Implications of afforestation vs. secondary succession for soil properties under a semiarid climate

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Abstract

Afforestation or secondary succession after cropland abandonment are different strategies to restore soil ecosystem services such as nutrient cycling, soil conservation, and carbon sequestration. However, the studies on the effects on soil-property dynamics after land-use changes are limited in semiarid regions. In this context, an experimental area with a semiarid climate allowed the assessment and comparison of physicochemical soil properties (soil organic C [SOC], soil total N [TN], available P [AP], available K [AK], cation-exchange capacity [CEC], bulk density [BD], pH, available water-holding capacity [AWHC], and C:N ratio) after *Pinus halepensis* afforestation and secondary succession following agriculture abandonment in 1994. The impact of 12 soil-preparation treatments for planting on soil properties was also evaluated. For this, soil samples (0-10 cm deep) from the afforestation were taken in 1998, 2002, 2007, 2010, 2013, and 2016, and from abandoned cropland in 2010, 2013, and 2016. In afforestation, soil-preparation treatments did not alter differentially the soil properties after 22 years. Significant differences among years were found in SOC, TN, AP, AK, CEC, pH, and C:N. BD changes were detected neither in afforestation nor in abandoned cropland. After 22 years, only SOC, AK and the C:N ratio proved significantly higher in afforestation than in abandoned cropland. In general, soil properties improvement (i.e. SOC, TN, AP, AK, and CEC) was slow after afforestation and abandoned cropland likely due to the legacy of the previous land use (cereal crops) and the semiarid climate influence.

Key words: land-use changes, *Pinus halepensis,* abandoned cropland, Mediterranean region, soil-preparation treatments

1. Introduction

Land-use changes have been identified as major drivers of global change because of their impact on ecosystem services and climate (Anaya-Romero et al., 2016). In the temperate climatic domain, the Food and Agriculture Organization of the United Nations (FAO, 2016) has issued a warning concerning a net reduction of agricultural land areas and a net increase in forest areas. For instance, in Europe, 70 million hectares of land cover has changed over the period 1950-2010 (Fuchs et al., 2013), including more than 21 million hectares of new forest areas recorded from 1990 to 2015 (FAO, 2016). To quantify the impact of these land-use changes on soil quality is essential because most of the ecosystem services are related to soil functions (i.e. carbon sequestration, water regulation, nutrient recycling, fertility). Increasing our knowledge about the effects of land-use changes is even more urgent in vulnerable areas such as southern Europe (Metzger et al., 2006; Adhikari and Hartemink, 2016; Zethof et al., 2019).

Afforestation of agricultural lands (*sensu* IPCC, 2000) and cropland abandonment are among the most frequent land-use changes in that region (Fuchs et al., 2013; Novara et al., 2017). Afforestation has been proposed as a strategy to mitigate CO_2 emissions as well as to prevent soil erosion and restore soil properties and forest ecosystems (Fernández-Ondoño et al., 2010; Zhang et al., 2018). Agricultural land abandonment may also help to recover the native vegetation and functions, the soil quality, and the ecosystem services they provide through secondary-succession processes (Novara et al., 2017; Romero-Díaz et al., 2017). In this sense, the scientific community has held debates concerning which strategy would be better and faster for improving soil quality and other ecosystem or biological parameters (ecologically and/or economically): active restoration (afforestation) or passive restoration (secondary succession following agriculture abandonment) (Ruiz-Navarro et al., 2009; Nadal-Romero et al., 2016; Zethof et al., 2019).

A wide range of physiochemical soil parameters can be used to evaluate soil quality (Costantini et al., 2016). Soil organic carbon (SOC) is considered the parameter of soil quality par excellence (Lal, 2004). SOC, and cation-exchange capacity (CEC) as well as soil total N (TN), available P (AP), and available K (AK) are crucial for carbon sequestration, soil fertility, and vegetation recovery (Ruiz-Navarro et al., 2009; Deng et al., 2017; Qiu et al., 2018). Other physicochemical soil parameters such as pH, bulk density (BD), and the C:N ratio may also have a key role in the soil functionality and the restoration of degraded lands and biodiversity (Wan et al., 2018; Zhang et al., 2018). Finally, available water-holding capacity (AWHC) contributes to several ecosystem services such as water purification and biomass production (Costantini et al., 2016). However, the dynamics of these soil properties after land-use change are not well understood, and they have been poorly studied in semiarid areas (Deng et al., 2017; Liu et al., 2018).

