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Impact of Farmland Abandonment on Water Resources and Soil Conservation in Citrus Plantations in Eastern Spain

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Abstract: Due to the reduction in the prices of oranges on the market and social changes such as the ageing of the population, traditional orange plantation abandonment in the Mediterranean is taking place. Previous research on land abandonment impact on soil and water resources has focused on rainfed agriculture abandonment, but there is no research on irrigated land abandonment. In the Valencia Region—the largest producer of oranges in Europe—abandonment is resulting in a quick vegetation recovery and changes in soil properties, and then in water erosion. Therefore, we performed rainfall simulation experiments (0.28 m^2 ; 38.8 mm h^{-1}) to determine the soil losses in naveline orange plantations with different ages of abandonment (1, 2, 3, 5, 7 and 10 years of abandonment) which will allow for an understanding of the temporal changes in soil and water losses after abandonment. Moreover, these results were also compared with an active plantation (0). The results show that the soils of the active orange plantations have higher runoff discharges and higher erosion rates due to the use of herbicides than the plots after abandonment. Once the soil is abandoned for one year, the plant recovery reaches 33% of the cover and the erosion rate drops one order of magnitude. This is related to the delay in the runoff generation and the increase in infiltration rates. After 2, 3, 5, 7 and 10 years, the soil reduced bulk density, increase in organic matter, plant cover, and soil erosion rates were found negligible. We conclude that the abandonment of orange plantations reduces soil and water losses and can serve as a nature-based solution to restore the soil services, goods, and resources. The reduction in the soil losses was exponential (from 607.4 g m^{-2} in the active plot to 7.1 g m^{-2} in the 10-year abandoned one) but the water losses were linear (from 77.2 in active plantations till 12.8% in the 10-year abandoned ones).

Keywords: agricultural land management; irrigated fields; erosion; abandonment; soil properties

1. Introduction

Citrus plantations are widespread due to the increase in the fruit demand around the world [1,2]. The traditional citrus production regions such as Valencia face a crisis due to production in other regions [3]. A social and economic change is taking place in traditional citrus production areas due to the ageing of the population, the competition of the large farms managed by companies, and social and economic changes [4]. The small size of traditional farms is also a key concern for the viability of

production [5]. Citrus production in Valencia is facing technical modernization in large farms, with drip irrigation and highly mechanized systems where labor is reduced [6] but the soil and water losses are enhanced (Keesstra et al., 2019). In front, we have traditional small size farms, with flood irrigation and high labor costs that result in low income for the farmers. Moreover, in the Valencia region, the ageing of the farmers and the social changes (to be a farmer is not attractive for the new generation) and low income associated with farming results in farmland abandonment [7].

Land abandonment has been widely researched in the last 50 years [8,9]. This is a consequence of the changes in the economy of developed countries rather than triggered different drivers [10,11]. From an environmental point of view, abandonment results in an increase in the infiltration rates [12] due to vegetation recovery [13]. Soil erosion is also reduced by the effect of the vegetation cover and the recovery of organic matter [14].

The research carried out on recent land abandonment was done in rainfed land. This is due to the fact that the abandonment took place in rainfed land that did not evolve to irrigation [15]. The intensification of the agriculture contributed to increasing the land irrigated; meanwhile, the one that was less productive, usually the rainfed one, was abandoned. The research carried out on irrigated land is recent and focuses mainly on socioeconomic issues [16]. The abandonment provides ecosystems services such as carbon sequestration, water storage, soil properties, and seed bank fate improvements [17]. This response to land abandonment is widespread around the world [18–20].

Research on the abandonment of traditional irrigation farms was restricted until now to the historical, archaeological, and ecological approach [21–23]. There is no information about the changes in soil hydrology and soil erosion once the abandonment takes place in traditional flood irrigated land. This paper is the first approach to understand the effect of irrigated farmland abandonment on soil erosion and runoff discharge. Our main goal is to determine how the soil and water resources change once abandonment takes place and how to evolve along a decade with the use of plots in use or abandoned for 1, 2, 3, 5, 7 and 10 years.

