Article

Diagnosis of compaction in soils cultivated with corn in the Fraylesca Region, Chiapas

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Abstract

Soil compaction is a problem recently identified as one of the main constraints on the maize surface of the municipality of Villaflores in the region of The Frailesca, Chiapas, due to this, it needs to be studied with greater precision. The objective of this study was to characterize the problem of compaction on the mechanized surface cultivated with corn in the New Mexico commn. We studied 177 plots, in which the apparent density, organic matter and texture were determined at the depths of 0-20 and 20-40 cm. The owners of the properties were interviewed to obtain information about their cultivation practices and corn productivity levels. The results show that 83.3% of the studied area presented superficial compaction and 94.6% compaction in the subsoil (plow floor). The producers pointed out that in years with critical periods of drought the yields are reduced by 58%, which is correlated with the decrease of the porosity as a result of the compaction. The main causes of the compaction were the intensive tillage with machinery 100% of the sites, the very low content of 100% organic matter and the type of soil (luvisols and acrisols). The attention of the compaction problem requires a comprehensive corrective and preventive strategy that should take as a central element the elevation of the contents of organic matter, to reverse the current unsustainable management of the land.

Keywords: corn, soil, unsustainable management.

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Introduction

With an area of 798 023.9 ha, the region of The Frailesca stands out for its production of rainfed corn with 199 933 tons in 5 537 ha cultivated, it is considered the granary of Chiapas (Ministry of Finance of Chiapas, 2012, Martínez and Espinosa, 2014). According to López *et al*. (2008), the Frailesca is located as the second region with the largest area with great potential for corn cultivation with 84 096 ha.

However, several years ago, several studies (Van Nieuwkoop *et al*., 1992; Pulleman *et al*., 2008) have shown that maize yields in the region have been decreasing, mainly due to the low general fertility of crops. soils with around 25% of the properties with a percentage of aluminum saturation higher than 20%, considered critical for corn cultivation (Tasistro, 2012), sub superficial compaction, inadequate crop nutrition, monoculture of corn with burning of crop residues, soil erosion and the implementation of inappropriate agronomic management practices that limit the productive, ecological and economic potential of corn production systems.

With regard to compaction, the diagnoses detected in mechanized soils cultivated with corn, the presence of a hard layer at an average depth of 12.4 cm (±4.1). As a result of the studies carried out since 2010 by INIFAP, CIMMYT and IPNI, subsoiling stood out as an immediate alternative to break up the compacted layer, as part of an integral strategy for the productive rehabilitation of soils (López *et al*., 2016). Due to the effects shown by subsoiling in the spring-summer crop cycle of 2015, in which there was a severe drought problem, which caused total loss of production in most corn plots compared to the plots subsoiled, which were only partially affected, a great interest has been generated in the producers to apply the technology in their plots, especially in the common of New Mexico, municipality of Villaflores, where the demonstration modules are established.

The objective of the study was to analyze the problem of compaction of maize soils in the New Mexico common, municipality of Villaflores, as a preliminary phase for the design and implementation of a pilot program of productive rehabilitation.

Materials and methods

The study was carried out in the New Mexico common, municipality of Villaflores within the Frailesca region that is part of the physiographic regions Sierra Madre of Chiapas and Central Depression (Figure 1); the relief of the land is formed mainly of mountain ranges and valleys with heights between 279 and 2 755 masl. The subhumid climate predominates with rains in summer with precipitation between 1 000- 2 600 mm during the May-October period. The Lithosols, Regosols, Acrisols and Luvisols soils together occupy 80% of the area.

The compaction problem was studied in the flat corn areas where the producers work the soils with the tractor use equipped with a plow or disc harrow, for this reason, the hillside lands with slopes greater than 20% were excluded. The works were carried out during the first quarter of 2016.

