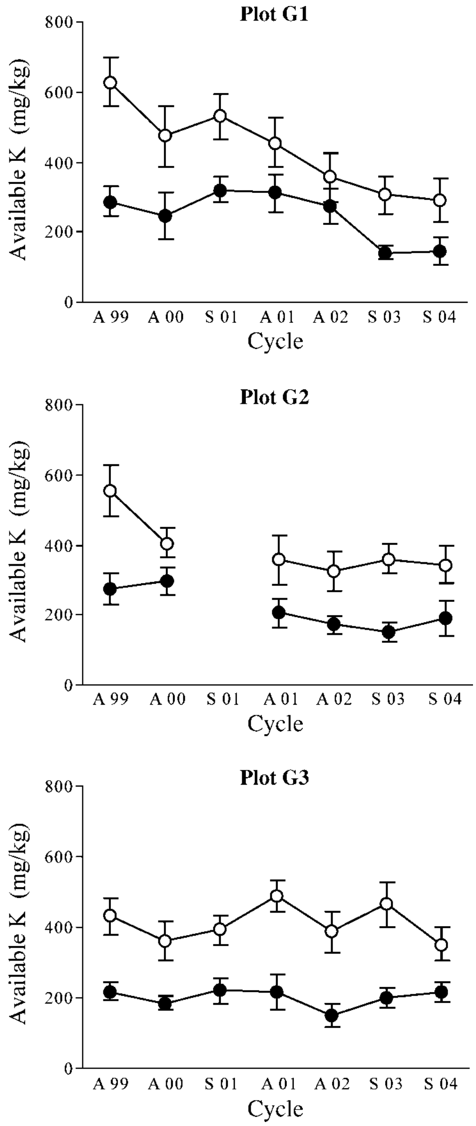

Fig. 4. Values of available K in the three greenhouse plots (G1, G2, G3) across different cultivation cycles ranging from autumn (A) 1999 through spring (S) 2004. Mineral plots (closed circle); organic plots (open circle). Error bars indicate standard deviations of means (n = 8).

studies were performed in acidic soils. However, our soil is calcareous and in these soils the pH is correlated with the partial pressure of CO_2 (Brucker and Rouiller, 1987); in alkaline medium the CO_2 produces bicarbonate by consuming OH^- and so avoids pH increase. Plant roots and microorganisms yield CO_2 when respiring and this could be the reason for a lower pH because of the higher microbiological activity in our organic plots (Melero et al., 2006). However, this pH decrease is small due to the buffer character of the SOM. In addition, the mean pH of the vegetal compost used is lower than that of the calcareous soil of our plots.

Electrical Conductivity

The results obtained in the study indicated that there were no significant differences in electrical conductivity (EC) between organic and mineral fertilizations (Fig. 6). The figures also show great fluctuations among cultivation cycles.

In general, after the absence of new crops (i.e., no fertilization) EC decreased, and that is shown in samples taken in the next season. Only the absence of fertilization in autumn 2003 does not clearly show this behavior. The highest increase is detected in autumn 2001, in organic and in mineral plots, probably due to the high fertilization performed in late spring 2001 that made most of the mineralization occurred in summer and so resulted in the rise of salinity. Hao and Chang (2003) found that repeated large organic applications increased the EC, especially in nonirrigated conditions. In our case the organic amendments applied did not increase significantly the soil salinity.

