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# EVOLUTION OF SOIL CHEMICAL VARIABLES IN AN ORGANIC CELERY CROP DURING THE CONVERSION PERIOD TO ORGANIC FARMING

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## Abstract

For this study two fertilisation assays were carried out in an experimental field. The first assay (F1) used a sheep manure amendment, following the stipulations of European regulations concerning organic agriculture practices, and the second assay (F2) followed conventional agricultural practices of the area using inorganic fertilizers (313; 37 and 566 kgha$^{-1}$ of N, P and K, respectively). Over a three-year period, samples of the arable soil layer were taken monthly in order to analyse the soil properties as indicators of soil quality (organic carbon, total Kjeldahl nitrogen, C:N ratio, Olsen P, electrical conductivity, pH in water and 1M KCl, cation exchangeable capacity, and exchangeable bases (Mg, K and Na).

The experimental plot managed using organic agriculture techniques showed significantly better conditions for crop development than the conventionally managed plot: higher quantities of organic matter (22.4 and 17.4 gkg$^{-1}$, respectively) and nitrogen ( 3.0 and 2.5 gkg$^{-1}$, respectively), a higher cation exchange capacity(14.4 and 12.2 cmol(+)kg$^{-1}$, respectively) and greater availability of phosphorus ( 45.4 and 27.1 mgkg$^{-1}$). No significant differences were observed as regards pH (8.0 in both plots) or the C/N ratio (7.7 and 7.1, respectively). Despite the short trial period of only three years, these results suggest that the agronomic model based on organic agriculture has a beneficial effect on soil properties and contributes to the function of soil as C sink.



*Keywords:* Organic agriculture, fertilization practices, sheep manure, conversion period, soil quality

## 1. INTRODUCTION

The current model of intensive agriculture is not the most appropriate and certainly does not reflect the trends towards the sustainable farming practices demanded by society and driven by national and international institutions. Since the 1990s, many studies have found that farming activities targeted exclusively at obtaining higher yields have led to the gradual degradation of the natural environment with a subsequent loss in productive capacity (Khalid and Rachid, 2004). This is mainly due to the excessive use of agrochemicals and inorganic fertilizers, inadequate tillage practices and the need to use poor quality irrigation water. The end result has been a decrease in soil

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porosity, erosion resistance (Martínez-Casasnovas and Sánchez-Bosch,2000; García-Orenes et al. 2009), the greenhouse gas exchange capacity (Wienhold et al.2004; Bastida,2008) and the water holding capacity, accompanied by nutrient deficiencies, especially in semiarid regions such as southern Spain,where this study was conducted. Therefore, many scientists have proposed the development and implementing of agronomic models that incorporate all production factors but viewed from a sustainable perspective. Such sustainability includes both socioeconomic aspects related to economic feasibility, as well as environmental aspects that guarantee the minimal impact on agricultural ecosystems and sustainable exploitation that preserves biodiversity.

The transition from conventional to organic farming is accompanied by changes in an array of soil chemical properties and processes that affect soil fertility (Clark et al. 1998). These changes affect crop nutrient availability either directly, by contributing to nutrient pools, or indirectly, by influencing the chemical and physical environment of the soil (Bulluck et al., 2002). Soil organic matter (OM) is an important source of nutrients for plant growth which needs to be maintained for agricultural sustainability.

Some studies have found that organically managed systems are less productive than conventional systems (Mäder et al. 2002), while others have indicated that they can be as productive as conventional ones (Posner et al. 2008).

OM is probably the most influential component of a soil's properties and therefore the effect of organic amendments on these properties has received renewed attention in recent years. Studies that compare organic and conventional farming in soils point to higher OM and macronutrient contents in organic farming (Herencia et al., 2007), although quite the contrary has also been reported (Gosling and Sheperd, 2005), emphasizing the need to carry out specific studies in different agro-ecosystems.

Mediterranean soils have limited amounts of OM and its loss results in the decline of soil fertility and structure (Bernal et al. 1998; Zalidis et al. 2002). OM plays an essential role in soil quality, among other reasons because it contributes to the stability of clay-humic complexes and to fertility. Organic fertilisers release nutrients gradually, allowing the roots time to absorb them and avoiding leaching and the subsequent loss of nutrients. At the same time, these fertilisers return part of the mineralised organic matter to the soil and help maintain the nutrient cycle. A reduction in the organic matter content leads to a deterioration of the soil's physical-chemical properties and, consequently, to the loss of long-term productivity (Hansen et al. 2001; Baran et al. 2004). Agronomic practices, which include the type of crop, crop rotation and waste management, have a considerable bearing on the content of organic matter in the soil and, especially, on the fractions which are most sensitive to changes induced by such practices.

The role of the edaphosphere in the carbon cycle is very important since it stores about 75% of total $CO_2$ captured in terrestrial environments (Mermut 2002, Lal2004). Thus, agricultural practices which minimize organic matter mineralization or even increase the organic carbon (OC) content of a soil will not only be relevant for their influence on soil properties, but also for the positive role in mitigating the greenhouse effect. Most studies on carbon sequestration by soil have been carried out in wet-temperate (Heath et al., 2002) or tropical (Fearnside, 2000) regions. However, hardly any research has been carried out into C sequestration by soils in Mediterranean climatic areas. In spite of this, areas with a Mediterranean climate have a large potential to fix atmospheric $CO_2$ through appropriate soil management and use.