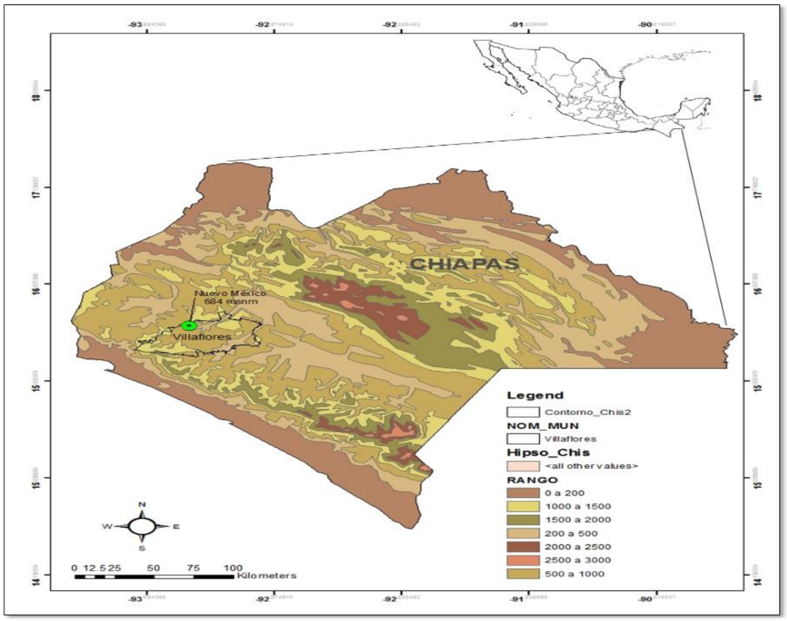

Figure 1. Map of New Mexico, Villaflores, Chiapas.

In a grid of 500 m x 500 m, 177 points were geographically distributed, in which the bulk density (DA) was determined as an indicator of compaction (Blanco, 2009) and by the excavation method (Dane and Topp, 2002; Recio, 2009), at each point samples were taken at the depths 0-20 cm and 20-40 cm to make a total of 354. The DA was calculated by dividing the weight of the dry extracted soil (g) by the total volume (cm^3) of water. Additionally, in each sample, organic matter (MO) and texture were determined according to Official Mexican Standard NON-021-RECNAT-2000. The producers of the sampled farms were interviewed to obtain information about their cultivation practices and maize productivity levels. To identify possible effects of the compaction on the root growth of the plants, the DA values were grouped by soil textural class, based on the criteria indicated by USDA (1999).

The data were analyzed using SAS with measures of centrality and dispersion, analysis of variance, correlation and regression analysis (Gomez and Gomez, 1984; Steel and Torrie, 1986).

For the zoning of the compaction problem, the soils were grouped into compaction classes (without problem, mild, moderate and severe) depending on the interaction between the textural class and the DA value, taking as a reference USDA criteria (1999) , the class without problem corresponds to the cases where the value of DA is below the ideal value assigned to each textural class and the serious class, when the value of DA is above the value considered critical for the growth of roots in each textural class (Table 1).

From spatial analysis and interpolations of the georeferenced data (Watson and Philip, 1985) of texture and DA of the 177 sampled sites, using ArcMap, the primary maps of texture and DA were generated and later through the superposition of both; He obtained the map with the compaction classes. The weighted inverse distance method (IDW) was used for the interpolation, which determines the cell values through a linearly weighted combination of a set of sample points, where the weighting is a function of the inverse distance. This method is based mainly on the inverse of the distance raised to a mathematical power; the power parameter allows you to control the significance of known points in the interpolated values based on the distance from the output point. Its result is a positive real number and its default value is 2 (Watson and Philip, 1985).

Table 1. Classes of compaction according to textural class and bulk density.

Textural class	Bulk density (g cm^{-3}) by compaction class			
	No problem	Slight	Moderate	Severe
Silty clay	< 1.1	1.1 - 1.39	1.39 - 1.58	>1.58
Clay	< 1.1	1.1 - 1.39	1.39 - 1.47	>1.47
Loam, clay-loam, loamy sandy clay	< 1.4	1.4 - 1.6	1.6 - 1.75	> 1.75
Loam silty clay, silty loam	< 1.4	1.4 - 1.55	1.55 - 1.65	> 1.65
Sandy loam	< 1.4	1.4 - 1.63	1.63 - 1.8	> 1.8
Silt	< 1.3	1.3 - 1.6	1.6 - 1.75	> 1.75
Sand	< 1.6	1.6 - 1.69	1.69 - 1.8	> 1.8

Results and discussion

The problem of soil compaction

The results of table 2 indicate that, on average, the values of bulk density in the subsoil exceed 0.14 g cm^3 to those of the surface, and this difference is statistically significant (Prob. 0.00006). Also in the subsoil, the highest and lowest maximum bulk density values were presented.

Table 2. Bulk density statistics (g cm^{-3}) according to soil depth.

Statistical	Depth	
	0-20 cm	20-40 cm
Mean	1.46	1.6
Minimum	0.73	0.77
Maximum	1.93	2.19
Standard deviation	0.16	0.22
Coefficient of variation (%)	11.18	13.76
Test of F (Prob.)	0.00006	

In Table 3 it is observed that 65.5% of the sites present surface compaction because the value of DA determined, is greater than the value considered as ideal for each textural class (USDA, 1999). The 12% is located in a situation, where there could be affectations for the root growth and 1.7% the compaction presents restrictions for the growth of the roots of the crops. It should be noted that in all the sites a crust was observed in the first 5 cm of depth, defined by FAO (2016), as the formation of a thin impermeable layer on the surface of the soil.

