# Soil quality in a semi-arid Mediterranean soil as affected by tillage system and residue burning

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**Abstract**
We used principal component analysis (PCA) of soil physical, chemical and biological attributes to evaluate differences induced by three different tillage systems (conventional tillage (CT), reduced tillage (RT) and no-tillage (NT)), and stubble burning under NT (NTSB) in the topsoil of a carbonate-rich soil in semi-arid Mediterranean Spain. PCA resulted in three factors with eigenvalue >1, grouping parameters related to organic matter quality, physical status and organic N, respectively. These factors explained 82.71% of the variance. Scores for the different treatments grouped NTSB and CT for organic matter quality, NTSB with NT for soil physical status, and identified NTSB as the most different treatment for N parameters. Burning crop residues under NT affects the quality of organic matter and the N cycle more than the physical quality of the soil, which was better under NT and NTSB. The impact of stubble burning on the N cycle appears as a promising field of research.

**Key Words**
Soil quality, soil enzymes, stubble burning, semi-arid land, carbonate-rich soils.

## Introduction

Many soils in semi-arid Mediterranean Spain are poor in organic matter. Intense agricultural management has resulted in poor soil quality (SQ) in many areas (Andrade 1998). Tillage and management of residues have been seen to modify SQ (Bescansa *et al.* 2006, Moreno *et al.* 2009) in these soils. For instance, no-till (NT) leads to greater organic matter contents and better physical condition (Fernández-Ugalde *et al.* 2009). Stubble burning is a controversial practice. Despite of its known environmental disadvantages, it is still practiced in many areas worldwide. It is usually justified as an efficient way of fighting pests and diseases. It is also useful to eliminate the excess of crop residues in some cases. When stubble is burnt shortly before seeding, and with low-intensity fires, it has been observed to alter the quality of organic matter (Virto *et al.* 2007) in semi-arid NT soils.

Soil quality, which has been defined as the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health (Doran and Parkin 1994), must be assessed accounting for both inherent and dynamic soil properties and processes and must be holistic (Karlen *et al.* 2003). SQ evaluation must therefore include the study of soil physical, chemical and biological properties (Doran and Parkin 1994). Best SQ indicators are those parameters which have greatest sensitivity to changes in soil function (Andrews *et al.* 2004).
The objective of this study was the evaluation of SQ in relation to different tillage practices and residue management, including stubble burning under NT on a carbonate-rich soil in semi-arid Mediterranean Spain. We considered a set of physical, chemical and biological properties, and compared their sensitiveness and their response to management practices. Then we run a principal component analysis (PCA) in order to evaluate the main differences found in the topsoil after 10 years in relation to management, and to identify the most sensitive indicators in relation to management in this soil.

## Materials and Methods

### *Site description and experimental design*

We studied the soil in an experimental field at Olite (42º27'19"N; 1º41'10"W; Alt.: 402 m a.s.l.) in Navarra (NE Spain). The soil is a Typic Calcixerept (Soil Taxonomy 2006). Climate is semi-arid Mediterranean with an annual average precipitation of 525 mm. Potential mean annual evapotranspiration is of 740 mm, and mean monthly annual temperature is 13.5 ºC.
The experiment was designed as a randomized complete block with four replicates (n=4). Four treatments were studied: conventional tillage (CT), reduced tillage (RT), NT with stubble standing (NT), and no-tillage with stubble burning (NTSB). Crop residue was incorporated into the arable layer in CT, which consisted of 0.25-m-deep primary tillage with a three-furrow mouldboard plough, then a smoothing pass with a float, and



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sowing using a coulter-seeder. RT consisted of chisel ploughing (0.15 m deep) and secondary tillage and seeding as for CT. For NT and NTSB, a direct seeder was used, which opened the seed-row 3 to 5 cm deep. For NTSB stubble was burnt in October just before seeding. Barley was seeded each year in October-November (158 kg/ha). Fertilization was done according to crop needs and was equal among treatments.

*Soil analysis*

Soil samples were collected in the topsoil (0-5 cm). Composite samples were air-dried and ground to pass a 2-mm sieve, except for analysis of dehydrogenase activity. In this case, soils were sieved to 2 mm in fresh. After sieving, those soil portions for enzyme activity determination were stored at 4ºC until analysed in laboratory. For aggregate stability, a portion of air-dried samples were forced to pass a 8-mm sieve. A set of physical, chemical and biological properties were determined.