2. Materials and Methods

2.1. Study Area

The research presented in this paper was carried out in the Canyoles River watershed, in the fluvial terraces (145 m a.s.l.) in the municipality of Canals (Valencia, Spain), a representative zone of the Mediterranean citrus plantation that was established along the 1960s. The farm properties are small in size in this region, and usually, all the farms are smaller than 1 ha and the average at the study site is 0.45 ha. The active field is flood irrigated and herbicide (Glyphosate) is applied any time the weeds germinate, which results in a bare soil surface. Once abandonment takes place there is a quick recovery of the vegetation. The climate is typically Mediterranean with a mean annual precipitation of 532 mm and a mean annual temperature of 16.2 °C. The soil is an Anthrosol [24] and the texture of the soil is clay-loam: 21% clay, 39% silt, and 40% sand. The planting pattern is 5 m × 4 m, the usual pattern for citrus in this agricultural area. The farm was flood-irrigated with freshwater from the Riu de Sants, which flows from the Massís del Caroig aquifer. The slope is negligible due to the land flattening and the effects of the floods on the fields. The soils are basic in pH (7.9). The observed soil profiles were very homogeneous as a consequence of tillage practices for centuries and land levelling. The study area was selected in the Pleistocene fluvial terrace of the Canyoles River (near the hamlet of Aiacor) and show 22% gravel content. The irrigation system (Sèquia de Ranés) flows from the nearby Riu de Sants spring. Irrigation takes place every 2 weeks in the summer and does not take place once the fields are abandoned. The management up until the time of abandonment was similar in all plots: herbicide (Glyphosate (N-(phosphonomethyl)glycine) and inorganic fertilizers (NPK—nitrogen, phosphorus, and potassium—0.8 Mg ha⁻¹ per year). Once the plots are abandoned, neither irrigation nor fertilization takes place.

2.2. Experimental Design

The experimental design was based on the fact that the study area has suffered since 2000 a progressive abandonment due to the low income in such small parcels, the dropping of the prices of the oranges, and the ageing of the landowners. Then we selected a farm that was active and the neighbouring farms that had been abandoned for 1, 2, 3, 5, 7 and 10 years (Figure 1A). At each farm, we selected 10 representative 1-m² plot where sampling and simulated rainfall experiments on 0.28-m² plots were carried out (Figure 1B). All the plots have *Citrus sinensis* plantations with Naveline variety and “Carrizo” rootstock.