Table 3. General relationship between bulk density (DA) on the soil surface (0-20 cm) and root growth based on soil texture.

Surface texture	Total cases	DA ideal		DA that can affect root growth		DA that restricts root growth	
		(g cm^{-3})	Cases	(g cm^{-3})	Cases	(g cm^{-3})	Cases
Loam	82	<1.4	29	1.69-1.8	6	>1.8	0
Loam-silty	38	<1.4	16	1.55-1.75	6	>1.75	1
Loam-sandy	38	<1.4	8	1.63-1.8	6	>1.8	1
Loam-clay	10	<1.4	4	1.60-1.75	2	>1.75	0
Loam-clayey-silty	4	<1.4	2	1.55-1.65	0	>1.65	0
Clay	2	<1.1	0	1.39-1.47	1	>1.47	1
Silty clay	1	<1.1	0	1.39-1.58	1	>1.58	0
Silt	2	<1.3	2	1.6-1.75	0	>1.75	0
Total	177		61		22		3
(%)	100		34.5		12.4		1.7

In the depth of 20-40 cm, the bulk density (DA) of 86.4% of the sites are above the value considered ideal. Similarly, the percentages of sites in which there could be impairments and restrictions on root growth increase to 29 and 24.4%, respectively. This problem is reported by FAO (2016), as “plow floor” caused by the decrease in pore volume as a result of compaction, which is reflected in a higher apparent density.

Table 4. General relationship between DA in the depth of 20-40 cm and root growth based on soil texture.

Textura subsuelo	Total cases	DA ideal		DA that can affect root growth		DA that restricts root growth	
		(g cm^{-3})	Cases	(g cm^{-3})	Cases	(g cm^{-3})	Cases
Loam	74	<1.4	7	1.69-1.8	15	>1.8	15
Loam-silty	27	<1.4	12	1.55-1.75	9	>1.75	2
Loam-sandy	22	<1.4	0	1.63-1.8	13	>1.8	4
Loam-clayey	21	<1.4	2	1.6-1.75	7	>1.75	5
Loam-clay-silty	14	<1.4	2	1.55-1.65	2	>1.65	9
Clay	11	<1.1	0	1.39-1.47	1	>1.47	8
Clayey-silt	3	<1.1	0	1.39-1.58	3	>1.58	0
Silt	2	<1.3	1	1.6-1.75		>1.75	0
Loam-clay-sandy	2	<1.4	0	1.6-1.75		>1.75	0
Sand	1	<1.6	1	1.69-1.8		>1.8	
Total	177		24		50		43
(%)	100		13.6		28.2		24.3

Zoning and spatial magnitude of soil compaction

In Table 5, it is observed that in the depth of 0-20 cm 83.3% of the surface presents a problem of compaction in its different categories, with slight compaction standing out in 65% of the area, followed by moderate compaction 11.7%.

Table 5. Surface (ha) by degrees of compaction according to soil depth.

Clase	Depth (0-20 cm)		Depth (20-40 cm)	
	Surface (ha)	(%)	Surface (ha)	(%)
No problem	128.14	16.87	41.15	5.42
Slight	494.13	65.06	134.73	17.74
Moderate	89.31	11.76	172.79	22.75
Severe	47.98	6.32	410.88	54.1
Total	759.55	100	759.55	100

For the depth of 20-40 cm, 94.6% presents compaction in its different categories, with the severe class standing out 54.1% of the area, followed by moderate and slight compaction 22.7 and 17.7% of the area, respectively. It is notorious that in the subsoil (20-40 cm) in addition to increasing the surface with compaction, the intensity of the problem is greater, as the categories of severe and moderate compaction predominate (Figure 3 and 4).

