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Accepted author version posted online: 24 Sep 2012.

To cite this article: Jesus de Torres, Enrique Garzón, John Ryan & Fernando González-Andrés (2013): Organic Cereal/Forage Legume Rotation in a Mediterranean Calcareous Soil: Implications for Soil Parameters, Agroecology and Sustainable Food Systems, 37:2, 215-230

To link to this article: http://dx.doi.org/10.1080/10440046.2012.726957

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Organic Cereal/Forage Legume Rotation in a Mediterranean Calcareous Soil: Implications for Soil Parameters

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In this study, we examined the effect of five years of organic farming on soil parameters of a dryland Mediterranean agroecosystem. The study involved a four-course rotation: barley/common vetch/oats/bitter vetch, with incorporation of crop residues into the soil, no fertilization, shallow tillage, and variable sowing practice. The overall effect of the organic rotation was to significantly affect soil organic matter (SOM), total nitrogen (N), and available phosphorus and potassium, even if these effects were inconsistent over the five years studied. Nevertheless, the overall effect of each crop in the rotation was to increase these soil quality parameters by comparison with the original values during the period of conventional cultivation. Given that SOM and total N content are key indexes of soil management sustainability, the principal finding was the positive effect of the rotation on them. Variable sowing had little influence on SOM, and had no effect on the other variables.

KEYWORDS organic farming, rainfed cropping, crop rotations, soil organic matter, total nitrogen, Spain

This research was funded by the Council of the Province of Valladolid in Spain.
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1. INTRODUCTION

In today’s crowded world, the pressure on the global soil resources have never been greater (Friedman 2008). The impact of population growth and increased affluence, in addition to climate change, are posing enormous challenges to all involved with land use: researchers, policymakers, and farmers (Godfray et al. 2010). Issues of land use are particularly acute in regions of the world where rainfall is comparatively low and where water resources are limited, a situation that is likely to be exacerbated by competing societal demands for water other than for production agriculture (Turner et al. 2011). The Mediterranean Basin exemplifies much of society’s concerns about land use. Although historically a center of origin of many of the world’s crops, notably cereals and pulses, and of settled agriculture, Mediterranean agriculture has always been plagued by drought caused by low and erratic rainfall (Kassam 1981). The issue of drought still dominates the fortunes of the region, especially the Near East or West Asia (Kaniewski et al. 2012). Dryland Mediterranean agroecosystems are inherently fragile (Stewart and Robinson 1997), with the traditional cereal mono-cropping being deemed unsustainable in the long run (Yau et al. 2003). Despite the commonalities across the region, which is characterized by a Mediterranean/contemplaneous climate, there are regional differences related to the degree of economic development with respect to land use issues.

Given the constraints of rainfall, allied to socioeconomic factors, much effort has been made in recent decades to improve the agricultural sector of the Mediterranean region, particularly in the area of crops and land management, with two main focal points of dryland research, that is, Syria in the east Mediterranean (West Asia) and Spain in the northwest Mediterranean, as well as related research in Italy. In West Asia, rotations involving both forage and food legumes were seen as having considerable potential to make the region’s rainfed farming viable from the biophysical and economic viewpoints (Ryan, Singh, and Pala 2008). Particular emphasis has been given to the introduction of forage legumes as an alternative to fallow and continuous cereal cropping (Cooper et al. 1987). Thus, the response to land use intensification is underpinned by agronomic research on improved management practices as well as associated economic considerations. The most effective approach to such research has been through the medium of long-term crop rotation trials.

