Europ.J.Hort.Sci., **71** (4). S. 183–191, 2006, ISSN 1611-4426.

Yield and Quality of Sequentially Grown Cherry Tomato and Lettuce under Long-Term Conventional, Low-Input and Organic Soil Management Systems

S. Moccia[1)], A. Chiesa[1,2)], A. Oberti[1)] and P.A. Tittonell[2)]
([1)]Department of Horticulture, University of Buenos Aires, Buenos Aires and [2)]Department of Soil Science, University of Lomas de Zamora, Buenos Aires, Argentina)

Summary

Besides to conventional fertiliser use, organic and low-input technologies are being increasingly used for soil management in vegetable production. However, different factors operating during crop growth (i.e. the pre-harvest factors) and related to soil properties may affect yield and quality of vegetable crops. The present research aimed to study how different soil management regimes influence soil physical and chemical properties and how these affect yield and some quality traits of two major vegetable crops. We focused on lettuce, a major crop in the area under both conventional and organic production, and on cherry tomato, which is increasingly grown in organic vegetable systems. The soil management systems were: conventional (CM), following recommended fertilisation rates; low input (LI), using minimum fertilisation rates as needed; and organic, including manure application (MA) and incorporation of oat as green manure (GM) and of maize residues (MR). Preliminary results indicate that after 7 years of rotating vegetable crops soil properties tended to improve with some systems: e.g. lower bulk density and higher porosity with MA; higher cation exchange capacity (CEC) with MA and CM. After these 7-year pre-treatments, significant differences in crop growth and yields were observed for cherry tomato and lettuce grown under different production systems, but not for the overall quality indicators. The highest yields of cherry tomato were achieved with CM and MA, due to increased number of fruits per plant, with no differences in fruit weight. Lettuce yields were generally higher with CM compared to LI, although the effect was different for different types of lettuce: the leafy type produced higher yields per area whereas the Latin type produced heavier individual plants. Under organic soil management systems, the relative survival and the visual quality of the Latin type was reduced by *Botrytis cinerea* infections. The results of the study indicated that plots that underwent long-term applications of 15 t ha^{-1} manure every two years produced similar yields than conventional systems and had comparable soil fertility attributes. However, the visual quality of the end product may be affected under organic systems. As observed for lettuce, cultivar choice may also play a role, since some lettuce types appeared to be more suitable for such systems than others.

Key words. *Lycopersicon esculentum* – *Lactuca sativa* – organic fertilisers – long-term soil fertility management – nutrient management

Introduction

In recent years, great interest has been directed to the capacity of sustainable vegetable production systems to provide safe, quality food while preserving the environment and the production resources, and meeting the various socio-cultural and economic requirements of farmers and society (Serageldin 2003). The development of technologies that are alternative to those of the 'conventional' vegetable production systems, namely organic and/or low-external-input technologies, has largely occupied the governmental and even the private research agendas during the last decades (e.g. Uvah and Coaker 1984; Miller and Cowles 1990; El-Shinawy et al. 1999). Efforts were mainly concentrated on reducing the risks of toxicity to the consumers and the environment, reducing the impact on the resource base for future production or maintaining acceptable production levels relying on few or virtually no agrochemical inputs, by adopting process-based technologies (i.e. inter-crops, rotations, etc.) (Tittonell et al. 2006).

Conventional soil fertility management of vegetable crops frequently leads to poor overall nutrient use efficiency, as mineral fertilisers are normally applied in excess of crop requirements and a large proportion of the applied nutrients is lost, having serious consequences for the environment (Byrnes 1990). Sustainable low-input and/or organic vegetable production systems require sound technologies for soil and nutrient management to ensure crop productivity and avoid undesirable emissions to the environment, thereby increasing the efficiency of nutrient 'capture' within the system. Both low-input and organic approaches to soil management have revolved around different forms of organic matter applications (manure, crop residues, etc.) and/or use of soil amendments based on organic materials such as algae biomass, slow release mineral fertilisers or synthetic soil additives such as water-storing polymers (e.g. HORNICK and PARR 1987; CREAMER 1996; TITTONELL et al. 2002). These different technologies aim to ensure nutrient supply to crops in the short term, to maintain desirable physicochemical soil properties for crop growth in the long term, or both. However, the use of soil amendments suitable for organic vegetable production may be constrained by their regional availability or, when local organic resources are used (e.g. farm yard manures or residues from arable crops), by their variable nutrient contents and intrinsic quality (e.g. lignin to N ratio).

In the field, the economic reality is more likely to dictate the type of vegetable crops that are grown and the method used to produce them (SHEWFELT and HENDERSON 2003). In a vegetable production area where an increasing number of farmers are intending to turn their conventional systems into (certified) organic systems, the availability of organic nutrient resources is critical. Thus, the organic vegetable production systems should be integrated as best as possible with currently co-existing farming activities in the area that can provide them organic resources for soil management, such as arable farming or livestock keeping. The benefits of using organic resources for soil management, however, are often underrated when comparisons with the conventional systems are made in a short term (i.e. 1 season). In a long term (i.e. >5 years), the continuous use of organic resources for soil management may induce favourable conditions in the soil, in terms of physical properties and the built-up of nutrient stocks, that may have a favourable impact on vegetable production. Virtually no study has been conducted in our region to show the long-term effect of using locally available organic resources into vegetable production systems, relative to conventional fertiliser use. Few studies (e.g. MOCCIA et al. 1999) have shown the effect of changes in soil properties induced by organic soil management on yield and quality of locally-grown vegetables.

