Effect of different management practices on soil properties of Mediterranean paddy fields

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***Abstract*—** Rice crop cultivation in Mediterranean environments traditionally involves intensive and expensive tillage practices that may change for the worse the soil's original physical and physicochemical properties. The aim of the present study was to determine the short- and long-term effects of aerobic rice production, combined with conventional and no-tillage practices, on soils' physical and physicochemical properties. A field experiment was conducted for three consecutive years (2011, 2012 and 2013), with four treatments: anaerobic with conventional tillage and flooding (CTF), aerobic with conventional tillage and sprinkler irrigation (CTS), aerobic with no-tillage and sprinkler irrigation (NTS), and long-term aerobic with no-tillage and sprinkler irrigation (NTS7). Highest TOC (15.6, 15.5 and 16.2 g kg^{-1}), AH (1.60, 1.33 and 1.76 g kg^{-1}), AF (1.03, 0.993 and 0.998 g kg^{-1}) and total N (0.143, 0.106 and 0.143%) values were obtained by NTS7 in all three years, thus the mid- and long-term implementation of no-tillage combined with sprinkler irrigation may be considered to be a sustainable management system for rice farming under semi-arid Mediterranean conditions.

***Keywords*—** aerobic rice, soil, conservation agriculture

I. Introduction

WORLD rice production has suffered for years from an important lack of investment regarding research on and development of new management techniques, slowing down the implementation of beneficial innovations [1]. Environmentally, modern approaches to rice crop intensification have damaged important natural resources, causing significant increases in soil salinity, water pollution, and health problems derived from high pesticide concentrations in water and food, as well as increased greenhouse gas emissions [2]. The agriculture sector is highly exposed to the risks accompanying climate change [3]. Therefore, possible global climate changes associated with increased atmospheric concentrations of greenhouse gases are likely to affect the efficiency of agricultural production systems [4]. Together with this, one of the major challenges facing rice farming is to produce the same or more with less water, labor, and chemicals, so as to ensure the sector's long-term sustainability [5]. In order to avoid long-term supply and demand imbalances, innovations are needed in agronomic management and technology. In particular, the development of alternative rice farming systems may contribute to reduce the aforementioned negative effects and to increase productivity [6]. Research on these management techniques needs to mainly focus on a rational and sustainable use one essential natural resource such as soil.

Rice crop cultivation in Mediterranean environments traditionally involves intensive and expensive tillage practices. The leveling, ploughing, cross-harrowing, and final puddling may be direct causes of dramatic decreases in soil quality, initiating processes that may change for the worse the soil's original physical properties. These result in organic matter and nutrient depletion, increased penetration resistance due to the creation of plough pan and surface crust, as well as increased acidity and reduced microbial activity [7]. Furthermore, new studies carried out under Mediterranean conditions [8] show an important increase in heavy metal content in both soil and grain after several years of rice monoculture using conventional tillage practices and flood irrigation.

There are currently many proposals regarding soil conservation in intensive agriculture environments. Most of them are centered on the concept of "conservation agriculture". Conservation agriculture is a modern alternative for resource-saving crop production that strives to achieve acceptable profits from high and sustained production levels while concurrently conserving the environment. It is characterized by three interlinked principles: minimal mechanical soil disturbance, permanent organic soil cover, and diversification

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of either crop rotations in the case of annual crops or plant associations in the case of perennial crops. These principles reach their greatest expression with the technique known as no-tillage, extensively used to increase soil organic matter, to control soil degradation, and to increase water holding capacity [9].

The aim of the present study was therefore to determine the short- and long-term effects of sprinkler vs flood irrigation and no-tillage vs conventional tillage on soils' physical and physicochemical properties in semi-arid Mediterranean conditions.

II. Materials and Methods

A. Site Description

A field experiment was conducted in 2011, 2012 and 2013 on a Hydragic Anthrosol [10] with 16.96% clay, 35.87% silt, 47.17% sand. The experimental field was located in Extremadura, south western Spain (39° 06' N; 5° 40' W), with Mediterranean climate (rainfall <480 mm, with hot and dry summers).