A long-term trial (14 years) in Syria (340 mm/year) clearly showed the value of forages such as vetch (*Vicia sativa*) as a basis for supporting sheep (*Ovis aries*) and as an alternative to both fallow and cereal mono-cropping (Ryan et al. 2010). In a water-stressed area, such legume-based rotations led to greater water-use efficiency (Pala et al. 2007). In other trials with focuses on animal management with wheat (Christiansen et al. 2011) and barley (Ryan et al. 2011), and with residue management for barley (Pala et al. 2007).
Soil Parameters in an Organic Cereal/Forage Legume Rotation

2008), the potential of vetches was reinforced. Much emphasis has been placed on common vetch (*V. sativa*) in the Mediterranean region (Jones and Singh 1995) and, more recently (Larbi et al. 2011), on bitter vetch (*V. ervilia*).

In the western Mediterranean region, parallel agronomic research addressed the issue of cereal-based rotations, as well as the evolving practice of conservation agriculture (Cantero-Martínez et al. 2003; López-Bellido et al. 2010; Melero et al. 2011). Despite what is already known about cropping systems agronomy, the quest will continue for more suitable crops as well as for better systems for growing those crops, such as manipulating seeding rates and weed control. However, concerns about land use sustainability in the northwest Mediterranean are more typical of the developed world rather than the developing world, as typified by Syria in West Asia. Thus, in Spain, sustainability refers to crop diversification with less dependence on nutrients and pesticides, and for this reason organic agriculture is now a realistic option.

Organic agriculture according to the European organic production standards (EU 834/2007) is potentially attractive in the northwest Mediterranean because of the higher prices obtained by farmers for the organically certified products. In view of the growing importance of organic agriculture, there has been a corresponding increase in associated research, especially in areas where water is not a major limiting factor (Rutkoviene et al. 2009; Leifeld and Fuhrer 2010). However, in contrast to traditional rainfed agriculture, few, if any, scientific studies have been carried out for organic production for cereals under rainfed Mediterranean conditions.

Valid and reliable assessment of any rotation cropping system requires a longer-term perspective (Karlen 1994; Ryan, Singh, and Pala 2008). In the absence of such long-term data, soil indices of sustainability are a more plausible alternative, especially involving a key indicator of soil quality as influenced by cropping, that is, soil organic matter (SOM), which reflects soil aggregation and related parameters such as water infiltration and hydraulic conductivity (Masri and Ryan 2006). In one of the few studies where soil aspects of Mediterranean rotations were considered (Ryan, Masri, Ibrikci, et al. 2008), SOM was shown to rapidly respond to the various rotations, with similar trends for total soil nitrogen (N), a critical factor in organic production where fertilizers are not used.

The region of Castilla and León in inland northern Spain, with a dry Mediterranean climate, has been historically known for cereal production, and currently produces about 1.5 million hectares of wheat (*Triticum aestivum*) and barley (*Hordeum vulgare*). Given these facts, it was deemed appropriate to introduce the novel idea of organic, rainfed cereal production and provide a preliminary assessment of indicators of sustainability. Thus, we examined the influence of a cereal-based rotation (two cereals in rotation with two forage legumes for grain harvest) and associated variation in crop sowing technique, on SOM and related nutrient availability. Weeds are one
of the major problems in organic farming, and agronomic practices as the sowing technique is a chief strategy for weeds control (Stockdate et al. 2001).

2. MATERIAL AND METHODS

2.1. Experimental Site

The location for this on-farm experiment was at Matallana, near Valladolid in Spain (Lat/Long: 41°9′ N 4°8′5″ W, 830 m.a.s.l.) in the region called Torozos. The soil at the site is classified as lithic xeric Haplocalcid (Soil Survey Staff 2003), that is, a shallow soil with some free calcium carbonate in a relatively arid environment. The main soil characteristics in the topsoil layer were a pH of about 8.3, low calcium carbonate content (4%), and a sandy clay loam texture. The climate is dry temperate continental Mediterranean with average (last 30 years) annual maximum and minimum air temperatures 17.2°C and 4.9°C, respectively, and rainfall 434 mm. Rainfall peaks on average occur in autumn (November/December) and late spring (April/May). For the years of the experiment, monthly temperatures, and rainfall data are presented in Figure 1. The annual rainfall for the five years was 383 mm in 2003–2004, 114 mm in 2004–2005, 301 mm in 2005–2006, 704 mm in 2006–2007, and 427 mm in 2007–2008. Thus, considerable yearly rainfall variability characterizes the region.