However, the management technologies used under different production systems (conventional, low-input, organic) may impose important variation in the environment in which crops develop. Under organic management systems the impact of diseases and/or nutrient limitations due to e.g. lack of synchrony between nutrient release and crop demand may have an impact on the final quality of the crop product harvested. Such quality changes may be verified in their chemical composition as well as in their external appearance (ELIA et al. 1997). For a number of widely consumed leaf and fruit vegetables, WORTHINGTON (2001) showed important differences in chemical composition between organically and conventionally grown crops. External and internal quality changes were reported for lettuce under e.g. different organic and mineral fertilisation rates (GIANQUINTO and BORIN 1996).

Here we present the results of research that was undertaken to study the influence of long-term soil management systems on the yield and quality of outdoor vegetable crops, considering in this case a fruit crop such as cherry tomato and several varieties of lettuce. Cherry tomato is increasingly grown by organic growers due to the somewhat higher prices paid for such quality product (HOBSON and BEDFORD 1989), which compensates for lower yields attained under the organic system, and due to its greater tolerance to pests and diseases (NUEZ 1995). Lettuce is the main crop in our region, widely grown by conventional and organic growers, and subject to important quality variation throughout the year (CHIESA et al. 2003). Different options for long-term soil fertility management were evaluated on a sequence of two consecutive crops, as part of a longer term crop rotation plan. The organic soil management systems tested were conceived to make use of locally available animal manures and crop residues, and to integrate double-purpose crops such as oat or barley in the system, which can be used as fodder for traction animals and incorporated as green manures. This study was also seen as a necessary step towards the development of approaches to ensure quality of vegetable products throughout the production chain, while embracing the attempts to design sustainable horticultural systems.

Materials and Methods

The experiments were conducted in the research unit of the Horticultural Department at the University of Buenos Aires (34 ° 45 ‘ S: 60 ° 31 ‘ W), Argentina, on a clay loam Argiudoll (28 % clay; 42 % silt). Mean rainfall and temperature regimes in the area are presented in Fig. 1. Experimental open field plots of about 1000 m^2 have been managed under conventional, low-input and organic production systems since 1994. The plots managed as conventional (CM) received the locally ‘recommended’ fertilisation rates (100, 50 and 50 kg ha^{-1} N, P and K, respectively) without soil analysis and chemical control of pests and diseases, similar to those used in commercial farms. In plots managed under the low-input approach (LI) minimal fertilisation rates were used as necessary, according to the crop grown, its stage and performance (during experiment 2, no fertiliser was applied in these plots – see below). The long-term, organic soil management strategies consisted of manure applications at a rate of ca. 15 t ha^{-1} every two years (MA, in 1994, 1996, 1998 and in 2000); incorporation of vegetative oat (*Avena sativa*) biomass (sowing density: 50 kg ha^{-1}) into the soil as green manure every season after two previous cuts were done for haying (GM, ca. 6 t ha^{-1}), and surface applica-

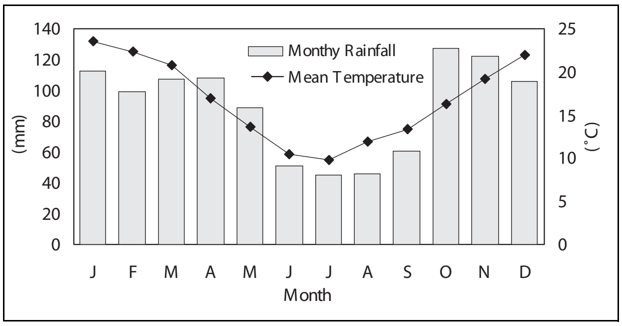

Fig. 1. Mean rainfall and temperature regimes at the experimental field of the Horticultural Department, University of Buenos Aires, Argentina (34 ° 45 ‘ S: 60 ° 31 ‘ W).

Table 1. Approximate annual macronutrient inputs under the different soil management systems during 7 years.

Treatment	Regime*	Nutrient input (kg $ha^{-1}year^{-1}$)		
		Nitrogen	Phosphorus	Potassium
Conventional**	100 CAN/100 DAP/100 KNO_3	78.0	46.0	36.5
Low input**	80 CAN/30 DAP	42.6	15.0	0.0
Animal manure	7.5 t ha^{-1} (40 % DM)	45.0	7.5	23.0
Green manure***	4 t ha^{-1} (50 % DM)	30.0	4.0	18.0
Crop residues	3.5 t ha^{-1} (30 % DM)	10.5	2.1	9.6

*Values were estimated rather than measured, except for the mineral fertilisation rates, and nutrient concentrations were derived from tabulated values (Palm et al. 2001)
**This regimes correspond only to the year 2000
***Strictly, these nutrients were not 'added' to the soil but rather recycled, incorporated with oat biomass (nutrients were partially exported as hay biomass)
CAN: calcium ammonium nitrate; DAP: di-ammonium phosphate; DM: dry matter

tion and incorporation of maize (*Zea mays*) stalks every autumn (MR, ca. 3.5 t ha^{-1}). All soil amendments were incorporated for 7 years up to experiment (Exp.) 1, and were not repeated before Exp. 2. Table 1 gives an approximate value for the macronutrient inputs applied to the soil annually under each of the soil management systems before Exp. 1 (2000), calculated from standard values and yield estimates for the GM (not measured). In fact, the latter did not receive any nutrient input during the 7 years, and the effects of incorporating GM were only expected on soil properties related to increased soil C contents. Before 1994, the experimental field that had been normally used for grain crops, stayed uncropped for 3 years.