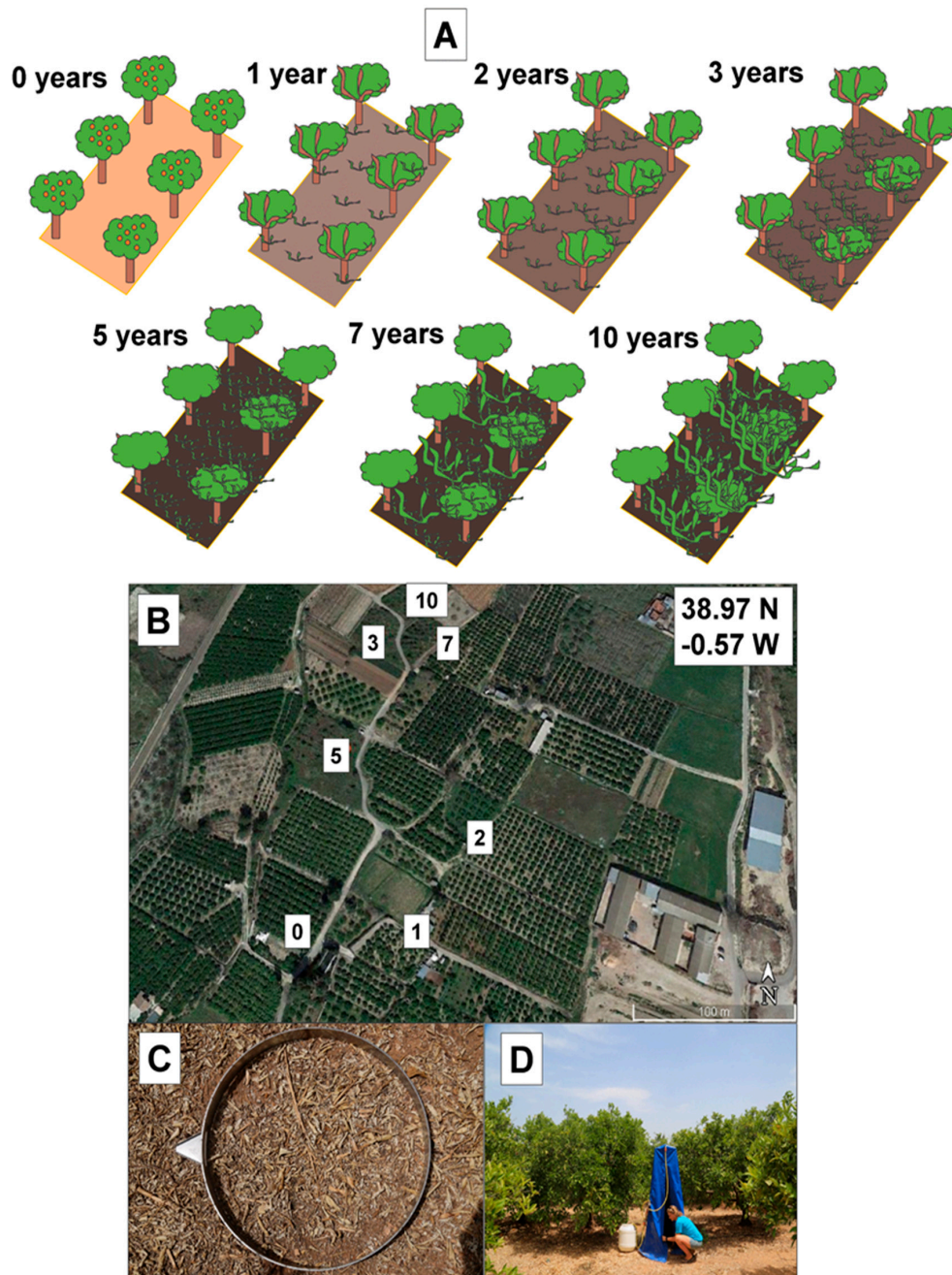


Figure 1. Scheme of the study plots (A), localization of the experimental fields (B), ring plot in the active farm (C), and field campaign (D).

2.3. Soil Sampling

The seven experimental fields show different ages of abandonment. Age 0 is the active field with no weed cover due to the use of herbicides, and 1, 2, 3, 5, 7, and 10 years are the fields that were abandoned along the last decade. The soil sampling took place in August 2014 during the Mediterranean summer drought. Ten soil samples were taken from the top 6 cm of the soil using a 100 cm³ steel cylinder. We measured gravimetric soil water content (SWC) and bulk density (BD). Moreover, soil samples were weighed, oven dried at 105 °C during 24 h, and weighed at room temperature to estimate organic matter by the dichromate method [25]. Also, grain size distribution was calculated by the pipette method. Vegetation cover, stones, and soil crusts were estimated using 100 pins evenly distributed in the rainfall simulation plot.

2.4. Rainfall Simulation Experiments

Seventy experiments (10 repetitions × 7 plots) during 1 h for the active and 1, 2, 3, 5, 7, and 10 years of abandonment were carried out at 38.8 mm h⁻¹ rainfall intensity on the circular paired ring plot (0.28 m²; Figure 1C,D). These rainfall events are characterised by a return period around 2 years in the eastern Iberian Peninsula and have been used widely in rainfall simulation experiments [26]. All experiments were carried out when the soil moisture was low during the last week of July 2014 with no rainfall events to avoid variability among plots. Runoff was collected each 1-min interval and total water loss was calculated. Then, the runoff coefficient was obtained by means of the percentage of rainfall water flowing through the ring plot. In the laboratory, runoff samples were desiccated (105 °C, 24 h) and soil loss was obtained based on the weight basis per area and time (g m² h⁻¹). Furthermore, it was also possible to quantify time to ponding (time required for 40% of the surface to be ponded; T_p, s), time to runoff initiation (T_r, s), and time required by runoff to reach the outlet (T_{ro}, s). Those parameters show how the runoff initiation takes place and how ponding is transformed into runoff and how the runoff reaches the runoff outlet.

2.5. Statistical Analysis

Descriptive statistics were calculated (mean, median, maximum, and minimum) and used for further statistical analysis. Soil properties were represented in linear graphs in order to show their evolutions during the studied period using Excel software (Windows, Redmond, Washington, DC, USA). The number of points used for each analysis corresponded to all measurements done at each location. Then, the hydrological response was represented as polar graphs dividing by intervals (natural breaks) the obtained results. Finally, soil erosion results were depicted in scatterplots using SigmaPlot 12.0 (Systat, Chicago, IL, USA). Statistical differences were evaluated performing an ANOVA one-way test to check the statistically significant differences among years of abandonment. If the normality test failed (Shapiro–Wilk), a Tukey test was conducted when the homogeneity variance fails (Levene's test). Finally, a Spearman rank correlation coefficient was carried out in order to assess the possible connection between environmental plot characteristics and soil erosion results.

3. Results

3.1. Soil Properties

The soils of the seven study sites affected by different times since abandonment show changes that can shed light into the evolution of the soil properties upon abandonment (Figure 2). Antecedent soil moisture is reduced from 14% to 5.1% in ten years of abandonment. Bulk density does not show significative changes after 1 year of abandonment (from 1.38 to 1.37 g cm⁻³), but after that, the values decrease to 1.15 g cm⁻³ in the tenth year of abandonment. On the contrary, organic matter and plant cover quickly increased after the abandonment, showing changes from 0.93 to 1.79% and from 1.1 to 90.3%, respectively. The cover of rock fragments varies among plots, reaching the maximum values in

the plots after 1, 2, and 3 years of abandonment. Finally, the development of soil crusts also shows a drastic decrease from the active plot (83.4%) to the 10 years abandoned plot (3.4%).