2.2. Farming System Before the Start of the Experiment

Before September 2003, when the organic farming started, the farming system was a conventional monoculture of winter cereals (wheat and barley),

**FIGURE 1** Rainfall and monthly mean temperatures recorded during the course of the experiment (color figure available online).
with one fallow year every four to five years. The cereal straw from the preceding crop (cut to 10–15 cm) was removed after being baled and the remaining stubble was incorporated into the soil by subsequent tillage. Before 1991, stubble was burned in order to facilitate the tillage for the next crop, but this practice was stopped after that. Tillage was done by ploughing to a depth of 30 cm in early autumn with a mouldboard plough, which was followed by secondary tillage with a disc harrow for seedbed preparation.

2.3. Experimental Design and Crop Rotation

From the starting date of the experiment (October 1, 2003), the farming system changed to organic according to prevailing organic production standards (EU 834/2007). After the transition period (2003–2004 and 2004–2005) required for organic certification, the farm was fully certified as organic.

The experimental setup consisted of four plots. In each plot, the crop rotation was a four-course rotation with the cropping sequence: Barley/common vetch for grain harvest/oats (*Avena byzantina* C. Koch)/bitter vetch for grain harvest (Figure 2). Each crop, both cereals and legumes were cultivated alone, so legumes were not interplanted with the cereal. Therefore, the rotation was a fixed factor, and each year we harvested

![Experimental design](image.png)

**FIGURE 2** Experimental design. Letters within the experimental units refer to the sowing technique: R regular seeding rate; T twin rows, H high seeding rate. Refer to text for details.
each crop in a different plot. The sowing technique was the independent variable to be tested, thus, the statistical design was a randomized complete block design with three blocks (Figure 2). Therefore, the sowing technique was assigned at random within blocks, and they were the following: (1) regular seeding rate, corresponding to the usual sowing density in the area, in single rows 16.5 cm apart: barley 170 kg ha\(^{-1}\), common vetch 130 kg ha\(^{-1}\), oats 150 kg ha\(^{-1}\), and bitter vetch 100 kg ha\(^{-1}\); (2) twin rows with the same density as before, with interrow hoeing, with the twin rows set 16.5 cm apart, leaving 49.5 cm between each two rows; (3) high seeding rate in single 16.5 cm rows (to improve crop competition against weeds): barley 240 kg ha\(^{-1}\), common vetch 190 kg ha\(^{-1}\), oats 190 kg ha\(^{-1}\), and bitter vetch 140 kg ha\(^{-1}\). The experimental unit was 180 m\(^2\) (60 m \(\times\) 30 m). The total number of experimental units was 36, consisting of 4 plots \(\times\) 3 sowing techniques \(\times\) 3 replications.

2.4. Residues Management and Tillage
During the harvest process, the loose straw of each crop was chopped by the combine harvester and spread on the ground, and both the straw and the stubble were incorporated into the soil by tillage. Primary tillage was done in late summer or early autumn (September 1–October 7), depending on the onset of seasonal rains, and was relatively shallow using a chisel to a depth of 15 cm. This was followed by a secondary tillage with a light cultivator for seedbed preparation. Prior to sowing, weeds were allowed to germinate and sprout for about 10 days, then the weed seedlings were eliminated with a light “ducksfoot” cultivator, following a common practice for weed control in organic farming (Stockdale et al. 2001).

2.5. Sowing, Harvesting, and Other Agronomic Practices
The seeds used for sowing were obtained by organic farming procedures and the varieties selected were well adapted to the area: for barley Hispanic (2-row), for common vetch Senda DA-247, for oats Byzantina, and for bitter vetch Torozos. Registered varieties were used for barley and common vetch, while local ecotypes were used for oats and bitter vetch. Sowing was carried out with a conventional seed drill in mid-October (10–20) depending on the date of tillage and the first rains of the season.

