Article

Effect of direct sowing on soil properties and irrigation water use in maize in Sinaloa, Mexico

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Abstract

Sinaloa is the main producer of corn nationwide, however, excessive tillage and the practice of monoculture corn for more than 30 years, have caused loss of soil fertility, lower water retention and increased production costs. In order to evaluate the effect of the direct seeding system (SD) on the physical-chemical properties of the soil and on the water use efficiency of the corn crop, a study was conducted in the north of Sinaloa, Mexico for three years' agricultural cycles under sprinkler irrigation (central pivot), where the treatments were established 1) SD; and 2) conventional tillage of the region (LC) in 0.5 ha each. The properties of the soil evaluated were organic matter (MO), bulk density (Da), total porosity (E), pH and electrical conductivity (CE). In addition, two fixed stations with sensors were installed at three depths of the profile (30, 60 and 90 cm) to measure the behavior of usable humidity (HA) and soil temperature (Ts). The results showed that in the third cycle the organic matter reached a value of 1.47% in SD, while in LC it remained 1%, the pH and the CE showed slight decrease. It was also observed in SD greater stability of humidity in the soil profile, with an increase of 4.62% of HA and a reduction of 1 ºC of Ts, which allowed to eliminate an irrigation of relief that represents a saving of 800 m^3 ha^{-1}. The elimination of this irrigation and the work of preparing the land and controlling weeds reduced production costs by 20%.

Keywords: water saving, climate change, cost reduction, soil improvement.

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Introduction

The world surface under irrigation is of the order of 20%, mainly located in arid and semi-arid zones, which require irrigation to ensure commercial yields and also show high spatial and temporal variability in the volumes available from their sources of supply (FAO, 2011). In Mexico, irrigated agriculture is concentrated in coastal areas, which according to a study conducted by Ojeda *et al*. (2011) are in a vulnerable condition to the effects of variability and climate change with increasingly frequent and intense extreme weather events (cyclones, frosts and droughts).

The application of water at the plot level is deficient since it is mainly used for irrigation by gravity by furrows without previous design or application of irrigation technologies, high pressure to optimize the irrigation plot (Ojeda *et al*., 2012), it is common water restriction for irrigation due to the recurrence of periods of low availability by organisms that administer water, which can generate water stress to crops. It is estimated that at the farm level less than 45% of the water applied to the plots is used; the rest is lost by drainage and deep percolation, with the consequent loss of mobile fertilizers and soil (Sifuentes *et al*., 2015).

One of the main causes of environmental degradation and low profitability of crops, is the inadequate management of traditional production systems, before this different alternative have been proposed to conserve and protect the soil, one of them is the use of tillage zero or direct seeding, whose study began in the thirties (Duley and Russell, 1942). The practice consists in leaving the residues of the previous harvests on the surface of the land, without breaking or turning the soil, as is traditionally done.

Soil cover with stubble reduces the effect of erosion and increases the content of organic matter, thereby improving the physical, chemical, biological, and soil fertility (Rodríguez *et al*., 1987). The physical properties of the soil show a great spatial variability, both horizontally and vertically and are subject to continuous changes in natural conditions, especially with the intervention of man through tillage systems (Pla, 1993), due to this has indicated that tillage is a dynamic process that causes profound changes in the physical properties of the soil, which can persist for variable time depending on soil conditions and climate, which can strongly affect the development of crops (Onofiok, 1988; Pla, 1993).

Faced with this problem, minimum, reduced and direct tillage systems, unlike conventional systems where vegetable residues are incorporated and shredded, have shown both national and global potential for greater conservation of soils, water and consequently a reduction of degradation processes; in addition, a significant decrease in energy expenditure, with the consequent savings in the investment of the production process (Bravo, 1995; Lal, 1997).