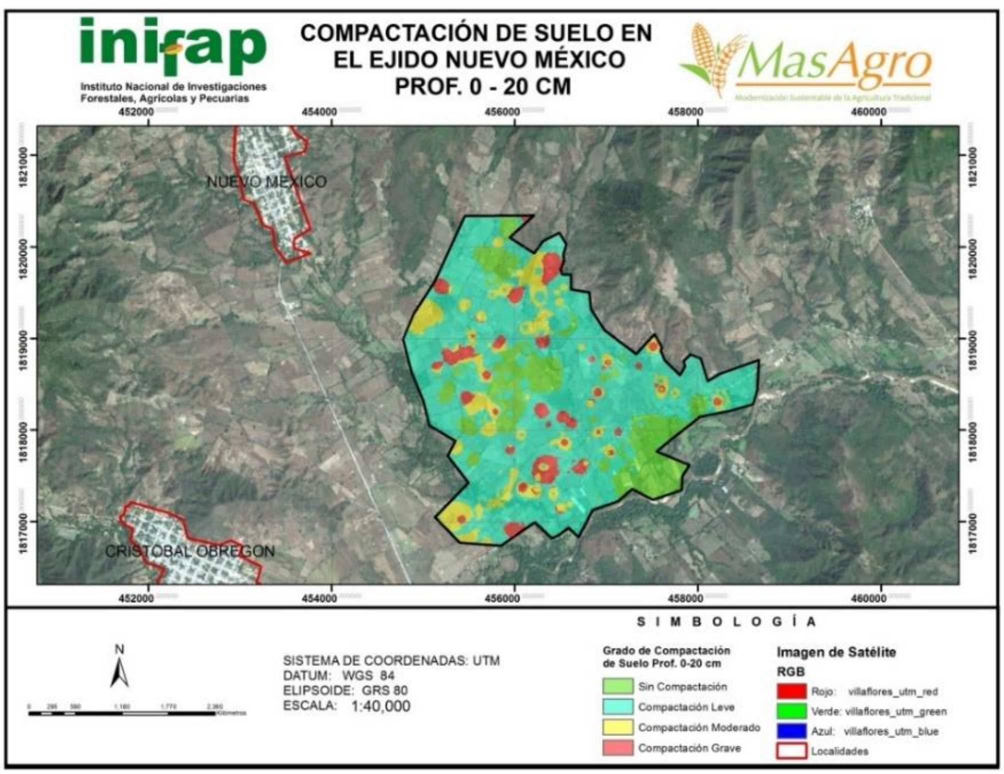

Figure 2. Distribution of soil compaction at depth 0-20 cm.

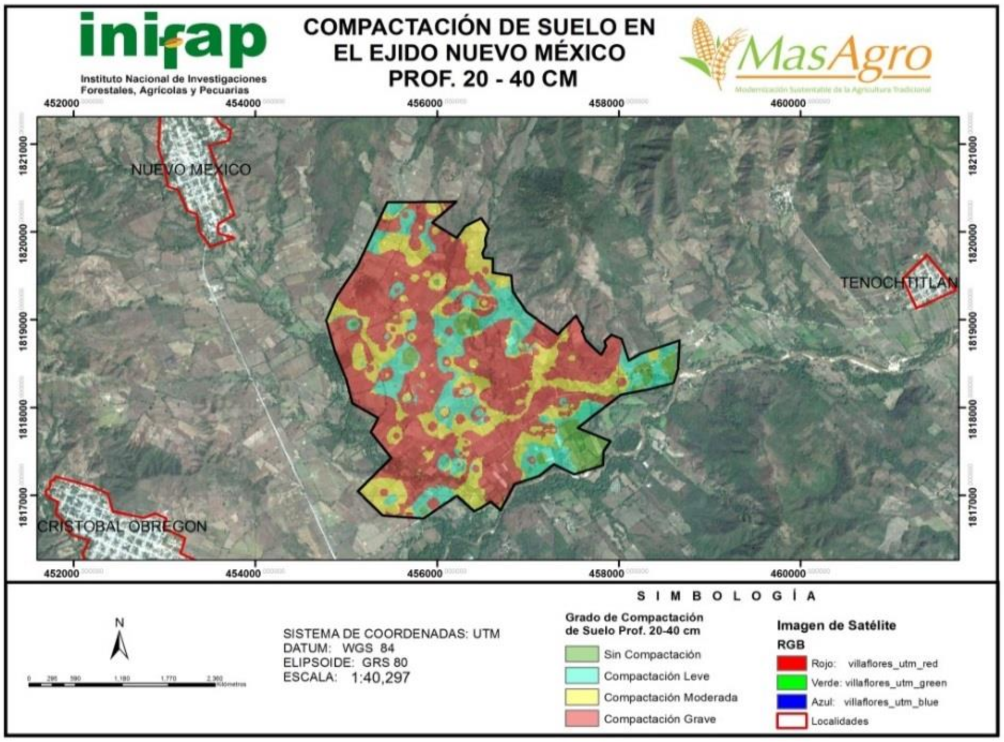

Figure 3. Distribution of soil compaction at depth 20-40 cm.