Experiment 1 (spring – summer 2000)

Biomass production and yield quality of cherry tomato (*Lycopersicon esculentum* var. *cerasiforme*) as affected by the technology for soil management were evaluated. Cherry tomato Hybrid DRC 142 F1 (morphologically determinate) was used. Seedlings were raised in a greenhouse on multi-cell polystyrene planter flats, using a substrate prepared with 2 mm-sieved soil, compost and perlite (1:1:1). On November 13th 2000, 63-day seedlings were transplanted to open field plots with a stand density of 3.3 plants m^{-2}, using mulch consisting of a black polyethylene film. A randomised block design with three replicates was used; the experimental units consisted of single (replicate) plots randomised within soil management plots. Harvest started 85 days after transplant, with fruits in a turning-to-red stage, and proceeded for 29 days for all treatments. Harvested fruits were weighted and the yields per plant and per area were calculated; for a sub-sample of fruits, their content of soluble solids was measured by means of a refractometer (Aoac 1990). Whole plants were also sampled from each plot (27 per plot) at harvest. Roots, shoots and fruits were separately weighted, dried at 75 °C for 72 h and re-weighted. Partition coefficients were calculated by relating the dry weight of the different plant parts with the total dry weight per plant. The harvest index (HI = fruit yield / total biomass yield) was determined after 29 days of harvesting for a sub-sample of 3 plants per plot.

Experiment 2 (winter – spring 2001)

The behaviour of three widely known lettuce types (Leafy, Latin and Butterhead) grown under the different soil management systems (i.e. conventional, organic and low-input) after a cherry tomato crop was evaluated. The varieties of lettuce used were the leafy type 'Maravilla' (M1), the Latin type 'Gallega' (G1) and the butterhead type 'Reina de Mayo' (R1). Seedlings were raised in a nursery greenhouse (winter 2001) on polystyrene planter flats filled with a sand, compost and vermicompost (1:1:1) substrate and transplanted to open field with 2 fully expanded true leaves on August 24th 2001; a black film mulching was used. A split-plot design with three replicates was used, with soil management as whole plots and lettuce type as small plots. Plants were counted periodically during the crop cycle and the relative survival for each treatment and variety were calculated. All plots were harvested 57 days after transplant. A sub-sample of 5 plants was taken from each experimental unit to measure stem length (cm) by split-cutting them. The fresh and dry [72 h at 75 °C] weights of entire plants (marketable product) were determined and their dry matter content (%) was calculated. A visual quality scoring was adopted, considering colour, turgidity, size, shape, presence of coloured spots or heterogeneity caused by pests, diseases or nutritional deficiencies, and symptoms of any kind of damage – excluding those produced by handling. The following scale (1 to 5) was adopted: Score 1 was very poor, non-commercial; Score 2 was poor; Score 3 was regular; Score 4 was good; and Score 5 was very good, optimal visual quality.

Soil analysis

Topsoil samples (0–20 cm) were taken from all plots at the beginning of the treatments (1995) and before transplanting cherry tomato (2000); plots were sampled at 5 different points with an auger, these sub-samples were mixed and a composite sample from each plot, of about 0.75 kg, was sent to the laboratory. They were chemically analysed following standard, widely used procedures: pH was determined in water (1:2.5); total nitrogen was determined by sulphuric digestion (i.e. the Kjeldahl method

Table 2. Results of the chemical soil analysis at the beginning (1994) of the long-term treatments (soil management systems) and before planting cherry tomato (Experiment 1 - 2000).

Soil properties	Initial values	Treatment				
		CM	LI	MA	GM	MR
Soil organic C (g kg^{-1})	14.3	19.4	15.4	24.0	16.8	17.3
Total N (g kg^{-1})	1.6	2.5	2.0	2.5	2.0	2.0
C:N	8.9	7.8	7.7	9.6	8.4	8.7
Extractable P (mg kg^{-1})	9.9	20.4	14.0	21.9	10.6	12.9
pH water (1:2.5)	7.8	6.7	6.7	7.0	6.8	6.9
Exchangeable cations ($cmol_{(+)}$ kg^{-1})						
Ca^{2+}	9.8	10.2	9.0	10.0	5.7	8.3
Mg^{2+}	n/a	3.6	2.4	2.2	1.4	2.0
Na^{+}	n/a	1.3	1.4	1.1	1.0	1.2
K^{+}	n/a	2.5	2.3	2.4	1.6	2.0
CEC ($cmol_{(+)}$ kg^{-1})	14.1	20.4	17.5	21.4	14.6	16.0

CM: conventional management; LI: low input; MA: manure amendments; GM: green manure (oat); MR: maize residue; CEC: cation exchange capacity

Table 3. Results of the physical soil analysis for the different treatments (long-term soil management systems) before planting cherry tomato (Experiment 1 - 2000).