Direct seeding can be an option to reduce the vulnerability of irrigation zones to extreme events, as a result of the impact of climate change, which in recent years in Mexico and particularly in northern Sinaloa has increased climate variability. For the north of Sinaloa, they reported an increase of 1 °C for the year 2020 and its effect on the growth and water demands of the corn crop (Ojeda *et al*., 2011). Direct seeding can represent a viable alternative to improve the physical, chemical and biological properties of the soil, contributing to the reduction of CO_2 emissions in the atmosphere.

The objective of this work was to evaluate the evolution of the physical-chemical properties of the soil and the efficiency in the water use of the corn crop in two treatments: 1) direct sowing (SD) and 2) conventional tillage (LC) under irrigation by sprinkling (central pivot), was done during three agricultural cycles in the north of Sinaloa, Mexico.

Materials and methods

The work was carried out during three autumn-winter (OI) 2009-2010, 2010-2011 and 2011-2012 agricultural cycles, at the Valle del Fuerte Experimental Field (CEVAF) of the National Forestry, Agriculture and Livestock Research Institute (INIFAP), located in the arid zone of northern Sinaloa, Mexico, with geographic coordinates of 25.76° north latitude and 108.86° west longitude at a height of 20 meters above sea level. The experiment was established on a clay-textured soil typical of the region, with a usable volumetric moisture content (HA) of 0.155 cm^3 cm^{-3}, bulk density (Da) of 1.2 g cm^{-3} and organic matter (MO) content. 0.78%. The plot is part of the Irrigation District 075, Rio Fuerte, Sinaloa, one of the largest in Mexico (CONAGUA, 2015). A plot with sprinkler irrigation (central pivot) of one ha was used with two treatments: 1) direct sowing (SD) and 2) conventional tillage (LC) on a surface of 0.5 ha each.

The accumulated annual precipitation in the study area is 350 mm and it is concentrated from july to september with 70% of the accumulated rainfall in the year, while from february to may it is not significant. The annual values of the accumulated reference evapotranspiration (ETo) vary from 1 600 to 1 700 mm; it exceeds precipitation all year round because irrigation is required to ensure commercial yields of the crops.

For the scheduling of irrigation in real time, the Irrimodel© computer system of INIFAP was used to manage irrigation through the internet, developed by Sifuentes *et al*. (2013). This software offers the following benefits: 1) calculates the water demand of the crop; 2) generates irrigation plans under different scenarios of water availability and types of irrigation systems; 3) predicts irrigation using a water balance model with a high level of precision, according to the phenological development of the crop, using the concept of day degrees (ºD), documented by (Ojeda *et al*., 2006); and 4) it facilitates the monitoring of the irrigation of one or more plots in an agricultural cycle.

To know the evolution of the physical-chemical properties of the soil, the following soil properties were analytically determined: organic matter (MO), bulk density (Da), pH and electrical conductivity (CE) in each treatment. To measure the moisture balance in the soil profile, two fixed stations with humidity sensors type WatchDog-FDR were installed in each treatment at three depths (30, 60 and 90 cm) in a control area of 20 m^2, which they monitored soil moisture at 15-minute intervals. In the same stations, a soil temperature sensor 5 cm deep was installed on the surface.

The MO was determined by the Walkley and Black method modified by Walkley, which is based on the oxidation of organic matter with the dichromate of potassium (oxidizing agent), titled the excess of this with ferrous sulfate of normality known (reducing agent), using the following equation:

$$\%MO=\left[1-\frac{P}{T}\right]\times 1.34 \qquad 1)$$

Where: T= are the mL spent in the titration of the control; P= the mL spent in the titration of the problem.

