Long term effect of conservation tillage in a corn-oat rotation system on corn and forage oat yield in the north-central region of Mexico

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Abstract
Among the main constraints to adopting conservation tillage in the semiarid zones in Mexico's north-central region are: low acceptance among farmers, need of specialized machinery, use of herbicides, and above all, the need to utilize stubble to feed animals. The objective of this study was to assess the effect of different tillage methods in an irrigated corn-oat rotation system on corn grain, stubble, and forage oat yield. Seven tillage methods were evaluated: 1) traditional plow and disk (P+D), 2) disturbing the upper 0-4 in layer (D), 3) without disturbing the upper 0-4 in layer (ND), 4) zero tillage with 0% soil cover (ZT+0%SC), 5) zero tillage with 33% soil cover (ZT+33%SC), 6) zero tillage with 66% soil cover (ZT+66%SC), and 7) zero tillage with 100% soil cover (ZT+100%SC). In each year from 1996 to 2007, corn was sowed on the spring while forage oat was grown during the fall-winter season. Corn grain yield results showed statistical differences among treatments ($p \leq 0.05$), where ZT+66%SC was the best treatment, surpassing by 90% the corn yield registered with P+D. The statistical analysis for corn stubble yield showed no differences ($p \geq 0.05$) among treatments. With ZT+66%SC, corn stubble production was increased 3.448 ton/ha compared with that of P+D, indicating that farmers can use 2.0 ton ha^{-1} to cover at least 33% of the soil surface. Forage oat yields within the seven treatments were not statistically different ($P \geq 0.05$), but all ZT treatments were no-till seeded. Our conclusions are that corn and forage oat can be no-till seeded, increasing corn production and keeping stable production of forage oat. These results can be used to provide evidence to farmers of the benefits of adopting conservation tillage.

Key Words
Irrigation, stubble, soil cover, plow, disk, farmers

Introduction

"The truth is that nobody has ever exposed a scientific reason to till". This phrase was made by Edward H. Faulkner in the 1940s, and he was largely criticized by his contemporaries (Faulkner 1974). Conservation tillage has been proved to be an alternative to conventional tillage, but it should be validated in areas where this technique is not actually used.

With his research results, Faulkner showed that erosion, soil impoverishment, and yield reduction are the results of inadequate soil management by farmers. He challenged the technological advancement of his time, about how to produce crops, declaring that plow is and has been the main enemy of soils. He declared that by leaving crop residues on the soil surface, instead of burying them at the bottom of the plow layer, nutrients will be provided for the next crop.

In Mexico, the plow's adoption has been without any discrimination for all soil types, climates, and crops. Technical guides recommended by research, teaching, and extension institutions present the use of plow and disk as the only option of soil tillage before sowing. Besides, conservation tillage has been promoted to farmers in the last 30 years with unsuccessful results, therefore the actual area at national level with conservation tillage does not surpass 10,000 ha, which is minimal compared to that of other Latin-American countries such as Brazil, where in recent years, conservation tillage has been implemented on 15 million hectares (Claveran 2000).

Soil erosion is one of the main problems that threaten the sustainability of agriculture, so the development of sustainable production systems should be a priority, while satisfying production yield and quality necessary for consumer demands (Osuna 2000). Conservation tillage is one of the most viable options to sustain natural resources, such as soil and water, and crop yields (Angeles and Rendon 1994; Valdes *et al.* 1994). With conservation tillage, soil is protected against water and wind erosion, loss of nutrients is reduced, more soil water is available to plants, and soil organic matter, infiltration, and flora and fauna are increased

(Figueroa 1975; Figueroa 1982; 1983; Jasso 1985; Barron 1987; Osuna 1987).

Among the main constraints to adopting conservation tillage in the semiarid zones in Mexico's north-central region are: low acceptance among farmers, need for specialized machinery, use of herbicides, and above all, the need to utilize stubble to feed animals (Salazar *et al.* 1994). The use of crop residues as soil mulch is a key factor to succeed in conservation tillage, given that the greater the quantity of residues left as soil mulch, the greater the protection against erosion. The use of crop residues, especially corn stubble, to feed animals is a strong constraint in the north-central zone of Mexico, therefore development of agricultural systems with conservation tillage should contemplate diversification and increase forage production (Cabrera 1988). Finally, the conservation tillage concept, which involves the combination of zero tillage with 30% of crop residues as soil mulch, should be modified according with different agricultural systems, soils, climate and crops to avoid the same mistake made with plowing and disking as a unique option of soil till. (Sanchez 1975; Ramirez 1982). The objective of this study was to assess the effect of different tillage methods in an irrigated corn-oat rotation system on corn grain, stubble, and forage oat yield.