The effects and causes of compaction

Figure 4 summarizes the effects and causes of the compaction problem. Among the effects of the "crusting" the producers pointed out the inhibition of the emergence of the seedlings and the decrease of the infiltration of water in the soil, which is the cause of waterlogging, runoff and erosion. This reduces the capacity of moisture conservation in the soil, and according to the producers, causes that the yield of corn is reduced up to 58% when there are critical periods of drought. The magnitude of the effects of "crusting" depends on the texture of the soil, the stability of the aggregates, the topography and the characteristics of rainfall (Pfister, 2000, FAO, 2016).

As regards the "plow floor", both its presence and its effects are not perceived by the producers due to its difficulty in locating it. However, this type of compaction is a problem that limits root growth and the amount of air and water available to the roots (Herrick and Jones, 2002). It also worsens living conditions for organisms by forming impermeable layers within the soil and inhibits nutrient and water cycles (Benzing (2001).

It should be noted that the indicators of poor soil health highlight the presence of sealing and crusting, erosion and compaction in the subsoil (FAO, 2016).

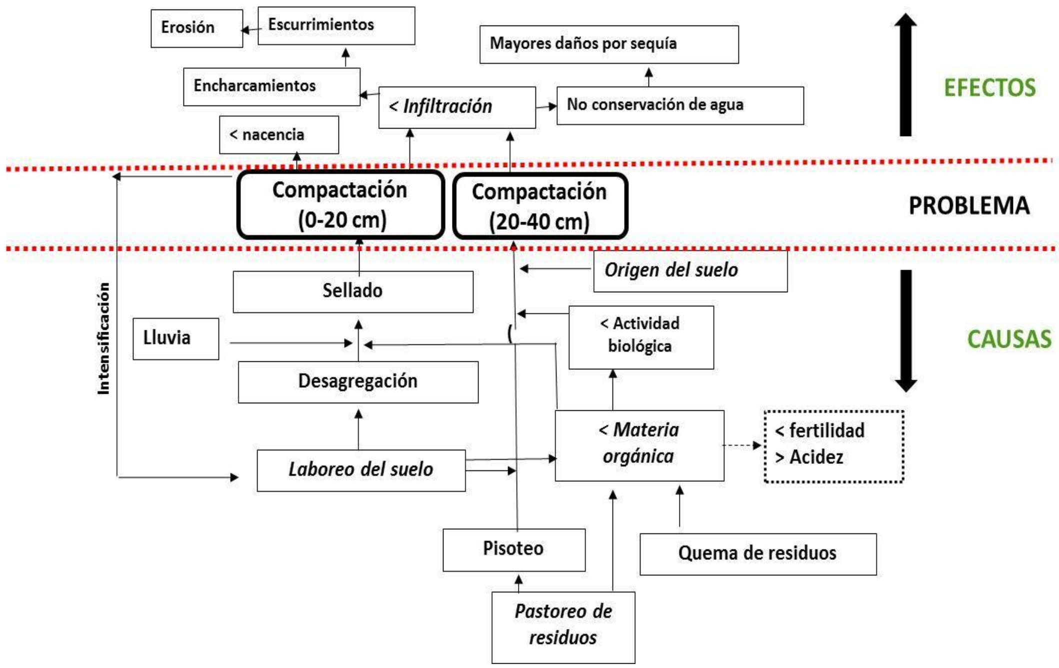

Figure 4. Cause-effect diagram of the problem of soil compaction.

Among the main causes of the problem of compaction in the study area, soil tillage with machinery, trampling of livestock, low content of organic matter and the origin of soils were identified.

Soil tillage

The preparation of the soil with machinery is one of the most deeply rooted practices in the New Mexico common, as it is practiced by 100% of the producers. 72% performs a harrowing step and 22% a plow and a harrow, or two harrows (Figure 5). No statistical differences were observed in the average values of DA between the types of soil tillage in the depths of 0-20 cm (Prob.= 0.2186) and 20-40 cm (Prob.= 0.7635) (Table 6 and 7).

