Effects of Organic Amendment Application on Soil Quality and Garlic Yield in Central-Western Argentina

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Abstract: We analyzed during two garlic crop cycles, the effects of chicken manure and vermicompost on soil chemical and biological properties in an agricultural farm irrigated with municipal wastewater of central-western Argentina. Also we evaluate garlic yield and possible health risks as resulting from the organic amendments and the wastewater use. We found that: a) different doses and types of amendments did not have any significant effects on soil fertility; b) chicken manure and soil before planting, had *E. coli* and *Salmonella* spp.; and c) crop yields were quite similar in all treatments, only treatments with 8 Mg ha^{-1} of both amendments (chicken manure and vermicompost) without N fertilized, were significantly higher than control in both garlic assays. These results are probably the consequence of heavily tilled soils and poor quality of irrigation water with high abundance of enteric bacteria and labile organic matter content. We conclude that to obtain beneficial effects on soil fertility from organic amendment application, wastewater treatment systems must be improved and tillage practices must be reduced.

Keywords: Chicken litter, Vermicompost, Municipal wastewater, *Escherichia coli*, *Salmonella* spp.

INTRODUCTION

Soils in arid regions are of scarce fertility due to the low soil organic matter (SOM) and available nutrient content, and low water holding capacity [1, 2]. One of the critical problems induced by transformation of arid zones in irrigation areas is SOM conservation, since soils of irrigation areas are heavily tilled and fertilized [3]. It is widely accepted that tillage and fertilization largely contribute to SOM loss, with negative consequences on soil structure, nutrient reserves and microbial activity [4, 5].

Therefore, irrigated areas are usually treated with organic amendments with the aim of restoring SOM and enhancing nutrient availability [6, 7]; however, the success of this practice depends on the particular soil dynamics in arid region. Dry climatic conditions such as drought and moisture pulses, high temperatures and evapotranspiration, strongly affect microbial activity and consequently decomposition rate, nutrient release and organic matter humification [8, 2].

One of the most important irrigated areas (350,000 ha) in Argentina is located in the central-western region in the Mendoza province, where irrigation is mostly carried out with river water and, to a lesser degree (10,000 ha), with wastewaters from a municipal treatment plant. It is known that municipal treatment plants in Mendoza are scarcely efficient and that often wastewater used for irrigation does not meet USEPA‘s regulations [9].

At present, a large amount of organic amendments are applied in this area of Mendoza province, because of the foreign market’s increased demands for safe and innocuous products. The so called “differentiated” agriculture of low environmental impact is based on minimal or no use of agrochemicals and on soil conservation [10]. The most frequently used amendments are animal manure from goat, chicken and horse, and refuse from regional industries such as grape and olive wastes, sawdust and wood shaving, composted or un-composted.

Composting processes aim at eliminating health-risk microorganisms and favouring organic matter stabilization, which allows incorporation a safe soil amendment with high humifying capacity [11, 12]. The most widely used methods to compost wastes are: traditional composting and vermin-composting. Combined composting (precomposting plus vermicomposting) is currently being prepared with the aim of guaranteeing the elimination of pathogenic organisms by the high temperature achieved during precomposting and obtaining a rapid formation of stabilized organic matter (humus) through earthworm activity during vermicomposting [13, 14].

Garlic (*Allium sativum* L.) is one of the vegetable crops of greatest economic importance in the province of Mendoza [15]. About 12,000 ha of the cultivated area are cropped with garlic and the crop profitability encourages the interest in improving the efficiency of garlic crop technology,

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especially regarding fertilizers and compost application. Although there is abundant international literature on the effects of organic amendment application, in Mendoza province their use in garlic is still empirical and dependent on farmers' criteria and experience [16].

There are few regional works available to evaluate the effect of the use of amendments on crop yield, but changes in soil fertility involved are neglected. Moreover, the persistence into the soils of health-risk microorganisms (from municipal wastewater irrigation and amendment) never was evaluated in Mendoza.

It is widely accepted that the most suitable parameters to evaluate changes in soil fertility are type and amount of SOM, nutrient availability [17, 12], and diversity and activity of soil microorganisms [18, 19]. Furthermore, USEPA [20] recommends detecting organisms that are indicative of sewage pollution (enteric bacteria and parasites) to evaluate the health risk.

We analyzed soil fertility parameters and enteric bacteria persistence with the aim of establishing: a) if the use of municipal wastewater and organic amendments (with and without composting) entails health risk in agricultural soils; and b) the effect of using different doses of organic amendments (alone or combined with chemical fertilizers) on soil fertility and garlic crop yield, in an agricultural farm of Mendoza, Argentina.

