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Carbon capture and pedogenetic processes by change of moisture regime and conventional tillage in Aridisols

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ABSTRACT

In recent years, conservation tillage has been promoted as a method of increasing the quality of agricultural soils; however, in the Aridisols of northeastern Mexico, this type of tillage is not practical because of the formation of natural crusts. Conventional tillage systems that include different culture practices have been used for six decades to increase the yields. However, little is known of the changes to the soil properties and modifications to the moisture control section. Six agricultural plots representative of 78,000 ha in districts of the state of Tamaulipas, Mexico were studied based on their management: rainfed or irrigated, with or without the incorporation of crop residues and with or without plot drainage. The results show that three moisture regimes occur in the soils according to the irrigation intensity and plot drainage: aridic, ustic and udic. The aridic regime presents the greatest organic carbon stock (58 Mg ha^{-1}), stability of aggregates in particles >2 mm in the arable layer and produces sorghum yields of up to 2.5 t ha^{-1}. In the udic regime, because of plot drainage and the incorporation of crop residue and manure, there is high biological activity; in addition, stability of aggregates is along the whole profile, alkalinisation and redox processes occur, and short-cycle maize yields are up to 10 t ha^{-1}. The different management practices for intense production modify the moisture regime but do not modify the organic carbon capture. The pedogenetic processes are related to the management intensity and cause the Aridisols to evolve into inceptisols in less than six decades of agricultural activity; however, only the redox processes are expressed in their classification despite a significant amount of calcitic features.

1. Introduction

Soils in an aridic moisture regime account for more than 12% of the surfaces worldwide, and in Mexico, they account for 38% of its territories, which are mainly located in the central northern region of the country. In natural conditions, these soils are generally not suitable for the production of food, but when incorporated with agricultural activity such as irrigation and the use of fertilisers, they are highly productive (Brady and Weil, 2012). However, the variation rate of the soil's edaphic properties caused by the modification of the moisture regime has been poorly investigated.

According to Birkeland (1999), irrigation alters the climate that relates to the organic matter content (Keil and Mayer, 2014), particle size (Sandler, 2013) and presence or absence of calcium carbonate (Blecker et al., 2013). In addition, irrigation causes changes in the physical, chemical, morphological and microbial activity properties (Giubergia et al., 2013) as well as in the soil erodibility (Hussein et al., 1992).

The changes in the edaphic properties are well characterised in Mollisols and Alfisols with high natural fertility (Richter and Tugel, 2012), and such changes have been specifically studied in other soils or in the laboratory. Flood simulations (Hassannezhad et al., 2008) and evaluations of moisture gradients (Carlson and Pierce, 1955; Khormali et al., 2006) with sprinkler irrigation (De-Campos et al., 2009) or complementary irrigation in direct seeding (Giubergia et al., 2013) have been studied. However, studies of the intensity of these processes in Aridisols, changes in the formation processes and ways in which these processes modify their classification have not been presented.

The soils of the irrigated or rainfed districts of the state of Tamaulipas, which is in northern Mexico, have been incorporated into production systems since 1954. Since then, management practices such as windbreak barriers and the incorporation of organic matter from crop residue and irrigation systems (Gutiérrez-Castorena et al., 2008) have been used. According to Richter and Tugel (2012), soil moisture surveys provide little

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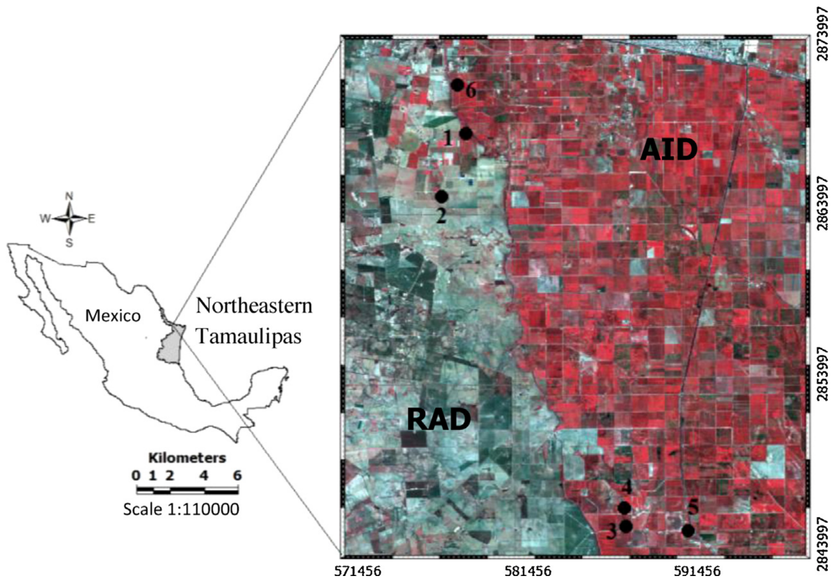