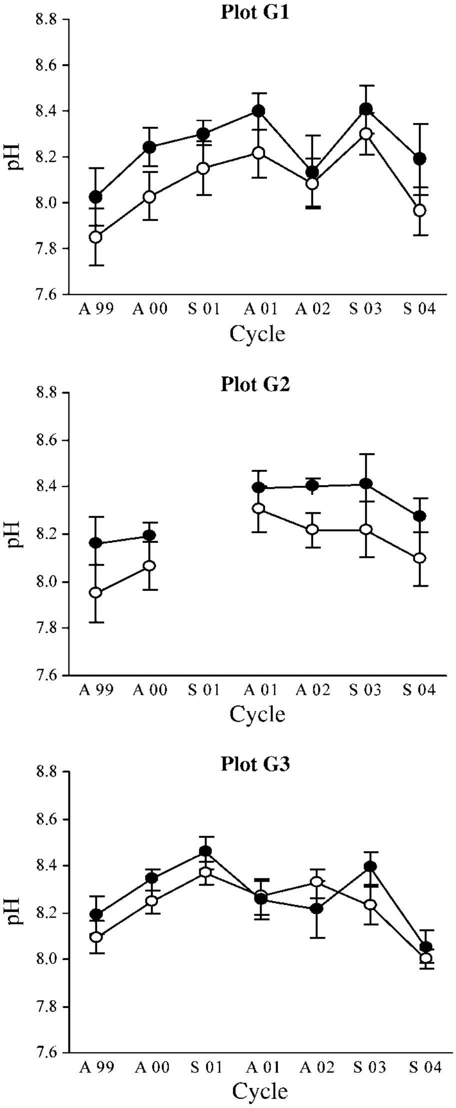

Fig. 5. Values of pH in the three greenhouse plots (G1, G2, G3) across different cultivation cycles ranging from autumn (A) 1999 through spring (S) 2004. Mineral plots (closed circle); organic plots (open circle). Error bars indicate standard deviations of means (n = 8).

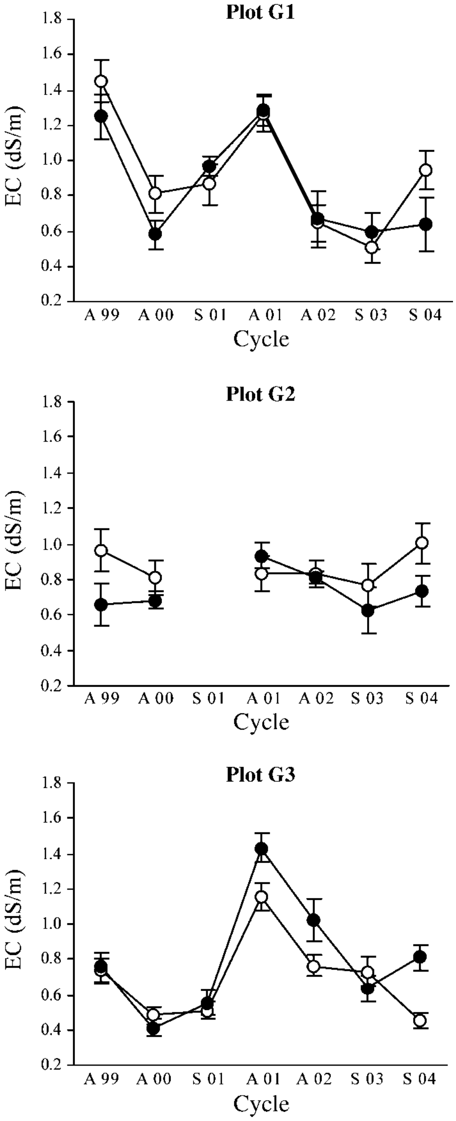

Fig. 6. Values of electrical conductivity (EC) in the three greenhouse plots (G1, G2, G3) across different cultivation cycles ranging from autumn (A) 1999 through spring (S) 2004. Mineral plots (closed circle); organic plots (open circle). Error bars indicate standard deviations of means (n = 8).

Fertilization Effect on Crop Quality

Crop quality refers to the edible part of vegetables and results are shown in fresh plant material used by consumers.

Nitrogen

The N content in the edible part of the different crops is shown in Table 6. Nitrogen concentration was significant different in some cycles for bean, beetroots, chard (*Beta vulgaris* L. var. *cicla*), tomato (*Licopersicon esculetum* Mill.), pepper (*Capsicum annuum* L.), and marrow (*Curcubita pepo* L.) (for instance, in tomato the differences were significantly different only in autumn 2001). In these cases, it is interesting to emphasize that generally the highest values of N were observed with mineral fertilization (Table 6). Other authors found similar results: Phillips et al. (2002) in bean, Clark et al. (1999) and Colla et al. (2002) in tomato. Very few studies show higher content in organic crops, as was found by Schuphan (1974) in carrot, cabbage [*Brassica oleracea* (Capitata Group)], and lettuce. In other studies performed by Lairon et al. (1984) in lettuce and Warman and Havard (1998) in potato tubers (*Solanum tuberosum* L.) and sweet corn (*Zea mays* L.), differences were not found between organic and mineral fertilization.