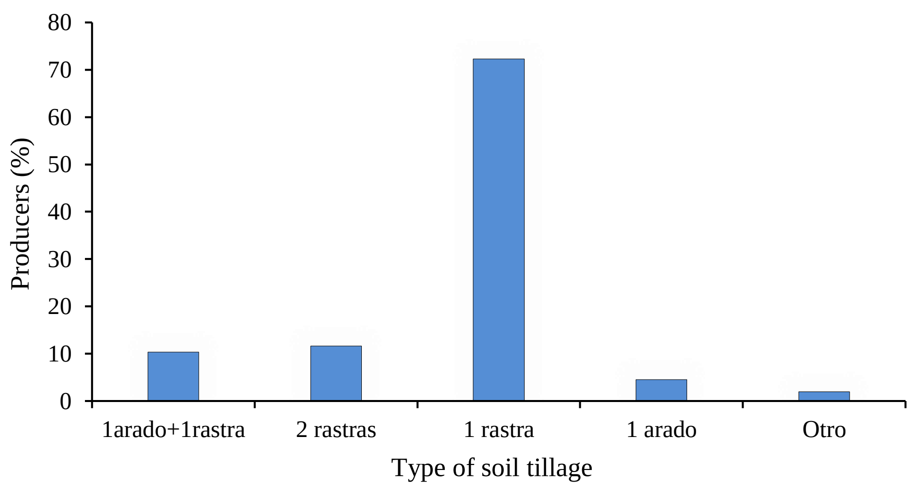

Figure 5. Types of soil tillage practiced by producers.

Table 6. Bulk density (DA) (g cm^{-3}) according to the type of soil tillage on the surface (0-20 cm).

Estatistical	Soil tillage			
	1 plow+1 dredge	2 dredge	1 dredge	1 plow
Mean	1.54	1.45	1.45	1.45
Standard deviation	0.109	0.179	0.175	0.111
Coefficient of variation (%)	7.06	12.4	12.08	7.69

Table 7. Bulk density (DA) (g cm^{-3}) according to the type of tillage in the subsoil (20-40 cm).

Statistical	Soil tillage			
	1plow+1dredge	2 dredge	1 dredge	1 plow
Promedio	1.61	1.66	1.6	1.61
Standard deviation	0.204	0.264	0.223	0.167
Coefficient of variation (%)	12.67	15.9	13.95	10.38

The negative effects that tillage generates on soil structure are documented, especially the destructive effects of disk implements. While a good structure requires the balance between fine, medium and, to a lesser extent, thick pores, the tillage generates exclusively thick pores (Benzing, 2001). Intensive tillage over the years has an effect on the composition of the mineral particles (reduction of the clayey fraction) and on the decrease in the content of organic matter (Nacci and Páez, 1995). Verhulst *et al*. (2015) indicates that tillage has very important direct and indirect effects on the aggregation of soil particles, such as: direct breakage of aggregates and an increase in the replacement of aggregates; breakage of root fragments and mycorrhizal hyphae, which are the main binding agents for macroaggregates; a redistribution of the organic matter of the soil is generated that influence the stability of the macroaggregates and when reducing the macrowildlife populations (for example, earthworms) it diminishes its potential effects on the aggregation of the soil.

Another factor that contributes to tillage compaction is the wheel forces of the machinery (Usaborisut and Niyamapa, 2010) and the used agricultural implements. Because the preparation of the land is done when the soil is wet, the tillage has a maximum potential to generate compaction in the soil. Agricultural machinery compacts soil in agricultural and livestock lands deeper than rain and animal load. The plow leaves a loose surface layer and a dense subsoil because it applies a pressure that ranges between 0.76 and 0.95 kg cm^{-2} (Agüero and Alvarado, 1983).

The tillage of the soil has acquired in the maize areas the character of destructive spiral. The tillage to destroy the structure of the soil and reduce organic matter, causes surface sealing and lack of porosity, consequently the soil hardens and forms the “crusting” whose effects are easily identified by the producers. In order to break this recurring “crusting”, producers have had to move the soil every year with machinery, becoming this practice, a necessary evil with beneficial effects of short duration and harmful for the floors as the years go by.

The zero adoption of zero tillage promoted by government programs in past years is largely explained by the presence of the destructive spiral. According to the producers with zero tillage, waterlogging is generated and the crop suffers more damage when there are periods of severe drought. In this sense, FAO (1993) points out that no-tillage systems are less effective in soils with poor internal drainage and in those with problems of compaction, so it suggests eliminating these limitations previously.

Cattle grazing

The 71% of producers practice the corn-livestock system, which involves planting corn at the beginning of the rainy season and introducing at the end of the crop cycle and during the dry season (January to April), cattle to graze harvest residues. In Table 8, it is observed that there is no statistical difference in the average apparent density values due to livestock grazing at the two depths studied.

Table 8. DA values (g cm^{-3}) according to livestock grazing and depth.

