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Article

Accumulated impact of conservation agriculture on soil properties and corn yield

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Abstract

The preparation of the soil with more trailing fallow destroys the structure of the soil and degrades its physical properties. Conservation agriculture is an alternative that improves soil quality and crop yield. The objective of this study was to evaluate the cumulative impact of conservation agriculture on soil physical properties and corn yield. The study was carried out in an experimental plot with different tillage methods and 22 years old in the Experimental Field San Luis, of the INIFAP, in Soledad de Graciano Sánchez, SLP. The treatments of fallow plus harrow (B+R) and zero tillage were compared with 33% of the area covered with crop residues (LC+33% C). From 2012 to 2017, the XR-45 corn hybrid was planted in a rotation irrigating corn-oat fodder. By not altering the soil structure with LC+33% C for 22 years, there was a positive impact on porosity, bulk density, infiltration, aggregate stability and mechanical strength, which allowed an increase of 51.08% in yield of corn with respect to that obtained with B+R. The destruction of the soil structure with the B+R degrades the physical properties studied and was reflected in a lower yield of corn. Conservation agriculture is an alternative to improve soil quality and corn yield.

Keywords: hardness, infiltration, porosity, stability.

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Introduction

The mechanization of the field is a great technological achievement of humanity, since it lightened the work of farming, agronomic conduction and crop harvesting. However, the most common tasks of soil preparation, such as fallow plus harrow, were accepted and disseminated without a scientific evaluation as to its effect on soil quality and crop development (Faulker, 1974; Figueroa, 1999). The opportunity to work large extensions motivated its use and overshadowed the negative effects that from the beginning appeared in the soil by destroying its structure and leaving it without plant protection for long periods, exposed to the erosive action of wind and rain (Tiscareño *et al*., 1999; FAO, 2015).

Soil structure and its stability play a decisive role in a variety of physical processes such as infiltration, moisture retention, erosion reduction, mechanical resistance to penetration, root development and aeration among others (Osuna *et al*., 2006), so that their deterioration contributes to the degradation of the soil, with the consequent reduction of agricultural production and ecological stability (Huggins and Reganold, 2008). The problem of wind erosion or ‘dust bowl’, registered during the decade of the 1930s in the Great Plains in the United States of America, is an example of the problem generated by improperly working the land to be incorporated into agriculture (Faulkner, 1974).

When the soil profile was inverted, the vegetation cover that protected it was destroyed, as well as its structure, breaking up the soil particles, which were exposed to the action of the wind, generating large dustholes that caused a health problem in the inhabitants and a deterioration in the soils when they were eroded and where these sediments were deposited (Egan, 2006). Given this problem, two currents in agricultural production were generated from that time, one that adopted without reservation the use of agricultural implements and that led to the green revolution and the other, was the one that sought an agriculture that did not completely disturb the soil, leave crop residues and rotate crops, which is currently known as conservation agriculture (Sojka and Upchurch, 1999; Cook *et al*., 2009). In the Plateu of northern central Mexico, Osuna *et al*. (2016), quantified a soil loss of 30 t ha^{-1} with conventional tillage compared to soil and water conservation practices.

In Mexico, the model that was most popularized as a soil preparation method for planting crops and was accepted without experimental evidence in different climates, types of soil and humidity condition was the use of fallow and harrow (Figueroa, 1982 and 1999). Mexican producers and technicians, until before the 1990s, were educated on the basis of this model of agricultural production, which remains one of the most entrenched practices in the production of food in the countryside and with a strong resistance to however, currently there is scientific information on alternative methods of soil preparation that are different from the traditional fallow plus harrow (Velásquez *et al*., 1997; Jasso *et al*., 2001).

An alternative that can improve or solve the problems caused by excessive continuous tillage is conservation agriculture (Reicosky, 2003; Lal *et al*., 2004; Mitchell *et al*., 2015). Conservation agriculture is defined by three main actions: a) that the soil moves as little as possible to carry out the sowing of crops; b) protect the surface of the soil with crop residues; and c) crop rotation is practiced (Giller *et al*., 2015).