MATERIALS AND METHODS

Study Area

The experiment was conducted in an agricultural farm in Fray Luis Beltrán, province of Mendoza, central-western Argentina (33° 00´ S; 68° 38´ W). The climate in the area is arid, with very high temperatures in summer (average 25°C) and very low values in winter (average 10°C), and a mean annual rainfall of 250 mm. The soil is typic Torrifluvent, sandy-loam, with low SOM [21]. The native vegetation corresponds to the Monte phytogeographic region: a xerophytic shrubland with dominance of the genus *Larrea*, and presence of *Acacia caven*, *Atriplex* spp., *Porlieria microphyla*, and some cactus species. The experimental area was cleared and devoted to irrigated vegetable production 15 years ago, the last two crop sequences being onion (*Allium cepa*) and squash (*Cucurbita* spp.). In the previous years, the experimental area had been alternately devoted to horticultural crops and green manure (tomato, barley and pepper).

Organic Amendments Used

Two types of organic amendments were used in the experiment: a) chicken litter, composed of chicken manure and rice bran (CL), and b) vermicompost (VE) produced from a blend of similar parts of horse litter (horse manure and wood shaving) and cow manure. This mixture was precomposted for 20 days; after this period, earthworms (30,000 *Eisenia foetida* m^{-2}) were introduced to prepare vermicompost by windrow method [22]. During vermicomposting (120 days), optimal humidity and temperature conditions were maintained (90% and 35° C, respectively), through aeration and irrigation of windrows.

Experimental Design

Two assays were conducted during two garlic crop cycles (2005 and 2006) in two different experimental sites within a 16-ha farm. This experimental design was selected for replicating the farmer real management (the same species never is cropping two consecutive years in the same site). In each experimental plot (4 x 62 m) garlic (white genetic type) was planted in 8 rows (in-row spacing of 0.50 m). The clove seed was treated with fungicides and hand-planted in the row at 8.33-cm intervals (12 clove m^{-1}), with a resulting density of 240.000 plants ha^{-1}. In both (2005 and 2006) garlic cycles, planting and harvest dates were May and November, respectively. The sites were irrigated by flooding before planting (15 days) to favour salt leaching from the soil; later, the crop was watered along the furrows with a frequency of 1 to 3 waterings/month (14 waterings in total) and an approximate flow of 600 m^3 ha^{-1} on each watering. To prevent treatment mix, each plot was isolated by mean of water collector furrows.

The water used for flooding irrigation and the first 12 waterings was obtained from municipal wastewater treatment plant of Mendoza city, whereas groundwater (250 m deep) was used for the last two waterings. Experimental design was completely randomized, with 10 treatments and one control (without amendments or fertilizers) (**T**), with five replications. Treatments consisted in one or two applications of amendments or fertilizers during the crop cycles. Doses and methods of application were those usually used by garlic farmers from the region [16].

One-application treatments (at planting) were: a) 4 Mg ha^{-1} of CL (CL4); b) 8 Mg ha^{-1} of CL (CL8); c) 4 Mg ha^{-1} of VE (VE4); d) 8 Mg ha^{-1} of VE (VE8); e) 4 Mg ha^{-1} of CL + 80 kg N ha^{-1}, (as ammonium sulfonitrate) (CL4-N); f) 4 Mg ha^{-1} of VE + 80 kg N ha^{-1}, (as ammonium sulfonitrate) (VE4-N); and g) 160 kg of N ha^{-1} (as ammonium sulfonitrate) (N).

Two-application treatments (at planting/after 4 months) were: a) 14 Mg ha^{-1} of CL + 45 kg N ha^{-1} and 115 kg P ha^{-1} (as ammonium phosphate) / 10 Mg ha^{-1} of CL + 65 kg N ha^{-1} (as ammonium sulfonitrate) (2CL-2N); b) 14 Mg ha^{-1} of CL + 45 kg N ha^{-1} of 115 kg P ha^{-1} (as ammonium phosphate) / 65 kg N ha^{-1} (as ammonium sulfonitrate) (CL-2N); and c) 14 Mg ha^{-1} of CL + 45 kg N ha^{-1} and 115 kg P ha^{-1} (as ammonium phosphate) / 10 Mg ha^{-1} of CL (2CL-N).

In 2006 assay the CL4, N and 2CL-2N treatments were not evaluated. At planting, the amendments were spread in the soil surface and incorporated by ploughed into the soil (25 cm in depth), whereas, in the second application (after 4 months), the amendments were applied on the furrow heads and spread by irrigation water.