Quite apart from the above considerations, comparisons of organic with conventional systems are complex and difficult (Watson et al. 2008), due to differences in soil types, crops, edaphic and climatic conditions, type and amounts of amendments.

The purposes of this study were: (1) to assess the changes in several soil chemical variables in relation to the method of crop management followed over a period of three years, assessing the capacity of the soil as a carbon sink in each situation; (2) to relate the differences observed to the pedological processes and (3) to determine how useful the measured variables are as indicators of soil quality.

## 2. MATERIALS AND METHODS

### Experimental design and soil sampling

The experiment area, characterised by a cold continental Mediterranean climate, is located in the municipality of Huéscar (Granada, Spain) in an agricultural field planted with celery (*Apium graveolens* var. *dulcis* cv.*"Golden Spartan"*) and watered using a high-frequency local irrigation system. Soil has a *Ap1-Ap2-Bw-Ckm* profile, which can be classified as Petrocalcic Palexeroll (Soil Survey Staff 2010), Petrocalcic Kastanozem (FAO-ISRIC-IUSS2006) according to the data shown in Table 1.

**Table 1.** General analytic data of initial soil (July 2005); OM= Organic Matter (gkg$^{-1}$); OC = Organic Carbon (gkg$^{-1}$); N= Total Nitrogen (Kjeldahl) (gkg$^{-1}$); C/N= C to N ratio; EC= Electrical Conductivity (dSm$^{-1}$); CEC= Cationic Exchange Capacity (cmol$_{(+)}$kg$^{-1}$)

| Hor. | Depth (cm) | $CaCO_3$ | OM | OC | N | C/N | pH $H_2O$ | pH ClK | EC | CEC |
|---|---|---|---|---|---|---|---|---|---|---|
| **Ap1** | 0-35 | 453 | 37.1 | 17.5 | 2.5 | 7.0 | 8.2 | 7.6 | 1.1 | 11.1 |
| **Ap2** | 35-52 | 402 | 21.4 | 12.4 | 1.7 | 7.3 | 8.3 | 7.6 | 1.5 | 12.3 |
| **Bw** | 52-65 | 349 | 23.5 | 13.6 | 1.7 | 8.0 | 8.4 | 7.5 | 1.3 | 18.5 |
| **Ckm** | +65 | 875 | - | - | - | - | - | - | - | - |

The celery growing season in the areas runs between July and October, while during the rest of the year the soil was kept fallow or sown with a mixture of cereals and legumes (*Avena sativa-Vicia sativa*) (Table 2).

**Table 2.** Crop succession on essay plot; column names refer to months of the year.

| | J | F | M | A | M | J | JL | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2005** | Fallow land | | | | | | Celery | | | | Fallow land | |
| **2006** | Cereal and legumes | | | | | | Celery | | | | Fallow land | |
| **2007** | Native vegetation | | | | | | Celery | | | | Fallow land | |

Before sowing the celery crop, the fields were prepared and chisel ploughed in order to ensure homogeneous conditions for both soil and irrigation. Likewise, the fields were tilled with a disk harrow machine before sowing the cereal and legume crop at the end of January. Both the plant residues from both the cereal and legume crops and the celery crop were used as a pasture for livestock and were not therefore incorporated in the soil.

The experimental design used was a "Randomized Complete Block" as described by Little and Hills (1978) with three replications. Each block was 9 m x 9 m in size. The fertilization trials (F1) consisted of an organic amendment (sheep manure) at 1.7 kg $m^{-2}year^{-1}$, in accordance with EC regulation (R CE 834/2007). Its analytical composition is given in Table 3. The organic amendment was mixed with the top 20 cm of soil, while the inorganic fertilization treatment was applied in the drip irrigation.

**Table 3.** Chemical analysis of sheep manure.

| variables | Mean value† | SD |
|---|---|---|
| Humidity ($gkg^{-1}$) | 436.0 | 7.0 |
| pH | 8.3 | 0.3 |
| EC($dSm^{-1}$) | 5.4 | 0.1 |
| Total carbon ($gkg^{-1}$) | 449.0 | 0.4 |
| Total nitrogen ($gkg^{-1}$) | 26.0 | 0.9 |
| C/N ratio | 17.0 | |
| Total Phosphorus ($gkg^{-1}$) | 7.7 | 0.4 |
| Total potassium ($gkg^{-1}$) | 25.2 | 2.0 |
| Total sodium ($gkg^{-1}$) | 1.1 | 0.2 |
| Total calcium ($gkg^{-1}$) | 20.2 | 3.1 |
| Total magnesium ($gkg^{-1}$) | 3.2 | 0.6 |
| Total iron ($mgkg^{-1}$) | 2.3 | 0.6 |
| Total copper ($mgkg^{-1}$) | 16.0 | 0.3 |
| Total manganese ($mgkg^{-1}$) | 640.0 | 20.8 |
| Total zinc ($mgkg^{-1}$) | 90.0 | 13.0 |

†dry matter values

The second fertilization essay (F2), used as control, was made according to a conventional cropping system in the area, with application rates based on recommended levels for NPK fertilizers in celery (313$kgha^{-1}$ ; 37 $kgha^{-1}$and 566 $kgha^{-1}$ of N, P and K, respectively).