Particle size-distribution (PSD), bulk density ($\rho_b$), aggregate stability and penetration resistance (PR) were chosen as physical properties. No differences were observed in PSD among treatments. PSD was therefore excluded for PCA (see below). The core method was used to determine $\rho_b$. Aggregate stability was determined with homogenized samples, by placing 100 g of dry aggregates in the top of a column of sieves of 6.3, 4, 2, 1, 0.5, 0.25 mm openings and shaking the whole in a rotary movement at 60 strokes/min for 60 s in a Retsch VS 100 device (Retsch GmbH & Co. Haan, Germany). For wet aggregate stability, a constant shower-like flux (6 L/min) of distilled water was applied from the top of the same set of sieves while sieving (60 strokes/min, 60 s). Aggregate stability was expressed as the mean weight diameter after dry ($MWD_d$) and wet ($MWD_w$) sieving, from which the calculated the $MWD_w$-to-$MWD_d$, as proposed by Lehmann *et al.* (2001). Penetration resistance (PR) was measured on site to a depth of 60 cm using a field penetrometer (Rimik CP20, Agridy Rimik Pty Ltd, Toowoomba, QLD, Australia). Nine PR measurements per plot were recorded at 15 mm depth intervals with the soil uniformly wet, to avoid differences in moisture content among treatments. For statistical treatment, PR of the 0-5 cm depth was calculated as a weighed average.

Soil pH, electrical conductivity (EC), carbonates, P and K contents were analysed as chemical properties. None of these parameters showed statistical differences among treatments, and so that, they were excluded in PCA (see below).

Finally, total soil organic C (SOC), C in the form of particulate organic matter (POC), total N (N) and N in the particulate organic matter (PON), SOC mineralization ($SOC_{min}$) and the activity of five soil enzymes were included as biological properties. Due to the elevated concentration of carbonates in the soil (~35%), total soil organic C (SOC) and C in the form of particulate organic matter (POC) were determined by wet oxidation (Walkley-Black). Particulate organic matter (0.053-2 mm in equivalent diameter, Cambardella and Elliot (1992)) was isolated by dispersion and sieving of 10 g samples of air-dried soil, using a method adapted from Marriott and Wander (2006). Total N and PON were determined by Kjeldahl digestion. The C-to-N ratio of total and particulate organic matter was calculated from SOC, N, POC and PON data. $SOC_{min}$ was estimated as the amount of $CO_2$ respired in a 14-days incubation at 55% field-capacity and 20 ºC. The activities of dehydrogenase and four enzymes involved in soil C (β-glucosidase), N (urease), P (acid phosphatase) and S (arylsulphatase) dynamics were determined according to a modification of Tabatabai (1994), as previously described (Rodríguez-Loinaz *et al.* 2008). Only differences in urease and acid phosphatase were observed among treatments. The activities of the other enzymes were excluded for PCA.

*Statistics*

Data were analysed using ANOVA (univariate linear model). Treatment means were compared using significant differences ($P<0.05$). As indicated above, only data corresponding to the variables showing significant differences among treatments were subjected to factor analysis using PCA. PCA allows grouping variables into statistical factors based on their correlation structure (Brejda *et al.* 2000). To eliminate the effect of different units of variables, factor analysis was done using the correlation matrix on the standardized values of the measured soil properties (Shukla *et al.* 2006). Using this correlation matrix, principal components (factors) with eigenvalues >1 were retained and subjected to varimax rotation with Kaiser to estimate the proportion of the variance of each soil variable explained by each selected factor (loadings). Factor scores for each sample point were calculated in order to evaluate the effects of the each treatment on the extracted factors. All statistical analyses were performed using SPSS 16.0.

## Results and Discussion

Principal component analysis identified three factors (PCA-F1, PCA-F2 and PCA-F3) with eigenvalues >1 (Table 1). They explained 53.93, 19.80 and 8.97 % of the variance, respectively. PCA-F1 had the highest positive loadings from SOC, C/N ratio, CE, POC, $SOC_{min}$ and phosphatase. This factor groups thus mostly parameters related to organic matter quality. PCA-F2 received the greatest loadings from $\rho_b$, PR and



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aggregate stability, grouping parameters related to the soil physical condition. Finally, PCA-F3 grouped the three studied parameters related to soil N (total N, PON and urease activity).