The degradation of the soil with inadequate methods of preparation for planting threatens more than 40% of agricultural soils and is a negative influence on the food security of a world population that by the year 2050 will reach 9 500 million people (Delgado *et al*., 2011). Agricultural production is related to the health of the soil, and organic matter is the main indicator (Cambardela and Elliot, 1992; Franzluebbers, 2010), in addition to a productive land is the best defense of the producers to climatic accidents, so that increasing organic matter in the soil and improving its structure are factors that will make it possible to provide sustainable responses to food security, the effects of climate change and the reduction of greenhouse gas emissions as established in the Paris Treaty on climate change signed by several countries, including Mexico (United Nations, 2015).

In this treaty, the international scientific community is asked to generate agricultural production practices that promote an increase of four per thousand in the content of soil organic matter (Bouma, 2009; Ministerio de agricultura del gobierno de Francia, 2015).

For more than 50 years, the soils of the Plateau of San Luis Potosí have been fallowed and tracked, where the result of these actions has been the deterioration of the productive capacity of the soil by destroying its structure and reducing its content of organic matter (Martínez *et al*., 2005). It is urgent to generate alternatives in the preparation of the soil that allow to revert and avoid a greater loss in its productivity capacity. Based on the aforementioned background, conservation agriculture is a viable alternative to improve and conserve soil quality, in such a way that the objective of this study was to evaluate the cumulative impact of conservation agriculture on physical properties of soil and corn yield.

Materials and methods

In 1995 a research plot was established in the San Luis Experimental Field, located at km 14.5 of highway 57, San Luis Potosí-Matehuala section, in the Common of Palma de la Cruz, Soledad de Graciano Sánchez, San Luis Potosí, located at coordinates 22º 13’ 45.78’’ North latitude and 100º 51’ 01.54’’ West longitude at an altitude of 1 838 m, with average annual temperature and precipitation of 16.2 °C 210 mm (CGSNEGI, 1995). The type of soil is classified as Feozem, with a sandy clay loam texture, with 1.4% organic matter, pH of 8.1 and EC of 0.81 dS m^{-1} and compaction problems in the entire profile. Water for irrigation registered an EC of 0.29 dS m^{-1}, RASaj of 1.26, low in salinity and sodicity.

The evaluated treatments were: fallow plus harrow (B+R) and zero tillage plus 33% soil cover (LC+33% C) which are distributed in a random block design with two replications and established in plots of 10 furrows to 0.825 m between each other (treatment B+R) or five beds of 1.65 m wide (LC treatment+33% C), in both cases, the length of the plots was 30 m. In the treatment with fallow, this practice was carried out with a plow disk at a depth of 0.3 m and the harrow was made at a depth of 0.15 m. Each year, the treatment of B+R was carried out twice a year, one before planting corn and the other before sowing the forage oats.

From 1995 to 2017, a rotation of fodder-fodder oats was carried out, where corn is sown in the spring-summer cycle and oats in the autumn-winter cycle. From 2012 to 2017 the hybrid XR-45 was planted. The population density employed was 70 000 plants per hectare, with a separation between rows of 0.825 m between them and 0.17 m between plants. It was fertilized with the formula 200-100-00 with 50% of the nitrogen and 100% of the phosphorus applied in the sowing and 50% remaining of the nitrogen in the second weeding. Irrigation of 10 cm of sheet was applied, when the sowing at the beginning of flowering had a depletion of the usable humidity of 40% and when flowering to physiological maturity reached 70% of the usable humidity.

The control of the weeds before sowing, for the LC+33% C treatment, was carried out with the application of the herbicide glyphosate at 1 400 g ia ha^{-1}, and after sowing, before the crop emerged, the pre-emerging atrazine herbicide was applied at 0.75 kg ia ha^{-1}. In the treatment of B+R, two mechanical wefts were performed, the first at 21 days after sowing (DDS) and the second at 35 DDS. The control of the armyworm was carried out with the insecticide Spinetoram at 5.87 ia ha^{-1}. To evaluate the yield of corn grain, two random samples of 6 m length were taken per treatment in the fifth row of each treatment. The results were analyzed according to the random block design with two subsamples and two repetitions.