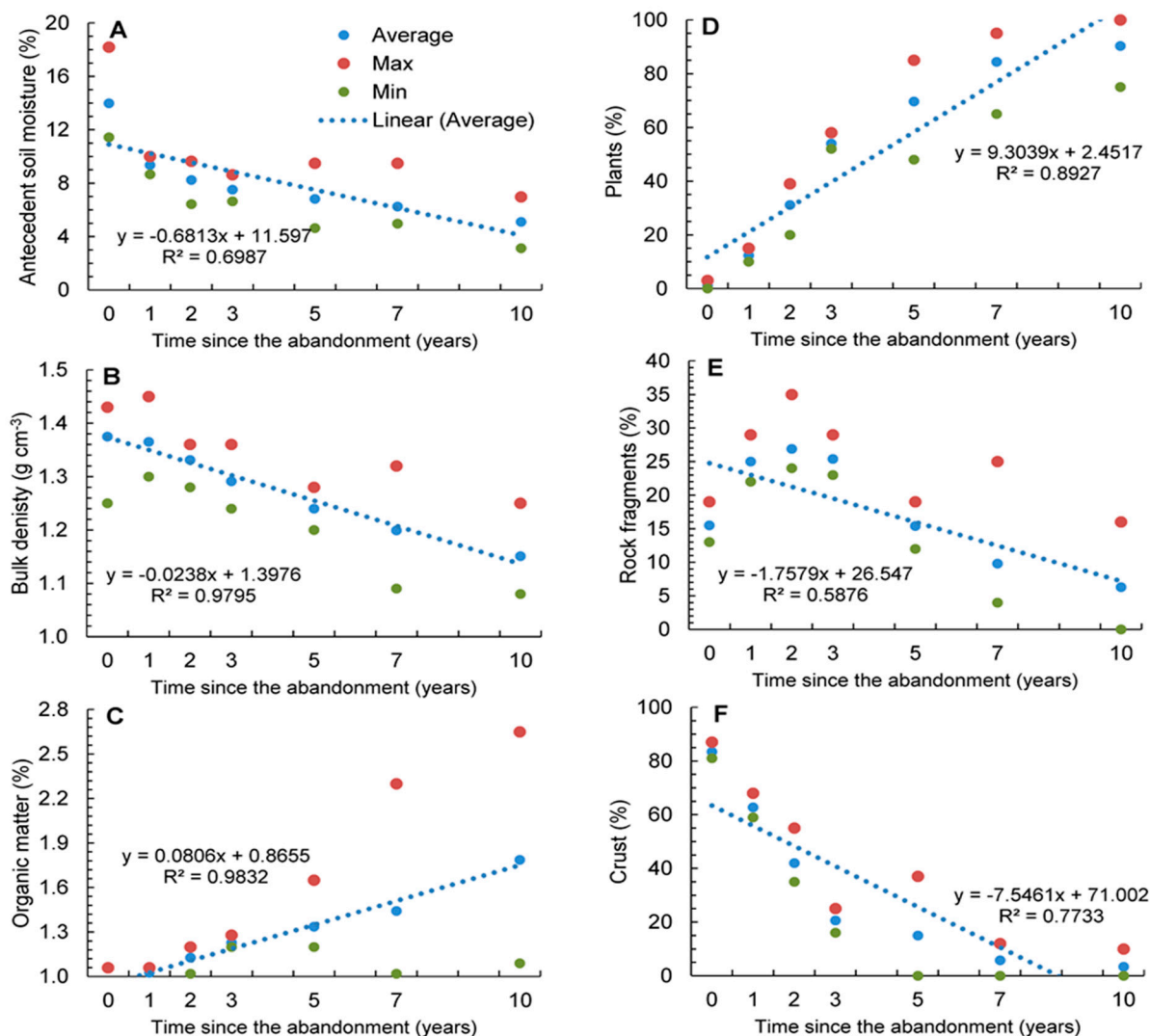


Figure 2. Variation of soil properties over different time periods since abandonment. (A) Antecedent soil moisture; (B) Bulk density; (C) Organic matter; (D) Plants; (E) Rock fragments; (F) Crust.

3.2. Hydrological Response

Figure 3 shows the time to ponding, time to runoff generation, and time to runoff in the outlet (seconds) represented in polar graphs. Table 1 shows the results of the Tukey test applied to all the seven study sites. The results show that among plots, there exists a clear statistically significant difference after the abandonment ($p < 0.001$). Time to ponding moves from 25.9 to 238.1 seconds, respectively, from the active plot to the 10 years abandoned one. Time to ponding was much delayed after seven years of abandonment. Runoff was generated after 47.2 seconds in the cultivated plot and after the runoff was delayed by 477.8 seconds. There was a clear trend that showed a progressive delay in the ponding and runoff initiation once the abandonment took place. Moreover, a clear variance among the 10 repetitions in each plot was also relevant, which could be affected by the uneven distribution of the plant recovery. The time to a runoff in the outlet was faster (88.3 s) in the active plot and delayed after the abandoned. The 10-year abandoned plot needed 917 s to achieve runoff at the outlet.