Arable layer samples (0-25 cm) were taken monthly during the celery growth, each sample being composed of subsamples from four different points of each plot (Table 4). The samples were air dried and sieved to 2 mm for subsequent analysis in the laboratory.

**Analytical methods.**

The variables selected for evaluation were those which may change according to soil use and management over relatively short periods of time and, as such, are regarded as suitable indicators of soil quality. Soil reaction (pH), organic carbon (OC), total nitrogen (TN), assimilable phosphorus (P) and the CEC provide a measure of a soil's capacity to supply nutrients to plants and to buffer the changes brought about by additions or amendments.

**Table 4. Sampling method .**F1 refers to plots with organic amendment (sheep manure) and F2 to plots with conventional treatment; for each treatment 3 replications were carried out in the experiment, being each sample of 4 subsamples taken in different points of each plot

| | **July** | **August** | **September** | **October** | **Total samples** |
|---|---|---|---|---|---|
| **2005** | Profile sampling | 3F1+3F2=6 | 3F1+3F2=6 | 3F1+3F2=6 | 18 |
| **2006** | 3F1+3F2=6 | 3F1+3F2=6 | 3F1+3F2=6 | 3F1+3F2=6 | 24 |
| **2007** | 3F1+3F2=6 | 3F1+3F2=6 | 3F1+3F2=6 | 3F1+3F2=6 | 24 |
| **Total samples** | 12 | 18 | 18 | 18 | **66** |

The analytical methods used were as follows: organic carbon (OC) by Anne's method (1945) modified by Duchafour (1970); total nitrogen (TN) by Kjeldahl's method as described by Duchafour (1970); assimilable phosphorus (P) by Olsen and Dean (1965) modified by Watanabe and Olsen (1965) and photocolorimetric determination in a Philips PU 8625 UV/VIS spectrophotometer; pH, Peech (1965) taking the measurement in a 1:1 suspension of soil/water and soil/ 1MKCl in a Beckman 50 pH-meter; Calcium Carbonate ($CO_3Ca$), Bernard calcimeter method (Lamas, 2005); electrical conductivity (EC) by Bower and Wilcox method (1965); cation exchange capacity (CEC) and the Na, K and Mg exchangeable bases by Chapman's method (1965). Na, K and Mg were quantified by atomic absorption spectrometry, while the CEC was obtained by determining the ammonium-N with 0.02 N $H_2SO_4$ using Bromocresol Green-Methyl Red as indicator.

Finally, the amount of C fixed in soil was calculated as the ratio between the difference of OC in the F1 and F2 plots in the last year of the experiment (2007) and the amount of OC in F1 plots during the same year, expressed as a percentage.

### Statistical methods.

Statistical analyses were made using the R software (Development Core Team 2009). Firstly, a Kolmogorov-Smirnov test was performed to ensure normality of all the variables in each fertilisation essay. Secondly, a Bartlett test was carried out for homocedasticity. When conditions of normality and homocedasticity could be assumed, a one-way ANOVA test was carried out to compare means of each variable between fertilization essays; otherwise, the non-parametric Wilcoxonrank sum test es was applied. In all the statistical tests, a significance level of 0.05 was chosen.

## 3. RESULTS

### Organic Carbon, Total Nitrogen, C:N ratio and Olsen P.

The values of organic carbon (OC) were significantly higher (W = 538, $p<0.001$) in plot F1 than in the control plot F2 (Table 5), ranging between 20.6 and 25.4 g $kg^{-1}$ and between 15.4 and 18.5 g $kg^{-1}$, respectively (Figure 1A). This fact can be directly linked to the application of organic amendment (sheep manure) to F1. Over the period of study there was a clear increase in OC content in the organically managed soil, especially in 2007, while for plot F2 the OC content was fairly stable, with a slight tendency to decrease. In other words, while in F1 the percentage of OC increased almost by 30% in the three years of study, in F2 it decreased by 6%; therefore, differences seemed to increase during the 3 years of essays.

**Table 5.** Evolution of organic carbon (OC, $gkg^{-1}$); Total Nitrogen (TN, $gkg^{-1}$);C-to-N ratio (C/N) and Olsen Phosphorus (P, $mgkg^{-1}$); displayed are mean values of the three plots ± standard deviation (SD); treatments:F1 =sheep manure; F2 =mineral fertilization

| Year | Treatment | OC | TN | C/N | P |
|---|---|---|---|---|---|
| 2005 | **F1** | 20.9±0.31 | 3.1±0.26 | 6.7±0.63 | 44.3±1.56 |
| | **F2** | 17.7±0.32 | 2.9±0.44 | 6.1±0.87 | 27.0±4.19 |
| 2006 | **F1** | 22.3±1,73 | 2.6±0.08 | 8.6±0.30 | 50.8±7.47 |
| | **F2** | 17.8±0.51 | 2.2±0.25 | 8.1±0.99 | 31.2±7.05 |
| 2007 | **F1** | 24.2±3.98 | 3.2±0.23 | 7.6±0.73 | 41.4±16.64 |
| | **F2** | 16.7±1.02 | 2.4±0.09 | 7.0±0.73 | 23.1±9.69 |
| **Mean** | **F1** | 22.4±2,01 | 3.0±0.19 | 7.5±0.55 | 45.4±5.01 |
| | **F2** | 17.4±0.62 | 2.5±0.26 | 7.0±0.86 | 27.1±4.10 |
| | **p-value** | *** | *** | n.s. | *** |