At the end of the spring-summer cycle of 2017, the following measurements were made apparent density, infiltration, mechanical strength and porosity. For the apparent density, the cylinder method with known volume in the strata of 0-0.025, 0-0.025-0.1 and 0.1-0.15 m was used. The infiltration was determined with the double cylinder method, at three random points in each treatment and repetition, with a duration of two hours. The mechanical strength was determined with a SC 900 digital penetrometer from Spectrum Technologies, Inc., which performs measurements of soil strength every 0.05 m in a profile from 0 to 0.45 m depth.

The porosity of the soil was determined in the layers of 0-0.05, 0-0.1, 0-0.2 and 0-0.25 m by obtaining undisturbed soil samples, which were dehydrated and impregnated with resin and a fluorescent pigment (Uvitex) in ultraviolet light. Horizontal sections were obtained at the depth of 0.05, 0.1, 0.2 and 0.25 m and analyzed by means of digital images with white light and ultraviolet light (González-Cervantes *et al*., 2004).

Results and discussion

Apparent density

Figure 1 shows the values obtained for apparent density in strata 0-0.025, 0.025-0.1 and 0.1-0.15 m. The statistical analysis reported significant differences ($p< 0.05$) favorable to the treatment with LC+33% C.

In the treatment of B+R the highest values of apparent density were obtained in the three depths analyzed (1 486 g cm^{-3} in the stratum 0-0.15 m), while in the treatment with the lowest value was reported (1 189 g cm^{-3} in the stratum 0-0.025 m). The above, indicates that the fallow destroys the continuity of the pores and the structure of the soil, in addition to sending below the soil surface the few residues of the crop, including the root. Later, with the passage of the harrow, the clods are practically pulverized, which leaves the soil particles loose and susceptible to being removed by the wind or water, as there is no vegetable protection on the surface (Osuna-Ceja *et al*., 2006).

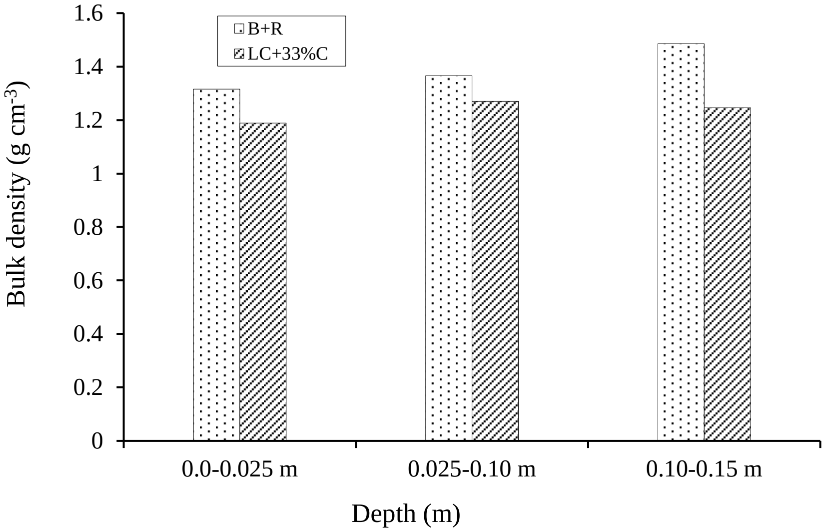

Figure 1. Apparent density in different strata of the soil profile, in lot with 22 years old with different tillage methods in the San Luis Experimental Field.