The soil showed higher Kjeldahl N content in organic plot and that N is not immediately available for plant uptake until mineralization. Nevertheless, in mineral fertilization N is immediately available to plants and an increase in plant uptake is typically found. However, the lower plant N in organic plots is not necessarily a negative condition because higher assimilation of N can produce high contents of crude protein, but at a lower quality (Magkos et al., 2003).

Table 6. Macronutrient content (wet basis) in the mineral and organic crop. Rotation 1999–2004.

Cycle†	Crop	Fertilization	N	P	K
			g kg^{-1}		
		Plot G1			
A99	marrow‡	–			
A00	bean§	–			
S01	tomato	min	1.24	0.21	2.40
		org	1.21	0.21	2.20
A01	chard	min	1.73	0.14*	2.24*
		org	1.81	0.15*	3.08*
A02	marrow	min	0.94	0.36	2.82
		org	1.01	0.32	2.54
S03	tomato	min	1.04	0.15*	1.59
		org	1.03	0.18*	1.68
S04	bean	min	2.97	0.38*	1.96*
		org	3.05	0.49*	2.82*
		Plot G2			
A99	bean§	–			
A00	chard	min	2.30*	0.43*	3.20
		org	2.10*	0.29*	3.16
A01	tomato	min	1.77*	0.34	3.38
		org	1.31*	0.38	3.76
A02	bean	min	3.78*	0.61	2.89*
		org	3.60*	0.64	3.75*
S03	beetroot	min	1.46*	0.59*	2.98*
		org	2.06*	0.93*	3.59*
S04	tomato	min	1.32	0.27	1.72
		org	1.32	0.28	1.81
		Plot G3			
A99	chard	min	1.96	0.35	2.72
		org	2.04	0.35	2.62
A00	tomato¶	–			
S01	carrot#	–			
A01	bean	min	3.09	0.50	2.10*
		org	3.13	0.48	2.42*
A02	tomato	min	1.80	28.0	2.12
		org	1.91	30.0	2.36
S03	peppers	min	2.01*	28.7	2.24
		org	1.75*	28.9	2.20
S04	marrow	min	2.04*	0.49*	2.55*
		org	1.27*	0.37*	2.06*

* Significant differences at $p < 0.05$ between organic and mineral fertilization.
† Letter is crop cycle (A, autumn; S, spring), and number is year of cycle.
‡ Crop seriously affected by oidium (erysiphe cichor), and mildium (*Phytoptora infectans*).
§ Crop seriously affected by rosquilla (Spodoptera Littoralis), and botritis (*Botrytis cinerea*).
¶ Crop seriously affected by mildium (*Phytoptora infectans*).
\# Crop seriously affected by weed competition.

Phosphorus

Total P content of the different crops is also shown in Table 6. In six crops there were differences between organic and mineral treatment. There are significant differences between organic and mineral nutrition in bean, beetroot, chard, tomato, and marrow, but only in some cultivation cycles and with different trends. Phillips et al. (2002) reported no differences in P concentration of organically and conventionally fertilized bean crops. Colla et al. (2002) and Wszelaki et al. (2005) reported higher P content in organic than in minerally fertilized tomato and potato crops, respectively. However, other studies showed higher P concentration in tomato and onion (*Allium cepa* L.) with mineral fertilization compared with organic crops (Warman, 2005). The values of P concentration reported in the literature did not show a clear trend for organic and mineral fertilized crops, as was observed in this study.

