THE IMPACT OF ABANDONMENT OF TRADITIONAL FLOOD IRRIGATED CITRUS ORCHARDS ON SOIL INFILTRATION AND ORGANIC MATTER

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RESUMEN

El abandono de los campos de naranjos se produce en las zonas de riego por inundación debido a cambios socioeconómicos y a los reducidos tamaños de las explotaciones. Por medio de un muestreo en campos con distintos años de abandono y de mediciones de la materia orgánica y capacidad de infiltración del suelo, se concluye que el abandono favorece el aumento de la materia orgánica y de la infiltración. Esa recuperación presenta una crisis en el año posterior al abandono, cuando aún no se ha recuperado la vegetación y el suelo está encostrado. El abandono es muy positivo para la recuperación de la materia orgánica del suelo y la infiltración, a pesar de la ausencia de riego y de fertilización.

Palabras clave: *Abandono, Agua, Materia orgánica, Cítricos, Valencia.*

ABSTRACT

Flood irrigated citrus orchard abandonment in eastern Spain is due to socio-economic changes and the small size of the farms. By means of a cylinder infiltrometer and measurements of soil organic matter we conclude that land abandonment favours an increase in total carbon and infiltration rates. The recovery showed a crisis in the first year after abandonment, when the vegetation did not recover and the soil was affected by a surface crust. Although the abandoned orchards did not received fertilizers or irrigation, the abandonment is positive for recovery of organic matter and infiltration rates.

Key Words: *Land Abandonment, Water, Organic matter, Citrus, Valencia.*

1. INTRODUCTION

Land abandonment has been the most active biological, geomorphological, pedological and hydrological agent in the Mediterranean Mountains during the 20th century (Cerdà, 1997; Lasanta *et al.,* 2000; Suárez-Seoane *et al.,* 2002; Poyatos *et al.,* 2003; Gehrig-Fasel *et al.,* 2007; Koulouri and Giourga, 2007; Cramer *et al.,* 2008; Arnáez *et al.,* 2011; García-Ruiz & Lana-Renault, 2011). Due to profound socioeconomic changes, population migration reduced human impact in the northern Mediterranean belt (Lasanta-Martínez *et al.,* 2005; Benayas *et al.,* 2007). In the 21st century, the intensification of agriculture (Tilman *et al.,* 2011; Cerdà *et al.,* 2012) concentrated food production and the use and abuse of the soil resource in areas where a mild climate and/or the water resources were available. Greenhouses and chemicals allow the concentration of agricultural production and as a consequence the abandonment of the land in nearby areas that are not productive enough (Figure 1). New producers in developing countries also contribute to the land abandonment of farms in the northern Mediterranean. One example of this change is the traditional citrus orchards irrigated by means of a millennia old system of ditches in the region of Valencia, where we found that abandoned farms are easily colonized by new vegetation. The soils of the "Huerta de Valencia" (Valencia gardens) and other gardens such as the ones in the Cànyoles River watershed near the city of Xàtiva were transformed into citrus orchards during the 20th century and now, and due to the low income of the farmers, they are being abandoned.

The soil system is affected by this process of intensification and land abandonment (Cerdà *et al.,* 2012) as the soil returns to be "managed" by the natural ecosystem and not by human management. Changes in the land use affect the soil, and as a consequence the water, biologic and atmospheric resources of the region (Biro *et al.,* 2013; Leh *et al.,* 2013; Gao *et al.,* 2014). The flood irrigation of soils (which had taken place for more than one millennia), chemical fertilization, and use of pesticides is removed and the soil

Figure 1. Intensification of production in Valencia (left) and Almería (right). The high productivity of greenhouses contributes to the land abandonment of nearby farms where productivity is lower. Moreover, the crop production is sold in the north-european markets, which increase the environmental impact of this intensified agriculture.

Figure 2. Abandoned citrus orchards. Vegetation recovery is very successful due to the high fertility of the soils and the abandoned trees. To the left the control plot (0 years of abandonment) and to the right the 20 years abandoned farm.

returned to be managed by the natural Earth cycles. We know that rainfed agricultural areas recover their vegetation and organic matter, increase water infiltration rates, and reduce soil losses after abandonment, but there is no information on the changes undergone by flood irrigated land after land abandonment as this type of abandonment is very rare due to the high productivity of the irrigated land.

The objective of this paper is to show how land abandonment is triggering changes in soil properties. The soil organic matter and steady state infiltration rates were measured to monitor changes in the soil properties on farms with different ages of abandonment.