Although there is no consensus for identifying the patterns of the evolution of soil parameters following land-use changes, several authors agree that, in semiarid climate, little soil improvement occurs after afforestation and farmland abandonment because of the slow course of the soil (Lesschen et al., 2008; Ruiz-Navarro et al., 2009; Wang et al., 2011). Moreover, the soil state prior to the land-use change (legacy) can appreciably affect the soil dynamics (Deng and Shangguan, 2017; Romero-Díaz et al. 2017; Liu et al., 2018), among other factors. For instance, several authors have pointed that differences in the quality of the organic input (litter and root), and its decomposability, may affect not only the SOC but also the changes in the TN and AP of the soil (Cuesta et al., 2012; Li et al., 2012; Zhang et al., 2018).

The effects over time of abandoned cropland and afforestation on the soil properties are varied and frequently contradictories. SOC and TN could decrease after land-use changes (Berthrong et al., 2009), or they could show increases that are not always significant (Martín-Peinado et al., 2016; Segura et al., 2016). Some authors have reported decreases in AP after afforestation (Chen et al., 2008) while others have found no significant changes over time (Deng et al., 2017), as some results found for abandoned crops (Wang et al., 2011). Although many authors have concluded that afforestation reduces pH and thus acidifies the soil (Jackson et al., 2005; Berthrong et al., 2009), a recent study has shown that afforestation can neutralize pH compared with non-afforested soils (Hong et al., 2018). Similarly, abandoned cropland could decrease the pH (Wang et al., 2011). However, other authors have detected no clear trend in pH over time since land abandonment (Lesschen et al., 2008). Previous works have found no recovery of BD after land abandonment or afforestation (Merino et al, 2004; Zhang et al., 2018; Zethof et al., 2019), whereas others have shown remarkable improvement (Wang et al., 2011; Korkanç, 2014). Finally, varied effects on soil-water content have been reported in semiarid areas (Derak and Cortina, 2004; Romero-Díaz et al., 2017; Cao et al., 2018).

Among the factors that may be involved in soil changes over time after afforestation are the soil-preparation treatments for planting the trees (Paul et al., 2002; Merino et al., 2004). Although their effects show some uncertainties related to local climate, initial soil conditions, and time since soil-treatment application, soil-preparation treatments may influence soil changes by reducing soil quality, mainly when the techniques imply severe soil disturbance, or such treatments can improve certain soil properties such as soil-water availability (Ruiz-Navarro et al., 2009; Löf et al., 2012; Zethof et al., 2019).

In a previous publication, changes in SOC after cropland abandonment or afforestation were assessed in a semiarid area after 20 years (Segura et al., 2016). Both land-use changes improved SOC, but no significant differences were found between land uses. Despite this, it is crucial to explore the changes over time of other soil parameters in an effort to understand how soils respond to these land-use changes as a whole in semiarid areas, where knowledge concerning these processes is deficient (Liu et al, 2018). This paper aims to gain a better understanding of the soil behaviour after land-use changes under semiarid climate. The specific objectives are to: (i) evaluate the impact of soil-preparation treatments on soil properties in afforestation, and (ii) investigate the soil-property changes in afforestation and abandoned cropland over time (1994-2016). We hypothesize that a slight improvement in soil-quality indicators such as SOC, TN, AP, AK, CEC, pH, BD, AWHC, and C:N ratio is expected in both afforestation and abandoned cropland.