Fig. 1. Location of the study area. AID (agricultural irrigation district), RAD (rainfed agricultural district), sampling sites (●).

information on the response of dynamic soil properties and effects of these changes on soil functioning; this result may represent a generalization of the benefits or inconveniences of certain management practices for different types of soils.

Detailed soil surveys and constant monitoring of the management practices performed in the region can provide precise information on why producers prefer conventional tillage practices with the incorporation of crop residue instead of the conservation tillage. Agricultural producers argue that soil compaction is avoided and water infiltration rates are increased with this type of management, whereas several research works have shown that conventional tillage is the cause of such problems.

In Aridisols, crust formation, sealing and surface runoff occur naturally (Brady and Weil, 2012), whereas in Mollisols and Alfisols, these processes are artificially generated by conventional tillage. Regardless of whether these processes are naturally or artificially occurring, they are disastrous for the growth of plants, so their management must be different. Therefore, the stated hypothesis of this study is follows: conventional tillage in Aridisols with the incorporation of crop residues in addition to modification of the moisture regime increases the carbon capture and stability of aggregates proportionally to its intensity; in addition, the edaphic properties and soil formation processes respond differentially with management.

The objectives of the present research work are as follows: (1) determine the changes in the edaphic properties of Aridisols under different management practices in intense production; (2) evaluate the stability of aggregates based on changes of the moisture regime and incorporation of crop residues under mechanized conventional tillage; and (3) establish a taxonomic classification of the soils with and without alteration of the moisture regime.

2. Materials and methods

2.1. Study area

The study area is located in northeastern Mexico, Tamaulipas state (Fig. 1) at an altitude between 29.1 and 33.4 m.a.s.l. The federal entity has been nationally recognized for its agricultural activity and food production (maize and sorghum) for 60 years. The agricultural region is composed of diverse agricultural districts such the high-tech rainfed district 010 San Fernando and irrigation district 026 Díaz Ordaz; this irrigation district receives water from the Marte R. Gómez Reservoir, which is fed by the lower San Juan River. The derivations of agricultural use average 382 M m^3 per year and provide a medium annual layer of 497 mm. The command area has 87,500 ha with approximately 77,000 ha authorized for irrigation. There are 225 km of main channels and 850 km of secondary and tertiary channels (Rymshaw, 1998).

The mean annual rainfall is 570 mm, which is irregularly distributed between August and September with torrential rains, and the mean annual temperature is 22 °C (Rymshaw, 1998). The moisture regime in the control section is aridic, and the temperature regime is hyperthermic (Soil Survey Staff, 2010).

The predominant soils in the study region are Vertisols and Calcisols (Rymshaw, 1998) or Vertisols and Aridisols (Gutiérrez-Castorena, 1997), respectively. Only the Aridisols were studied in this research, and they are characterized as presenting a regular relief with flat slopes and an absence of rocky outcrops or stoniness and normal internal drainage and an external drainage normal or receptor for runoffs. The parental material is sedimentary and composed of wind-deposited quartz sand bodies (INE, 2007). The arable layer, when dry, forms hard crusts that are between 2 and 5 mm thick, and the producers use highly mechanized conventional tillage to disaggregate these crusts.

The irrigation districts are composed of a plot mosaic under the same system of tillage (Fig. 2) and production of an intense monoculture (sorghum or maize), but they vary with regard to the hydric characteristics, organic matter (OM) incorporation and sub-surface plot drainage systems (Table 1). Sorghum is cultivated

Table 1
Site characteristics within irrigated and rainfed agricultural soils under different management strategies.

Sites	Rainfed	Irrigation	Incorporation of		Drainage underground	Distance to channel wrapper	
			OM	Manure		<250 m	>1500 m
1	X						
2	X		X				
3		X					X
4		X	X		X		X
5		X				X	
6		X	X	X	X	X	