2. MATERIALS AND METHODS

2.1. Study area and laboratory analysis

Six (1 control plus 5 abandoned) farms were selected in the western Cànyoles River watershed (Valencia Province, Eastern Spain) with different land abandonment ages. All the farms were located in the fluvial terraces of the Cànyoles River to avoid differences in the parent material and related soil properties. The soil is sandy loam and the organic matter is very low (1.24 % average). Measurements were carried out in July and August 2011 during the Mediterranean summer drought to avoid differences in soil moisture. The age of abandonment was 0 (cultivated/control), 1, 3, 6, 10 and 20 years since abandonment. All the abandonments were done without the removal of the trees (oranges, *Citrus sinensis*) and the plant recovery was very fast. A growth of zarzamora or blackberry (*Rubus ulmifolius*) and other weeds covered the soil and the trees 3 years after land abandonment (Figure 2). The abandoned trees acted as perches for birds, which contributed to the dessimination of vegetation. Ten composite soil samples were collected to determine the soil organic matter content at 0.2 cm depth and 10 ring infiltrometer measurements were carried out at each of the 6 study sites. A 10 cm diameter and 10 cm height cylinder infiltrometer was used to measure the infiltration envelope. The measurements lasted one hour. The Horton Equation (Cerdà, 1996) was fitted to determine the steady-state infiltration

Table 1. Average, standard deviation and coefficient of variation of the organic matter content at the 0-2 cm depth in soils affected by land abandonment of citrus orchards. Different letters represent significant differences at p<0.05. (N=10)

PLOTS	0	1	3	6	10	20
1	1.24	1.20	2.03	2.03	2.36	3.56
2	1.36	1.36	1.65	2.15	2.15	3.26
3	1.26	1.25	1.45	2.15	2.32	2.35
4	1.26	1.42	1.25	2.32	2.15	2.54
5	1.48	1.24	1.84	2.35	2.45	3.48
6	1.25	1.25	1.36	2.52	2.36	2.41
7	1.24	1.24	1.98	2.01	2.56	3.42
8	1.42	1.49	2.32	1.99	2.58	2.36
9	1.32	1.25	2.45	1.86	2.45	2.35
10	1.23	1.32	1.32	2.54	2.32	3.80
Average	1.31d	1.30d	1.77c	2.19bc	2.37b	2.95a
Std	0.09	0.09	0.43	0.23	0.15	0.60
CV (%)	6.67	7.20	24.18	10.58	6.21	20.26

rates. The soil organic matter content was measured following the Walkley and Black (1934) methodology.

2.2. Statistical analysis

Organic matter and soil steady-state infiltration did not followed the normal distribution. Thus, in order to identify significant differences among years the non-paramethric test Kruskal-Wallis ANOVA (KW) was applied. If significant differences were identified at a $p<0.05$ level, a Tukey HSD test was carried out in order to observe significant differences within years. Spearman coeficient was used to calculated the correlation between the studied variables. Correlations were considered significant at a $p<0.05$. Data analysis was carried out with Statistica 7.0 for windows.

3. RESULTS

The results show a rapid increase in vegetation cover that resulted in a progressive increase in soil organic matter. Significant differences were identified in the soil organic matter content among the studied years (KW=46.23, p <0.001). In the two earliest abandonment dates (0 and 1 year after the treatment), no significant differeces were observed. Three years after the treatment the soil organic matter increased and differed significantly (Table 1). The cultivated land (herbicide treatments) showed an average of 1.31 %

Table 2. Average, standard deviation and coefficient of variation of the steady-state infiltration rates in soils affected by land abandonment of citrus orchards. Different letters represent significant differences at a p<0.05. (N=10)

PLOTS	0	1	3	6	10	20
1	89	89	160	256	356	563
2	87	68	156	245	482	548
3	89	65	157	256	256	578
4	86	67	159	258	365	658
5	85	48	148	248	365	624
6	87	45	163	325	325	458
7	75	85	200	368	265	596
8	69	65	145	345	456	486
9	68	62	185	254	258	597
10	65	86	165	265	354	526
Average	80.00e	68.00e	163.80d	282.00c	348.20b	563.40a
Std	9.64	15.05	16.70	45.63	77.66	61.25
CV (%)	12.05	22.13	10.19	16.18	22.30	10.87

organic matter with a variation from 1.23 to 1.48 %. Once abandoned, and one year later, the organic matter did not show significant differences with the cultivated (control) plot. A slight increase was found in the measurements for 3, 6, 10 and 20 years of abandonment, when the organic matter content reached 1.77, 2.19, 2.37 and 2.95 % respectively. A significant correlation was observed between years of abandonment and the organic matter content (r=0.86, p<0.001).