When the calculated scores of PCA-F1, PCA-F2 and PCA-F3 for each soil treatment were analyzed, significant differences were found. Scores of CT and NTSB were equal among them and smaller than those of RT and NT for PCA-F1, suggesting that the characteristics of organic matter in CT and NTSB were similar. Virto *et al.* (2007) showed indeed that although SOC stocks were similar under NT and NTSB in this soil, organic matter in NTSB was less easily mineralizable than in NT, most likely due to the inherent recalcitrance of partially burnt and charred plant residues. PCA confirms this trend. Interestingly, phosphatase activity was also grouped in PCA-F1, indicating that P dynamics is related to organic matter in this soil, and is different in NT depending on residues being burnt or not. In this respect, it has been reported that trigger molecules or promoters released by organic materials stimulate the production of hydrolytic enzymes such as acid phosphatase (Martens *et al.* 1992). More interestingly, Olander and Vitousek (2000) found that phosphatase synthesis was inhibited in the presence of readily available inorganic P in soil.

**Table 1. Proportion of variance explained using varimax rotation for each of the factors with eigenvalue >1 (PCA-F1, PCA-F2 and PCA-F3) in the 0-5 cm depth. and scores of PCA-F1, PCA-F2 and PCA-F3 for CT (conventional tillage), RT (reduced tillage), NT (no till) and NTSB (NT with stubble burning).**

| | PCA-F1 | PCA-F2 | PCA-F3 |
|---|---|---|---|
| **Eigenvalue** | **7.012** | **2.574** | **1.166** |
| SOC (mg C/g soil) | **0.791** | 0.441 | 0.183 |
| C/N ratio | **0.826** | 0.452 | -0.170 |
| N (mg N/g soil) | 0.276 | 0.215 | **0.813** |
| CE (□S/cm) | **0.885** | -0.152 | 0.236 |
| POC (mg POC/g soil) | **0.798** | 0.385 | 0.172 |
| PON (mg PON/g soil) | -0.061 | 0.363 | **0.831** |
| $SOC_{min}$ (mg $CO_2$-C/g soil) | **0.814** | -0.102 | 0.115 |
| Bulk density (g/cm$^3$) | -0.053 | **0.859** | 0.287 |
| $MWD_w$ (mm) | 0.273 | **0.862** | 0.280 |
| $MWD_w$ /$MWD_d$ | 0.282 | **0.843** | 0.244 |
| PR (MPa) | 0.049 | **0.801** | 0.505 |
| Urease (□g N-$NH_4^+$/g soil/h) | 0.284 | 0.465 | **0.637** |
| Acid phosphatase (□g 4-NP/g soil /h) | **0.627** | 0.311 | 0.592 |
| **Scores** | | | |
| CT | -0.896 a | -0.568 a | -0.889 a |
| RT | 0.368 b | -1.025 a | 0.248 ab |
| NT | 1.312 b | 0.518 b | -0.196 ab |
| NTSB | -0.784 a | 1.076 b | 0.837 b |

Within columns, values followed by different letters belong to different Duncan's homogeneous groups (P<0.05), for each factor. Bold figures indicate the factor receiving the greatest loading from each soil attribute.

Scores for PCA-F2 were similar for CT and RT, and smaller than for NT and NTSB, which were equal among them. This indicates that the physical condition of the soil under NT was different to the tilled treatments, regardless of residue management.

Finally, scores for PCA-F3 were only different for NTSB. Considering that N fertilization was the same for all treatments, differences in N properties among plots must be related to the organic fractions of N. This is supported by the observed differences in PON and enzyme hydrolysis of organic N (*i.e.*, urease activity). Alterations of the soil organic N components due to fire in Mediterranean pine forest A horizons have already been described (Knicker *et al.* 2003). It seems that residue burning under NT can also alter the type of N compounds in the upper soil layer. Burning crop residues under NT affects thus more the quality of organic matter and the N cycle than the physical quality of the soil. While the impact of burning biomass on the soil C cycle has been intensely studied, the impact of residues burning under NT on the N cycle remains mostly unknown.

## Conclusions

The aim of this study was the evaluation of the effect of tillage and stubble burning under NT in the SQ of a Mediterranean semi-arid soil using PCA. We observed changes in the physical condition, organic matter and biological properties. As observed in other studies, the suppression of tillage (NT) resulted in more organic matter quality and different physical condition of the soil. Stubble burning under NT did not affect the physical quality of the soil, which was equal to NT, but induced changes in the organic matter. Organic matter in NTSB was similar to that under CT, and NTSB was different to all the other treatments in all the parameters studied in relation to the N cycle. If the best SQI are those more sensitive to changes in soil management, parameters related to organic matter quality, organic N and soil physical status should be evaluated to determine the effect of tillage practices and stubble burning under NT in this type of soils. In particular, the impact of stubble burning on the N cycle appears as a promising field of research.

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