Characterization of Amendments and Irrigation Water

We used the same amendments in both assays. Amendments were sampled directly from the transport bags before the first crop cycle (2005). Three combined samples (10 subsamples) of about 100 g of amendments were randomly taken. To characterize amendments, the following chemical and biological parameters were analyzed: a) water content by gravimetric method; b) ash by calcination; c) pH (p/v 1:1); d) electrical conductivity (p/v 1:5); e) total organic C by the wet-digestion method of Walkley and Black modified for plant material [23]; f) soluble organic C by Walkley and Black previously extracted with water at 80ºC [24]; g) humic and fulvic acids (HA and FA, respectively) following [25] ; h) lignin and cellulose content by enzymatic gravimetric methods [26]; i) total N by micro Kjeldahl; j) soluble N by micro Kjeldahl previously extracted with water at 80ºC [24]; k) nitrate and ammonium content by colorimetric methods; l) total Ca and Mg by compleximetric titration methods; m) total P by colorimetric methods ; n) total and exchange Na and K with flame photometric detectors [27]; and o) *Escherichia coli* and *Salmonella* spp. abundance following USEPA's recommended methodology [20]. Humic and fulvic acids were not analyzed in chicken litter because during extraction of humic compounds, some of the lipid fractions of manure organic matter can also be extracted [28].

We took five samples from surface water (0-20 cm in depth) from central irrigation ditch at income of experimental site. The irrigation water was chemical and biological characterized following USEPA's recommended parameters and methodology [20].

Soil Sampling Design and Analysis

Five soil sub-samples (0-20 cm in depth) were collected from each plot, which were pooled and homogenized to make up one sample. Sampling dates were one week before planting (after flood watering) and immediately after harvest.

The following chemical parameters were analyzed in the soil samples: a) pH; b) conductivity; c) SOM by the wet-digestion method of Walkley and Black [23]; d) humic and fulvic acids, following [25]; e) total N by micro Kjeldahl; f) nitrate by colorimetric method; and g) available P (phosphate) by colorimetric method [27]. Electrical conductivity and available P in soils were not analyzed in the harvest samples.

The abundance of the following groups of microorganisms was analyzed: a) nitrifiers, ammonifiers and cellulolytics (by the Most Probable Number method in specific liquid culture media [29]; b) saccharolytic fungi by plate counts in PDA medium (Potate Dextrose Agar [29]; c) N_2-fixing bacteria by plate counts in N-free medium (NFB) [30]; and d) *Escherichia coli* and *Salmonella* spp. following USEPA's recommended methodology [20]. Moreover, total heterotrophic activity was determined by soil respiration through CO_2 release method in the laboratory under standardized soil conditions [31].

Plant Sampling

At the end of each crop cycle, all plants from the five central rows in each plot were harvested. The harvested plants were left in the field for 2 days and then placed on trestles for drying (30 days). Yield was determined according to bulb weight.

Calculations and Statistical Analyses

The following calculations were made with soil data: CMI: C mineralization index (CO_2 -C/ SOM-C), HI: humification index (HA+FA/SOM), and bioavailable organic matter (BOM) by the difference between SOM and HA plus FA [32]. To compare the effect of the different treatments, data were statistically analyzed with ANOVA. To compare dynamics between sampling dates, percentages of variation with respect to initial soil were calculated and analyzed with ANOVA, using the function $\hat{y} = \arcsin\sqrt{y}$. Comparison of means was performed with Tukey test.

RESULTS

Significant differences were detected in most of the parameters analyzed between the two organic amendments applied in the assays. Chicken litter (CL) had higher content of all chemical parameters, except for lignin, water content, ashes, total Ca, and Mg, which were higher in VE (Table **1**).

Table 1. Chemical and Biological Properties (means ± SD) of the Organic Amendments Used. CL: Chicken Litter, VE: Vermicompost (P>0.05). na: Not Analyzed