A similar trend was found for the steady-state infiltration rate. Significant differences were observed in steady-state infiltration rates and the studied years (KW=55.11, p <0.001). As with soil organic matter, no significant differences were observed between the first two sampling dates. After the third year of treatment, steady-state infiltration rates increased and were statically different (Table 2). The increase from the third to the twentieth year moved from 164, to 282, 348 and 563 mm h^{-1} for 3, 6, 10 and 20 years of abandonment. The correlation between years of abandonment and steady-state infiltration rates was very high, 0.93, p<0.001. However, the year after abandonment the infiltration rates decreased to 68 mm h^{-1} from the 80 mm h^{-1} of steady-state infiltration found during farming. This was due to the development of a soil crust after abandonment, which reduced the infiltration rates.

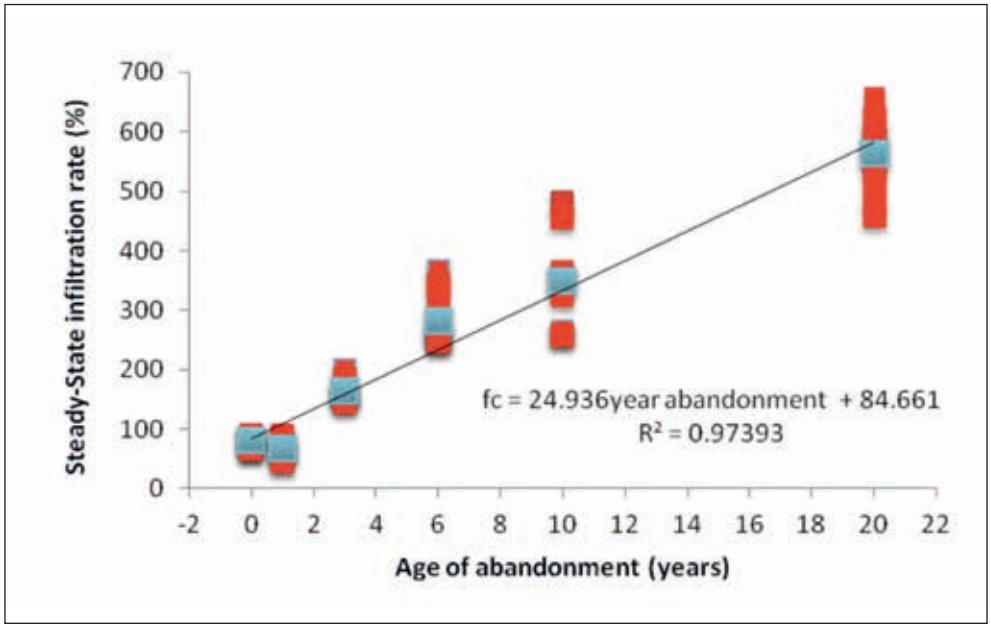

Figure 3. Land abandonment induced an increase in soil organic matter content.

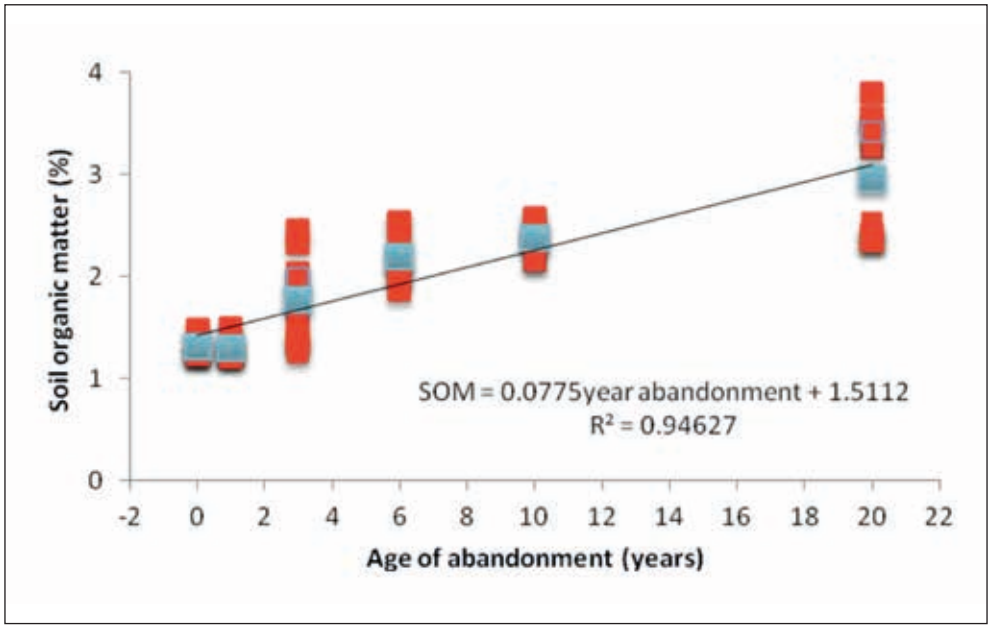

Figure 4. Land abandonment induced an increase in the soil steady-state infiltration rate.