Potassium

Among the 15 crops shown in Table 6, only six of them showed statistical differences in K content between mineral and organic treatment, and in five of these cases K concentrations were higher in organic crops. Phillips et al. (2002) and Wszelaki et al. (2005) reported no differences in K for bean and potato, respectively, but Warman (2005) found different trends depending on crops. In our case, tomato crops did not show differences between both treatments, but in the case of bean all of them presented higher K concentrations in the organic crop. However, in the rest of crops K concentration did not show a definite trend.

Nitrate

Table 7 shows the results of the nitrate concentration for the different crops studied. It is remarkable the influence of the type of soil fertilization on nitrate concentration on the edible parts of crops. Typically nitrate concentrations were lower in crops from organic plots than in those from mineral fertilization. Williams (2002) reported lower nitrate content in organically fertilized crops, particularly leafy vegetables, and Vogtmann et al. (1993) showed lower nitrate concentration in cabbage with organic fertilization compared with mineral fertilized crops, but no significant differences occurred in carrot. Hajslova et al. (2005) and Malmauret et al. (2002) reported lower nitrate concentration in organic potato and tomato, respectively, compared with mineral crops.

The nitrate concentration in the plant is the balance between the nitrate uptake and its reduction by photosynthesis. Excessive applications or improper timing of commercial fertilizer or animal wastes can lead to excessive nitrate levels in the plant (Maynard et al., 1976). Low nitrate content in the edible part of the plants is

Table 7. Nitrate concentration (wet basis) in the edible part of different crops studied. Rotation 1999–2004.†

Crop‡	Plot	Cycle	Fertilization: Mineral	Organic
			mg kg^{-1}	
Chard	G3	A99	870.4 a	546.4 b
	G2	A00	2113.5 a	1274.3 b
	G1	A01	1061.4 a	749.3 b
Tomato	G1	S01	15.2 a	4.9 b
	G2	A01	6.4 a	6.0 a
	G3	A02	nd§	nd
	G1	S03	nd	nd
	G2	S04	nd	nd
Bean	G3	A01	185.6 a	150.9 a
	G2	A02	275.4 a	306.5 a
	G1	S04	108.2 a	11.7 b
Marrow	G1	A02	884.6 a	405.4 b
	G3	S04	221.9 a	249.1 a
Beetroot	G2	S03	235.4 a	249.1 a
Pepper	G3	S03	82.2 a	17.7 b

† Means followed by different letters denote significant difference ($p < 0.05$) between organic and mineral crops.
‡ Only included the crops analyzed.
§ nd, not detectable.

very important for human health, due to its potential transformation to nitrites, which have the highest possibility to interact with hemoglobin and affect blood oxygen transportation (Causeret, 1984) In addition, it can be combined with secondary amines yielding nitrosamines, with cancerigenic effects (Farré and Frígola, 1987). Quantities of nitrate in edible portions of crops are influenced by numerous factors, including environmental conditions, soil properties, or plant genotype (Bosch et al., 1991). Since the influence of solar radiation and temperature play an important role in nitrate accumulation, this could be one of the reasons for the different values in the same crop in different cultivation cycles.

Crop Yield

Table 8 shows the crop yields obtained in mineral and organic plots from 1999 until 2004, although some cycles are not present due to crop failure associated with diseases as indicated in Table 6. Crop problems were very important in the autumn/winter crops (1999, 2000, and 2002) due to the climatic conditions resulting in high humidity in the greenhouse, which favored crop diseases. Therefore, it is very important to control the humidity in greenhouses. In addition, there were problems with the use of seeds (i.e., carrot and beetroot) because of weed competition. Therefore, transplanting is advisable with nursery plants.

In accordance with the reference values of agronomic production in the Guadalquivir River Valley (C.A.P., 2001), the production in the first years of our experiment was lower for both mineral and organic fertilized plots. Nevertheless, in 2001, 2003, and 2004, the production in organic plots was the same or superior to the reference values.

Few statistically significant differences in yields were observed between plots organically amended and plots fertilized with synthetic fertilizer (Table 8). In our study, differences in yield were not detected in 17 of the 20 crops studied.