Soil properties	Unit	Treatment				
		CM	LI	MA	GM	MR
Bulk density	t m^{-3}	1.14	1.10	0.94	1.10	1.14
Total porosity	% v/v	56.30	57.80	63.80	57.70	56.10
Field capacity (0.3 bar)	% v/v	33.30	30.90	31.10	31.60	32.00

CM: conventional management; LI: low input; MA: manure application; GM: Green manure (oat); MR: maize residue

– BREMER 1960), the WALKLEY and BLACK (1934) method was used to determine soil organic carbon, and the BRAY and KURTZ (1945) method was used for extractable P; exchangeable cations were determined by photometry and the cation exchange capacity (CEC) by titration with $(NH_4)^+$ 1 N at pH 7. Undisturbed samples taken in winter 2000 were also physically analysed for bulk density, total porosity and field capacity (0.3 bar).

Statistical analysis

Results were subjected to analysis of variance (ANOVA) according to their experimental design, and treatment means were compared using the Tukey test ($P<0.05$). The analyses were performed using Genstat Release 6.

Results

Changes in soil properties after different long-term soil management systems

For all soil management systems, an increase in the average value of most soil properties was observed after 7 years (Table 2), compared to their initial values (after 3 years of fallow). Most chemical soil properties in 1994 were at around moderate to slightly low levels, according to local reference values (e.g. INTA 1980). Before Experiment 1 (2000), soil properties (chemical and physical) measured in the plots amended with manure (MA) tended to be more favourable compared with those of the other soil management treatments (Tables 2 and 3). MA plots had larger soil C and extractable P values, a higher C:N ratio and a greater cation exchange capacity (CEC) than the rest of the treatments, and together with the CM plots, the higher total N values; after 7 years of manure amendments, these plots tended to have a larger total porosity as well. The plots where oat was used as green manure (GM) had the lowest nutrient levels in the soil after 7 years, which were also comparable to those in which maize stalks (MR) were incorporated. Plots managed under the conventional system in the region (CM) had values for most soil properties that were close to those of MA. The low input plots (LI) had C, N and P levels comparable to those of the GM, though the level of exchangeable cations was closer to the MA.

Soil C and total N levels were notably improved in MA and CM plots; for the soil management systems in which

Table 4. Yields and yield components of cherry tomato under different soil management systems.

Soil management system	Yield per plant (g plant^{-1})	Yield per area (g m^{-2})	Yield components	
			Number of fruits (fruits m^{-2})	Mean fruit weight (g)
CM	1597 a	5270 a	544 a	9.6 a
LI	1298 b	4283 b	461 b	9.3 a
MA	1548 a	5155 a	540 a	9.6 a
GM	1150 c	3829 c	391 c	9.8 a
MR	1311 b	4366 b	478 b	9.1 a

CM: conventional management; LI: low input; MA: manure amendments; GM: green manure (oat); MR: maize residue
Means followed by the same letter do not differ significantly (Tukey, $P<0.05$).

Table 5. Partition coefficients for the dry weight of roots, stems, leaves and fruits and harvest index of cherry tomato under different soil management systems.

Soil management system	Partition coefficients				Harvest index (29 days)*
	Roots	Stems	Leaves	Fruits	
CM	0.04	0.23	0.27	0.46	0.61
LI	0.06	0.21	0.21	0.51	0.63
MA	0.08	0.24	0.20	0.48	0.62
GM	0.08	0.24	0.23	0.45	0.61
MR	0.06	0.23	0.17	0.53	0.60

CM: conventional management; LI: low input; MA: manure amendments; GM: green manure (oat); MR: maize residue
*Calculated with fruit dry weight yields after 29 days of harvesting for a sub-sample of 3 plants per plot

no mineral fertilisers were used (MA, GM and MR) the C:N ratio of the soil organic matter as well as the topsoil pH (water 1:2.5) were more stable, compared with CM and LI. Extractable P was more than doubled from its original value in CM and MA plots. The levels of Ca^{2+}, Mg^{2+} and K^{1+} were the lowest for the GM plots.

Yield and dry matter partition of cherry tomato

Significant differences in fruit yield per plant and per area were observed under the five soil management systems (Table 4). The plots managed with fertilisers for 7 years (CM) and those amended with manure (MA) produced the largest yields, followed by the MR and LI ($P<0.05$). Yields obtained in the GM plots were on average 26 % smaller than those of MA. Yield differences were due to the number of fruits obtained per plant for each treatment, as the individual weight of fruits did not vary between them and plant densities remained the same in all treatments throughout the experiment. The results presented in Table 4 indicate that the number of fruits per plant was positively related to plant size, and that the smaller number of fruits per plant in GM plots was somehow compensated by a non significantly larger individual fruit size. The fraction of the dry matter partitioned towards fruits (Table 5) tended to be higher for the treatments producing intermediate yields (LI and MR); partitioning towards leaf biomass was more favoured under CM, whereas root biomass tended to be more favoured under MA and GM. The differences in the contents of soluble solids and total dry matter in the fruits harvested from the different treatments were also not significant (data not shown); the grand means were 6.15 % (±0.24) for the former and 8.36 % (±0.65) for the latter. Fruit and total biomass production per plant by the end of the harvest period varied consistently between treatments, as the average harvest indexes calculated for them were comparable.