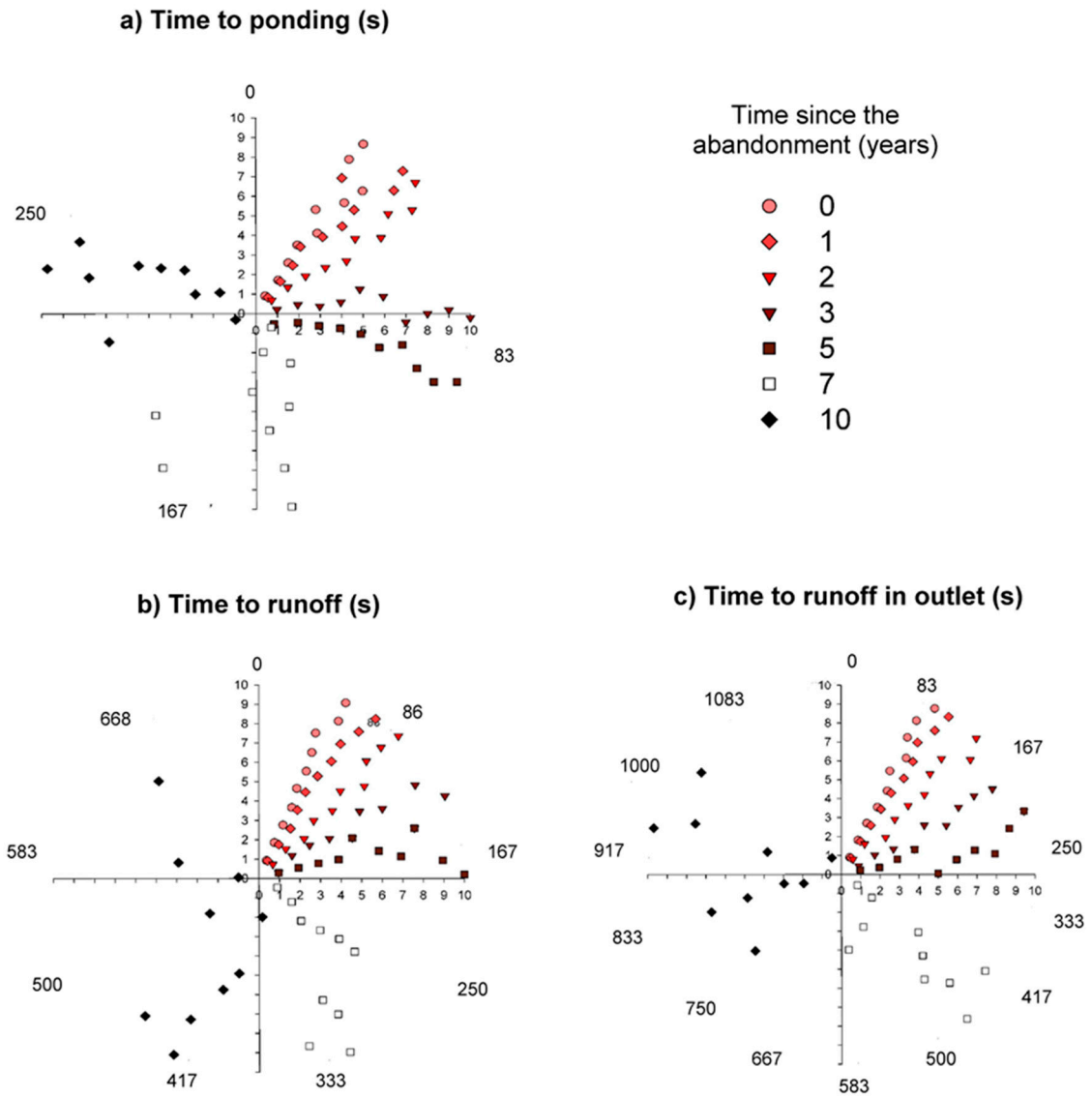


Figure 3. Hydrological response depending on the period of abandonment (360° = range of values).

Table 1. Statistical differences of hydrological responses and soil erosion results among periods of abandonment. Tp: time to ponding; Tr: time to runoff generation; Tro: time to runoff in outlet; Rc: runoff coefficient; SC: sediment concentration; SL: soil loss.

