Nitrogen availability as affected by ten years of cover crop and tillage systems in southern Brazil

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The use of conventional tillage in southern Brazil on farms with moderately sloping landscapes results in severe water erosion. When this system is used without any conservation practice, up to 20 Mg of soil can be lost for each Mg [ha.sup.-1] of grain harvested (Eltz et al. 1984). In response to extension programs initiated in 1979 (Wunsche et al. 1979), this situation has been changed. Currently, conservation tillage and winter cover crops are used in corn and soybean production system. Corn is one of the most important crops in the region, but the average yield in Rio Grande do Sul is 2.87 Mg [ha.sup.-1], being limited mainly by the low quantity of fertilizer N applied.

Conservation tillage and cover crops are important management tools for improving short-term erosion control, and increasing long-term soil N reserves and N mineralization and enhancing soil productivity (Ebelhar et al. 1984; Frye et al. 1985; Wood et al. 1991). Most of the research about these topics has been carried out in a temperate climate. There is a lack of information about long term effects of tillage systems and cover crops on N availability in corn production in tropical and subtropical conditions. The objective of this study was to determine the impact of tillage and cropping systems on N availability for corn in a subtropical agroecosystem.

Material and methods

To evaluate the N availability in cropping and tillage systems, a long-term experiment was established in 1985 on a degraded soil. The soil at this site was classified as Paleudulf, distrofic, with low organic matter content and clay-loam texture. The climate of the region is subtropical with a hot wet summer classified as "cfa" in the Koeppen classification (Bayer 1992). The annual average rainfall is 1400 mm (55 in) and the average monthly temperature is 14 [degrees] C (57 [degrees] F) minimum and 25 [degrees] C (76.8 [degrees] F) maximum.

The experimental design used was a split-split plot with three replications. The main plots were tillage systems consisting of no-tillage and conventional tillage (moldboard plow + disk). Subplots were cover crops in corn (Zea mays L.) production systems: black oat (Avena strigosa Schreb.) a traditional system used by the region farmers; a binary mixture of black oat + common vetch (Vicia sativa L.); and an intensive system consisting of a binary mixture of black oat + common vetch with summer intercropped cowpea (Vigna unguiculata subsp. unguiculata L. Walp.). Subplots were rates of nitrogen applied in corn (0 and 120 kg N [ha.sup.-1]).

In 1995 the treatment that has a historic of black oat + vetch was replaced by vetch alone. All other cover crop treatments (traditional and intensive) were maintained according to the historic use. In this year, the subplots were also split in four N treatments: a) bare soil (weed-free using glyphosate) without N fertilizer; b) cover crop residues without N fertilizer, c) cover crop residues with 90 kg [ha.sup.-1] of N; and d) cover crop residues with 180 kg [ha.sup.-1] of N. The N fertilizer was urea banded without incorporation and split at planting, 25 and 43 days after corn emergence. The corn hybrid used in this experiment was Pioneer 3069, with a stand adjusted to 55,000 plants [ha.sup.-1]. Irrigation was scheduled using a tensiometer. Total soil N was determined in 1994 by sampling to depths of 0 to 2.5, 2.5 to 5.0, 5.0 to 7.5, 7.5 to 12.5, 12.5 to 17.5, 17.5 to 30.0 cm. Cover crop biomass and N content were determined in 1995 immediately previous to soil tillage by sampling 1.0 [m.sup.2]. Corn biomass and N uptake were evaluated at growth stage 6 (Hanway 1963). Corn grain yield was evaluated from area of 6.30 [m.sup.2] and the results reported on the basis of 13% moisture. N concentration in soil and crops was determined by micro-Kjeldahl digestion (Tedesco et al. 1985). Statistical analysis was performed by SAS and the differences between means were determined by LSD at 0.05.