2. Material and Methods

2.1. Study area

The research site is the experimental area of Cortijo de Becerra, located in the Guadix-Baza Basin, SE Spain at 950 m a.s.l., coordinates 37°25'44'' N, 3°05'29'' W (Fig. 1). The area has a Mediterranean semiarid continental climate with wide variability in temperature (i.e. minimum and maximum monthly mean temperatures are -2°C in January, and 33°C in July, respectively), and an annual mean precipitation of 313 mm yr^{-1}, which was highly irregular during the study period (1998-2016). The soil type is described as a Eutric Fluvisol (WRB, 2014) formed by periodical alluviums of sedimentary materials (i.e., sand and gravel). Soil shows variable stoniness and a shallow top layer heavily altered due to continued tilling for decades.

After more than 100 years of cereal crops growing in the area, the Regional Andalusian Government (S Spain) bought Cortijo de Becerra, and ploughing ceased in 1994. In the summer of 1995, 36 soil plots 40x25 m^2 were prepared for afforestation by means of 12 different soil-preparation treatments located following a randomized-block design with three replicates (Supplementary material). In each plot, 25 one-year-old seedlings of *Pinus halepensis* Mill. were planted the next winter (250 stem ha^{-1}).

In the abandoned cropland, the adjacent area that was not afforested, ruderal communities of annual species and pioneer woody species (*Artemisia barrelieri* Besser, *Helichrysum italicum* (Roth) G. Don, *Retama sphaerocarpa* (L.) Boiss.) became established due to secondary succession. The areas that were historically not ploughed were covered by scrublands and perennial grasslands dominated by *Macrochloa tenacissima* (L.) Kunth and *Rosmarinus officinalis* L. communities (see Navarro et al., 2006 for more details).

2.2. Soil sampling and field measurements

In afforestation, soil samples for physical and chemical analyses were randomly taken in April in 1998, 2002, 2007, 2010, 2013, and 2016 in permanent subplots of 10x10 m^2 systematically placed in the centre of each afforested plot (36 samples each year = 12 treatment x 3 replicates). In the abandoned cropland (the non-afforested areas), 9 composite soil samples per year were randomly taken in April in 2010, 2013, and 2016. Due to afforested plots and abandoned cropland had been cereal crops, we can assume that sites were similar concerning the initial soil physical and chemical characteristics to compare the time course of the soil-quality properties.

Both in afforestation and in abandoned cropland land uses, soil samples were taken from 0 to 10 cm, where tillage practices produce marked effects on soil properties and soil aggregates (Acín-Carrera et al., 2013), and differences between afforested and non-afforested sites mainly happen (Fernández-Ondoño et al., 2010; Martín-Peinado et al., 2016). Besides, three unaltered soil samples were randomly taken using a cylinder of 5 cm high to determine the bulk density (Blake and Hartge, 1986) for afforested and abandoned plots.

The tree density was recorded in the afforestation subplots (10 x 10 m^2) in order to explore the possible effects of stand characteristics in soil properties over the study period (Supplementary material). The only forestry practise consisted of pruning the pines to 1 m above the soil level to let sunlight penetrate into the tree mass in 2010. Cut branches were removed from the subplots.

2.3. Soil analysis

After all the soil samples collected, they were air-dried at room temperature to constant weight, sieved (<2mm) and analysed using standard methods (MAPA, 1994). The main soil properties selected for analyses were: (i) texture (clay, sand, and silt), which was determined with the Robinson's pipette method (SCS-USDA, 1972); (ii) bulk density (BD) by the method of Blake and Hartge (1986), corrected by the Throop et al. (2012); (iii) available water-holding capacity (AWHC), calculated as the difference between soil water retained at -33 kPa and at -1500 kPa (Cassel and Nielsen, 1986) and multiplied by depth (dm) and by BD (Mg m^{-3}); (iv) pH (in water 1:2.5) was measured using a pH meter; (v) cation-exchange capacity (CEC) by saturation with sodium after washing with alcohol and extraction of the sodium adsorbed with NH_4OAc 1 N (SCS-USDA, 1972); (vi) calcium carbonate content by calcimeter method (Bascomb, 1961); (vii) soil organic carbon (SOC), by the wet oxidation with dichromate method (Tyurin, 1951); (viii) soil total nitrogen (TN) by Kjeldahl method (Bremner, 1965); (ix) available phosphorus (AP) by Olsen's method (Olsen and Sommers, 1982); (x) available potassium (AK) by the ammonium acetate method (SCS-USDA, 1972). We also used the soil C:N ratio, calculated using soil organic carbon and soil total nitrogen data.