	CL	VE	P
water content (%)	17.23 ± 0.49	37.40± 0.08	0.0003
ash (g kg^{-1})	348 ± 55.6	650.6 ± 19.2	0.0184
pH	8.69 ± 0.06	7.64 ± 0.06	0.037
conductivity (dS m^{-1})	11.53 ± 0.07	3.22 ± 0.10	0.0001
organic C (g kg^{-1})	195 ± 1.0	146 ± 2.0	<0.0001
soluble C (g kg^{-1})	14 ± 0.5	0.5 ± 0.05	<0.0001
humic acids HA (g kg^{-1})	na	2.7	
fulvic acids FA (g kg^{-1})	na	9.6	
lignin (g kg^{-1})	0.0	185 ± 5.0	<0.0001
cellulose (g kg^{-1})	597 ± 3.0	175 ± 1.0	<0.0001
total N (g kg^{-1})	26.4 ± 0.2	10.8 ± 0.1	0.0009
soluble N (mg kg^{-1})	132 ± 1.00	3.6 ± 0.10	<0.0001
soluble phenols (g kg^{-1})	62.5 ± 2.5	7.5 ± 1.01	<0.0001
nitrate (mg kg^{-1})	6635 ± 14.14	2370 ± 7.07	<0.0001
ammonium (mg kg^{-1})	548 ± 73.48	4.22 ± 0.48	0.009
C/N ratio	7.38 ± 0.20	13.53 ± 0.30	0.0180
total P (g kg^{-1})	15.9 ± 1.9	7.1 ± 0.8	0.0264
total K (g kg^{-1})	25.9 ± 1.1	4.8 ± 0.3	0.0013
total Na (g kg^{-1})	5.5 ± 0.7	3.8 ± 0.1	0.0794
total Ca (g kg^{-1})	14.9 ± 4.3	66.4 ± 3.4	0.0056
total Mg (g kg^{-1})	5.9 ± 0.3	12.1 ± 1.3	0.0233
soluble Na (g kg^{-1})	4.8 ± 0.3	1.4 ± 0.01	0.0034
soluble K (g kg^{-1})	18.1 ± 0.9	1.6 ± 2.0	0.008
Escherichia coli (log g^{-1})	2.3 ± 0.80	0	<0.0001
Salmonella spp. (log g^{-1})	2.7 ± 0.07	0	<0.0001

As it was expected, there were no organisms indicative of health risk in VE, unlike CL, in which there were *Salmonella* spp. and *E. coli* (Table **1**). The irrigation water had high hardness and salinity and elevate organic matter, total and inorganic N content and great amount of health-risk microorganisms (Table **2**).

Table 2. Chemical and Biological Characteristics of Irrigation Water in the Experimental Site (means ± SD)

	means ± SD
pH	7.47 ± 0.37
Conductivity (μmhos/cm)	2062 ± 77.0
Ca^{+2} (mg L^{-1})	257.50 ± 90.30
Mg^{+2} (mg L^{-1})	55.83 ± 32.42
Na^{+} (mg L^{-1})	203.00 ± 37.01
K^{+} (mg L^{-1})	18.80 ± 3.64
CO_3^{-2} (mg L^{-1})	0.00
CO_3H^- (mg L^{-1})	351.75 ± 71.65
Cl^- (mg L^{-1})	249.20 ± 82.28
SO_4^{-2} (mg L^{-1})	669.20 ± 351.15
Total hardness (mg L^{-1})	873.75 ± 341.64
Total N (mg L^{-1})	24.80 ± 2.45
NO_3-N (mg L^{-1})	17.6 ± 10.53
NH_4-N (mg L^{-1})	2.27 ± 0.55
Organic matter (g L^{-1})	10.40 ± 6.33
PO_4-P (mg L^{-1})	6.07 ± 0.47
Total Coliforms (log g^{-1})	3.18 ± 2.88
Faecal Coliforms (log g^{-1})	2.18 ± 0.47
Escherichia coli (log g^{-1})	1.95 ± 0.99

The soils before planting of the both experimental sites were sandy-loam, neutral to slightly alkaline, moderately saline and with low SOM. Carbon mineralization index (CMI) was greater than 1 (tendency to lose C), HI indicated high proportion of humic substances relative to SOM (Table **3**). Moreover, the soils had high nitrate content and abundant microbial populations of all the groups analyzed, with prevalence of ammonifiers and N-fixing, followed by saccharolytic fungi, cellulolytic organisms and, to a lower degree, nitrifiers. Notably, before amendment application, the soils of both experimental sites had health-risk bacteria (*E. coli* and *Salmonella* spp.) (Table **3**).

Table 3. Soil Chemical and Biological Properties Before Garlic Plantation in both Assays, 2005 and 2006 (means ± SD)

	2005	2006
pH	7.77 ± 0.17	7.86 ± 0.22
conductivity (dS m^{-1})	3.67 ± 0.72	3.50 ± 1.32
organic matter (g kg^{-1})	7.47 ± 1.1	10.21± 2.78
humic acids (g kg^{-1})	0.62 ± 0.3	0.60 ± 0.70
fulvic acids (g kg^{-1})	0.66 ± 0.3	0.64 ± 0.54
bioavailable organic matter (g kg^{-1})	6.20 ± 0.6	8.97 ± 2.55
humification index (%)	8.11 ± 3.79	8.23 ± 6.65
nitrate (mg kg^{-1})	142 ± 25.1	176 ± 91.4
available P (mg kg^{-1})	44.63 ± 6.33	37.8 ± 4.77
nitrifiers (log g^{-1})	4.42 ± 0.27	3.40 ± 1.28
ammonifiers (log g^{-1})	6.48 ± 2.39	5.47 ± 1.44
cellulolytics (log g^{-1})	4.78 ± 0.49	4.36 ± 1.11
Saccharolytic fungi (log g^{-1})	5.83 ± 0.36	4.45 ± 1.49
N_2 fixers (log g^{-1})	6.54 ± 1.00	4.08 ± 0.44
Salmonella spp. (log g^{-1})	2.57 ± 0.72	1.66 ± 0.78
Escherichia coli (log g^{-1})	1.64 ± 1.58	0.41 ± 0.12
soil respiration (mg CO_2 g^{-1} 7d^{-1})	0.40 ± 0.06	0.25 ± 0.08
C mineralization index	2.59 ± 0.67	1.12 ± 0.41