As weed control is a key issue in organic farming, the twin rows sowing technique needed two interrow hoeings to eliminate weeds. For cereals, the first tillage was done at the phenological Stage D (full tillering), and the second in stage J with two nodes visible (Keller and Baggiolini 1954). For the vetches, the first tillage was in March in the vegetative phase, and the second at the end of flowering (Berger et al. 2002).
Harvesting of cereals and legumes was carried out with a plot combine (Wintersteiger), generally from July 1 to 15, depending on the climatic conditions of the year. Therefore, all the crops were harvested for grain, both cereals, and legumes. The harvesting of vetch grain for animal feed is the most common use of vetches in the region. The harvester chopped and scattered the straw on the ground after threshing. The aboveground residues from each crop were weighed and then returned to the soil for subsequent incorporation. No other agronomic practices were carried out and no external inputs, except for the seeds, were used in the production system.

2.6 Soil Sampling and Chemical Analysis

As the main objective was to evaluate the effect of the rotations on soil quality, soil samples (0–15 cm) were collected with an Ejelkamp probe two days prior to sowing, and involved nine 200 ml samples per experimental unit, collected in a 3 × 3 grid throughout each experimental unit. The samples were immediately transferred under cool-box conditions to the laboratory, air-dried at room temperature, put through a 2 mm sieve, and analyzed according to the guidelines of the Soil Conservation Service (1984). Organic carbon was analyzed using the Walkley-Black procedure, N by the Kjeldahl method, the pH was measured in 1:2 soil water, and the available phosphorus (P) content was determined by the Olsen method. Concentration values for potassium (K) were determined by inductively couple plasma-atomic emission spectroscopy (ICP-AES). The content of total phosphorous was also determined, and the average content was 600 mg kg of soil$^{-1}$, or about 35 times the content of readily available or assimilable P, a ratio that is common in most soils.

2.7. Statistical Analysis

The data were analyzed in two steps. First, the evolution of the soil chemical parameters, or changes throughout the five years considered, was analyzed for the pooled data of crops and sowing techniques. The statistical procedure was one-way analysis of variance for repeated measurements, based on the general linear model (Hand and Taylor 1987). The within-subject variables were each of the soil chemical parameters across the five years. As the soil samples were collected at the beginning of each agricultural campaign, the first data of 2003 corresponded to the values at the end of the conventional farming system, just before the start of the transition process to organic farming.

The Mauchly’s test was used to check sphericity of the variances-covariance matrix. In our case, the condition of sphericity was not met for any variable, because the Mauchly’s test statistics was significant, which
implies that there were significant differences between the variance of differences. So we needed to use an estimate of sphericity (Greenhouse and Geisser 1958) to correct the degrees of freedom and to produce a valid $F$ value. As the model only included repeated measurement factors, instead of post hoc comparisons, we used the paired $t$ test procedure to compare all pairs of levels of the independent variable, applying a Bonferroni correction, and the resulting probability value was used as the criterion for the statistical significance.

The second statistical analysis was carried out to quantify the effect of the preceding crop and the sowing technique on the soil chemical parameters. In the latter case, a combined analysis of variance appropriate to the complete randomized design was performed using the general linear model. The software package IBM SPSS statistics version 19.0 was used for all the analysis.

3. RESULTS

As the soil chemical properties are affected by the inputs to the soil system, it is pertinent to first present the average amount of biomass incorporated each year for each crop, over the five-year period. Thus, the amount of loose straw and stubble varied with crop in the rotation and the year (Table 1). In general the amount of residues was highest for oats, followed by common vetch, barley, and bitter vetch. Similarly, because of growing conditions are related to seasonal rainfall, average crop yields, and thus residues, were highest in 2005–2006 and lowest in 2004–2005.