2.4. Statistical analysis

Shapiro-Wilk and Levene tests were applied to check normality and homoscedasticity, respectively. Logarithmic transformations of AK, AWHC, and carbonates were necessary to fulfil normality and homoscedasticity requirements to perform parametric tests (presented data are not transformed). Also, exploration of the residual versus the fitted-value plot and quantile-quantile plot were used for model diagnosis. Non-parametric analyses were made as an alternative in case of assumption violation.

Several analyses were performed to determine the possible effects of soil-preparation treatments on soil properties of afforested plots (SOC, TN, AP, AK, CEC, BD, pH, AWHC, and C:N ratio). Firstly, one-way analyses of variance (ANOVAs), or Kruskal-Wallis tests, were used to identify whether total increases of soil properties could be affected by soil-preparation treatments. Total increases (Δ) were defined (final measurement in 2016 —initial measurement in 1998), except for pH (2016-2002) and CEC (2013-2007) because of missing data in some of the years. Secondly, differences over time and the effects of soil treatments carried out for planting on each soil property were tested by repeated-measures analysis of variance (RM-ANOVA). The Tukey-HSD test was performed for *post hoc* comparisons. Also, statistical comparisons between afforested plots and abandoned cropland were performed by two-sample t-tests and the two-sample Wilcoxon test (nonparametric test) for the years 2010, 2013, and 2016. The relation among soil properties was explored using Pearson and Spearman correlations**.** The α level of statistical significance in all cases was 0.05.A spatial ordination method based on the correlation matrix (principal component analysis, PCA) was used to evaluate the similarity among the study plots spatially arranged within an ordination diagram according to SOC, TN, AP, and AK for the last study year (2016). The soil properties were standardised.

Statistical analyses were performed in R (R Development Core Team, 2017), Statistix 9.0 (Analytical Software, USA). The PCA was carried out through CANOCO 4.5

following the criteria of ter Braak and Smilauer (2002), and Leps and Smilauer (2003).

3. Results

3.1. Effects of soil-preparation treatments on soil properties in afforested plots

In general, soil-preparation treatments for planting the trees did not affect the afforestation soil properties when the total study period was considered (Table 1). Although significant pH differences were observed among treatments, no different groups were reflected by the Tukey pairwise comparison.

Any of the soil properties showed significant differences among treatments over time (Table 2). On the contrary, the results evidenced significant differences among years, except for BD (Table 2 and Fig. 2.VII). Significant differences were also found for the interaction of treatment and year on AP, AK, and pH (Table 2).

From 1998 to 2016, SOC significantly increased by 9.10 mg C g^{-1} ± 6.4 (mean ± SD), when afforestation reached the highest SOC (Fig. 2.I). SOC was statistically lower in 1998 than in 2007, 2010, and 2013. Also, SOC was significantly lower in 2002 than in 2007, 2010, and 2013.

The total increase of TN was 0.71 mg N g^{-1} ± 0.51 (mean ± SD) (Fig. 2.II). TN significantly increased from 1998 to 2002 as well as from 2002 to 2007. Afterwards, TN remained nearly unchanged.

Significant changes appeared over time in AP (Fig. 2.III). This element significantly increased from 1998 to 2002, when started to decline until 2016 and its value was closer to the firstly reported in 1998. Although AK registered a similar trend (Fig. 2.IV), significant increases were found between 1998, 2013, and 2016. The total rise in AK from 1998 to 2016 was 54.97 mg K kg^{-1} ± 52.83 (mean ± SD).