Effect of Amendments on Soil Fertility and Yield

After harvest of the both assays, soils of all treatments had similar chemical and biological characteristics (Tables **4** and **5**), except soil respiration (lower in CL-4N, N and T); and nitrate content (greater in T) in the 2005 assay (Table **4**). Soil characteristics between planting and harvest, of both (2005 and 2006) assays, differed significantly depending on

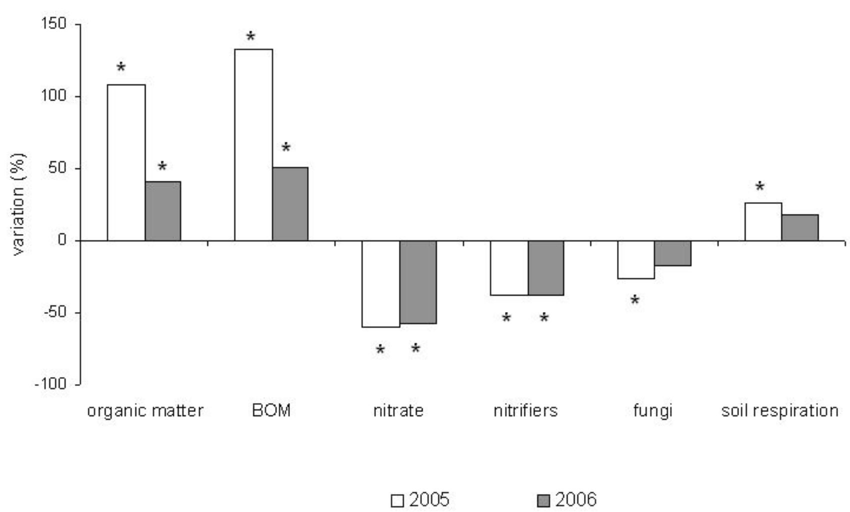

Fig. (1). Variations (%) between initial soil values (before planting) and after-harvest soil values (mean of all treatments) in both garlic crop cycles (2005 and 2006). BOM: bioavailable organic matter. *indicates significant differences between sampling dates for each parameter (P<0.05).

Table 4. Soil Chemical and Biological Properties of each Treatment at 2005 after Garlic Crop Harvest. CL4: 4 Mg CL ha^{-1}; CL8: 8 Mg CL ha^{-1}; VE4: 4 Mg VE ha^{-1}; VE8: 8 Mg VE ha^{-1}; CL4-N: 4 Mg CL ha^{-1}+80 kg N ha^{-1}; VE4-N: 4 Mg VE ha^{-1}+ 80 kg N ha^{-1}; N:160 kg of N ha^{-1}; T: control; 2CL-2N: 14 Mg CL ha^{-1}+ 45 kg N ha^{-1}+ 115 kg P ha^{-1}/10 Mg CL ha^{-1}+ 65 kg N ha^{-1}; CL-2N: 14 Mg CL ha^{-1} + 45 kg N ha^{-1} + 115 kg P ha^{-1}/65 kg N ha^{-1}; and 2CL-N: 4 Mg CL ha^{-1}+ 45 kg N ha^{-1} +115 kg P ha^{-1}/10 Mg CL ha^{-1}. For each Parameter, Different Letters Indicate Significant Differences among Treatments (Tukey test P>0.05)