The loose soil particles when coming into contact with rainwater or irrigation tend to regroup, but due to the fact that almost all the biomass of crops is removed and the oxidation of organic matter is exposed to weathering with fallow and harrow, the content of organic matter in the soil is each cycle of lower culture, so that the particles adhere to each other forming a caked structure, with very little porosity, which when drying, for its low content of organic matter hardens, hindering the growth of the root and consequently of the crop (Cambardela and Elliott, 1992).

The result is that, in a given volume, a greater weight of soil can be accommodated, which generates higher values of apparent density than those obtained with zero tillage. In no-tillage treatments, the soil structure is not destroyed, maintaining a continuity in the pores, the roots remain in place and each year the organic matter content increases, so that the weight of the soil in a given volume it was lower in the LC+33% C treatment, which allowed to obtain lower values of apparent density to those registered with B+R.

By not altering the soil structure for 22 years, in the LC+33% C treatment, the formation of a structure with greater porosity was favored, mainly in the upper layer of 0-0.025 m, while in the treatment with B+R the soil was compacted.

Infiltration rate

One of the benefits of conservation agriculture is the increase in the infiltration rate in the soil (Figueroa, 1982, 1999). Figure 2 shows how the initial infiltration, in the test performed at the end of the corn crop cycle, with B+R was 0.398 cm h^{-1} versus 9.398 cm h^{-1} in the LC+33% C treatment. The infiltration at the end of the two hours of testing was 0.0201 and 0.8276 cm h^{-1} for the treatments with B+R and LC+33% C, respectively.

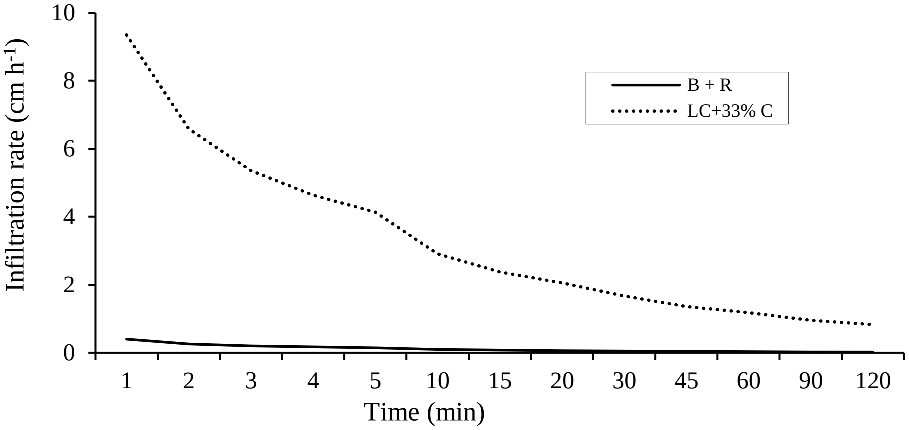

Figure 2. Infiltration speed in batch with 22 years old with different tillage methods in the San Luis Experimental Field.

In the treatment with LC+33% C as the soil profile was not altered with the use of the fallow, the aggregates and the porosity was not destroyed, so a more porous structure was maintained, as well as a continuity in the length of the pores in the soil profile. This better porosity was the result of not altering with any type of tillage the structure of the soil, the contribution of the roots of the plants of previous cycles, which after decomposition leave a significant amount of macropores in the upper stratum of the soil, in the case of the root of the corn crop and an important volume of roots of smaller diameter, in the case of oats and triticale.

By maintaining and improving the porosity in the no-tillage treatment, the hydrodynamic properties thereof, especially the infiltration rate, benefited compared to treatment with B+R. In this treatment, the structure of the soil and therefore the porosity and its continuity in the soil profile were destroyed, so the infiltration in these treatments was slower, which agrees with that reported by Martínez *et al*. (2014).

Another factor for the low infiltration in the treatment B+R was the low stability of soil aggregates when it came into contact with water. In Figure 3, two aggregates are observed, one of the treatments with B+R and another with LC+33% C, before being submerged in the same volume of water.

Figure 3. Clods of treatments with B+R and conservation agriculture (LC+33% C).