Meanwhile, CEC increased by 6.96 $cmol_c$ kg^{-1} ± 1.40 (mean ± SD) from 2010 to 2016 and the results showed statistical differences for each year measured (Fig. 2.V). Also, the pH significantly varied over time, but no significant change was found between the first year measured, 2002, and 2016 (Fig. 2.VI).

The AWHC declined by 6.76 mm ± 4.23 (mean ± SD) from 1998 to 2016 (Fig. 2.VIII). The C:N increased by 4.49 ± 3.69 (mean ± SD) at the end of the period with regard to 1998, and significant differences were found between 2002, 2007, 2010, and 2016 (Fig. 2.IX).

3.2. Relationship between tree density and soil properties

Significant and positive correlation between tree density (supplementary material) and SOC was found in 2016 (r= 0.36, *p-value* <0.05). We found a significant positive correlation between SOC and CEC over time (r=0.57, *p-value* <0.001 in 2007; r=0.46, *p-value* <0.01 in 2010; r=0.42, *p-value* <0.05 in 2013), between CEC and TN (r=0.63, *p-value* <0.001 in 2007; r=0.63, *p-value* <0.001 in 2010; r=0.51, *p-value* <0.01 in 2013), and finally, between AK and CEC in 2007 (r=0.57, *p-value* <0.001).

Tree density was significantly correlated with C:N ratio in 2010 (r= 0.41, *p-value* <0.05), 2013 (r= 0.47, *p-value* <0.01), and 2016 (r= 0.50, *p-value* <0.01).

3.3. Changes in abandoned cropland soil properties over time

For the abandoned cropland, no significant changes were found for SOC, TN, AP, AK, and AWHC (Table 3). The pH and BD showed practically no changes from 2010 to 2016 (Fig. 2.VI, VII). However, CEC and the C:N ratio significantly increased over time (Table 3). No statistical changes were found for CEC between 2010 and 2013, or for C:N between 2010 and 2016 (Fig. 2.V, IX).

3.4. Soil properties in afforested sites comparing with abandoned cropland

Afforested subplots and abandoned cropland did not significantly differ in soil texture or soil carbonate content (Table 4), but the contrary was true for sand and silt content in 2013 (Wilcoxon test W = 81.5, *p-value* <0.05; and t-test t = 2.8906, df = 43, *p-value* <0.01, respectively).

SOC between land uses did not show significant differences until 2016 (Fig. 2.I). In that year, SOC in afforested subplots was higher than in abandoned cropland (t-test result t = -2.9059, df = 43, *p-value* < 0.01).

No differences were found in TN, AP, BD, or AWHC (Fig. 2.II, III,VIII). In 2013, CEC and pH were significantly higher in the abandoned cropland (t-test result for CEC t =

2.1228, df = 43, *p-value* <0.05; Wilcoxon test result for pH W = 231.5, *p-value* <0.05). In 2016, AK proved higher in afforested subplots (t-test results t = -3.1219, df = 43, *p-value* <0.01).

The main differences between land uses were found in the C:N ratio. Afforested sites showed a higher C:N than did the abandoned cropland in 2010 (t = -3.1741, df = 43, *p-value* <0.01), 2013 (t = -2.6834, df = 43, *p-value* <0.01), and 2016 (t = -4.8804, df = 35.512, *p-value* <0.001).

3.5. Plot spatial ordination

In 2016, SOC was strongly linked to TN and AK in the PCA (Fig. 3). Clay and tree density were positively associated with SOC, TN and AK whereas pH, sand, silt, BD, and AWHC were negatively associated. A wide group of afforested subplots showed higher SOC, TN and AK than the abandoned sites, but it was not so clear for AP. In fact, 16 afforested subplots (from 36) were practically identical to the abandoned cropland in terms of SOC, TN, AK, and AP. For afforested sites, we did not observe any pattern of grouping regarding soil treatments.