Response of different lettuce types

Differences between soil management systems were observed for the final fresh weight of individual lettuce plants (Fig. 2), but they were less marked for the yields per area (Table 6). Plant sizes tended to decrease in the sequence: conventional – organic – low input, although for the butterhead type the smallest plants were harvested in GM and MR plots. There was also an effect of the genotype (Fig. 2), which varied for the different production systems (although the interaction was not significant, $P<0.05$). For the leafy type, the largest yields were harvested from the CM and MA plots, whereas for the Latin type the largest yields were harvested from CM, with no significant differences between the other treatments. Due partly to phenotypical differences between these cultivars, the butterhead type produced the smallest plants under all soil management systems. For the yields per area, a significant interaction Soil Management system (SM) x Lettuce Type (LT) was observed (Table 6), making it difficult to interpret the results of the means compari-

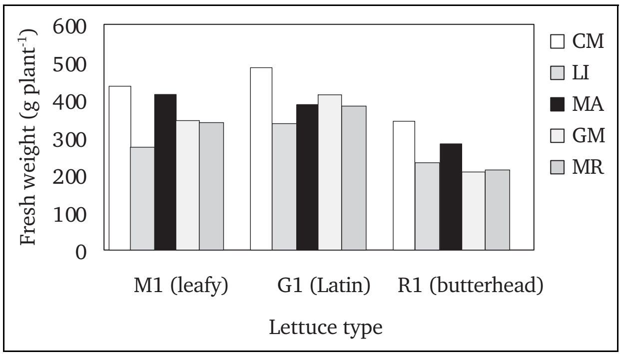

Fig. 2. Fresh weight of individual plants at harvest for three lettuce types grown under different production systems: CM is conventional management (high intensity of fertiliser use); MA, GM and MR are organic options for soil management (manure, green manure and maize residues); LI is low input management (few fertiliser used). Vertical bar indicates minimum significant difference according to the Tukey test (P<0.05).

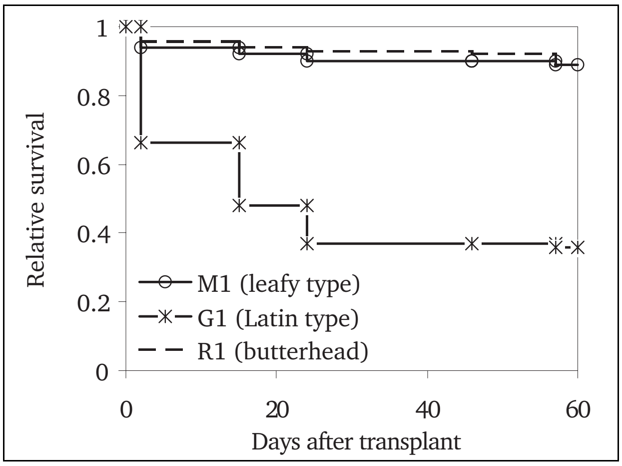

Fig. 3. Cumulative relative survival of lettuce plants grown under organic soil management systems (incorporation of manure, green manure or maize residues). Reduction of plant stands of Latin lettuce were due to fungal diseases.

son (Tukey test). Nevertheless, larger yields tended to be obtained under CM as well as in the organic MA plots, and the leafy type (M1) had the best average performance amongst the varieties tested. The lack of consistent statistical differences in yields per area was also due to the variability introduced by the important reduction of the plant stands caused by several fungal diseases (particularly by *Botrytis cinerea*). The Latin type, which tended to produce large individual plants in all production systems (cf. Fig. 2), was highly susceptible to such diseases and showed the highest rates of mortality under the three organic systems (considered together in Fig. 3).

For the dry matter content, there were some significant (P<0.05) differences between the averages for each soil management system (Table 6) and not between lettuce types. Clearly, plants grown under CM had the lowest average values. The length of the stems, an overall quality attribute and an indicator of development rate and stage, did not vary significantly between soil management systems; due to genotypical differences, stems of the leafy type M1 were significantly (P<0.05) longer. The length of the stem tended to be longer in plants from CM plots, indicating a faster development rate associated to stem elongation.

Statistical differences for the visual quality score (VQS) were observed between soil management systems and not between lettuce types. However, strong interaction between these factors was observed, which was consistent with the variable degree of disease damage experienced by the Latin type G1 under the organic (MA, GM, MR) systems. Lower VQS's for the organic systems were mainly associated to differences in plant size, yellowing and turgidity for R1, plant health for G1, and stem elongation for M1. Under LI, low VQS's were associated with plant size, coloured spots and heterogeneity caused by both nutrient deficiency and plant diseases.