When coming into contact with the water, the clod with B+R immediately began to fall apart due to the pressure that the water exerted on its particles, while the clod with LC+33% C only released few soil particles and because of the manipulation exercised to take the sample (Figure 4).

Figure 4. On the left, the B+R clod began to dissolve on contact with water, on the right, the clod with conservation agriculture was almost intact.

After one minute, in Figure 5 the size of the two clods is observed. The clod with B+R almost fell apart. While the zero-tillage remained more integral.

Figure 5. Size of the clods with B+R and conservation agriculture, after one minute of being submerged in water.

The above, helps explain what happens in each irrigation or rainy event in the treatment with B+R where the soil structure is destroyed and its organic matter content each cycle is lower because of extracting all the biomass of the crops year after year. In each irrigation or rain, soil aggregates tend to be destroyed, releasing the soil particles by the pressure exerted by the irrigation sheet or rain (Tisdall and Oades, 1982). These loose particles cause a clogging of the little porosity present in this treatment, which causes the infiltration rate to be very slow (Reicosky, 2003; Mitchell *et al*., 2016).

In contrast, in the no-tillage treatment, the soil aggregates have greater stability and are not destroyed by contact with water, that is, their soil particles are more adhered to each other by the organic matter that has accumulated in these treatments, coupled with the fact that the pores have a greater continuity in the profile of the soil since they were not destroyed by the fallow or harrow. In Figure 3 it can be seen that the no-till clod has a greater number of roots, which help to hold and maintain more stable soil particles than in the B+R clod, in which they are practically not observed residues of roots so that the aggregates do not have the cohesive capacity that organic matter gives, easily disbanding on contact with water.

Mechanical resistance of the soil

The mechanical resistance of the soil with different tillage treatments at the end of the corn crop cycle is presented in Figure 6. The soil compaction at that stage was greater in the treatment of B+R, at 25 cm depth, with 6 000 kPa, while the resistance in the LC+33% C treatment at that same depth was 491 kPa. This shows the negative effect on soil quality when fallowing and tracing the soil as soil preparation methods for sowing, since the soil structure is destroyed and, due to the low content of organic matter, the particles they rearrange in a massive way and when drying, they compact and harden the soil profile.

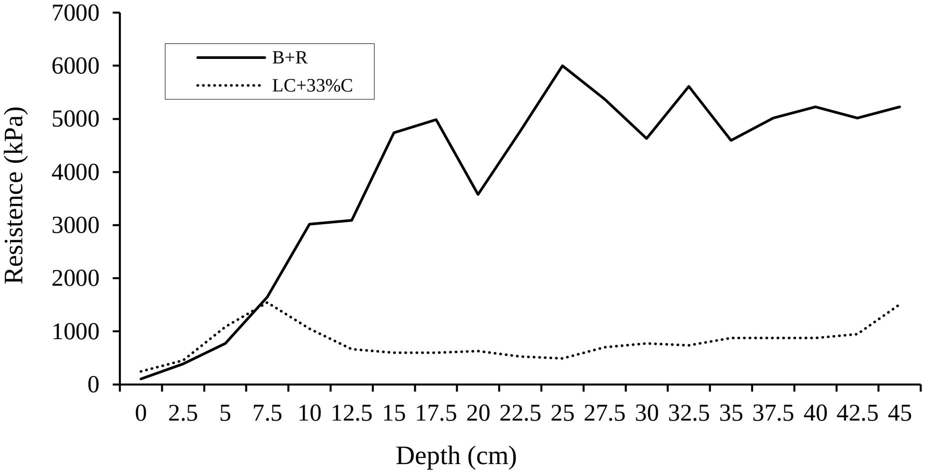

Figure 6. Mechanical soil resistance with different methods of soil preparation at the end of the crop cycle with irrigation corn in the San Luis Experimental Field.