The Da was determined by the cylinder method of known volume, sampling was carried out in each treatment, at the beginning and at the end of each crop agricultural cycle at a depth of 0-15 cm. The samples were weighed wet and then dried in a stove at a temperature of 105 °C for 48 h: the dry weight (Ms) was determined, which was used to obtain the bulk density with equation 2 cited by Narro (1994). In addition, the same samples were used to calculate soil porosity.

$$Da=\frac{Ms}{Vt} \qquad 2)$$

Ms is the mass of the solids of the sampled soil (g) and Vt the total volume of soil analyzed (cm^3). The moisture content of the soil was determined by the gravimetric method using auger before each of the 10 irrigations applied, at depths 0-30 and 30-60 cm. The estimation of the volumetric moisture content was made with equation 3.

$$\theta_v=\frac{Mw}{Ms}\times Da \qquad 3)$$

Where= Mw is the mass of water in the sample (g), Ms the mass of the solids (g) and Da the bulk density expressed in g cm^{-3}. The values were used to calculate the irrigation sheet and compare with the irrigation sheet generated by the Irrimodel©.

HA was estimated with the equation HA= Θ_{cc} -Θ_{pmp} and the empirical models proposed by Rawls and Brakensiek (1983), which use as variables: Texture, MO and Da, as shown below:

$$\theta_{cc}= 0.3436 - 0.0018(arena) + 0.0039(arcilla) + 0.0228(MO) - 0.0738(Da) \qquad 4)$$

$$\theta_{pmp}= 0.0854 - 0.0004(arena) + 0.0044(arcilla) + 0.0122(MO) - 0.0182(Da) \qquad 5)$$

Where the values of sand, clay and MO are given in percentage and Da in g cm^{-3}. The humidity constants (θ_{cc} and θ_{pmp}) are expressed in volumetric units (cm^3 cm^{-3}).

The pH was measured with a Zeromatic potentiometer in dS m^{-1} and CE in a Wheatstone Model RI.26 conductivity bridge at 25 °C.

Each applied irrigation was evaluated in terms of application efficiency (Ea) by means of the formula:

$$Ea=\frac{Ln}{Lb}\times 100 \qquad 6)$$

Where: Ln= is the net irrigation sheet or crop water requirement (cm); Lb= represents the applied irrigation sheet (cm); Ea= is expressed in (%).

To determine the yield (R) of the grain, samples were taken at five representative sites located in the two central rows of each treatment in an area of 7.6 m^2, for each site.

With the values of R expressed in kg ha-1 and the volume of total water applied (Vta) in m^3 ha^{-1}, water productivity (PA) was estimated, which indicates the relationship of R with respect to Vta, that is, the kilograms of grain produced by each m^3 of water applied (kg m^{-3}) (Bessembinder *et al*., 2005).

Results and discussion

Regarding the impact of the direct sowing and conventional tillage systems, it was observed that in the last agricultural cycle the MO content in SD reached 1.47% from an initial content of 0.78%, while in LC it reached only 1% of the same initial content. This indicates that there was a positive effect on the incorporation and transformation of crop residues (Figure 1). These results indicate that SD improves the MO content, microbial activity and the level of soil fertility, favoring the sustainability of this resource (Espinoza *et al*., 1998).

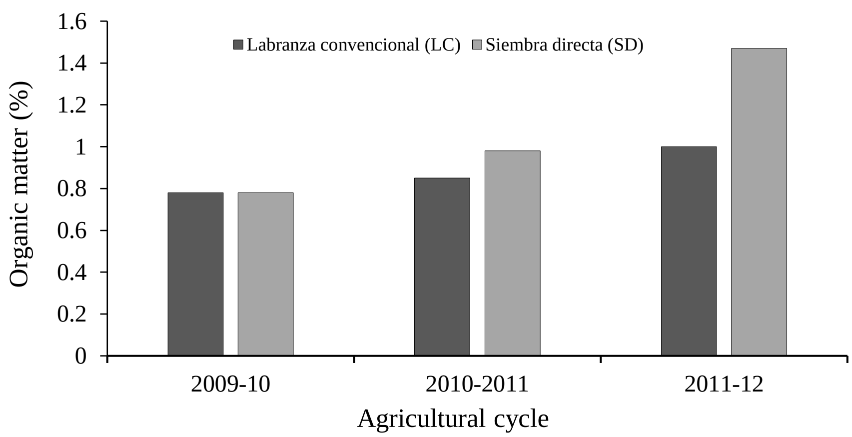

Figure 1. Comparison of soil organic matter content in three agricultural cycles in direct sowing (SD) and conventional tillage (LC) systems.