The first statistical analysis described the changes in soil chemical parameters throughout the five years of the experiment (Table 2). While SOM tended to be significantly higher as time progressed, the effect was not consistent; in fact SOM values in 2004, 2006, and 2007 were significantly higher than that detected in the initial year (2003), while in 2005 SOM was similar to 2003. In contrast, total N values were more consistent, all values subsequent to 2003 were higher. The C/N ratio reflected the relative

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Barley</td>
<td>2,199</td>
<td>1,198</td>
<td>3,307</td>
<td>2,153</td>
<td>2,214</td>
</tr>
<tr>
<td>Common vetch</td>
<td>4,263</td>
<td>1,915</td>
<td>3,857</td>
<td>3,865</td>
<td>3,470</td>
</tr>
<tr>
<td>Oats</td>
<td>6,892</td>
<td>2,673</td>
<td>10,232</td>
<td>4,165</td>
<td>5,991</td>
</tr>
<tr>
<td>Bitter vetch</td>
<td>1,709</td>
<td>679</td>
<td>1,873</td>
<td>1,692</td>
<td>1,488</td>
</tr>
<tr>
<td>Yearly Mean</td>
<td>3,766</td>
<td>1,616</td>
<td>4,812</td>
<td>2,968</td>
<td></td>
</tr>
</tbody>
</table>
TABLE 2 Average values of soil chemical parameters, during the first five years of the experiment. Data show the evolution of the analyzed parameters after organic farming conversion, for the pooled data of crops and sowing techniques.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sampling date (October 10–20, depending on year)</th>
<th>Trend line</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2003</td>
<td>2004</td>
</tr>
<tr>
<td>Soil organic matter (%)</td>
<td>1.15a</td>
<td>1.33c</td>
</tr>
<tr>
<td>Total N (‰)</td>
<td>0.85a</td>
<td>0.88ab</td>
</tr>
<tr>
<td>C/N</td>
<td>7.81bc</td>
<td>7.55bc</td>
</tr>
<tr>
<td>P (Olsen) (mg kg$^{-1}$)*</td>
<td>17.17</td>
<td>17.50</td>
</tr>
<tr>
<td>K$^+$ (mg kg$^{-1}$)</td>
<td>363a</td>
<td>459d</td>
</tr>
<tr>
<td>pH</td>
<td>8.29ab</td>
<td>8.42d</td>
</tr>
</tbody>
</table>

Letters corresponded to paired $t$ test comparisons applying Bonferroni correction (see text for details). Significance value $p < 0.05$.

*No significant differences.

Changes in both SOM and total N, and the values ranging from 7 to 8. P values showed no clear trend over the five-year period, in contrast, available K was higher in each experimental plot after the first year, though not consistently so. Although soil pH was measured each year, the minor fluctuations between years were of no practical importance, since pH does not effectively change to any degree where solid-phase calcium carbonate is present to buffer the pH.

The second type of analysis was carried out to ascertain the effect of the preceding crop and the sowing technique in each soil parameter. This analysis also permitted us to compare the values of the soil parameters before starting the organic farming with the values after each of the crops in the organic system. While the preceding crop had significant influence in all the parameters (Table 3), the sowing technique only affected the SOM, and only then at the 5% level. The only significant interaction between the preceding