Traditionally, fallowing is considered more harrowing as the only method to prepare the soil for sowing. On the one hand, producers are right to choose this traditional method, because according to the information in Figure 6, the hardness in the soil profile from 0 to 0.45 m is very high. With this hardness, technically it is not recommended to carry out a direct sowing, since there would be problems to deposit the seed at a suitable depth for its germination. Subsequently, the roots of the crop would not develop properly and consequently the crop either.

Given a hardness of this magnitude, even above 2 000 kPa, (Figueroa, 1999; FAO, 2015), recommend using such tasks as subsoil, fallow and harrow to decompact and reduce the hardness of the soil and favor planting, emergence and development of the crop.

When fallowing and tracing the soil a vicious circle is generated, because at the beginning of the crop the soil is completely loose, it does not represent an obstacle for the germination of the seeds, however, at the end of the cycle, the hardness that the soil presents it leaves no alternative but to use the fallow harder again. When direct sowing, in the treatment with LC+33% C, in permanent beds of 1.65 m in width, the sowing is carried out in separate rows 0.825 m. When the sowing of the crops coincides, year after year, the accumulation of roots and stem stumps that are left after cutting the corn and oats or triticale area are favored. This accumulation of organic matter in that area of sowing allowed the soil not to be compacted at levels such as those reported in the treatment of B+R.

The presence of traces of roots improved the structure of the soil and the stability of the soil aggregates (Tisdall and Oades, 1982) and facilitated the development of new roots, which will contribute to a better development of the following crop root (Sojka and Upchurch, 1999). Here the negative circle of hardening of the soil is broken and a positive circle is generated where each cycle the residues of the roots will favor a better development of the next crop root. That is the reason why soil hardness values in the no-tillage treatment reported values lower than 1 600 kPa in the soil profile at the end of the corn crop cycle.

In 2015 and 2017, this positive effect, generated by the accumulation of roots in the sowing area of the permanent beds, contributed to obtain an emergency of the population density higher than 95% after a rainfall of only 5 mm, while in the treatment with B+R the emergence of plants was affected in 45%. Due to the low stability of the aggregates and the low organic matter of the soil, in the treatment with B+R, the occurrence of 5 mm of rain was enough to generate a dry and hard crust on the surface of the soil, which prevented the normal emergence of corn seedlings.

The soil compaction in the treatment with B+R started from the first rain or relief irrigation and reached its maximum at the end of the crop cycle. This compaction affected the normal development of corn throughout the cycle. Figure 7 shows the effect of this soil compaction on the development of the corn crop 45 days after sowing in the B+R treatment, observing how the soil cracks and hardens when dried.

Figure 7. Soil compaction in the treatment with B+R.

Figure 8 shows that in the treatment of LC+33% C there is no indication that the soil is compacted.

Figure 8. No cracks in the soil surface as an indicator of less soil compaction in the LC+33% C treatment.

Porosity

Soil porosity is generated by the aggregation of soil particles and is affected by the amount of organic matter, soil fauna and stability of soil aggregates (Huggins and Reganold, 2008). Figure 9 shows the porosity values in the treatments of B+R and LC+33% C in the strata of 0-0.05, 0.05-0.1, 0.1-0.2 and 0.2 to 0.25 m. The total porosity in all depths evaluated was higher in the LC+33% C treatment in relation to the B+R.

It stands out that, in the layers of 0-0.05 and 0.05-0.1 m, the total porosity was higher in 86 and 100% in the treatment with LC+33% C in relation to that observed in B+R. These results agree with the values of lower apparent density reported for the treatment of LC+33% C, where by not destroying the soil structure with any tillage method, it allowed to maintain and improve the aggregation of the soil particles, in addition to have the presence of pores formed by the decomposition of the roots and the activity of the fauna in the first 10 cm, while in the treatment with B+R the soil started again the generation of porous spaces from the aggregation of soil particles and the presence of roots after being fallowed and tracked.