B. Field Experiment

Prior to beginning the study, the experimental area was cropped with rice (Oryza sativa L.) using the traditional management practices in the region (deep ploughing and waterlogging), and a part of the field had already been devoted to direct seeding and sprinkler-irrigated rice in the 7 years preceding the experiment. The field was divided into twelve plots of 140 m² (7×20 m) each, that were subjected to the following four management regimes: (CTF) applying the techniques that are conventional in the region, i.e., tillage to 30 cm and flooding with continuous water flow; (CTS) conventional tillage and sprinkler irrigation; (NTS) conservation agriculture techniques (no-tillage and seeding by direct drilling) and sprinkler irrigation; and (NTS7) the same conservation agriculture techniques (no-tillage and direct drilling) and sprinkler irrigation but where this management regime had already been in use for 7 years in order to observe any long-term changes. Each treatment was replicated thrice in a completely randomized design.

C. Crop Culture

Mouldboard ploughing was applied to 30 cm depth prior to sowing in the CTS and CTF treatments. In the NTS and NTS7 treatments, each year after harvest, the crop residues were left on the soil surface and the soils were left untilled. In contrast, all crop residues were withdrawn from the CTS and CTF plots. The amount of irrigation water applied for the sprinkler irrigated treatments was enough to keep soil moisture over 70% of field capacity [11]. For the flood irrigation, the aim was to keep the water level constant. In all three years (2011, 2012, and 2013), composite fertilizer 9-18-27 (550 kg ha^{-1}) was applied in April as basal in all treatments, and N was applied in the form of urea in two splits of 200 kg ha^{-1} at tillering and 150 kg ha^{-1} at the panicle initiation stage.

D. Soil Sampling and Analysis

Soil samples from each plot were taken using a manual auger. The depths were: 0-20 cm for physicochemical properties; 0-10 cm for enzymatic activities; and 0-10 and 10-30 cm for aggregate stability. Three subsamples were taken randomly from each of the three replicate plots at the beginning of the study (March 2011), and each year after harvest (October 2011, 2012, and 2013). In October 2011 and 2013, when the soil water content was near field capacity [12], the soil penetration resistance was measured in the field down to 45 cm depth using a hand penetrometer with 1 cm² conical tip. Texture was determined by sedimentation using the Robinson pipette method [13] after destruction of the organic carbon with H_2O_2 and chemical dispersion using $Na_4P_2O_7$. Total organic carbon (TOC) content was determined by dichromate oxidation [14]. Water soluble organic carbon (WSOC) was extracted with de-ionized water at a 3:1 water-to-soil ratio. Humic acids (HA) and fulvic substances (fulvic acids + humins, FA) were extracted with a solution of 0.1 M $Na_4P_2O_7$ + NaOH at a 10:1 extractant-to-sample ratio, and, to precipitate humic acid, the supernatant was acidified to pH 2 with H_2SO_4. The WSOC and the TOC associated with each fraction of HA and FA were determined by dichromate oxidation and measurement of the absorbance at 590 nm [15]. A combination electrode was used to measure electrical conductivity (EC) in a saturated soil extract and the pH in a 1:1 (w/v) soil/water mixture. Total nitrogen (N) was determined by the Kjeldahl method [16], and phosphorus (P) by the Olsen method [17]. Aggregate stability (AS) was determined following the Sun method [18] which uses a single 0.250 mm sieve and an apparatus with a stroke length of 1.3 cm and frequency of 35 cycles min^{-1}, and sodium hydroxide as dispersant. Table I gives some selected properties of the soil samples taken at the beginning of the study (March 2011).

Table I. Soil physicochemical properties prior to the trial.

	TOC (g kg-1)	HA (g kg-1)	FA (g kg-1)	EC (μS cm^{-1})	pH	N (%)	P (mg kg^{-1})
NTS7	15.3	1.22	1.03	0.472	6.24	0.119	20.6
NTS	8.56	0.481	0.626	0.733	5.54	0.101	19.2
CTS	8.68	0.459	0.594	0.740	5.46	0.097	19.5
CTF	8.50	0.460	0.605	0.739	5.53	0.098	19.3

TOC: Total organic carbon; **HA**: Humic acid; **FA**: Fulvic acid; **EC**: Electrical conductivity; **N**: Total nitrogen; **P**: Phosphorus.

E. Statistical Analysis

Statistical analyses were performed using the IBM SPSS Statistics 22.0 program package. The data were checked for normality and homoskedasticity. A one-way ANOVA was used to analyse soil and agronomic properties, the Duncan test to determine significant parameter differences between treatments and years, and the Pearson correlation coefficient to study possible correlations between different parameters. Differences were considered statistically significant at a p-value of less than 0.05.