4. Discussion

4.1. Effects of soil-preparation treatments on soil properties

The impacts that soil-preparation treatments for planting exert over time on soil properties have been studied for several environments and pine species (Ruiz-Navarro et al., 2009; Nadal-Romero et al., 2016). Our results showed no effects of treatments on soil properties after 22 years of afforestation on the topsoil layer (0-10 cm). However, the number of samples could be likely insufficient (n=3 per treatment) to detect these effects, mainly when soils in Rambla de Becerra are highly heterogeneous.

Over the early phase of afforestation, several authors have reported that site-preparation techniques may affect soil properties (Paul et al., 2002; Bocio et al., 2004; Merino et al., 2004; Cortina et al., 2011). Unfortunately, we were not able to detect possible treatment effects on the soil in the first few years, when the impact of soil treatments could be most evident, because soil properties were analysed after 3 years of planting.

Furthermore, the site preparation impacts on the soil properties may vary depending on several factors such as soil disturbances derived from the techniques applied, the soil status prior to the disturbance, and climate. For instance, mechanical terracing or heavily mechanized treatments are not recommended in semiarid Mediterranean areas (Maestre and Cortina, 2004; Löf et al., 2012; Garcia-Franco et al., 2014). Although these techniques were not applied in Rambla de Becerra, differences in the soil among treatments may not be evident because (i) initial soils were highly degraded and mechanical methods did not worse differentially them, and (ii) the sampling strategy, including the lack of observations in deeper soil layers and the limited sample size, might have affected the ability to find these differences.

4.2. Time course of soil properties in afforestation site

Overall, our results showed a total SOC, TN and AK increase after 22 post-afforestation years. The SOC and TN results were in agreement with recent findings from some authors for semiarid climate (Liu et al., 2018; Zethof et al., 2019). Interestingly, the total increase in AK could indicate an improvement in the ecosystem functions and vegetation recovery after afforestation (Sardans and Peñuelas, 2015; Qiu et al., 2018), especially in a semiarid area such as Rambla de Becerra. On the other hand, 22 years after afforestation we did not detect a total change in AP content. This is consistent with the conclusion of many authors (Richter and Markewitz, 2001; Smal and Olszewska, 2008; Deng et al., 2017).

Biomass production and climate variability in our area, which also determines plant input and decomposition, may explain the fact that SOC increases were not always significant among years (Segura et al., 2016; Deng and Shangguan, 2017). Significant increases in TN and AP can be associated with changes in vegetation structure and organic inputs over time. This fact would imply different decomposition rates because of the low-litter quality of pines comparing to herbaceous-understory biomass (Grünzweig et al., 2007; Zhang et al., 2018), which in our case was higher in the first years after planting (Segura et al., 2016). Furthermore, it might affect the composition of microbial and fungal soil communities, influencing also AK and C:N ratio (Wang et al., 2011; Chen et al., 2016). Even though the increases in SOC, a balance between N fixation and nutrient uptake by plants (pines and understory-vegetation) could not affect the TN after 2007 (Li et al., 2012).

Significant decreases in P and K availability after 2007 and 2010, respectively, could be related to the higher nutrients demand by trees and its immobilization in the living plant biomass (Chen et al., 2008; Cuesta et al., 2012; Deng et al., 2017). Li et al. (2019) reported that lower soil temperature by vegetation cover might decrease AP, which will be decomposed by microbial communities. Also, the changes in AP and AK could depend on the dominant species. Several authors have found higher demand of these nutrients in conifers (Podwika et al., 2018; Li et al., 2019). However, we observed that AK improved in the last year of our study. Ruiz-Navarro et al. (2009) reported that slow increases in extractable K could be promoted by leaching from pine litter decomposition and its influence on the soil. The so-called 'pumping' effect, in which high levels of AK on the surface of forest soils may come from the K uptake by roots from deeper soil layers to the topsoil (Sardans and Peñuelas, 2015; Chen et al., 2016), could explain the significant AK increase in 2016, although sampling from deeper layers are needed to test this hypothesis.