	CL4	CL8	VE4	VE8	CL4-N	VE4-N	N	T	2CL-2N	CL-2N	2CL-N
pH	8.0	8.1	8.0	7.9	7.9	7.9	7.9	8.1	8.0	7.9	8.0
organic matter (g kg^{-1})	15.0	17.4	14.9	14.7	12.9	14.5	16.2	14.9	14.9	17.9	16.0
humic acids (g kg^{-1})	0.5	0.3	0.7	0.3	0.2	0.4	0.7	0.4	0.6	0.9	0.2
fulvic acids (g kg^{-1})	0.6	0.7	1.0	0.9	0.6	0.5	0.7	0.7	0.7	0.4	0.5
bioavailable organic matter (g kg^{-1})	13.7	16.5	13.2	13.5	12.1	13.5	14.9	13.8	13.5	16.5	15.3
humification index (%)	3.3	1.7	4.7	2.0	1.5	2.7	4.3	2.7	4.2	5.2	1.2
nitrate (mg kg^{-1})	40.7 c	53.0 b	41.7 c	43.7 c	46.5 c	31.8 c	62.7 b	102.5 a	65.0 b	95.2 b	62.7 b
nitrifiers (log g^{-1})	2.85	2.58	3.42	2.67	2.48	2.48	2.71	2.48	3.20	2.79	2.83
amonifiers (log g^{-1})	5.99	5.75	6.21	4.13	5.52	5.97	6.13	5.95	6.17	4.48	4.71
cellulolytics (log g^{-1})	3.24	4.94	7.15	3.65	5.33	5.74	4.78	5.65	4.74	3.85	3.95
Saccharolytic fungi (log g^{-1})	4.68	4.62	4.58	3.98	4.57	3.21	4.59	4.04	4.10	4.57	4.36
N_2 fixers (log g^{-1})	6.12	5.92	6.14	6.07	6.13	5.87	5.89	5.98	6.01	3.85	6.28
Escherichia coli (log g^{-1})	0	0	0	0	0	0	0	0	0	0	0
Salmonella spp. (log g^{-1})	1.10	1.36	0.10	1.16	1.00	1.00	1.00	0.00	0.00	1.16	1.00
Soil respiration (mg CO_2 g^{-1} 7d^{-1})	0.80 a	0.86 a	0.72 a	0.67 a	0.50 b	0.68 a	0.43 b	0.51 b	0.79 a	0.83 a	0.75 a
C mineralization index	2.51	2.33	2.28	2.14	1.77	2.32	1.24	1.61	2.45	2.18	2.25

Table 5. Soil Chemical and Biological Properties of each Treatment at 2006 after Garlic Crop Harvest. CL8: 8 Mg CL ha^{-1}; VE4: 4 Mg VE ha^{-1}; VE8: 8 Mg VE ha^{-1}; CL4-N: 4 Mg CL ha^{-1}+80 kg N ha^{-1}; VE4-N: 4 Mg VE ha^{-1}+ 80 kg N ha^{-1}; T: control; 2CL-N: 4 Mg CL ha^{-1}+ 45 kg N ha^{-1} +115 kg P ha^{-1}/10 Mg CL ha^{-}2; CL-2N: 14 Mg CL ha^{-1}+ 45 kg N ha^{-1}+ 115 kg P ha^{-1}/10 Mg CL ha^{-1}+ 65 kg N ha^{-1}. For each Parameter, Different Letters Indicate Significant Differences among Treatments (Tukey test P>0.05)

	CL8	VE4	VE8	CL4-N	VE4-N	T	CL-2N	2CL-N
pH	7.36	7.29	7.48	7.11	7.74	7.35	7.53	7.51
organic matter (g kg^{-1})	14.0	14.4	14.5	14.8	13.4	13.5	14.1	16.5
humic acids (g kg^{-1})	0.7	0.7	0.5	0.4	0.4	0.7	0.4	0.5
fulvic acids (g kg^{-1})	0.8	0.7	0.5	0.5	0.4	0.4	0.5	0.8
bioavailable organic matter (g kg-1)	12.5	13.0	13.5	13.9	12.6	12.4	13.2	15.2
humification index (%)	10.71	9.72	6.89	6.08	5.97	8.15	6.38	7.87
nitrate (mg kg^{-1})	43.33	87.50	61.17	83.93	42.00	82.17	102.33	96.50
nitrifiers (log g^{-1})	1.79	1.77	1.65	1.87	2.67	1.93	3.08	2.21
amonifiers (log g^{-1})	5.25	4.29	4.87	5.33	5.04	4.22	3.33	6.06
cellulolytics (log g^{-1})	5.08	4.87	4.99	5.49	5.84	5.13	5.83	5.37
Saccharolytic fungi (log g^{-1})	3.86	3.74	4.08	3.96	3.83	3.99	3.71	3.87
N_2 fixers (log g^{-1})	4.46	4.26	4.65	4.16	4.00	4.36	4.48	4.62
Escherichia coli (log g^{-1})	0	0	0	0	0	0	0	0
Salmonella spp. (log g^{-1})	0	0	0	0	0	0	0	0
soil respiration (mg CO_2 g^{-1} 7d^{-1})	0.35	0.26	0.21	0.30	0.22	0.28	0.30	0.40
C mineralization index	1.16	0.86	0.69	0.95	0.77	0.98	1.01	1.12

the parameters analyzed. Nitrate content and abundance of saccharolytic fungi and nitrifiers decreased while SOM and BOM content and soil respiration increased at harvest (Fig. **1**). Abundance of *E. coli* and *Salmonella* spp. also decreased throughout the crop cycles with almost undetectable values after harvest (Tables **4** and **5**). The crop yields were quite similar in all treatments; only yields of treatments VE8 and CL8 were significantly higher than control in both garlic assays (Fig. **2**).