III. Results and Discussion

A. Soil physicochemical properties

The soils' physicochemical parameters at 0-20 cm depth for the years 2011, 2012, and 2013 are listed in Table II. All the TOC values were low (Fig. 1), as is usual for agricultural soils in Mediterranean environments [9].

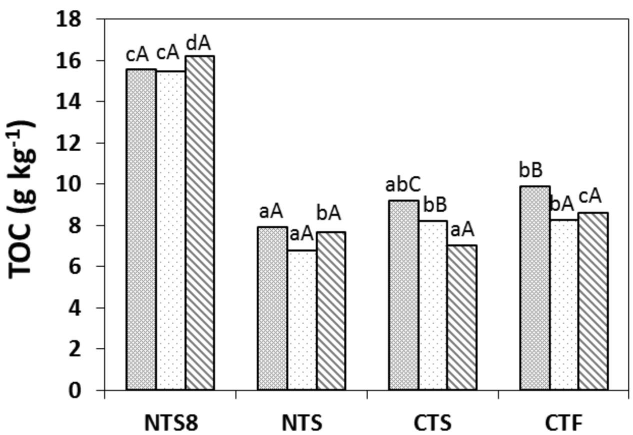

Figure 1.Effect of different management regimes on soil Total Organic Carbon (%) on years 2011 (▩), 2012 (□) and 2013(▧).

The highest values were for NTS7 in all three years (15.6, 15.5, and 16.2 g kg^{-1}), reflecting a major effect of long-term no-tillage practices on this parameter. Although increases in TOC have been observed in rice cultivation under flood irrigation [19], in the present case there were no significant variations of the TOC content in the NTS treatment over the three years studied (Fig. I).

Indeed, the short-term effects of no-tillage practices on TOC are complex, with widely varying results being reported that depend on such factors as climate, crop residue, and the crop management regime itself [20]. On the other hand, the CTS and CTF treatments showed significant declines (by 23.9% and 13.4%, respectively) in TOC content for 2013 compared to 2011. The irrigation method is an important factor that may help explain the differences in TOC losses between the CTS and CTF treatments. In this sense, it is important to note that organic matter mineralization is related to soil moisture balance, in particular, to the air-water ratio. Aerobic microbial activity in soil rises with increasing moisture content up to limits at which the amount of water reduces oxygen availability. The anaerobic conditions caused by the flooding in the CTF treatment may have resulted in a slower rate of organic matter decomposition than in the CTS treatment, in which the conditions for faster organic matter mineralization were more favorable.

The greatest FA content throughout the trial corresponded to NTS7. There were no significant changes in this parameter between years for the NTS7 or CTF treatments (Table II). It is important to recall that the management techniques applied in these two treatments did not differ from those applied prior to the experiment, reflecting a long-term stabilization. But the NTS and CTS treatments showed contrasting trends: while the FA content in NTS increased by 43.6% in 2013 relative to 2011 due to the annual input of organic matter, the FA content in CTS fell by 13.3% over the same period.

With respect to the HA content, all the treatments presented significant decreases in 2012 relative to 2011 (Table II), and

Table II. Effect of different management regimes on soil physicochemical properties.

	HA (g kg^{-1})	FA (g kg^{-1})	EC (µS cm^{-1})	pH	N (%)	P (mg kg^{-1})
			2011			
NTS7	1.60cB	1.03cA	1.51dC	5.84cA	0.143bB	16.4bA
NTS	0.833bB	0.532aA	0.906bB	5.91cB	0.081aA	11.5aA
CTS	0.604aB	0.676bB	0.698aA	5.63bA	0.074aA	9.26aA
CTF	0.627aB	0.634bA	1.26cB	5.15aA	0.086aB	11.1aA
			2012			
NTS7	1.33bA	0.993cA	0.490aA	5.92dA	0.106bA	19.0bB
NTS	0.514aA	0.579aB	0.857bA	5.92cB	0.072aA	18.0aB
CTS	0.515aA	0.685bB	1.09cB	5.84bB	0.078aA	21.6cC
CTF	0.481aA	0.661bA	1.27dB	5.21aB	0.079aA	26.0dC
			2013			
NTS7	1.76dC	0.998dA	1.26cB	5.84cA	0.173dC	20.8cC
NTS	1.13cC	0.764cC	1.38dC	5.22aA	0.104bB	21.9dC
CTS	0.908aC	0.586aA	0.753aA	6.24dC	0.094aB	12.5aB
CTF	0.984bC	0.639bA	1.08bA	5.33bC	0.114cB	17.2bB
Y	***	**	***	*	***	***
T	***	***	***	***	***	***
Y*T	***	***	***	***	***	***