Although only a six-year data series was available to evaluate the CEC dynamic, our results remained consistent with many studies showing CEC improvement or a trend to increase after afforestation (Miralles et al., 2009; Fernández-Ondoño et al., 2010; Martín-Peinado et al., 2016). Results from previous works have been used to suggest that significant increases in CEC may indicate a better soil-nutrient status because of its relation with SOC, TN and AK (Liao et al., 2012; Ruiz-Sinoga et al., 2012; Luo et al., 2016).

For the study area, bulk density has remained unchanged for 22 years. Some authors have reported greater BD after afforestation as a result of factors such as previous historical agricultural land use and site-preparation techniques (Merino et al., 2004; Miralles et al., 2009; García-Franco et al. 2014), while others have remarked that higher above- as well as belowground biomass production may decrease bulk density (Korkanç 2014; Zeng et al., 2014; Chen et al., 2016; Zhang et al., 2018). In any case, our results suggest that possibly not enough time has elapsed for changes in BD to be detected (Jaiyeoba et al., 2001; Cunningham et al., 2015). This lack of the

BD improvement after land-use change may explain the AWHC decreases despite the significant SOC gains over time (Zeng et al., 2014; Chen et al., 2016; Wu et al., 2016).

Similarly, no total increase has been detected in soil pH, even though we found significant changes over time that could be associated with different decomposition rates depending on climatic factors and inputs from pine litterfall (Ruiz-Navarro et al., 2009; Chen et al., 2016), which have been increasing mainly since 2007 in our experimental plots (Segura et al., 2016). According to Hong et al. (2018), properly selected species adapted to the area (i.e. Aleppo pine in Rambla de Becerra) could be expected to provide neutral soil pH over the long term. Like some authors, we found significant negative correlations between pH and both SOC and TN over time (Miralles et al., 2009; Deng et al., 2017).

Finally, we found a significant C:N increase with stand age. Similar results have been reported by many authors after afforestation with conifers (Smal and Olszewska, 2008; Berthrong et al., 2009; Martín-Peinado et al, 2016; Deng et al., 2017). Also, C:N increases can be related to gradual inputs from litterfall, and their low decomposition, which would improve the stability of SOC (Smal and Olszewska, 2008; Miralles et al., 2009; Cunningham et al., 2015;). Other authors have proposed that the C:N ratio also might increase because of soil-N uptake (Rytter et al, 2016). However, in our study, we found no significant fall in TN from 2013 to 2016, whereas SOC significantly increased in those years, resulting in a significant increase in the C:N ratio over time.

4.3. Soil properties comparison between afforested sites and abandoned cropland sites

Our results have shown that the effects of afforestation and abandoned cropland on soil quality may be difficult to detect in the midterm (20 years) in semiarid areas, as stated by other authors (Lesschen et al., 2008; Ruiz-Navarro et al., 2009; Liu et al., 2018). Indeed, the restoration age and previous land use may overwhelmingly influence soil-parameter dynamics after a land-use change. This is especially true in cultivation where long-term and persisting effects on soil can remain for decades

(Ruiz-Navarro et al., 2009; Jiao et al., 2012; Guo et al., 2018; Liu et al., 2018; Zhang et al 2018).

In general, differences between afforestation and abandoned cropland have been detected for a few parameters (SOC, AK, CEC, pH, and C:N ratio) in the first 10 cm of the soil, but only 22 years after the land-use change. In particular only 58.3 % of afforested sites showed an improvement in SOC, TN, AK, and to a lesser extent, in AP comparing with abandoned cropland sites. However, these findings should be treated with caution. Some uncertainties in our results, including the difference found between land-uses in two texture fractions (silt and sand) in 2013, might be reduced by the increase of the sample size.

Regarding to SOC, a significant correlation with tree density was found only at the end of the study in 2016. Some authors have reported that both higher plant inputs in afforestation and more slowly decomposition of pine litter than shrubland litter could explain the differences between land uses (Grünzweig et al., 2007; Cuesta et al., 2012; Guo et al., 2018). Our findings are consistent with the results of several authors who reported significant improvement in SOC content after afforestation, which may need more than three decades to become statistically detectable (Fernández-Ondoño et al., 2010; Nadal-Romero et al., 2016; Zethof et al., 2019).