Discussion

The long-term soil management strategies under different production systems (conventional, low-input and organic) affected the growth and yield of the vegetable crops within the crop sequence studied here (cf. Tables 4 and 6, Fig. 2). This variation could be partly ascribed to the differences in soil properties that resulted from the long-term soil management system, affecting soil physical properties and the build-up of nutrient stocks (cf. Tables 2 and 3), and partly to the amount of nutrient inputs added to the soil prior to the Experiment 1 (cf. Table 1). The only organic soil management system that added substantial amounts of nutrients to the soil was the application of animal manure (MA). Yields under MA for both tomato and lettuce (except for the Latin type) were similar to those obtained under the conventional system (CM). After 7 years of treatment, the soil properties of MA and CM plots were almost similar, except for slightly lower soil C and extractable P contents in CM. The annual input of C in the CM plots was represented only by crop residues, whereas the build up of extractable P resulted from the annual application of ca. 50 kg ha^{-1} of P. When animal manures are used important amounts of other nutrients such as Ca, Mg and Zn are added to the soil (Palm et al. 2001).

The use of double-purpose oat as green manure (GM) led to poorer soil quality attributes compared to the other treatments, leading in its turn to poorer yields of tomato and lettuce, and inducing almost no differences in soil properties after 7 years of treatment compared with the original conditions. The use of GM without other nutrient inputs is not recommended from this perspective, unless a N-fixing legume could be intercropped with oat to improve fodder and green manure quality (increased N input). However, legumes grow poorly and fix few N when e.g. P, K or Ca are limiting (Giller et al. 2002). The application of maize residues brought a small amount of nutrient inputs to the soil every year (cf. Table 1); when applied in autumn, the nutrients (N) released during the winter are subject to losses, as shown for other temperate regions (e.g. Habets and Oomen 1994). The smallest yields of tomato and lettuce were obtained under the low-input system (LI), most probably due to the poor availability of macro nutrients; e.g. the amount of extractable P in the soil after 7 years of treatment was lower

Table 6. Yield and quality attributes of three lettuce types grown under different soil management systems. Treatment means, analysis of variance (ANOVA), and means comparisons (Tukey test).

Lettuce type (LT) / Soil management (SM)	Yield per area ($g\ m^{-2}$)[1]	Dry matter content (%)	Stem length (cm)	Visual quality score (1 to 5)[2]
Leafy (M1)				
CM	3160	4.74	8.40	4.2
LI	2100	6.19	7.66	2.9
MA	3180	4.54	7.42	3.3
GM	2520	6.72	7.36	3.2
MR	2640	5.94	7.66	3.0
Standard deviation	±900	±1.32	±1.49	±0.5
Latin (G1)				
CM	2380	3.89	7.57	4.1
LI	1500	6.15	7.13	3.5
MA	1690	5.57	6.68	2.8
GM	1690	5.52	6.11	2.3
MR	1530	6.77	6.05	1.9
Standard deviation	±520	±1.25	±1.17	±0.7
Butterhead (R1)				
CM	2590	5.02	6.77	4.4
LI	1650	5.30	5.33	3.6
MA	2170	4.73	5.81	4.2
GM	1500	6.65	4.62	3.0
MR	1510	6.25	4.55	3.1
Standard deviation	±670	±1.16	±1.32	±0.8
ANOVA significance				
SM effect	*	*	NS	*
LT effect	*	NS	*	NS
Interaction SM x LT	*	NS	NS	*
Tukey test (α=0.05)				
LT means				
M1	2720 a	5.63 a	7.82 a	3.3 a
G1	1760 b	5.58 a	6.71 b	2.9 a
R1	1880 b	5.59 a	5.42 b	3.7 a
SM treatment means				
CM	2710 a	4.55 b	7.58 a	4.2 a
LI	1750 b	5.88 ab	6.71 a	3.3 ab
MA	2350 ab	4.95 ab	6.91 a	3.4 ab
GM	1900 ab	6.30 a	6.05 a	2.8 b
MR	1900 ab	6.32 a	5.99 a	2.7 b

[1]Values were rounded-up to the closest 10^{th} multiple
[2]Score 1: very poor, non commercial; Score 2: poor; Score 3: regular; Score 4: good/acceptable; Score 5: very good visual quality
CM: conventional management; LI: low input; MA: manure amendments; GM: green manure (oat); MR: maize residue. Plant materials: cv. ‘Maravilla’ (M1), cv. ‘Gallega’ (G1) and cv. ‘Reina de Mayo’ (R1).
NS, *, **: non significant or significant differences, at probability levels of 0.05 and 0.01, respectively
Means followed by the same letter do not different significantly according to Tukey (5%).

than the locally accepted limit of 15 mg kg^{-1}, below which P fertilisation is considered economically viable (García 2001).