Estatistical	Surface soil (0-20 cm)		Subsoil (20-40 cm)	
	Grazing	No grazing	Grazing	No grazing
Mean	1.48	1.41	1.61	1.61
Standard deviation	0.17	0.15	0.22	0.24
Minimum	0.73	1.15	0.77	0.89
Maximum	1.93	1.79	2.19	1.93
Prob. F	0.3777		0.3235	

It is probable that the lack of influence of the trampling on the apparent density is due to the fact that the weight of the cattle tampers little on an already compacted soil, or else, to the low water content that the soil contains when it is grazed (Taboada, 2007). In this context, the transit and trampling of livestock have a more severe negative effect on the detachment of soil particles and the low integration of organic matter into the soil due to the consumption of crop residues.

The origin of the soil

Of the 1 170.4 has agricultural hectares that the New Mexico common, 63.3% (740.8 ha) are located on land that is worked with machinery and of these, 64.4% (477 ha) are located on Luvisol type land and 24.4% (180.75 ha) in Acrisols, in which the sampling points were distributed. These types of soils are very susceptible to compacting and form “plow floor” when they are worked for a long time with machinery and disc implements, since their characteristics of accumulating clay in the subsurface horizon “Argic” (FAO, 1988) facilitate the compaction process when they are moistened.

This is one of the reasons why in the soils analyzed a greater DA is observed in the subsoil associated with the presence of a higher percentage of clay (Table 9). In fact, in the subsoil a greater percentage (28%) of sites were grouped in soils with loamy loamy textures, silty clay loam, clayey, and silty clay, with a higher content of clays (Table 4).

Table 9. DA data and clay content.

Depth	DA (g cm^{-3})		Clay (%)	
	Mean	CV (%)	Mean	CV (%)
0-20 cm	1.46	11.18	16.25	53.01
20-40 cm	1.6	13.76	23.28	46.49
Prob. F	6.48E-05		0.003	

Organic matter (MO)

Table 10 shows the organic matter (MO) values classified according to the criteria indicated in Official Mexican Standard NON-021-RECNAT-2000 for volcanic soils. It is observed that, both on the surface and in the subsoil, all of the sampled sites are located in the very low MO class. The average value found in the depth of 0-20 cm was 1.0% (±0.51) and 0.73% (±0.47) for the 20-40 cm depth respectively, with no statistical difference between the two groups.

Table 10. Content of MO (%) in the soil.

Clase	MO (%)	Surface soil		Subsoil	
		Cases	(%)	Cases	(%)
Very low	<4	177	100	177	100
Low	4.1-6	0	0	0	0
Mean	6.1-10.9	0	0	0	0
High	11-16	0	0	0	0
Very high	>16.1	0	0	0	0
Total		177	100	177	100

The low content of MO is a factor closely related to the vicious circle generated by soil tillage and compaction on the surface and subsoil. Its excessive mineralization by tillage, not only leads to hardening, but also to a lower biological activity, to the superficial sealing of the soil and to an increase in erosion. A set of inadequate cultivation practices by producers was detected. Cattle grazing consumes an average of 80% of the crop residues of the corn crop and occurs in 71% of the sites studied. The number of heads that shepherds explains 16% the percentage of waste left on the ground (r^2= 0.1574). After grazing 88% of the producers incorporate the remaining stubble with a harrowing step. The burning of waste is still carried out by 14% of the producers, and with it, the possibility of incorporating organic matter into the soil is totally eliminated.

The previous practices coupled with the non-incorporation of other sources of OM, has generated an insufficient recycling of organic waste, which has brought as a consequence, a progressive deterioration of the soil that evidences an unsustainable management of the land, by virtue that the MO is related to with all aspects of the soil, such as structure, ability to retain water, aeration, nutrient content and availability, pH, cation exchange capacity and long term even in texture (Benzing, 2001, Carter, 2002).

The possible solutions

To stop or reverse the unsustainable management of the land presented by the producers of the New Mexico common and similar zones, an integral corrective and preventive strategy is required, which should take as a central element the elevation of the contents of organic matter. Based on the analysis of the causes (Figure 5), the possible alternatives that should be considered for a productive rehabilitation of the soils were identified with the producers of the study area, placing in first order the corrective measures permanently accompanied by the preventive measures (Figure 6).