The higher AK content in afforested sites could be explained by the 'pumping' effect (Sardans and Peñuelas, 2015; Chen et al., 2016). In south-eastern Spain, Fernández-Ondoño et al. (2010) reported inconclusive soil K results in an older afforestation stand than ours after comparing it with open areas but only at 5 cm soil depth. Significant increases in CEC have been found in both afforestation stands and abandoned cropland, indicating that SOC increased with time after these land-use changes (Jaiyeoba, 2001; Guo and Gifford, 2002; Liao et al., 2012; Ruiz-Sinoga et al., 2012). Although significant differences were found in silt and sand but not in clay, higher clay in abandoned cropland could influence the significant difference in CEC found between both land uses in 2013. In any case, we would need more data to check whether the differences between land uses persist or are local due to the high variability in Rambla de Becerra soils.

Higher C:N ratios in pine plantations than in unplanted areas (abandoned cropland or grasslands) have been widely explained by many authors as being due to different litter-decomposition rates (Cuesta et al., 2012; Martín-Peinado et al., 2016). Finally, we found statistical differences in pH in 2013 that disappeared in 2016, presumably because decomposition rates could be locally affected by climate as well (Ruiz-Navarro et al., 2009; Podwika et al., 2018).

With findings similar to ours, several authors have reported no differences between land uses in TN (Jiao et al, 2012; Martín-Peinado et al., 2016). Indeed, Lizaga et al. (2019) suggested that natural revegetation boosted the soil N and that soil quality was similar under land abandonment and *Pinus halepensis* afforestation after 50 years. In a sub-Mediterranean climate, Nadal-Romero et al. (2016) also reported no significant changes in TN, P, pH, and BD when comparing *Pinus nigra* and *Pinus sylvestris* afforestation to natural succession after more than 50 years. Similar soil texture and bulk density as well as plant input increases in both afforestation and abandoned cropland could explain the lack of differences in AWHC at the end of the study period (Korkanç et al., 2014; Chen et al., 2016; Wu et al., 2016; Romero-Díaz et al., 2017).

In our work, several limitations exist: (i) only the top-soil (0-10 cm) was analysed, (ii) the relatively small number of samples in afforested plots (n=3 per treatment), and (iii) a composite-sample strategy was carried out in order to minimize the soil variability taking into account the limited logistic resources. Further research will consider these aspects.

Especially in semi-arid environments, the natural recovery of the ecosystem after the abandonment of agricultural activity is not always possible (García-Ruiz, 2010; Perino et al., 2019). In the view of our results and the relative youth of the afforestation, we could expect a higher soil improvement in the afforestation than in the abandoned cropland with time, at least in SOC, TN, CEC, AK, and BD. Afforestation could be an effective strategy to recover soil properties faster, but also ecosystem services related to carbon sequestration, nutrient cycling, and recreation (Smith et al., 2019). In order to better decision-making, factors such as lithology, texture (especially clay content), slope, proximity to seed sources, species, and time needed to reach the reference ecosystem should be considered before any intervention (García-Ruiz, 2010; Cuesta et al., 2012; Liu et al., 2018). Finally, all stakeholders should be taking an active part in order to decide what is the more suitable restoration strategy (secondary succession or afforestation) after the agricultural abandonment (Perino et al., 2019).

Conclusion

Although our results should be interpreted with caution, the soil treatments for planting did not exert marked influence on afforestation soil properties in agreement with our hypothesis. Furthermore, the changes in the soil properties after land-uses changes were slow in the midterm (22 years). According to our results, more than two decades are required to detect a relevant improvement in important soil properties (SOC, TN, AK, and CEC) in semiarid climate. More time would still be necessary to observe a BD decrease. In any case, afforestation can restore SOC and AK in semiarid Mediterranean soils faster than abandoned cropland. For further research about the effects of land-use change in soil properties, larger sample size and sampling in deeper soil layers would be needed.

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