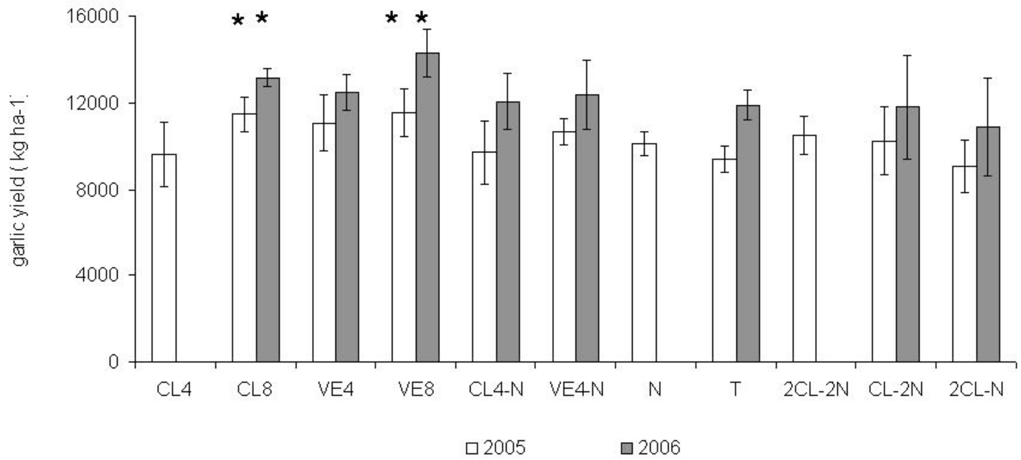

Fig. (2). Garlic yield (kg ha^{-1}) for each treatment from two crop cycles (2005 and 2006). Bars corresponding to Standard Error. *indicates significant differences between amendment treatments and control for each crop cycle (P<0.05).

DISCUSSION

Health Risk Involved in the Use of Amendments and Municipal Wastewater

Chemical quality of amendments employed in this work agrees with findings reported in the literature. Chicken litter had low water content, high proportion of cellulosic matter (from rice bran) and high soluble N content, characteristic of faeces of birds fed on protein-enhanced diets [33, 18]. Vermicompost exhibited the typical characteristics of stable, good quality products (high humus and ash content) obtained from animal manures [13, 14, 34, 35].

As it was expected, precomposted VE does not posse health risk bacteria, which make it highly safe to use [11, 36], whereas enteric bacteria persist in CL (non-composted manure), despite the low humidity content [37]. This observation supports USEPA‘s regulations [20], which do not allow the application of non-composted manure (even when it is dry) to horticultural crops [13].

The presence of *E. coli* and *Salmonella* spp. in the soils before applying the amendments indicates that the enteric microorganisms detected in the irrigation water persist in the soils. The flood watering before planting due to the anaerobic soil conditions, might have favoured the high persistence of these bacteria [38]. In contrast, the decrease in the amount of enteric bacteria at the end of the crop cycle might be related to the use of underground water in the last two waterings. Farmers usually use underground water in the last waterings with the aim of guaranteeing health quality of garlic.

Effect of Amendments on Soil Fertility

Surprisingly, our results from two garlic cycles show that, although the situations assayed are highly different in doses and types of amendment and fertilizers, none of the treatments had a differential effect on soil fertility characteristics. These results might be due to the following factors: a) the crop management practices usually implemented in irrigation areas; b) climate conditions; and c) irrigation water quality. All these factors define a very particular dynamics in soils, which allow us to interpret our results focusing on the two objectives sought in the application of amendments and fertilizers: to increase SOM content and nutrient availability to the crop.

SOM Content

Unlike findings of Ros *et al.,* [19], our results do not show a differential increase of SOM in the treatments with high doses of organic C (4680 kg ha^{-1} in 2CL-2N and 2CL-N). Frequent watering and tillage probably favour microbial activity (due to the mixture and breaking of residues and to increased aeration and humidity), which produces great soil C losses as CO_2 [39]. Our results suggest that under these management conditions, the entire C incorporated can be metabolized by microorganisms, thus failing to improve the original soil conditions.