TOC: Total organic carbon; **HA**: Humic acid; **FA**: Fulvic acid; **EC**: Electrical conductivity; **N**: Total nitrogen; **P**: Phosphorus. ANOVA factors are **Y**: Year; **T**: Treatment; **Y*T**: Interaction Year*Treatment; *, ** and *** significant at α levels of 0.05, 0.01 and 0.001, respectively; **NS**: not significant. Different letters show significant differences (p<0.05) between treatments in the same year (lower case letters) and between years within the same treatment (upper case letters).

reached their highest values in 2013. That this pattern is independent of the type of management and irrigation technique points to the influence of external factors. In particular, high rainfall was recorded in autumn 2012, with very wet months of September, October, and November months [21]. There was some 40 mm of rainfall prior to the 2012 soil sampling, which may have slowed down organic matter humification in all the treatments. Then, the more favorable weather conditions in 2013 generated the major rise in HA content due to the cumulative humification of organic matter left over from 2012 as well as that of 2013.

The EC values were highly variable, reflecting the great spatial variability of this parameter in field conditions. In 2013, after three years of the trial, the lowest value of this parameter corresponded to the CTS soil and the highest to the two no-tillage treatments (NTS7 and NTS). The TOC accumulation in the no-tillage treatments and the organic matter depletion in CTS may help to explain these contrasting trends. In the literature, there is no consistent pattern in the effects of no-tillage practices on EC. While in a long-term experiment (13 years) ref. [22] observed EC values that were lower in soils under no-tillage than under conventional tillage, ref. [23] observed the contrary, although neither of those works studied the influence of the irrigation system.

The treatments greatly influenced the pH levels. There was acidification of the NTS7 and NTS soils in 2013 relative to 2012. This was probably because of a build-up of organic residues on the surface as was noted by ref. [24] in studying topsoil acidification in no-tillage maize and wheat plots. On the other hand, the pH of the CTS soil rose (by 10.8%) from 5.63 in 2011 to 6.25 in 2013. The CTF soil showed a similar trend, but with a much smaller increase in pH (by 3.50%). This behavior in the two conventionally tilled treatments is related to the changes in TOC content discussed above, with the rises in pH being explicable by the losses of organic matter in these treatments (Table II).

The total nitrogen (N) was significantly correlated with the TOC content ($r=0.769$; $p<0.01$), with, in all three years, the highest values corresponding to the NTS7 treatment and the lowest to CTS. This effect of long-term no-tillage on soil nitrogen is coherent with the observations of other works ([23], [25]) for different crops and environmental conditions, with, in all cases, there being significant increases in N under no-tillage relative to conventional tillage systems.

In 2011, NTS7 had the highest P levels, while there were no significant differences between the rest of the treatments. In 2012, the highest levels corresponded to the conventional tillage soils (CTS and CTF). This trend was reversed in 2013, however, when the highest values corresponded to the no-tillage treatments (NTS7 and NTS). While a study involving sprinkler irrigated corn [26] found no significant differences in the P content of soils under conventional and no-tillage practices, the present results are coherent with those of a study of agricultural soils in southern Spain [27] in that, in the mid to long term, no-tillage practices may enhance the P content in Mediterranean soils.

B. Soil physical properties

Aggregate stability (AS), expressed as the stable fraction percentage (Table III), is a key factor in soil fertility [28]. It has been found to be significantly correlated with TOC ($r=0.935$; $p<0.01$), FA ($r=0.773$; $p<0.01$), and HA ($r=0.891$; $p<0.01$) for the 0-10 cm depth, and with TOC ($r=0.656$; $p<0.01$), FA ($r=0.907$; $p<0.01$), and HA ($r=0.867$; $p<0.01$) for the 10-30 cm depth. These results highlight the importance of organic matter and humic substances in stabilizing soil structure. For this reason, the highest values of AS corresponded to NTS7 for all three years and for both depths. In the NTS treatment, there was a significant increase in AS in 2013 in the 0-10 depth, and even more importantly in the 0-30 depth. The CTS and CTF treatments also showed increases in AS in 2013 reflecting the greater HA content, but these increases were not comparable to those of the no-tillage treatments.