As regards total nitrogen (TN), higher values were recorded in all three years in the samples from F1 (Table 5), with significant differences ($F_{1,64}$=14.01, $p$< 0.001) between the treatments at a 99% level of confidence. There was no clear trend in this variable over the period of assay, since it fell from 2005 to 2006 and decreased from 2006 to 2007 in both treatments. In short, the overall tendency was a slight increase in the organic plot, rising from 3.0 g kg-1 in 2005 to 3.2 in 2007, i.e, an increase of 6.6%,and a clear decrease (20.7 %) in the control plot F2 (from 2.9 in 2005 to 2.3 in 2007), as shown in Figure 1B.

The differences found in the C/N ratio (Table 5) between treatments were not statistically significant ($F_{1,64}$=2.541, p=0.118) and the C/N ratio ranged between 6.0 and 8.8 in the organic-amended plots, and between 5.1 and 8.9 in the mineral-amended plots: the average values are shown in Figure 1C.

Assimilable phosphorous (P) differed significantly between treatments (W = 529, $p$< 0.001), with a higher average value in F1 than in F2: 45.4 and 27.1 mg $kg^{-1}$, respectively (Table 5). The amount of P supplied with the sheep manure was similar to the amount supplied with mineral fertilizers; however, the available P content in F1 was double than in F1 than in F2. Values ranged between 33.6 and 54.3 mg $kg^{-1}$ in F1 plots, and between 13.9 and 37.7 mg $kg^{-1}$ in F2 plots (Figure 1D).This variable showed no clear trend during the study period, since it increased in both treatments from 2005 to 2006 but then decreased in 2007. Overall, a slight decrease in the available P content a slight decrease of available P content was observed during the essay both in F1 as in F2,althoughgreater availability of this element was apparent in the course of the sheep manure essay (F1).

**pH values, calcium carbonate and electrical conductivity.**

The values of pH, both in water and in KCl, were apparently greater in F2 over the course of the experiment (Table 6), with mean values of 7.9 and 8.0 in water for F1 and F2, respectively, and 7.4 and 7.5 for the samples measured in KCl, although the differences recorded were not statistically

significant (*p*= 0.342 and *p*= 0.949, respectively). This value increased in the course of the experiment in both essays; however, the rise was more noticeable in the control plot (F2).

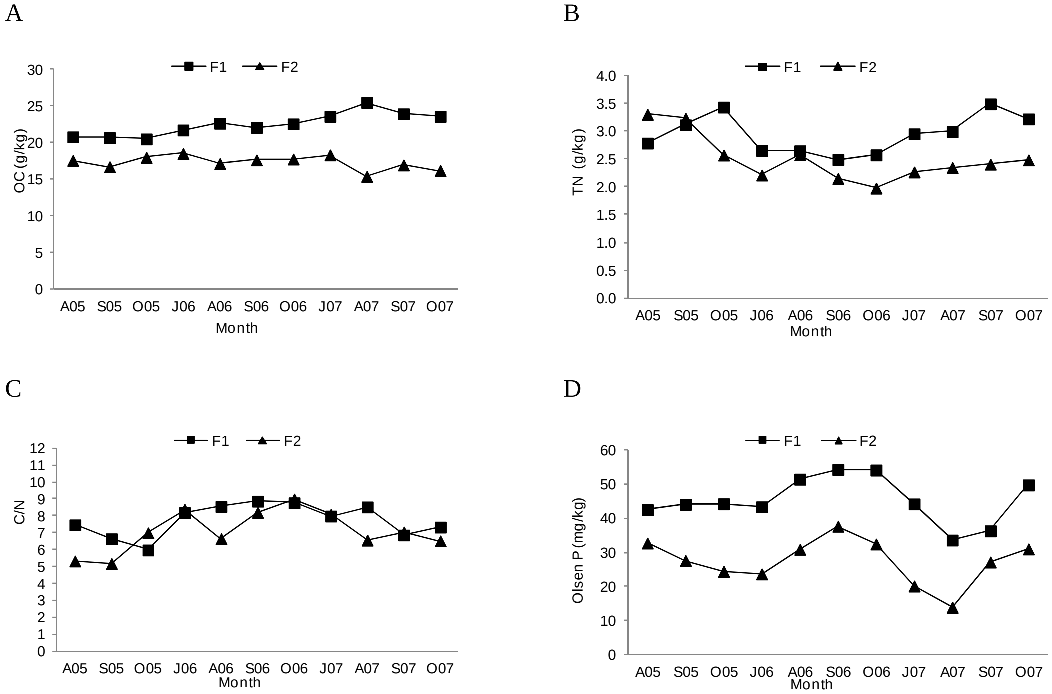


**Figure 1.** Evolution of soil constituents in organic and mineral plots. A: Organic carbon (OC); B: Total nitrogen (TN); C: C/N ratio; D: Assimilable Phosphorus (P Olsen). Cultivation cycles ranging from July (J) through August (A), September (S) and October (O) and 3 years (2005, 2006 and 2007).