TABLE 3 Mean squares of the combined analysis of variance to study the effect of the previous crop and the sowing technique in soil chemical parameters.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>d.f.</th>
<th>Soil organic matter (%)</th>
<th>Total N (‰)</th>
<th>C/N</th>
<th>P Olsen (mg kg$^{-1}$)</th>
<th>K$^+$ (mg kg$^{-1}$)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Previous crop (C)</td>
<td>4</td>
<td>0.17105***</td>
<td>0.00046**</td>
<td>2.327***</td>
<td>197.3***</td>
<td>37560.4***</td>
<td>0.178***</td>
</tr>
<tr>
<td>Sowing technique (T)</td>
<td>2</td>
<td>0.08585*</td>
<td>0.00026</td>
<td>0.484</td>
<td>19.7</td>
<td>14748.1</td>
<td>0.013</td>
</tr>
<tr>
<td>C × T</td>
<td>8</td>
<td>0.01022</td>
<td>0.00019</td>
<td>0.661</td>
<td>84.1***</td>
<td>4087.3</td>
<td>0.004</td>
</tr>
<tr>
<td>Error</td>
<td>165</td>
<td>0.02282</td>
<td>0.00011</td>
<td>0.486</td>
<td>13.8</td>
<td>5955.9</td>
<td>0.007</td>
</tr>
<tr>
<td>Total</td>
<td>180</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
TABLE 4 Mean values of soil chemical parameters before the start of the experiment and after the different crops of the organic rotation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Previous (conventional farming)</th>
<th>After oats</th>
<th>After barley</th>
<th>After common vetch</th>
<th>After bitter vetch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil organic matter (%)</td>
<td>1.148a</td>
<td>1.331c</td>
<td>1.233b</td>
<td>1.228b</td>
<td>1.182b</td>
</tr>
<tr>
<td>Total N (‰)</td>
<td>0.85a</td>
<td>0.90b</td>
<td>0.91bc</td>
<td>0.96c</td>
<td>0.90b</td>
</tr>
<tr>
<td>C/N</td>
<td>7.81c</td>
<td>7.92c</td>
<td>7.68bc</td>
<td>7.34a</td>
<td>7.39ab</td>
</tr>
<tr>
<td>P Olsen (mg kg(^{-1}))</td>
<td>17.2b</td>
<td>19.8c</td>
<td>18.5bc</td>
<td>19.8c</td>
<td>14.2c</td>
</tr>
<tr>
<td>K(^{+}) (mg kg(^{-1}))</td>
<td>363(^{a})</td>
<td>451c</td>
<td>403b</td>
<td>394(^{ab})</td>
<td>390(^{ab})</td>
</tr>
<tr>
<td>pH</td>
<td>8.29b</td>
<td>8.44d</td>
<td>8.34c</td>
<td>8.25(^{a})</td>
<td>8.36c</td>
</tr>
</tbody>
</table>

Means comparison is based on Tukey test.
The mean values followed by the same letter did not significantly differ at \( p < 0.05 \).

crop and the sowing technique was for the P content, the interpretation of which is uncertain.

A comparison of soil chemical parameters showed some significant differences between values with the prior conventional system and those after each crop in the organic-based rotations (Table 4). As the parameter of most importance in relation to soil quality, SOM values were consistently higher after each of the four rotation crops compared with the original value of 1.15%, with oats being highest at 1.33% and the barley and vetches intermediate. As total N is a consistent component of SOM, values of total N followed the same trend as SOM itself. The C/N values predictably ranged between 7 and 8 with no discernible trend. In contrast to SOM and total N, values for Olsen P were divergent with respect to the conventional system, with values being higher after oats, barley, and common vetch, but lower after bitter vetch. Again in contrast to Olsen P, values for available K were all higher after the rotational crops by comparison with the original conventional cropping system. As indicated for the data in Table 2, the slight variation in soil pH could not be expected to have any practical significance.