Vogtmann et al. (1993) reported that organic treatments lowered vegetable yields the first 2 yr of treatment, but yields did not differ after the third year. Rebounding productivity may be associated with beneficial changes in soil organic matter and organic matter–dependent soil properties (Liebhardt et al., 1989). Yields of crops grown either with organic or mineral fertilization can be equivalent (Reider et al., 2000; Warman, 2005). Drinkwater et al. (1995) suggested that other components such as cultivar and management skill were more significant in determining yields than the specific type of input or cultural practice employed.

Table 8. Crop yields in the mineral and organic plots and reference values of the study. Rotation 1999–2004.

Cycle	Plot	Crop†	Mean mineral	Mean organic	References values‡
			Mg ha^{-1}		
A99	G1	marrow§	17.48	19.15	65.00
A99	G2	bean¶	9.36	8.41	18.20
A99	G3	chard	426.67	378.62	–
A00	G1	bean	–	–	18.20
A00	G2	chard	250.17	229.81	–
A00	G3	tomato	–	–	95.00
S01	G1	tomato	73.28	74.01	95.00
S01	G3	carrot	–	–	–
A01	G1	chard	273.56*	340.76*	–
A01	G2	tomato	92.97	92.54	92.54
A01	G3	bean	23.18	20.68	18.20
A02	G1	marrow#	21.69	26.79	65.00
A02	G2	bean#	6.75	6.83	18.20
A02	G3	tomato††	48.31*	38.69*	95.00
S03	G1	tomato	61.43	54.44	95.00
S03	G2	beetroot‡‡	–	–	–
S03	G3	peppers	85.42	81.35	85.00
S04	G1	bean	48.18*	19.77*	18.20
S04	G2	tomato	121.52	106.01	95.00
S04	G3	marrow	45.42	51.21	65.00

* Significant differences at $p < 0.05$ between organic and mineral crops.
† No numerical value indicate crops seriously affected and there were not productions.
‡ No numerical value denote no references in bibliography (C.A.P., 2001).
§ Crop affected by oidium (erysiphe cichor), and mildium (*Phytoptora infectans*); nevertheless, the yield was determined.
¶ Crop affected by rosquilla (*Spodoptera littoralis*), and botritis (*Botrytis cinerea*); nevertheless, the yield was determined.
# Crop affected by botritis (*Botrytis cinerea*), but the yield was determined.
†† Crop affected by mildium (*Phytoptora infectans*), but the yield was determined.
‡‡ Crop affected by weed competition. Yield was not determined.

CONCLUSIONS

The type and amount of organic amendment described in this research is suitable to maintain an adequate level of soil organic matter, Kjeldahl N and available P, and K in greenhouse soil, even higher than that obtained by application of the mineral fertilizer. No clear differences were found in pH and electrical conductivity for both fertilization types.

With regard to the effect of different fertilization type on mineral concentration in greenhouse crops, very few compositional differences were found. There was a trend of higher N concentration in mineral crops and higher K concentration in organic crops. Nevertheless, the results were variable depending on the crop, season cycle, and year.

The use of vegetal compost and fresh vegetable residues and the elimination of synthetic fertilizers results also in a lower nitrate concentration in crops, which can provide benefits for human health.

Few statistically significant differences in yields were observed between plots fertilized with organic amendment and plots with synthetic fertilizer. The lower production in the first years has been due to the handling problems in the greenhouse, fundamentally, by disease produced by climatic conditions and not for the type of fertilization.

We conclude that it is important to control the type, amount, and form of incorporation of the organic matter to the soil. The continuous addition of organic matter is important to maintain yield and SOM content, which can be easily oxidized under the climatic conditions of our soils located in the Mediterranean region and especially those of the greenhouse (high humidity and temperature). Organic matter increase is particularly important in Andalusia, the region of our study, where the levels of organic matter in agricultural soils are normally less than 10 g kg^{-1}.

Fundamentally it is more important to maintain an adequate content of organic matter in soil than the theoretical application of a pool of nutrients, because a soil rich in OM can supply the necessary nutrients to crops and provide important fertility benefits.

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