**Table 6.**Evolution of $pH_w$ (1:1 soil-water), $pH_{KCl}$ (1:1 soil- 1M KCl), electrical conductivity (E.C., dS $m^{-1}$) and carbonates ($CaCO_3$,g kg $^{-1}$).Displayed are mean values of the three plots ± standard deviation (SD). Treatments:F1 =sheep manure; F2 =mineral fertilization.

| Year | Treatment | $pH_W$ | $pH_{KCl}$ | E.C. | $CaCO_3$ |
|---|---|---|---|---|---|
| 2005 | **F1** | 7.9±0.10 | 7.5±0.07 | 4.5±0.89 | 558±30.9 |
| | **F2** | 7.9±0.10 | 7.5±0.08 | 3.6.±1.11 | 565±19.7 |
| 2006 | **F1** | 8.0±0.09 | 7.6±0.08 | 4.5±0.87 | 560±28.7 |
| | **F2** | 8.0±0.10 | 7.6±0.09 | 3.5±1.03 | 586±47.5 |
| 2007 | **F1** | 7.7±0.22 | 7.2±0.18 | 4.3±2.01 | 529±24.1 |
| | **F2** | 8.0±0.10 | 7.3±0.17 | 3.0±1.11 | 537±35.4 |
| **Mean** | **F1** | 7.9±0.14 | 7.4±0.11 | 4.4±1.26 | 549±17.5 |
| | **F2** | 8.0±0.10 | 7.5±0.12 | 3.4±1.08 | 563±24.6 |
| | **p-value** | n.s. | n.s. | ** | n.s. |

The $CaCO_3$ contents were high in all the samples, reflecting the calcareous lithology of the study area, and there was no significant change during the three years of the experiment (Fig. 2C). The values of $CaCO_3$ ranged between 529g $kg^{-1}$ and586 g $kg^{-1}$**,** with slightly higher mean values in the conventional plots (F2) than in organic plots (F1) although this difference was not significant (p=0.188).

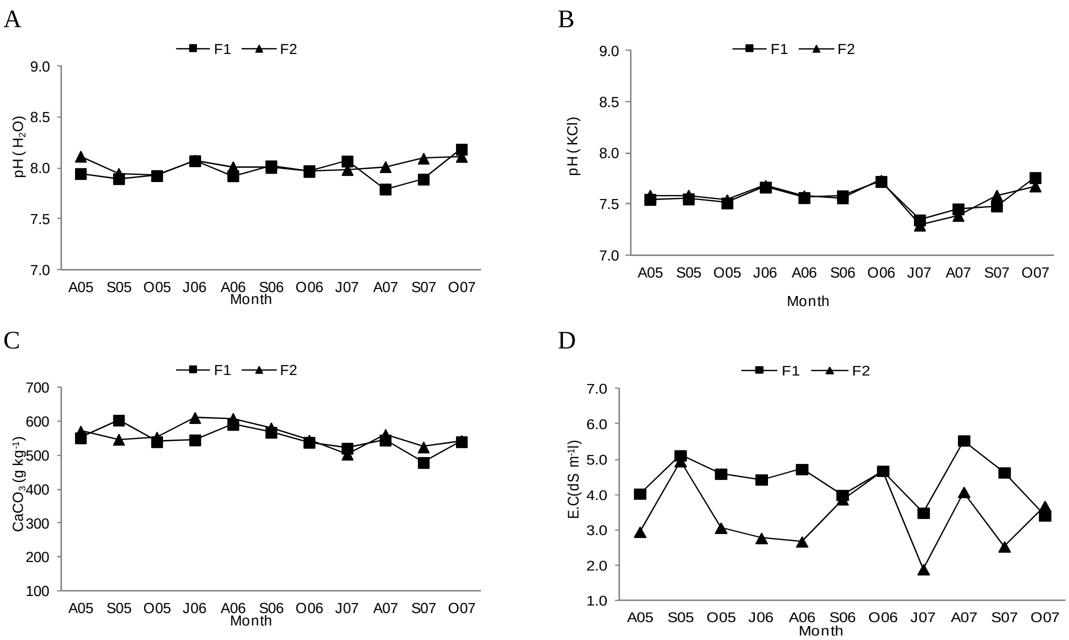


**Figure 2.** Evolution of pH, EC and $CO_3Ca$ in organic and mineral plots. A: pH in 1:1 suspension of soil/water; B: pH in 1:1 suspension of soil/KCl; C: Electrical Conductivity (EC); D: Calcium Carbonate ($CO_3Ca$).Cultivation cycles ranging from July (J)through August (A), September (S) and October (O) and 3 years(2005, 2006 and 2007.

The salinity of the soils was strongly affected by the farming activities over the three years of the experiment. The Wilcoxon test showed statistically significant differences between treatments (W = 435, $p< 0.01$). Thus, EC levels significantly increased during the three years of the experiment in F1 (organic-amended plots) and decreased in F2 (conventional-amended plots). The initial EC values in the A horizon increased three-fold in the mineral-amended plots (F2) during the first year of celery growing, and four-fold in the organic-amended plots (F1), reaching even higher values in some months of the following years of the study (Table 6). The evolution of EC within each year of the essay was similar in the three years, so each crop cycle showed values ranging between 4 and 5 dS $m^{-1}$ in the organic-amended plots (F1) and between 2.5 and 3.3 dS $m^{-1}$ in the mineral-amended plots (F2), with a strong increase in both treatments during the stage of maximum irrigation (F2) or maximum mineralization of the sheep manure (F1) (Figure 2D). Finally, in the last two months of vegetative growth, EC decreased to values similar to those at the beginning of the study.