In Figure 9 it is observed that, of the total porosity in the treatment with LC+33% C, 39% corresponded to the macropores (diameter >10 mm) against 16% in B+R. The macropores correspond to the pores left by the roots and the edaphic fauna and that have had an accumulated effect in the treatment with zero tillage, while with the B+R they are destroyed during the preparation of the soil before the sowing of corn and oats or triticale.

The mesopores (diameter between 2 and 20 mm) kept a percentage with respect to the total porosity of 17 and 13.5% for B+R and LC+33% C, respectively. These results help to explain the difference in the infiltration rate, since the treatment of LC+33% C presented macropores from the surface to a depth of 0.25 m, with which the water infiltrated faster than in the B+R, where the percentage of macropores was lower.

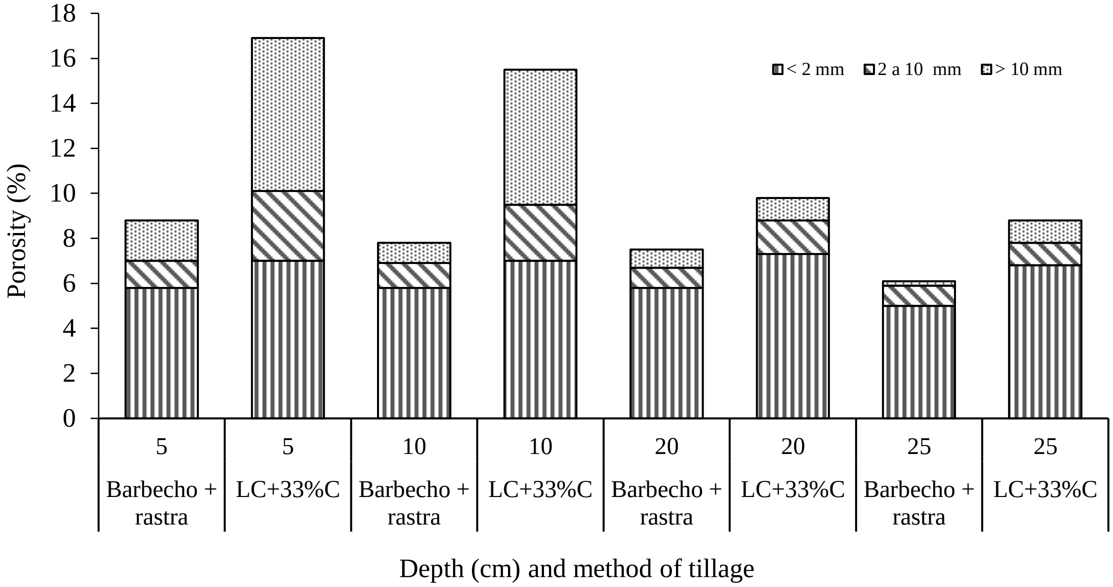

Figure 9. Porosity of the soil at different depths of the soil profile with different tillage methods in the San Luis Experimental Field.

Corn yield

The statistical analysis reported difference between treatment means (Tukey, α= 0.05) favorable to no-tillage treatment. Figure 10 shows the yield of corn grain obtained in the period from 2012 to 2016, where it is observed that the yield of corn grain in the no-tillage treatment was on average 51.68% higher than that registered with the treatment of corn. B+R in the last five years. The grain yield is the result that reflects the environmental conditions that the crop had during its development period. In the no-tillage treatment, the soil registered less compaction, greater porosity, greater contribution of organic matter to the soil, more stability of aggregates and greater infiltration speed, so the crop had better conditions in the soil to achieve higher yields than the 10 t ha^{-1}.