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Table 1. Total N soil at 0 to 30 cm in tillage and cover crop systems after 9 years (1985-1994) Treatments Total N (0 to 30 cm) Kg.[ha.sup.-1] Cover crop Oat/corn 3786 Intensive 4458 Tillage system(*) Conventional 4014 No-tillage 4231 LSD (0.05) for cover crop averaged over tillage systems = 329 * Tillage systems ns Interaction between tillage system and cover crop wasn't significant CV= 4.98%
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Results and discussion

Effect of long-term cover crops and tillage system on soil N reserves. To simplify the interpretation of results, only data regarding the effect of the oat/corn (traditional farming system) and oat + vetch intercropped cowpea (intensive system) in both tillage systems will be discussed. The N addition by above ground cover crops during the nine years period was estimated based on data collected in previous years by other researchers at the same experimental area (Bayer 1992); showed that under the legumes' cover crop there was approximately three times more N added as compared to a grass cover crop system [ILLUSTRATION FOR FIGURE 1 OMITTED]. Most of this difference was due to the biological [N.sub.2]-fixation by legumes in the intensive system. The N added by cover crops during this period, was similar for both tillage systems (Bayer 1992). The use of legumes in the intensive system, regardless of tillage system, increased total soil N in the top 30 cm as compared to oat/corn (Table 1). Tillage systems averaged over cover crops wasn't significant, although no-tillage has 217 kg [ha.sup.-1] more total soil N as compared to conventional tillage. The pattern of soil N distribution was different between the tillage cover systems [ILLUSTRATION FOR FIGURE 2 OMITTED]. There was an accumulation of N in the soil surface with no-tillage, while in conventional tillage the pattern of N distribution was more uniform in the profile. Similar results has been reported in many others experiments (Doran 1980; Wood et al. 1992; Bayer 1992). Nitrogen content in soil with the intensive cover management in no-till was 890 kg [ha.sup.-1] higher than in oat/corn system with conventional tillage. These results were obtained in the plots without addition of N fertilizer. The results confirm the importance of the using legume based crop system under no-tillage in restoring the N content in degraded soils.

Effect of historic cropping system on corn N uptake and yield. The use of the subplot in which the soil was kept bare without addition of N fertilizer allows an evaluation of soil N mineralization. Use of legumes, regardless of tillage system, increased corn N uptake by 10.7 kg [ha.sup.-1] (intensive system) when compared to the traditional system (oat/corn). Although this difference wasn't statically significant, it suggests a gradual increase in soil N mineralization [ILLUSTRATION FOR FIGURE 3A OMITTED]. This increase was associated with an increase in the size of soil N pool by cover crops (Table 1). McCracken et al. (1989) after 10 years of experimentation with cover crops, tillages and N rates, grew corn without cover crops and N fertilization, using procedures similar to this experiment. They estimated the historic effect of vetch (Vica villosa Roth) increased corn N uptake to 28.0 kg [ha.sup.-1] when compared to rye (Secale cereale L.). Their estimation is twice that reported in our experiment. Since the history of cover crops and the duration of the experiments were similar, the different impact in N availability by cover crops was likely due to the differences in climate and soil where these experiments were carried out.

Table 2. Dry mass, N content and ratio C/N of cover crops averaged over tillage systems in 1995

Cover crop	Dry mass	N Content	Ratio C/N(*)
	Mg [ha.sup.-1]	Kg [ha.sup.-1]	
Black oat	5.13	42.3	49
Common vetch	3.87	110.0	14
Black oat+vetch	6.20	106.6	23
	LSD (0.05) = 1.14	LSD (0.05) = 18.1	
	CV = 26.4%	CV = 24.1%	

* Estimation based in 40% of carbon in dry mass

Corn yield was positively affected by cover crop history, but it was less sensitive to the frequency of legumes in the cropping system than was N uptake [ILLUSTRATION FOR FIGURE 3B OMITTED]. The intensive system increased yields by 0.55 Mg [ha.sup.-1] as compared to the historic use of the oat/corn system. McCracken et al. (1989) found an increase of 1.31 Mg. [ha.sup.-1] in plots with a historic use of vetch cover when compared to rye/corn. In both experiments, the increase in corn yield can be credited to the increase in soil N availability by the long term use of legumes.