**Cation Exchange Capacity (CEC) and exchangeable bases.**

The CEC did not showed significant differences between treatments (p= 0.079), with average values of 14.4cmolkg$^{-1}$ for F1 and 12.2 for F2 (Table 7). This variable increased slightly for both treatments from 2005 to 2006 but decreased in 2007, although these changes were not statistically significant.

**Table 7**. Evolution of Cation Exchange Capacity (CEC, cmol$_{(+)}$ kg$^{-1}$) and exchangeable bases content (g kg$^{-1}$): Potassium ($K^+$), Sodium ($Na^+$) and Magnesium ($Mg^{2+}$).Displayed are mean values of the three plots ± standard deviation (SD). Treatments:F1 =sheep manure; F2 =mineral fertilization.

| Year | Treatment | CEC | $K^+$ | $Na^+$ | $Mg^{2+}$ |
|---|---|---|---|---|---|
| 2005 | **F1** | 14.1±1.04 | 0.77±0.01 | 0.54±0.01 | 0.96±0.03 |
| | **F2** | 11.8±0.89 | 0.56±0.01 | 0.44±0.01 | 0.85±0.03 |
| 2006 | **F1** | 14.6±0.47 | 0.93±0.11 | 0.48±0.02 | 0.88±0.04 |
| | **F2** | 13.3±0.91 | 0.45±0.15 | 0.36±0.03 | 0.85±0.04 |
| 2007 | **F1** | 14.5±0.58 | 1,09±0.39 | 0.26±0.03 | 0.81±0.12 |
| | **F2** | 12.2±0.42 | 0.29±0.03 | 0.24±0.03 | 0.64±0.06 |
| **Mean** | **F1** | 14.4±0.83 | 0.93±0.17 | 0.43±0.14 | 0.88±0.14 |
| | **F2** | 12.2±0.81 | 0.49±0.06 | 0.35±0.11 | 0.78±0.15 |
| | **p-value** | n.s. | * | n.s. | n.s. |

As regards the exchangeable bases, the contents of sodium, magnesium and potassium were greater in the organically managed plot (F1) than in the conventionally managed one (F2), although these differences were only statistically significant in the case of potassium ($W = 287$, $p < 0.05$), as revealed by the non-parametric Wilcoxon rank sum test.

The evolution of potassium over the three years showed an inverse trend in both treatments, since it increased in F1 from 0.77 g kg-1 in 2005 to 1.09 g kg-1 in 2007, while in F2 it decreased from 0.56 to 0.29 g kg-1. Within each cycle, the dynamics of K also differed between the organic and conventional-amended plots (Fig. 3B). In the first year of the experiment (2005), the K values in F1 increased to reach a maximum in August, and decreased in September and October. In June 2006, K values were similar to values found at the beginning of 2005 and increased in F1 plots from then onwards to values close to 1.1 g kg-1 in October 2007. On the other hand, in the conventional plots (F2) K gradually decreased until the end of the experiment in October 2007. Adsorption by the celery crop was maximal in the second half of vegetative development.

The evolution of exchangeable Na showed a clear parallel downward trend during 2005 and 2006for both treatments, with higher values in F1 (Figure 3C), although the differences recorded between fertilization treatments were not statistically significant ($W = 258.5$, p-value = 0.1163). In contrast, Na values increased slightly during the last cycle of the experiment (2007).

Finally, there were not significant differences in Mg values between the treatments (W = 255, p-value = 0.14).The highest value was showed by the F1 plots (0.88 g kg$^-$1) while the average value in F2 plots was 0.78 g kg$^{-1}$. The trend of assimilable Mg in F1 plots was akin to that found in F2, decreasing from 0.96 to 0.81 g kg$^{-1}$ in F1 and more markedly, from 0.85 to 0.64 g kg$^{-1}$, in F2

(Table 7). In contrast, the Mg content increased during each crop cycle (June to October), especially in 2005 and 2007, while in 2006 this trend was less pronounced (Figure 3D).