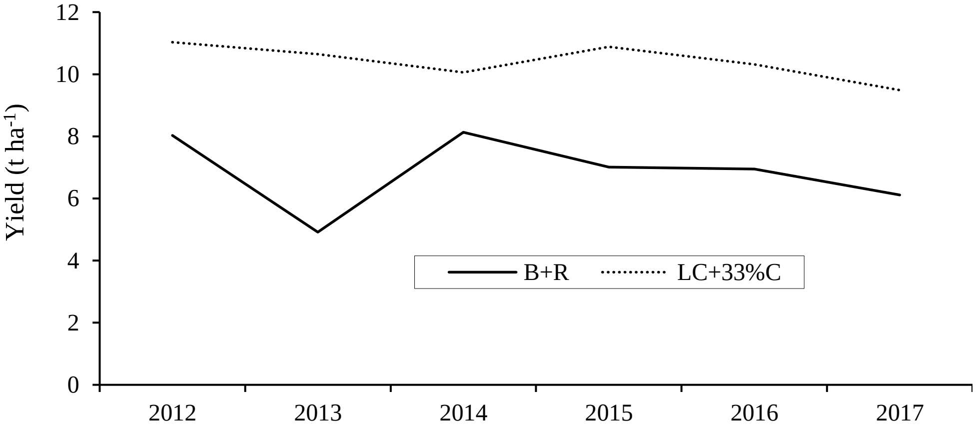

Figure 10. Corn grain yield with different tillage methods in the San Luis Experimental Field in the period from 2012 to 2017.

Financial analysis

In Table 1 a financial analysis is presented between the treatments of B+R and LC+33% C to determine the production cost of one kilogram of corn.

Table 1. Financial analysis to determine the production cost of one kilogram of corn with different tillage methods in the San Luis Experimental Field.

Concept	B+R	LC+33%C
Fallow ($ ha^{-1})	1 000	0
Dredge ($ ha^{-1})	500	0
Herbicide ($ ha^{-1})	0	600
Furrowed ($ ha^{-1})	300	0
Fertilization (dose 180-80-00)	6 200	6 200
Irrigation ($ ha^{-1})	5 000	5 000
Seed (65 000 seeds ha^{-1})	3 850	3 850
Weeding ($ ha^{-1})	450	0
Weed control ($ ha^{-1})	650	650
Pest control ($ ha^{-1})	650	650
Threshing ($ ha^{-1})	2 400	2 400
Total cost ($)	21 000	19 350
Yield (t ha^{-1})	6 858	10 402
Gross income ($)	34 290	52 010
Cost to produce a kilogram of corn ($)	3.062	1.86

For B+R the production cost of one hectare was $21 000.00, so the cost to produce a kilogram of corn was $2 997.00. For the case of no-tillage treatment, the production costs were $19 350.00 and that of producing a kilogram of corn was $1 828.00. The difference in production costs between these two treatments was the cost of preparation of fallow and dredge soil, with a value of $1 500.00 plus $450.00 of weeding, for a subtotal of $1 950.00.

In the treatment with LC+33% C, $600.00 was used for weed control before sowing, which resulted in savings of $1 350.00 per hectare in relation to B+R. This financial analysis does not reflect the benefit that conservation agriculture leaves on the soil, such as the increase in organic matter, better stability of soil aggregates and infiltration and less compaction, among other factors.

Conclusions

By not altering the soil structure for 22 years in the treatment of LC+33% C, a difference in the porosity of the first 0.1 m, 100% higher than that registered in the treatment of B+R, was favored. The difference in porosity was reflected in a lower less compact bulk density in the treatment of LC+33% C and more compact in that of B+R. The initial infiltration in the treatment of LC+33% C, was favorably affected by the greater porosity and bulk density in this treatment when registering a value of 9.398 cm h^{-1}, while in the treatment with B+R, the initial infiltration it was affected by the lower porosity and greater apparent density and registered a value of only 0.398 cm h^{-1}.

The mechanical resistance of the soil in the B+R treatment registered a value of up to 6000 KPa, while in the treatment with LC+33% C, the maximum value was 1 544 KPa. The yield of corn grain was higher with the LC+33% C treatment given the differences in soil quality in the treatment of LC+33% C compared to the treatment with B+R. Land preparation costs were reduced from $1 800.00 with B+R to $600.00 with LC+33% C. The production cost of one kilogram of corn was reduced by 39% with LC+33% C in relation to that obtained with B+R.

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