Considering all studied years, a significant correlation was also found between soil organic matter and steady-state infiltration rates ($r=0.76$, $p<0.001$) (Figure 3 and 4).

4. DISCUSSION

The traditional flood irrigated gardens of the Mediterranean have shown high productivity, but the production of citrus in other regions of the world and the arrival of high technology drip irrigation systems, the small size of the farms and socio-economic changes (ageing of the farmers and urban pressure) have resulted in the abandonment of many of the orchards. The abandonment favoured the recovery of native vegetation and a return to natural water and nutrients cycles. Our results found that although there is no irrigation and fertilization following abandonment, the soils moved from 1.3 to 3 % organic matter content after 20 years, and the steady-state infiltration rate increased from 80 to 563 mm h^{-1}. This increase in infiltration rates was due to the development of macropores by soil biota that contributed to a deeper infiltration of the wetting fronts. The macropore flow should also be related to the development of water repellent soils as a consequence of the high water repellency of the organic matter (Granged *et al.,* 2011). This topic should receive additional research as the land abandonment leads to recovery of the soil fauna (Peng *et al.,* 2012). A soil crust developed the year after abandonment resulting in a reduction of the infiltration rate; this was due to the lack of vegegation and the bare exposed soils immediately after abandonment.

The research in the Cànyoles River watershed demonstrates that land abandonment increased organic matter in the soils and as a consequence reduced CO_2 emissions to the atmosphere. Other researchers have found that soils are a key component in the carbon balance in the Earth system. This is because cultivation results in a reduction of soil organic matter content due to oxidation and the lack of organic fertilizers (Brevik, 2012; Srinivasarao *et al.,* 2014). This is also demonstrated by enclosures that show recovery of soil properties such as organic matter once the land is protected (Özcan *et al.,* 2013). The recovery of the plants and other soil biota increase carbon fixation (Yan-Gui *et al.,* 2013), and changes in land use are the key factors that determine the changes in organic matter (Fialho & Zinn, 2014). Although fertilization can lead to recovery of soil organic matter (Jaiarree *et al.,* 2014), the study developed in the Cànyoles River basin demonstrates that once abandoned, the citrus orchards increase organic matter in the soil and as a consequence the infiltration rates increase. The abandonment results in the fixation of atmospheric CO_2 (Barua & Haque, 2013).

The abandonment also results in an increase in soil infiltration rates that contribute to changes in the hydrological response of the soil, slopes and watershed (García-Ruiz *et al.,* 2011). And the reduction in the runoff contributes to a reduction in soil losses (García Ruiz *et al.,* 2010). This is a potential explanation for the fast recovery of the soil organic matter as there are no soil and litter losses due to erosion, which is a common characteristic in citrus plantations (Cerdà *et al.,* 2009; Xu *et al.,* 2012). These increases in soil organic matter and infiltration rates, in turn, contribute to enhanced soil quality in the abandoned orchards (Brevik, 2009).

Previous research has shown that human disturbances can cause noticable changes in soil properties, including organic matter content and infiltration rates, for over one-hundred years following cession of the disturbance (Sharratt *et al.,* 1998; Brevik & Fenton, 2012). Other research has demonstrated that degradation of the soil resource can still be detected in some abandoned agricultural soils hundreds of years after abandonment (Sandor & Eash, 1991). Therefore, even though significant recovery of soil properties has been noted in the abandoned citrus orchards of Eastern Spain, continued study that tracks potential additional changes over time is warranted.

5. CONCLUSIONS

The research conducted in citrus orchards abandoned during the last 20 years in Eastern Spain demonstrates that orchard abandonment contributes to an increase in the soil quality with increases in the organic matter content and infiltration capacity of the soils. The lack of irrigation and fertilizers did not prevent to a quick vegetative recovery and soil organic matter increase. Additional research that continues to track changes in the properties of the soils in these abandoned orchards over time is warrented.

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