4. DISCUSSION

As one of the few reported multiyear studies of soil parameters in relation to dryland crop rotations under “organic” agriculture conditions, this field trial from Spain revealed some predictable trends as well as some lessons for such long-term field trials. Although no consideration was made of the crop yields in this article, it is apparent that any meaningful analysis of production under such rotations would necessarily involve conducting the trial for several more years at least. In view of accepted criteria for long-term rotation trials, whether conventional or organic, this five-year study would not even qualify as being long term (Ryan, Singh, and Pala 2008). Assessment of crop yields is particularly problematic in view of the seasonal variation in rainfall.
The influence of seasonal rainfall was particularly evident in our study, where yields in 2004–2005 were less than half the normal with only about 25% of the long-term average rainfall during that season. Thus, rainfall dictates the amount of cereal residues contributed to the soil in such organic systems of production. Indeed, it is of interest to note that only in one of the five years (2006–2007) was seasonal rainfall above average. Crop yield data from a 14-year conventional cereal-based rotation (Ryan et al. 2010) showed the same variation in response to varying rainfall. Notwithstanding the shortcomings of the trial from the production standpoint, the data from this study and other conventional systems suggests that changes in soil parameters may be more readily expressed as a function of the rotation and associated biomass inputs.

Of prime concern is SOM, especially in view of its controlling influence on aggregation and water relations (Masri and Ryan 2006). Most studies of cropping systems, where residues are returned and tillage operations are minimal so as to reduce mineralization, showed an increase in SOM, however small. Such a trend was observed in our study, but with interseasonal variation. In the only comparable study of SOM in a long-term rotation trial, Ryan, Masri, Ibrikci, et al. (2008) showed a slight increase over the years, with decreases in a few years. Similarly, monthly SOM analyses during each year also demonstrated a cyclical pattern, especially in terms of the more labile SOM fractions (Ryan et al. 2009). Had monthly sampling occurred in our study, it probably would have shown the same variation. In the Ryan et al. (2008b) study, SOM was more influenced by the type of crop than changes with years of the trial, with forages such as medic and vetch having the greatest effect on all SOM fractions. In our study, the rotational effect on SOM was again evident, with values following oats being much higher than the other crops. The high input of cereal residues (Table 1) from oats may have contributed to the increased SOM.

While SOM has an indirect effect on crops, N has a direct effect and therefore is of relevance in organic systems of production where commercial mineral N fertilizers are not allowed; in such cases, the required N has to come from manures, added crop residues, or rotations with legumes that biologically fix N from the atmosphere. As total N is related to SOM, the pattern over the five cropping season was similar. The relatively small increases in total N have to be attributed to the legumes in the rotation, especially common vetch, since no farm manures were used and the contribution of the cereal straw to soil N is low. This result is consistent to the conventional rotation study of Ryan, Masri, Singh, et al. (2008), who showed that forage legumes increased total soil N, as well as inorganic forms, ammonium, and nitrate, which were not assessed in our study.

As organic production systems are driven by nutrients, the impact of the rotation on P and K is of interest. At the initiation of the study following years of conventional cropping, including the use of chemical fertilizers, the
Olsen P values were still considerably in excess of the critical value for dryland crops in the Mediterranean region (Ryan and Matar 1992). With a value of 17 mg P kg\(^{-1}\), it is likely that cropping could continue for several years without the need for an external input of P (Ryan, Ibrikci, et al. 2008). Given the dynamic nature of P in soils, and the limited input of P from crop residues, the lack of any consistent trend in available P with time was not surprising. With routine chemical fertilization from conventional dryland agriculture, a buildup in available P would have occurred (Ryan, Ibrikci, et al. 2008). Vetches in general extract from the soil high rates of P for grain protein production (Berger et al. 1999), but the remaining Olsen P was significantly higher after common vetch, indicating that it might be more efficient in the assimilation of insoluble forms of mineral P, than the bitter vetch, although the low crop residues from bitter vetch could have also accounted for the overall low P value after that crop.

As with P, the levels of available K were considerably above the critical value for crop growth, and typical of semi-arid soils in general, which are normally well supplied with K due to inherent mineralogy and the absence of a leaching regime due to low rainfall. The seasonal variation in K may have been due in part to input of residues. Spatial variability and, thus, sampling variability, may also have contributed to the year differences in available K.