Methods

From 1996 to 2007, an irrigated corn-forage oat rotation system was conducted at the experimental station at San Luis, San Luis Potosi, Mexico. The site has a clay soil texture, a temperate dry climate, an annual average temperature of 16.2 ^{o}C, a frost free period from April to September, and an annual average rainfall of 210 mm (CGSNEGI 1995). Seven tillage methods were evaluated: 1) traditional plow and disk (P+D), 2) disturbing the upper 0-4 inches layer (D), 3) without disturbing the upper 0-0.10 m layer with a root cutter (ND), 4) zero tillage with 0% soil cover (ZT+0%SC), 5) zero tillage with 33% soil cover (ZT+33%SC), 6) zero tillage with 66% soil cover (ZT+66%SC), and 7) zero tillage with 100% soil cover (ZT+100%SC). A randomized block design with two repetitions was employed. Corn was seeded in the spring while oats were seeded in the fall of each year. Genotype for corn was the hybrid H-311 with 24,282 plants per acre and the genotype for oat was the variety Cuauhtemoc with a density of 100 kg/ha. A zero tillage planter with wavy disk at the front was used to cut the stubble. For fertilization and pest control, local INIFAP's recommendations were followed. Before sowing, weeds in the zero tillage treatments were controlled with Glifosfato (2 L/ha) and after planting; weeds were eliminated with the same herbicide and dose but applied with protected bell type sprayers so that the main crop was not damaged. Each crop was irrigated when 40% available soil water was registered. For irrigation, beds of 1.65 m were built, and two lines of plants were sown. Corn was sown in rows separated by 0.85 m and 0.078 m between plants. After harvest each year, corn stubble was chopped on the top of the beds leaving the different soil cover treatments (0%, 33%, 66%, and 100%). The furrows were reconstructed once a year. Four rows of oat were planted in each bed. Corn and oat forage yield was evaluated by sampling the 10.2 m^2 plots over 12 years. During the growing season of 2001, soil water content was monitored at 0-0-0.15 m and 15-0.30 m depths. Results were statistically analysed according with the experimental design employed by using the Statistical Analyses System (SAS Institute 1995).

Results

There was no statistical difference in yield among tillage treatments ($p \geq 0.05$) (Table 1). However, a trend of increasing forage oat productivity, 16% with ZT+0%SC as compared to P+D. These results were an indicator that soil was more compacted by plowing and disking than in the ZT treatments. Soil was not a limiting factor in the emergence, establishment, growth, or yield of forage oat (Table 1).

There was a yield reduction of 39 and 34% with D and ZT+100%SC in comparison with P+D. In the case of D, this reduction was explained by a compacted layer, detected at 0.20 m depth, indicating that when soil was just disked, a compacted layer developed, impeding adequate oat root development.

For corn grain yield, a statistical difference among treatments was seen ($p \leq 0.05$), where the best treatment was ZT+66%SC with 6.871 ton/ha, representing an increase of 90% in relation to P+D. In all treatments except P+D and D, there were two fewer irrigations during the corn growing season because of the stubble mulch effect. Soil water content was higher in those treatments as compared to P+D. The main reason for the different responses of corn and oat to the tillage methods evaluated were due to the higher air temperatures registered during the spring and summer months than that in the fall and winter when oat was grown. During the corn growing season, the stubble increased soil water content, resulting is higher corn yields. The higher soil water content measured in the ZT treatments compared to the P+D was the reason for

the superior corn and stubble yields.

Producing higher forage yields is a challenge in the north-central region of Mexico to implement the correct conservation tillage system. Because farmers use stubble to feed to their animals, only a part of the total residue production can be used as mulch. There was no statistical difference ($P \geq 0.05$) among treatments in stubble yield. With ZT+66%SC, corn stubble production was increased 3.448 ton/ha compared with that of P+D, indicating that farmers can use 2.0 ton/ha to cover at least 33% of the soil surface.

It is important to point out the forage oat, corn grain, and stubble yields obtained with ND, because with this treatment the soil profile was not inverted, reducing production costs. This method can be used as an intermediate step between traditional and conservation tillage and it is recommended for soils with compaction and drainage problems. In this study, soil mulch was not left on the surface, so there is a question to be answered by future researchers about the effect of stubble mulch with this tillage method on corn grain and forage oat yields.

It was evident that forage availability was increased 20% with ZT+33%SC and ZT+66%SC in comparison with that of P+D. Leaving crop residues on the soil surface is justified for the reduced need for irrigation water during the cycle of corn, as well as the incremental increases in soil organic matter.

Table 1. Forage oat, corn grain, and stubble yields (ton/ha) in an irrigated corn-forage oat rotation with different soil tillage. San Luis Potosi, Mexico.

Treatments	Forage oat (DM)	Corn grain (14% M)	Corn stubble (DM)	Total forage (DM)
	----------ton/ ha----------			
Plow and disk.	5.922a	3.604c	7.035a	12.957a
Disturbing the upper 0-10 cm layer.	3.633a	4.638bc	7.592a	11.225a
Without disturbing the upper 0-10 cm layer.	6.030a	6.008ab	10.376a	16.405a
Zero tillage with 0% soil cover.	6.874a	6.743a	9.677a	16.551a
Zero tillage with 33% soil cover.	5.403a	6.414ab	10.499a	15.902a
Zero tillage with 66% soil cover.	4.888a	6.871a	10.466a	15.354a
Zero tillage with 100% soil cover.	3.894a	6.472a	10.273a	14.167a

Means followed by the same letter are not significantly different at 0.05 probability according to the Turkey test.
DM = Dry matter.
M = Seed moisture

Conclusion

Conclusions for this study were that corn and forage oat can be grown without plowing the soil, increasing corn production and keeping stable production of forage oat.

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