Effect of N fertilizer and tillage on corn N uptake and yield. Averaged across N rates and three cropping systems, N uptake was greater in conventional tillage than in no-tillage [ILLUSTRATION FOR FIGURE 4A OMITTED]. Many others researchers have found similar results (Bandel et al. 1975; Groffman et al. 1987; McCracken et al. 1989). The trend of lower N uptake in no-tillage was probably due to increased N immobilization by microbial biomass in this system (Bandel et al. 1975; Doran 1980; Kitur et al. 1984; Groffman et al. 1987). However, corn yield was similar between tillage systems in 1995 [ILLUSTRATION FOR FIGURE 4B OMITTED], confirming a trend that happened in previous years in this experiment (Bayer 1992) and in others (Sarrantonio and Scott 1988; Varco et al. 1989; Edwards et al. 1988). Since the no-tillage system was more efficient in storing soil N from legume cover crops in top soil [ILLUSTRATION FOR FIGURE 2 OMITTED], in the long-term this system can increase soil N available for corn, sustaining yields.

Fertilizer-N replacement value of cover crops. Dry matter production and nitrogen content of cover crops in 1995 is shown in Table 2. The cover crop systems that included grass have the higher dry mass production, while the crop systems with legumes have the higher N content.

An estimation of the legume-N contribution to the corn in the cropping system was made by calculating the fertilizer-N replacement value. This value is the amount of inorganic N that would be required in a grass or fallow to produce an equivalent yield under legume/corn system (Hoyt and Hargrove 1986; Hargrove 1986). Although this method has some limitations (Hesterman et al. 1987; Frye et al. 1988; Reeves 1994), it is practical and can provide valuable information. The N equivalence (compared to the oat cover crop system) was estimated to be 38 and 61 kg [ha.sup.-1], respectively, for the intensive system and the vetch cover crop system [ILLUSTRATION FOR FIGURE 5 OMITTED]. These values are in the range of 15 to 200 kg [ha.sup.-1] found by Reeves (1994) in an extensive review of cover crop. The N provided by legumes was due to the combined effect of soil N mineralization from the historic cropping system and mineralization from immediate previous cover crop residues. The higher N equivalence in the vetch system was likely due to the lower C/N ratio (14:1) of the vetch cover crop residues as compared to the intensive system (oat + vetch) which had a C/N ratio of 23:1 (Table 2).

When legumes were used, corn yield for the zero fertilizer-N rate was greater than oat cover crop system; the corn yield for 90 kg [ha.sup.-1] of N wasn't different from the 180 kg [ha.sup.-1] N rate. However, for the black oat cover crop system was significant. In the vetch/corn system, the legume was capable of providing two-thirds of the N required for maximum corn yield, this is a typical result that has been reported by other researchers (McVay et al. 1989; Mitchell and Tell 1977; Fleming et al. 1981; Frye et al. 1985). Using the corn N uptake in bare (40.8 kg [ha.sup.-1]) and cover soil (77.4 kg [ha.sup.-1]) and N in biomass of vetch (110 kg [ha.sup.-1]) averaged over tillage system, the apparent N vetch recovery by corn was estimated to be 33.3%. This value is close to N recovery obtained by Varco et al. (1989) using the 15N technique.

Conclusions

The use of legumes in corn cropping systems in subtropical Brazil increased N soil reserve, regardless of tillage system. Increased soil N from legume cover crops induced increase in corn yield. In the vetch/corn system the legume was capable of providing two-thirds of the N required for maximum corn yield. The combined use of legume cover crops and no-tillage, by promoting increased soil N and crop N uptake, is an efficient management practice to promote soil sustainability.

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Interpretive summary

Soil erosion is a major problem on moderately sloping landscapes in southern Brazil. No-tillage and tillage were compared for corn production using various cover crop mixtures including black oat and common vetch. Nitrogen contribution from the legumes was evaluated by comparing yield response curves at various nitrogen rates. In the vetch/corn system the legume supplied two thirds of the N required for maximum corn yield.

Key words: conventional tillage, corn, cover crops, long-term experiments, legumes, N availability, no-tillage, N fertilizer equivalence, soil management.

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