In Da, no response was found in the three agricultural cycles, because the rate of decomposition or mineralization of crop residues is relatively slow. In addition Da, varies depending on the texture of the soil and the MO content, among other factors. The values found never exceeded 1.2 g cm^{-3} well below the density levels critical for plant growth in this type of soil (Botta *et al*., 2004, 2006).

The porosity of the soil (E) in SD had an increase of 10%, this has a direct influence on the root system of the plant because once the crop is harvested, the roots are buried in the soil. As time passes and with the help of soil microbial activity, waste is broken down and small channels are left in the soil profile that promotes greater porosity and water infiltration. In contrast, in LC there was a 9% decrease, this is due to the excessive use of agricultural machinery that over time cause soil compaction (Table 1).

Table 1. Results of apparent density and soil porosity in the three agricultural cycles.

Agricultural cycle	Direct sowing		Conventional tillage	
	Da (g cm^{-3})	Porosity (%)	Da (g cm^{-3})	Porosity (%)
2009-2010	1.2	47	1.2	47
2012-2011	1.2	52	1.2	44
2011-2012	1.2	57	1.2	38
Difference	1.2	10	1.2	9

The pH in SD decreased 6.73 in the last cycle from an initial content of 7.17, while in LC it increased 7.25 from the same initial content (Table 2). Direct sowing went through an acidification process that can be attributed to the nitrification process of the nitrogenous fertilizer applied to the soil surface. Similar results have been reported in soils managed with conservation tillage for long periods Blevins *et al*. (1977). The moderate acidity found in the 0-15 cm layer could be reflected in limited availability of P, Ca, Mg and to a lesser degree, for N, P and S for crops (Ortiz-Villanueva and Ortiz-Solorio, 1990).

In relation to the CE, in the SD it decreased 0.17% during the last cycle from an initial content of 0.5%, while in LC it increased to 0.89% from the same initial content. Therefore, a reduction in SD was recorded, while in LC 0.39% was increased, which indicates that the soil does not present any problem and is suitable for the development of any crop under irrigation (Table 2).

Table 2. Results of pH and electrical conductivity.

Agricultural cycle	Direct sowing		Conventional tillage	
	pH	CE (dS m^{-1})	pH	CE (dS m^{-1})
2009-2010	7.17	0.5	7.17	0.5
2012-2011	7	0.3	7.2	0.7
2011-2012	6.73	0.17	7.25	0.89

Soil temperature (Ts) is one of the most important properties because, between certain limits, it controls the possibilities of seed germination, root development, soil formation, soil-air exchange and evaporation of the soil humidity.

In (Figure 2) the behavior of Ts in the treatments in direct seeding and conventional tillage during two agricultural cycles is observed. In the 2010-2011 cycle, an average temperature of 20 °C was observed in SD and 19 °C in the LC with a difference of 1 °C. In the 2011-12 agricultural cycle, a temperature of 17 °C in SD and 18.6 °C in LC was registered, with a difference of 1.5 °C. This decrease is due to the surface cover that covers the entire floor of this treatment and reduces water losses through evaporation and therefore, translates into a lower temperature. This behavior is similar to the results reported by (López *et al*., 2000).