As the study was designed to consider management factors in organic systems, the possible influence of varying the seeding rates was assessed. That varying seed rate had only a slight significant effect on SOM is probably due to the fact that the lowest seed density was optimal for crop yields, and therefore had little differential effect on root biomass in the soil or crop residues returned to the soil. As long-term trials are relatively new in the dryland Mediterranean environment, constant monitoring is needed, with retention of factors that have major long term influence in the trial and deletion of others with less impact. In the long-term forage-oriented trial described by Christiansen et al. (2011), such monitoring led to the elimination of minor factors such as variable stocking rates that had little impact in the trial.

In summary, this study was unique in being the first of its kind dealing with multiyear rotation trials based on fully certified organic production principles in the Mediterranean region. Though long-term trials are not common in the Mediterranean region, and those that exist are of limited duration (Ryan, Singh, and Pala 2008), all trials so far were based on conventional production systems involving chemical fertilizers. An additional aspect was that the trial was conducted on a commercial farm rather than experimental stations in the case of the conventional trials; under such conditions, a non-organic or conventional control was not feasible. The trial reflected production systems applicable to the western Mediterranean region in contrast to the eastern Mediterranean region where organic production is still not considered. In focusing on soil quality parameters, the trial highlighted...
the potential of such organic production systems to build up SOM, a key component in achieving stability and sustainability in the long term. There was evidence of relatively rapid build-up of SOM under the environment of this study in contrast to similar studies in other environments (Marinari et al. 2006; Leifeld and Furher 2010). Based on the work of Sommer et al. (2011), shallow tillage is likely to be a factor in maximizing SOM build up.

Given the need to ensure adequate crop nutrition (N, P, K.) from within the production system, the long-term perspective is called for. Regardless of the nature of a long-term trial, such experimentation is compounded by variability in weather conditions from one cropping season to the next, impacting not only yields but soil parameters (Keatinge and Somel 1993). Thus, we conclude that such a trial should be continued for several years, with constant monitoring of soil dynamics, including the assessment of soil microbial activity, especially given their role in mineralization of cereal residues (Denef et al. 2001), and mycorrhizal fungi (Hayat et al. 2010) in maintaining fertility. Detailed assessment of the differential P uptake (Berger 1999; Hinisinger et al. 2005) by the crops in the rotation would add to the understanding of P in cropping systems. In addition, given the pivotal nature of SOM, the delineation of SOM fractions of varying solubility would add considerably to the notion of long-term cropping sustainably in the Mediterranean region. However, we are cognizant of the logistics and associated costs of conducting long-term crop rotation studies, especially in on-farm situations.

5. CONCLUSIONS

While much has been written about multiyear rotational studies from conventional agriculture in semi-arid areas, this study was unique in that it described soil parameters under an organic production system. Given that SOM and total N content are key indexes of soil management sustainability, the trial highlighted the potential of the organic rotation adopted to build up both soil components. SOM tended to be significantly higher as time progressed after the adoption of the organic system, but the effect was not consistent from year to year. In spite of such inconsistencies, the overall effect of each crop in the rotation was to increase SOM by comparison with the original values, as a consequence of residue return and minimal tillage operations. Another important point is the relatively rapid buildup of SOM under the environment of this study in contrast to organic farming studies in other environments. The total N of the soil increased, compared with the conventional monoculture of cereals. The increase can be explained as a combination of the turnover of all the crop residues, which returns to the soil part of the N extracted, and the reduction of the global consumption of soil N, as a consequence of the introduction of legumes. In the western Mediterranean region, cereals
mono-cropping in dry lands has become the hegemonic cropping system, but the study have demonstrated the sustainability potential of the organic farming, in absence of external inputs, adopting rotations based in cereals and legumes in alternate years, and incorporating all the residues into the soil. The higher price of organic products makes this an advantageous option from the economic and environmental viewpoint. The data suggest that for full expression of the effects of the system on soil parameters, the study should continue for several years.

REFERENCES