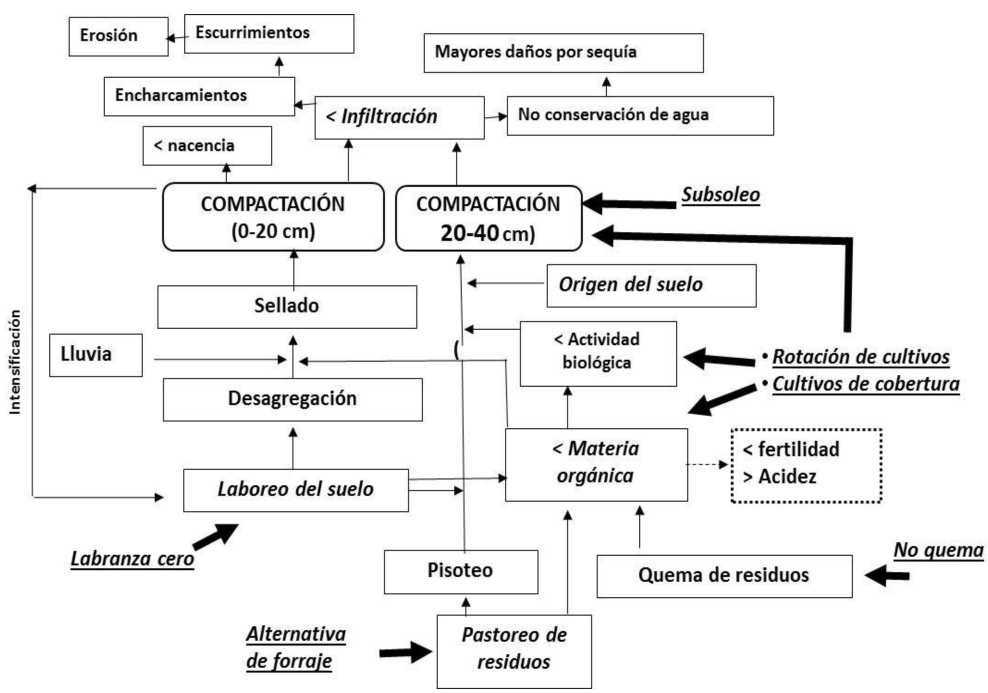

Figure 6. Alternative solutions to the problem of soil compaction.

Within the measures of remediation to the current problem of compaction particularly the "plow floor", two alternatives are proposed to break the hardened layer, the first one immediately through the subsoiling, and the second, gradually with the rotation of crops and sowing cover crops, or with the combination of both.

Subsoiling has the purpose of breaking up compact soil layers to reduce water runoff, increase water infiltration, promote aeration, stimulate root growth and the regrowth of already established plants, as well as promote the establishment of new seedlings (Barton *et al*., 1996; Ibarra *et al*., 2004). Evaluations carried out in the study area have reported that the subsoiling compared to the harrow treatment of the producer, increased 32% (1.7 t ha^{-1}) the yield of corn grain, 84% the length of roots and 5.1% the height of plants. The subsoiling when breaking the compacted layer, generated greater porosity so that the roots grew and the plants had greater opportunity to absorb nutrients and take advantage of the humidity that was deeper (López *et al*., 2017).

After the subsoiling, measures must be taken to stabilize the structure that has been loosened. To do so, it is first necessary to break the vicious circle by suppressing or regulating the tillage of the soil with machinery with the practice of zero tillage. Second, increase the levels of MO in the soil; through, to look for alternative sources of fodder to avoid the grazing of crop residues and sensitize the producers so as not to burn the plots and plant cover crops.

The promising species of cover crops that have been shown to be potential biological subsoilers are the bay grass (*Paspalum notatum*), the fescue grass (*Festuca elatior*), the Guinea grass (*Panicum maximum*), the alfalfa (*Medicago sativa*), the pigeon pea (*Cajanus cajan*) and cowpea (*Vigna unguiculata*). Fodder radish (*Raphanus sativus*) and nitrogen fixing shrubs *Tephrosia vogelii, Sesbania sesban* and *Gliricidia sepium* have also been identified as potentially useful (Barber and Navarro, 1994).

Conclusions

There is a generalized problem of compaction both in the surface (crusting) and in the subsoil (plowing floor), originated mainly by the intensive tillage of soils and the very low content of organic matter. The higher clay content in the subsoil in luvisol and acrisol soils makes them more susceptible to the compaction of the subsoil.

Unlike the superficial compaction that is taken care of every year with the tillage of the soil, the compaction of the subsoil due to its "invisibility" has received little attention in the maize areas so much by the producers as by the government institutions.

The zero adoption of no-tillage promoted by government programs in past years is largely explained by the presence of this compaction problem.

The attention to the problem of compaction requires an integral corrective and preventive strategy that should take as a central element the elevation of the contents of organic matter, which allows to reverse the current unsustainable management of the land.

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