This study also highlighted the importance of a proper crop and/or genotype choice according to the production system. Cherry tomato is normally regarded as a tomato type tolerant to pest and diseases – one of the reasons for its extended use in organic production systems. For fruit quality attributes such as dry matter and soluble solid contents, there were no differences between the management systems studied here, and the average values observed for these parameters (ca. 8.4 and 6.2, respectively) were in line with previous measurements from outdoor, organically grown cherry tomato in the region (MOCCIA et al. 1999). Although statistical analysis was not possible due to the sub-sample size, the partition coefficients indicated a trend towards more biomass allocation to roots under the organic systems (cf. Table 5). Differences in the total porosity of the soil under MA could have favoured root development, while an 'easier' availability of nutrients applied every year as fertiliser could have led to less biomass allocation to roots under CM. Variations in the root:shoot ratio of different annual crops are often related to water and/or nutrient stress, as crops need a larger root biomass to explore the soil when these resources are scarce (VAN KEULEN and WOLF 1986). Although plants under CM and MA had a better fruit setting (cf. Table 4), no differences for the allocation of the aerial biomass between vegetative and reproductive organs were observed (cf. Table 5), i.e. the value of harvest index did not change and remained similar to optimum values reported earlier (ca. 0.6 - NUEZ 1995).

In the case of lettuce, the choice of genotypes appears an important tool to ensure the sustainability of the organic production system. The locally widely consumed Latin lettuce (G1) proved to be highly susceptible to plant diseases, while deficiency symptoms were more evident in butterhead lettuce (R1), when grown organically. Few differences in the overall quality indicators were observed for these products (i.e. dry matter content and stem length), except for certain differences in their visual quality at harvest. However, wider differences in quality between management systems could be expected for other, more sensitive indicators that were not measured in this study, as e.g. changes in nitrate and/or ascorbic acid contents had been previously measured for lettuce plants subject to varying mineral fertilisation in the region (TITTONELL et al. 2001; CHIESA et al. 2003).

The decrease in dry matter content (DM %) for fertilised lettuce observed here (cf. Table 5), which is often associated with high N availability, confirms previous observations by the latter-cited authors and by others (e.g. GIANQUINTO and BORIN 1996). A higher DM% is normally associated with stresses during crop growth (REININK 1993), though it might be convenient for post-harvest handling and conservation (i.e. more water in tissues means more susceptibility to damage). However, SANTOS et al. (1998) used increasing rates of organic compost (from 0 to 90 t ha^{-1}) on lettuce production and observed a reduction in post harvest fresh weight losses, but also a decrease in the chlorophyll content during storage. The impact of larger yields with associated low DM% of heavily amended organic or conventionally fertilised crops on quality and post-harvest behaviour should be further studied.

Although agriculture techniques may affect nutrient composition, the main benefit of organic food seems to be the absence of pesticide residues, and it is not yet clear whether organic food is healthier than conventionally produced food. GENNARO and QUAGLIA (2003) presented extensive data showing a recurrently higher average vitamin C contents in organic vegetables (especially tomatoes, lettuce, spinach and cabbage), and weak trends indicating higher amounts of some nutritionally significant mineral in organic compared to conventional crops. This adds to the observed non significant trends showing less protein but of a better quality and a higher content of nutritionally significant minerals with lower amounts of some heavy metals in organic crops compared to conventional ones (WORTHINGTON 2001). Thus, as public concern about food quality and environmental consequences of horticultural production increases, it is necessary to further focus research on the nutritional quality of vegetable crops as affected by the various technological alternatives for a sound soil management in sustainable production systems.

The results presented here represent an initial step towards establishing relationships between the production systems (conventional, low-input and organic), their consequences for soil properties in the long term (soil C can also be seen as a biophysical sustainability indicator), and their impact on crop yield and quality. However, these results also showed that the only realistic option for soil management out of the three systems tested here (MA, GM and MR) was the use of animal manure, which next to improving soil physical properties provides nutrients for crop production. The low-input system tested here should be re-designed to meet crop nutrient demands more closely, while the use of green manures and crop residues should be seen as complementary options used in combination with other approaches for soil management.

References

AOAC 1990: Association of Official Analytical Chemists. Official Methods of Analysis of the AOAC International. 15th Edition, 2nd Revision, Washington DC, 2200 pp.

BREMER, J.M. 1960: Determination of nitrogen in the soil by the Kjeldahl method. J. Agric. Sci. **55**, 11–23.

BYRNES 1990: Environmental effects of N fertiliser use – An overview. Fertiliser Research **26**, 209–215.

BRAY, R.H. and L.T. KURTZ 1945: Determination of total, organic and available forms of phosphorus in soils. Soil Sci. **59**, 39–45.

CHIESA, A., D. FREZZA, A. FRASCHINA, G. TRINCHERO, S. MOCCIA and A. LEON 2003: Pre-harvest factors and fresh-cut vegetables quality. Acta Hort. **604**, 153–157.

CREAMER, N. 1996: A comparison of four processing tomato production systems differing in cover crop and chemical inputs. J. Amer. Soc. Hort. Sci. **121**, 559–568.

ELIA, A., P. SANTAMARIA, M. GONNELLA and G. IZZO 1997: Effects of two N levels and two NH_4^+:NO_3^- ratios on endive (*Cichorium endivia* L. var. c*rispum* Hegi). II. Accumulation of the major inorganic ions. Adv. Hort. Sci. **11**, 47–53.