Years	Tp	Tr	Tro	Rc	SL	SC
0 vs. 1	<0.001	<0.001	<0.001	0.536	0.005	<0.001
0 vs. 2	<0.001	<0.001	<0.001	0.007	<0.001	<0.001
0 vs. 3	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
0 vs. 5	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
0 vs. 7	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
0 vs. 10	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1 vs. 2	<0.001	<0.001	<0.001	0.036	<0.001	0.338
1 vs. 3	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1 vs. 5	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1 vs. 7	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
1 vs. 10	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
2 vs. 3	<0.001	<0.001	<0.001	0.205	<0.001	0.002
2 vs. 5	<0.001	<0.001	<0.001	0.014	<0.001	<0.001
2 vs. 7	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
2 vs. 10	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
3 vs. 5	0.002	<0.001	<0.001	<0.001	0.002	0.048
3 vs. 7	<0.001	<0.001	<0.001	<0.001	<0.001	0.014
3 vs. 10	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
5 vs. 7	<0.001	<0.001	<0.001	<0.001	<0.001	0.400
5 vs. 10	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
7 vs. 10	<0.001	<0.001	<0.001	0.005	<0.001	0.003

3.3. Runoff, Soil Loss, and Sediment Concentration

In Figure 4, runoff coefficient, sediment concentration, and soil loss are depicted in box plots. The runoff coefficient shows the highest rates in the active plot, reaching average values of 77.2% of the rainfall, with maximum ones of 96.3%. On the contrary, in the other plots, the average runoff coefficient descends to 71.8, 51, 42.3, 32.3, 22.3, and 12.8% for 1, 2, 3, 5, 7- and 10-years of abandonment, respectively. The highest variability can be observed after the second year of abandonment. In Table 1, it is possible to observe values with non-statistically significant differences in runoff coefficients between 0–1 year and 2–3-years after abandonment. Sediment concentration also shows a drastic decrease from the active plot to the 10-year abandoned field, obtaining values from 14.7 (maximum values of 20.4 g L⁻¹) to 1 g L⁻¹ (maximum values of 1.02 g L⁻¹). Table 2 shows that all the plots have significant differences in this parameter. The soil loss parameter also shows a decrease: from 607.4 (active plot), 271.4 (1 year), 150.3 (2 years), 62.8 (3 years), 33.46 (5 years), 19.7 (7 years) till 7.1 g m⁻² (10 years). Table 1 shows that between 1–2 years and 5–7 years of abandonment, no differences can be observed, but there are differences in other years.

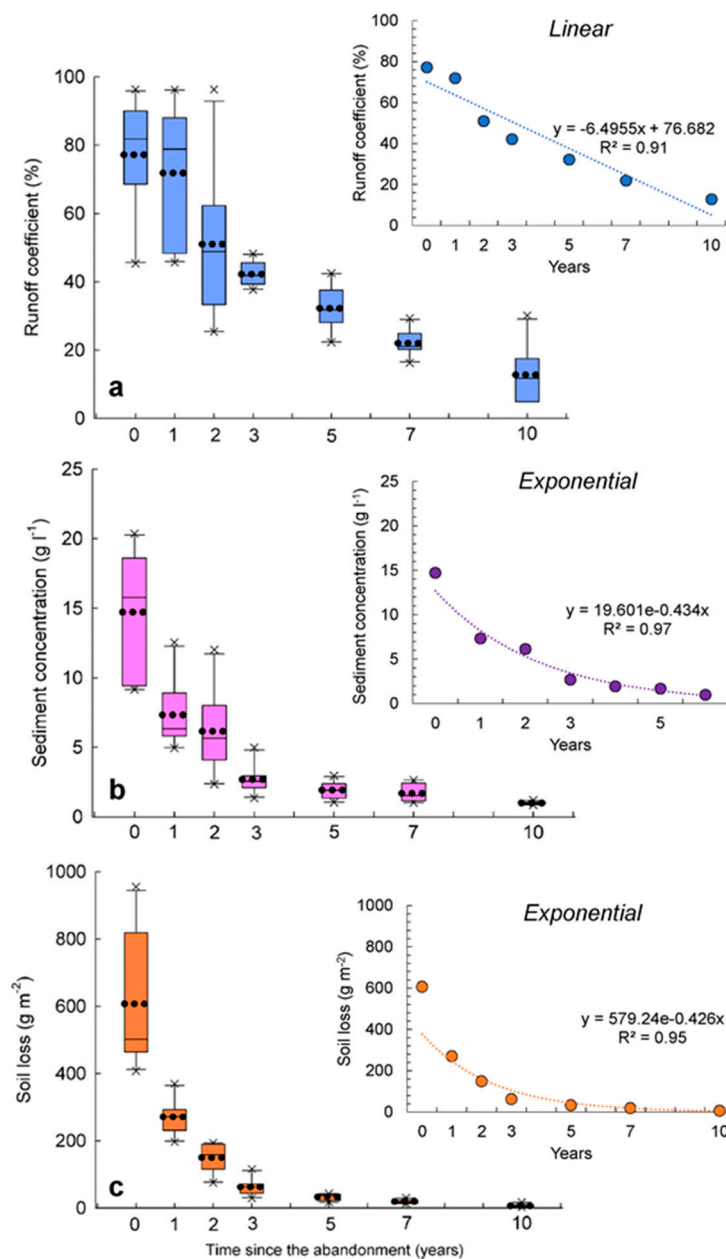


Figure 4. Evolution of the runoff coefficient, sediment concentration, and soil loss along the abandonment time from active plantations to 10-years old abandonment. Dotted line: average ($n = 10$). (a) Runoff coefficient; (b) Sediment concentration; (c) Soil loss.