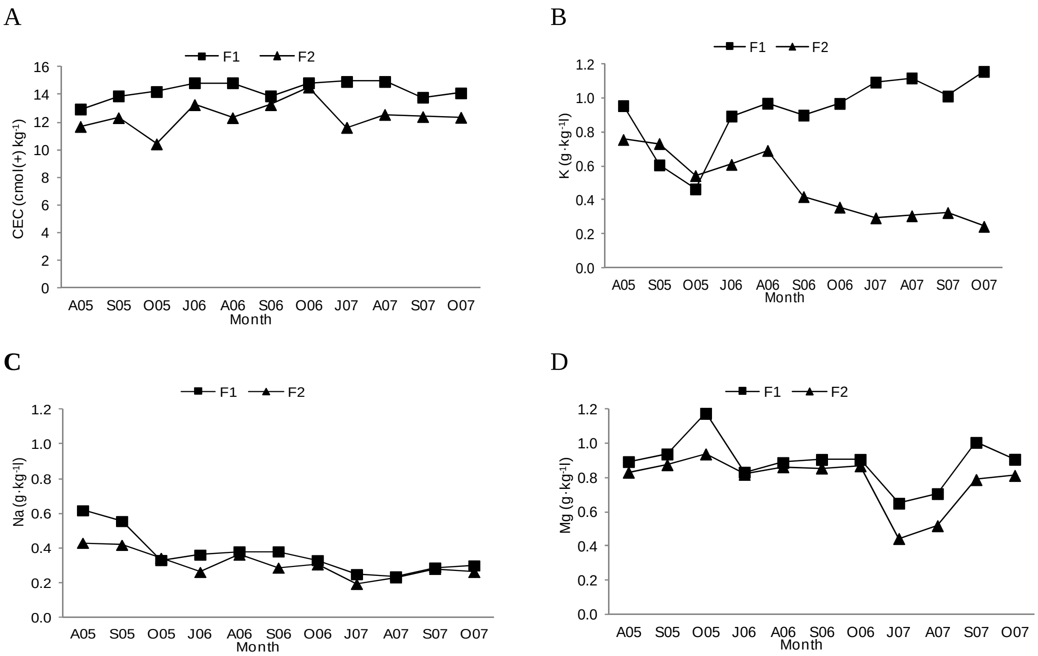


**Figure3.** Evolution of CEC and exchangeable cations in organic and mineral plots. A. Cation Exchange Capacity; B: Potassium; C: Sodium; D: Magnesium. Cultivation cycles ranging from July (J)through August (A), September (S) and October (O) and 3 years(2005, 2006 and 2007).F1 =organic plots (continue line); F2 = mineral plots (discontinue line).

## 4. DISCUSSION

### Organic Carbon, Total Nitrogen, C:N ratio and Olsen P.

Several authors have presented similar findings that organically managed soils tend to have a higher OC content than conventionally managed ones. In this sense, organic amendments showed beneficial effects on soil quality in the short term (Carpenter-Boggs et al.2000) and long terms (Leifeld et al. 2002). Likewise, Herencia et al. (2007) and Herencia et al. (2008) reached the conclusion that the OC content decreased less over time in organic plots than in conventional ones. The continuous addition of organic matter is important to maintain the soil organic carbon (SOC) content, which can be easily oxidized under the climatic conditions of soils in the Mediterranean region. According to the results, organic agriculture soils could have potential as carbon sink. Likewise, the use of manure amendments could be recommended to offset carbon emissions, especially in arable land, according to Article 3.3 and 3.4 of the Kyoto Protocol (Smith and Powlson2000; Ogle et al.2003). Such management practices imply an increase of 32 % in SOC compared with conventional agriculture (88.7 $10^6$ g $CO_2ha^{-1}$).

The stimulating effect of humic substances on plant growth has been related to the increased absorption of macronutrients. Many studies have concluded that organically managed soils tend to

have a higher TN content than conventionally managed ones from the first or second year of conversion (Warman 2005; Herencia et al. 2007; Herencia et al. 2008). The higher N contents in F1 plots (F1) could be partly due to the nutrients supplied with the fresh sheep manure, which also contains high amounts of $NH_4^+$-N (Scheller and Raupp 2005; Warman 2005) . However, this variable did not show a clear trend over the 3 years of the assay, since it fell from 2005 to 2006 and rose from 2006 to 2007 in both treatments.

As the N supplied through organic amendments is not immediately available for plants and must be mineralized, N mineralization is closely linked to OC pools and mediated by soil microorganisms. It is also widely accepted that one of the effects of tilling is to mix and aerate the soil (Vance, 2000), which stimulates microbial decomposition and therefore favours the increase in mineral ions, among others nitrogen forms, in the soil solution. Besides, the decrease in the conventionally managed plot (F2) can be attributed to extraction by the crop, as well as to the loss of TN due to leaching in autumn, winter and spring (when most rainfall occurred), since the fertiliser applied to the crop was mainly in the form of nitrates and ammonium, which are highly soluble. This hypothesis is corroborated by the fact that F2 showed higher levels of TN at the end of the growing season 2006 (Fig. 1B) than at the beginning of the growing season 2007 (2.0 to 1.8 g $kg^{-1}$). In addition, a trend was also observed within each crop cycle, as TN decreased in July and August and rose in September and October to the initial levels; this may be related to the consumption of this nutrient in the first half of the vegetative cycle, while in the second half, the crop fundamentally consumes K, Mg and Ca.

The amount of both organic and inorganic forms P in the soil is usually small and seldom represents more than 0.2 %. In calcareous soils, such as the one in the present study, most is precipitated as $Ca_3(PO_4)_2$ (apathite), a form that is not assimilable by plants. The amount of P in the soil solution represents only a small fraction of the plant requirements and thus the rest must be obtained from external inputs (amendments and fertilizers), involving a combination of biotic and abiotic processes.

In the last year of the study, Olsen P was still higher in F1 than in F2, but P fell sharply in both treatments, which cannot be fully explained, but may be related to the immobilization of this constituent. The greater concentration of P in F1 may be attributable to the positive action that the humic compounds had on the availability of this macronutrient. Other research carried out in similar environments (Bermúdez et al., 1993) has found that the addition of humic substances increases the bioavailability of P in the soil. This can be explained by the decomposition of these amendments, which may result in the concentration of organic acids that reduce P precipitation in the soil (Laboski and Lamb, 2003); hence, the amount of the P fraction would depend on the content of organic matter.