The increase in SOM detected during the crop cycle in all the treatments is related to an increase in BOM, but not to an increase in the humified fraction. These results would indicate that SOM increase would be due to a great contribution of labile organic matter in irrigation water (10%), which was constant and similar in all the plots [28, 40, 41]. The effect of effluent application with high labile C content has been frequently documented in the literature. For example, Hati *et al.,* [42], found a double amount of SOM content and microbial biomass in surface soil after application of effluents from a molasses-based alcohol distillery. Moreover, the increased soil respiration at the end of the crop cycle detected in this work is consistent with the presence of a great amount of labile C.

Likewise, and contrarily to what was expected, we did not find a greater amount of humus in the soils treated with VE. This disagrees with findings of other authors [12, 43], who state that the amount of humus present in compost are determinant for the increase of humus in the soil. This could suggest that the effect of incorporated humic substances from VE (1.23%) is not perceived because of the great amount of labile organic matter from irrigation water applied in all the treatments.

After harvest, labile organic matter from irrigation water is very likely to be rapidly metabolized due to the high microbial activity typical of warm summer [2, 38]. Thus, in early autumn the soil returns to its low SOM values recorded in the irrigation zone in Mendoza [21], as it was observed in the two sampling conducted before crop establishment.

Nitrogen Availability

Noticeably, nitrate content did not exhibit differences among treatments with different doses (0N to more than 700 kg N ha^{-1}), the type of N applied (organic or mineral), and double-application treatments. Likewise, the high chemical fertilizer doses applied with CL have favoured microbial growth and the consequent fast organic C consume and N release [4, 44]. Thus, one of the objectives of amendment use is not met: gradual release of nitrates from organic N to improve synchronization with crop requirements [34, 33, 45].

Again, the factor that might have contributed to homogenize available N distribution is the amount of N in irrigation water (24. 8 mg L^{-1}). It has been widely documented that wastewater has a great amount of N (organic and inorganic), which is an important nitrate contribution to the crops [28, 46]. The lower nitrate values at harvest sampling are a consequence of the uptake during the garlic crop cycle [44].

Effect of the Application of Amendments on Garlic Yield

The homogeneous yield values obtained in all treatments are consistent with the mean garlic yield in the area (11,000 kg ha^{-1}) (Burba, 1997). The only high yield obtained in the treatments with 8 Mg ha^{-1} of amendments (not combined with chemical fertilizers) would be indicating that the characteristics of slow N release persist in such amendments [47]. On the contrary, the application of chemical fertilizers favours nitrate loss through run off and leaching [4, 45]. Thus, yields in treatments using chemical fertilizers are not different from control yields, although the former were treated with high N doses (700 kg ha^{-1}) combined with a high amount of amendment (14 Mg ha^{-1}).

The effect of the slow N release from amendments can also justify the discrepancy of our results with those of Lipinski and Gaviola [16] in garlic crops in the area. These authors obtained highest yields with the application of chemical fertilizers at doses between 100 and 150 kg N ha^{-1}, whereas at high doses (225 to 300 kg N ha^{-1}) they observed lower yields with respect to the control. In this study, the highest yields with 8 Mg ha^{-1} of VE and CL were obtained at doses of 88 and 210 kg N ha^{-1}, respectively, whereas treatments with chemical fertilizers combined with amendments at doses between 120 and 735 kg N ha^{-1} have similar yields to the control, but not lower, as reported Lipinski and Gaviola [16].

Our results about effects of amendment doses on garlic yields agree with findings of Jack and Thies [48] (2006), however, other authors [6, 18] mentioned positive effects at doses higher than 8 Mg ha^{-1} (14-20 Mg ha^{-1}). Our results clearly show that 4 Mg ha^{-1} of amendments does not seem enough to increase crop yield. The lack of differences in garlic yield between one and two application dates and manure alone and combined with chemical fertilizers is in contrast with the concept of applying more nutrients at bulb-formation stage to compensate the greater demands of the crop [16].

CONCLUSIONS

We conclude that the use of municipal wastewater in the irrigation zone of Mendoza poses a high health risk and that neither the application of chicken litter (widely used by producers) nor of vermicompost can increase stable SOM. The particular dynamics of these soils and the type of irrigation water suggest that to reach important increase in soil fertility it is necessary to: a) improve wastewater treatment systems; b) use tillage systems that involve less soil disturbance; and c) apply a greater amount of amendment for longer periods.

Although more researches are need, we recommend favouring the increase of soil humus during the intercropping period, when no irrigation or tillage is needed, and eliminating the use of chemical fertilizers that do not modify yields or leave soil residual N and that favour loss of SOM and nitrate leaching. Thus, a more sustainable organic agriculture system could be managed without losing productivity.

CONFLICT OF INTEREST

None declared.

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