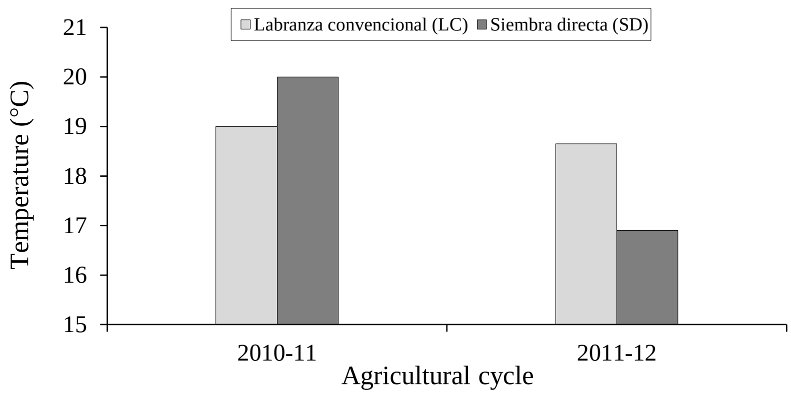

Figure 2. Average temperature obtained in agricultural cycle 2010-2011 and 2011-2012.

With respect to the moisture behavior in the soil profile, greater moisture stability was observed in SD throughout the soil profile, while in LC the moisture loss in the first stage of 0-30 cm was observed more quickly, due to the evaporation of the soil and this occurs mostly in the first stages of cultivation.

An increase of HA of 4.62% in SD was estimated while in LC it only reached 1.47% (Table 3). Confirming the conservative effect of crop residues (Fregoso *et al*., 2008). Figueroa and Morales (1996) indicate that, in most studies in Mexico, conservation tillage has conserved more moisture in the soil. These results are attributed to the function performed by the residue of corn left on the surface of the soil, being the decomposition in the layers that are in contact with the soil, since there are the best conditions of humidity and temperature for the greater soil microbial activity (Velázquez *et al*., 2002).

Table 3. Water storage capacity in direct seeding and conventional tillage.

Agricutural cycle	Direct sowing (SD)			Conventional tillage (LC)		
	CC	PMP	HA	CC	PMP	HA
2009-2010	51.3	35.5	15.8	51.3	35.5	15.8
2012-2011	51.8	35.8	16	51.5	35.6	15.9
2011-2012	52.9	36.3	16.6	51.8	35.8	16.1
Difference	+1.6	+0.8	+0.8	+0.5	+0.3	+0.3
Difference (%)	+3.1	+2.4	+4.6	+1	+0.8	+1.5

CC = field capacity; PMP = permanent wilting point; HA = usable humidity.

This humidity behavior in the soil allowed to apply nine irrigations in SD with a total sheet of 52.48 cm, while in LC were applied 10 with a total sheet of 54.18 cm. In this cycle, the possibility of a potential saving of 800 m^3 ha^{-1} in sprinkler irrigation was observed, with no loss in quality and grain yield.

The costs of production in direct seeding were lower when the use of agricultural machinery was reduced. Due to the tendency of increase of organic matter and the increase of the amount of straw on the surface, less presence of weeds was observed.

The water productivity in the last cycle was 1.51 and 1.38 kg m^{-3} for SD and LC respectively, derived from water savings and an increase of 6% in yield. This reflects the importance of maintaining optimum moisture conditions to achieve maximum yield potential.

Conclusions

The system of direct sowing production in the three agricultural cycles evaluated, contributed to the improvement of the physical-chemical properties of the soil. There was an increase in the content of organic matter, slight reduction in electrical conductivity (CE), tendency to lower the pH and in apparent density there was no response. In addition, the capacity of retention of usable humidity in the soil was increased by 4.7% with respect to the initial value and a reduction of 1.5 ºC of the temperature of the soil surface.

The increase of usable matter and humidity allowed to eliminate an irrigation of equivalent help to save a volume of 800 m^3 ha^{-1}. A 6% increase in yield was obtained and the water productivity was 1.51 kg m^{-3}, 0.13 units higher than LC. It was possible to reduce corn production costs by 20%, with respect to the traditional system, in the areas of land preparation, cultivation and weed control (effect of straw cover). This technique represents an alternative to reduce the vulnerability of irrigation zones to extreme events (drought and frost) and climate change, in addition to improving soil properties.

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