Table III. Effect of different management regimes on soil stable fraction (%).

Depth (cm)	NTS8	NTS	CTS	CTF
		2011		
0-10	46.1cA	10.1aA	12.3abB	17.0bA
10-30	22.7cB	5.31aA	5.48aA	8.19bB
		2012		
0-10	43.0bA	11.7aA	6.60aA	12.9aA
10-30	18.5bA	5.51aA	2.56aA	3.45aA
		2013		
0-10	40.6bA	17.9aB	12.3aB	16.7aA
10-30	20.9cAB	11.8bB	5.69aA	7.19aB

Different letters show significant differences ($p<0.05$) between treatments in the same year (lower case letters) and between years within the same treatment (upper case letters).

Fig. 2 shows the penetration resistance results for 2011 and 2013. One observes that, for both years, there was greater compaction in the upper layers of soil for the no-tillage treatments (NTS7 and NTS), and that the compaction of the conventionally tilled treatments (CTS and CTF) increased with depth to surpass that of the no-tillage soils, until reaching a maximum at 20-25 cm. Beyond this depth, the CTS and CTF values decreased down to levels similar to those for NTS7 and NTS. This pattern suggests that the conventional tillage generated a plough pan, and highlights the importance of taking depth into account when considering variations in penetration resistance [29]. The pattern of the two no-tillage curves is also coherent with the finding of a study on rainfed wheat cropping with a no-tillage regime [30] that penetration resistance increased faster with depth in the top layers of the soil than in deeper layers.

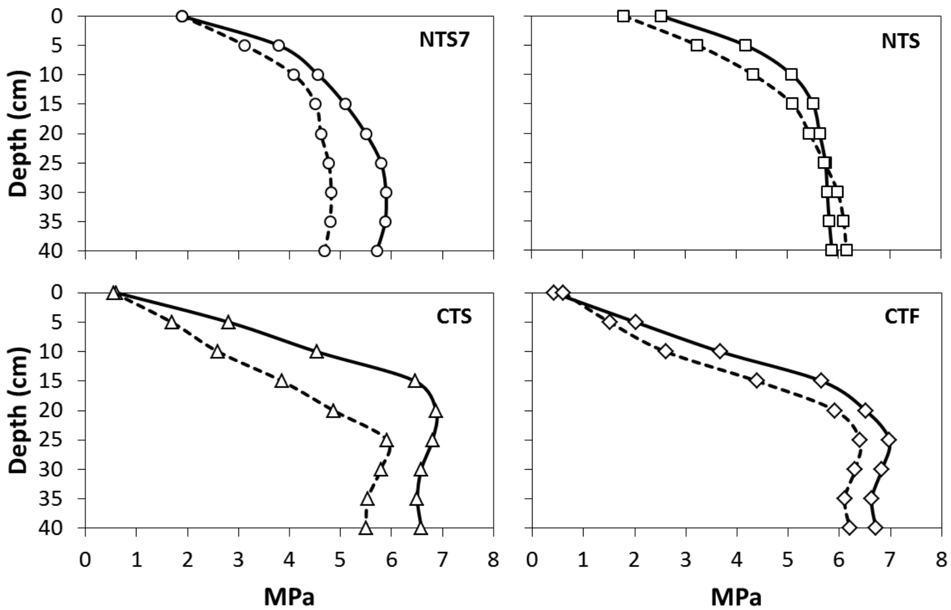

Figure 2. Effect of different management regimes on soil penetration resistance. Treatments are: NTS7 (∘), NTS (□), CTS (▵) and CTF (⋄). Years are: 2011 (▬) and 2013 (▪▪).

IV. Conclusions

This study has shown that the implementation of aerobic rice crop combined with no-tillage practices may induce important transformations in the soil, leading to major improvements in its physical and physicochemical properties, increasing organic matter content, soil aggregate stability and overall fertility. This is especially so after long-term implementation of the strategy. In sum, the mid- and long-term implementation of no-tillage combined with sprinkler irrigation may be considered to be a sustainable management system for rice farming under semi-arid Mediterranean conditions.

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