Table 2. Spearman rank coefficient between environmental factors, hydrological responses, and soil erosion. SM: antecedent soil moisture; BD: bulk density; OM: organic matter; Plants: plant cover; Rock: rock fragment cover; Crust: soil crust; Tp: time to ponding; Tr: time to runoff generation; Tro: time to runoff in outlet; Rc: runoff coefficient; SC: sediment concentration; SL: soil loss.

Variables	Tp	Tr	Tro	Rc	SC	SL
SM	-0.84	-0.84	-0.85	0.77	0.80	0.77
BD	-0.85	-0.86	-0.85	0.80	0.81	0.75
OM	0.82	0.83	0.83	-0.77	-0.76	-0.70
Plants	0.95	0.95	0.95	-0.87	-0.88	-0.84
Rock	-0.56	-0.54	-0.54	0.59	0.49	0.49
Crust	-0.93	-0.93	-0.93	0.85	0.85	0.81

In Table 2, it can be observed that only the rock fragment cover does not show a high correlation with the hydrological responses and soil erosion results. On the other hand, the highest Spearman rank coefficient values were obtained between the development of a high plant cover and the positive relationship with Tp (0.95), Tr (0.95), and Tro (0.95), and the negative one with Rc (−0.87), SSC (−0.88), and SL (−0.84). Moreover, high positive correlations were observed with the OM contents. On the contrary, higher values of antecedent soil moisture, bulk density, and soil crust were highly correlated with Tp, Tro, and Tro, and Rc, Sc, and SL.

4. Discussion

The use of developing countries as food producers, an increase in agricultural productivity, and the use of fossil fuels that reduce the need for animal traction and then for food production for them has reduced the need to use part of the agriculture land [27,28]. This abandonment has environmental consequences such as changes in water resources, vegetation cover and floristic composition, fauna, and soil properties, which will affect also earth system functioning as they will control the biogeochemical cycles [29–33]. Agriculture land abandonment is not a new issue from a social, economic, and environmental point of view [34], but what is new is the agriculture technology that was developed after War World II which has led to the widespread abandonment and contributed to the restoration of the vegetation and fauna and the reduction in the soil losses in many parts of the world [35,36].

The research on the impact of abandonment of agriculture on environmental issues focused on rainfed land [37], as the irrigated land used to be intensified [38,39]. Our research contributes to new data generated in flood irrigated land that is being abandoned due to socioeconomic changes. The findings demonstrated that the soils are able to recover plant cover and soil organic matter once abandoned as other authors demonstrated in other types of agricultural land [17,40]. The changes in plant cover will affect fauna such as has been demonstrated by other colleagues [41–43] and soil properties. The non-utilisation of irrigation has generated soils which contain a lower amount of water (antecedent soil moisture), which could affect some other pedological processes such as organic matter development or aggregate stability [44,45]. Considering these changes, the diminution of soil bulk density is also a relevant factor that could affect soil erosion activation [46]. As Bienes et al. [47] observed in Central Spain, significant changes in bulk density used to appear after the abandonment took place due to plant recolonization because of the root development and organic matter increase. In our study area, weeds, grass, and small shrubs were distributed in little patches that directly affect these pedological changes.

The plant cover (weeds) was mainly *Paretaria Judaica*, *Conyza sumatrensis*, *Amarathus hybridus* L., and *Chenopodium album*. Once abandoned, the cover of *Paretaria Judaica* increased, but other plants appeared such as *Avena fatua*, *Asparragus* sp., and *Rubus ulmifolius* that finally became the dominant species.

Once the land was abandoned, we also observed a significant difference in the rock fragment cover. Possibly, the surface wash and tillage could remove the fine material and more rock fragments were visible on the surface [48,49]. However, after the third year of abandonment, the vegetation cover reduced neither the crust nor the rock fragments in the soil surface. This would also be an interesting topic for research in the future because of its direct impacts on soil erosion processes and biogeological systems.