**pH values, calcium carbonate and electrical conductivity.**

The values of pH, both in water and in KCl, were apparently greater in F2 throughout the experiment, although there were not statistically significant (Table 6, Figure 2A and 2B). This finding differs from that of other researchers, who found a lower pH (Haraldsen et al., 2000), or even a higher pH (Van Diepeningen et al., 2006) in plots receiving organic amendments.

The pH may be unaffected by the soil management method in short-terms experiments, which could be explained by the buffer capacity of soil, which is related with the $CaCO_3$ contents, CEC, and base saturation. On the one hand, pH is correlated in calcareous soils with the partial pressure of $CO_2$ (Brucker and Rouiller., 1987); in alkaline medium the $CO_2$ produces bicarbonate by consuming $OH^-$ and so prevents the pH from increasing. On the other hand, root and microbial

respiration produces $CO_2$, which could induce a lower pH due to the higher microbiological activity of organic plots (Melero et al. 2006).

In terms of EC, this behaviour reflects a balance between the input of anthropogenic salts (either in the form of soluble fertilizers in F2 or released by mineralization of the organic amendments in F1), and the outputs by leaching, gas losses and crop removal. Also, crops are known to absorb more salts during the final stage of vegetative development, once they reach maturity (Rincón, 2001). Likewise, this behaviour indicates that the organic amendments in F1 increased soil salinity, as has also been reported by Hao and Chang (2003), perhaps due to the extensive decomposition of OM, suggesting that the quality and ratios of fertilization may need to be corrected in F1 in order to avoid this trend, while conventional fertilization (F2) seemed to be better adjusted to crop needs.

**Cation Exchange Capacity (CEC) and exchangeable bases.**

The CEC, which determines the retention and availability of nutrients such as $K^+$, $Ca^{++}$ and $Mg^{++}$, depends on the humus and clay contents in the soil. As the content of clay was similar in both assays, the differences in CEC must have been due to the organic matter. It has been estimated that organic matter accounts for 30-60% of the soil's exchange capacity, and so increasing the organic matter content also increases the CEC value of the soil and the reserves of assimilable cations. These results confirm those obtained in other studies (Bending et al., 2004; Liu et al., 2006; Bulluck et al., 2002;Martínez et al., 2003; Morari et al.,2008), which describe an improvement in CEC due to the addition of organic matter compared with soils treated with conventional fertilization. Nevertheless, this increase was not proportional to the increase in organic carbon contents between 2005 and 2007 and may, rather, be related to the composition of the organic amendment, since fresh sheep manure had a low humification degree and so the chemically active components responsible for CEC would have been small.

The gradual increase of assimilable potassium content in F1 plots from June 2006 onwards suggest that mineralization rates may have been greater than in 2005, which would also explain the behaviour of TN in these stage, while the decrease observed in F2 plots in the same period may be explained by the large losses due to extractions by the crop. These results agree with those of Bulluck et al. (2002).

The decrease in Na values during the study can be related to the solubility of this nutrient, as Na can be absorbed by the celery crop as a substitute for K, or leached due to the use of high amounts of water (6000 to 7000 $m^3$ $ha^{-1}$ $year^{-1}$) for celery irrigation. In the same way, the increase observed in 2007 was possibly related with a more efficient irrigation treatment and the release of Na in the exchange complex. Mineralization of the organic matter (F1), and also Na inputs as residues in some fertilizers used in F2 (e.g.KCl), may also explain the slight increase in this element observed during the last year of the experiment.

In the case of Mg, this nutrient did not increase in the plots that received organic amendment, as might have been expected attending to Bulluck et al. (2002) and Morari (2008).The decrease of this nutrient during the 3 years may have been due to the uptake of this cation by the crop, which contrasts with the increasing trend of Mg within each crop cycle. On the other hand, the decrease between the end of a cycle and the beginning of the following one during the winter months could be related to the fixation or immobilization of Mg in the form of the less soluble CaMg(CO3)2due to lower temperatures. Hao and Chang (2003) observed differences in the mobility of K and Mg in the soil, reporting that K significantly accumulated at the soil surface whereas Mg increased with soil depth.

## 5. CONCLUSIONS

This study has shown that the use of sheep manure as fertiliser rather than inorganic fertilisers results in favourable changes in some soil properties and constituents. During the study period there was a clear increase in the OC content in the organically managed soil, while the OC content in control plots was quite stable, with a slight trend to decrease. The N, available phosphorus, magnesium and potassium contents were higher in the organically managed plots (F1) than in the control plots F2. Positive changes were also observed in the cation exchange capacity (CEC) and the C/N ratio in the plot treated with manure. However, the pH both in water and in potassium chloride, and the C/N ratio showed no significant differences between treatments.

The salinity of the soils was strongly affected by the farming activities developed in the three years of the experiment, reaching higher values in F1 than in F2, which may indicate that fertilizer quality and ratios should be revised.

Regarding the influence that organic agriculture could have on the potential of soil as C sink, the use of manure amendments can be recommended to offset carbon emissions, since organic management practices imply an increase of 32 % in soil organic carbon (SOC) compared with conventional agricultural practices.

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