EL-SHINAWY, M.A., E.M. ABD-ELMONIEN and A.F. ABOU-HADID 1999: The use of organic manure for lettuce plants grown under NFT conditions. Acta Hort. **486**, 315–318

GARCÍA, F. 2001: Balance de fósforo en los suelos de la región pampeana. Informaciones Agronómicas Del Cono Sur No. 9, INPOFOS Cono Sur, Buenos Aires, Argentina, pp. 1–3.

GENNARO, L. and G.B. QUAGLIA 2003: Food safety and nutritional quality of organic vegetables. Acta Hort. **614**, 675–680.

GIANQUINTO, G. and M. BORIN 1996: Quality response of crisphead lettuce and kohlrabi to mineral and organic fertilisation in different soils. Adv. Hort. Sci. **10**, 20–28.

GILLER, K., G. CADISCH and C. PALM 2002: The North-South divide! Organic wastes, or resources for nutrient management? Agronomie **22**, 703–709.

HABETS, A.S.J. and G.J.M. OOMEN 1994: Modelling nitrogen dynamics in crop rotations in ecological agriculture. In: NEETESON, J.J. and J. HASSINK (eds): Nitrogen mineralisation in agricultural soils; Proc. Symp. held at the Institute for

Soil Fertility Research, Haren, The Netherlands, 19–20 April 1993. AB-DLO Thema's, AB-DLO, Haren, pp. 255–268.

HOBSON, G. and L. BEDFORD 1989: The composition of cherry tomatoes and its relation to consumer acceptability. J. Hort. Sci. **64**, 321–329.

HORNICK, S.B. and J.F. PARR 1987: Restoring the productivity of marginal soils with organic amendments. Am. J. Altern. Agr. **2**, 64–68.

INTA 1980: Carta de Suelos de la República Argentina. Instituto Nacional de Tecnología Agropecuaria (INTA), Buenos Aires, Argentina. 263 pp.

MILLER, J.R. and R.S. COWLES 1990: Stimulo-deterrent diversionary cropping: a concept and its possible application to onion maggot control. J. Chem. Ecol. **16**, 3197–3212.

MOCCIA, S., A. OBERTI ARNAUDO and D. QUIROGA 1999: Parámetros fisiológicos y productivos de tomate 'Cherry' en sistemas de producción orgánica. Proceedings of the XXII National Congress of Horticulture, Sep. 28 – Oct. 1, 1999, Tucumán, Argentina.

NUEZ, F. 1995: El cultivo de tomate. Ed. Mundi Prensa. Madrid, España. pp. 793.

PALM, C.A., C.N. GANCHEGO, R.J. DELVE, G. CADISCH and K.E. GILLER 2001: Organic inputs for soil fertility management in tropical agroecosystems: Application of an organic resource database. Agric. Ecosys. Environ. **83**, 27 –42.

REININK, K. 1993: Relationship between effects of seasonal change on nitrate and dry matter content in lettuce. Sci. Hort. **53**, 35–44.

SANTOS, I. C. Dos, V.W.D. VICENTE and G.V. MIRANDA 1998: Comportamento de dez cultivares de alface adubadas com composto de lixo urbano. Pesquisa Agropecuária Brasileira **33**, 157–161

SERAGELDIN, I. 2003: Nurturing and nourishing the world's poor: Important roles of horticulture in sustainable development. Chronica Horticulturae **43**, 4–10.

SHEWFELT, R. and J. HENDERSON 2003: The future of quality. Acta Hort. **604**, 49–57.

TITTONELL, P.A., J. DE GRAZIA and A. CHIESA 2001: Effect of nitrogen fertilization and plant population during growth on lettuce (*Lactuca sativa* L.) postharvest quality. Acta Hort. **553**, 67–68.

TITTONELL, P.A., J. DE GRAZIA and A. CHIESA 2002: Adición de polímeros superabsorbentes en el medio de crecimiento para la producción de plantines de pimiento (*Capsicum annuum* L.). Hort. Brasileira **20**, 641–645.

TITTONELL, P.A., S. DE HEK, J. DE GRAZIA and J.C. CERIANI 2006: Designing cropping systems for integrated crop management. Agr. Tropica et Subtropica (in press).

UVAH, I. I. I. and T.H. COAKER 1984: Effect of mixed cropping on some insect pests of carrots and onions. Entomologia Experimentalis et Applicata **36**, 159–167.

VAN KEULEN, H. and J. WOLF 1986: Modelling of agricultural production: weather, soils and crops. Pudoc, Wageningen, The Netherlands. 479 pp.

WALKEY, A. and C.A. BLACK 1934: An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acidification method. Soil Sci. **37**, 29–38.

WORTHINGTON, V. 2001: Nutritional quality of organic versus conventional fruits, vegetables and grains. J. Altern. and Complem. Medicine **7**, 161–173.

Received October 05, 2004 / Accepted September 09, 2005

Addresses of authors: S. Moccia (corresponding author), A. Chiesa, and A. Oberti, Department of Horticulture, University of Buenos Aires, Av. San Martín 4453 (1417) Buenos Aires. Argentina, and P.A. Tittonell, Department of Soil Science, University of Lomas de Zamora, Ruta 4, Km 2 (1836) Llavallol, Buenos Aires, Argentina, e-mail: smoccia@agro.uba.ar.