Our research confirms that after the abandonment there was a sudden reduction in overland flows that is shown in delayed ponding and runoff generation. This means that more water infiltrates. However, our measurements also demonstrate that the amount of water flowing through and on the soil is also reduced after the abandonment takes place. This can be due to the reduction in the effective rainfall as the interception increases with the growth of the vegetation and the development of a litter layer [50,51]. The impact of the litter was researched by the pioneer study of Facelli and Pickett [52] and found that litter plays a key role in the water balance. Rainfall interception in abandoned fields is related to the vegetation recovery, and the higher the biomass means a lower the net precipitation on the soil [53].

The loss of water reaching the soil after the abandonment of land changes the hydrological cycle, such as Hou et al. [54] found in the Loess hillslopes in China, Šraj et al. [50] in Slovenia, and Otero et al. [55] in Catalonia (Spain), where a loss of stream biodiversity and water availability was found. Those findings are highlighted by García-Ruiz and Lana-Renault [13] along with their review on the hydrological and erosive consequences of farmland abandonment in Europe. The impact of abandonment shows less water availability and more water used by the vegetation. This results in a river discharge reduction such as was demonstrated in the Central Spanish Pyrenees by Beguería et al. [56] or in Slovenia where the Dragonja River reduced the sediment delivery due to the loss of the runoff discharge as a consequence of the natural afforestation [57]. The use of water by the vegetation (transpiration) also resulted in the loss of water available by plants such as Moreira et al. [58] found in the Amazon on abandoned pastures, Rambousková et al. [59] in the abandoned fields in the Bohemian Karst, and Farrick and Price [60] in the Sphagnum restoration in peatlands.

Our research at the Canals municipality demonstrated that the reduction in the water yield was efficient as a consequence of the abandonment (from 77.2% in the active orange plantation to 12.8% in the 10-years abandoned plots), but the reduction shows a linear correlation (0.91; Figure 4a). However, for the sediment concentration and soil loss, the reduction followed a negative exponential trend with an adjustment of 0.97 and 0.95, respectively (Figure 4b,c). This trend in the reduction of soil and water losses were also found in previous literature. Ruecker et al. [61]; Koulouri and Giourga [62], and Lesschen et al. [63] found this trend in abandoned Mediterranean terraces, Cerdà [12] in southeastern Spain in a semi-arid landscape, Liu et al. [64] in the Loess Plateau, and Arnáez et al. [65] in the La Rioja region, wherein the Camero Viejo district they found that abandonment controlled the soil erosion rates and landscape evolution. Land abandonment is a recurrent topic in the Mediterranean, and Portuguese examples confirm our findings here: control of soil losses by vegetation recovery [66].

Abandonment could be seen as a nature-based solution such as the use of straw in forest fire affected land [66,67] to the high erosion rates found in agricultural land [68], and could be used as a strategy to balance the carbon cycle [69] and rehabilitate the soils under the millennia-old use of agriculture [70]. The research carried out at the Canals Municipality shows that abandonment could be positive from an environmental point of view, but there is also the risk of a forest fire as the vegetation could be very flammable during the Mediterranean summer drought [71]. Thus, the next essential step of research is to find the optimal management of the abandoned orchards, and maybe it can be used as a recreation area for nearby urban citizens [72]. This could be a successful solution in the Mediterranean where agriculture land abandonment in the last decade also takes place in the surroundings of city areas due to the economic crisis [69] and for which similar responses have been shown in other developed countries [73]. How urban changes occur is related in one way to the environmental conditions [74] but also to the cultural impact of humans [75].

Once the fields are abandoned, the vegetation recovery takes places as a mosaic of plants and this response results in an increase in the spatial variability such as other authors found along climatological gradients [76]. We found this increase in the spatial distribution due to the formation of tussocks, or bare and plant covered patches, which is a clear factor in soil erosion, but with more intensity after the second year of abandonment [77]. Our findings are based on a local survey and should be used to supply basic information to develop proper models of water balance and soil erosion [78] that will shed light onto the effect of other management systems such as organic farming, land abandonment or cover crops and mulches [79,80].

5. Conclusions

Citrus plantation abandonment results in a recovery of the vegetation cover and soil organic matter, and a reduction in the soil bulk density drought and soil moisture. Plant recovery is the key factor that determined a linear reduction in the runoff discharge (from 72 till 13% of the rainfall) over ten years of abandonment. The soil losses dropped from 607.4 g m^{-2} in the active plot to 7.1 g m^{-2} in the 10 years after abandonment took place. We conclude that the abandonment of orange plantations

could reduce soil and water losses if there is a proper plant recovery, which allows it to be considered as a potential nature-based solution to restore the soil services, goods, and resources.

Author Contributions: A.C.: investigation, methodology, data acquisition, data preparation, writing, supervising. O.A.: data analysis, data preparation, writing. E.T.: investigation, methodology, data acquisition, data preparation, writing. J.R.C.: data analysis, data preparation, methodology, writing.

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