EFFECTS OF SOIL MANAGEMENT ON DENITRIFICATION

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INTRODUCTION

Denitrification, the reduction of NO_3^--N to the gases N_2O and N_2 and their subsequent loss to the atmosphere, is an anaerobic process. However significant denitrification losses have been observed on seemingly well-aerated Saskatchewan soils (Aulakh 1983, Colaco 1979). These losses have been attributed to the existence of anaerobic microsites (Norstadt and Payne 1984). Anaerobic microsites form when the physical and microbial conditions are such that the supply of oxygen to a microsite in the soil cannot meet the demand. This may arise from intense microbial activity at a point within the soil or slow gaseous diffusion rates within large water-saturated aggregates (Galsworthy et al. 1978, Smith 1977). The occurrence of anaerobic microsites and, hence, denitrification depends on physical and microbial soil properties such as water content, air porosity, aggregate size, temperature, soil respiration and substrate levels.

Denitrification has been shown to vary between fallow and cropped land and between conventionally and zero-tilled soils (Aulakh et al. 1982,1984). The objective of this study is to relate variations between management systems to soil properties and to obtain estimates of annual denitrification in the Black soil zone.

METHODS

Denitrification and soil properties were monitored on long term management plots at the Agriculture Canada Research Station at Melfort, Saskatchewan. The soil is an orthic Black chernozem (Melfort silty clay). The treatments studied were conventionally and zero-tilled plots in a wheat fallow rotation. A more detailed description of the treatments is given in Selles et al. (1984).

The site was sampled five times between May and October in 1986 and six times between April and September in 1987. Measurements were made at three different depths; 2.5-10 cm, 10-17.5 cm and 17.5-25 cm, and were replicated three times.

Denitrification rates were measured using the acetylene inhibition method of Aulakh (1983). Moisture content, air porosity and soil respiration measurements were made on core samples. Soil respiration was also calculated from field measurements of CO_2 concentrations in gas sampling tubes using the method of de Jong and Schappert (1972). Soil temperature was measured using thermocouples installed at the sampling depths. Bulk soil samples were taken and standard analyses for NO_3^-, NH_4^+ and water-soluble carbon were performed. Daily precipitation and air temperature data were obtained from the Environment Canada Meteorological Station on the research farm.

The effects of management on denitrification were examined using analysis of variance and protected least significant differences. Regression analysis was used to study the relationships between denitrification and the soil properties. A logarithmic transformation was applied to denitrification and soil respiration values to normalize their distribution. All other variables exhibited normal distributions.

RESULTS AND DISCUSSION

Estimated annual denitrification losses are shown in Table 1. Losses range from 104 kg/ha from the chemical summerfallow in 1987 to 9 kg/ha from the zero till wheat in 1987. The rate of denitrification was highest in both years on the chemical (zero-till) summerfallow plot and it was significantly ($P>0.05$) greater than denitrification on the other plots. Fallow treatments had significantly higher denitrification than cropped treatments in 1987 ($P>0.001$), but there were no significant differences between cropped zero and conventionally tilled plots.

Table 1. Estimated annual denitrification losses.

Treatment	1986	1987
	Denitrification kgN/ha/yr	
ZF (Zero-till Fallow)	72	104
CF (Conventional till Fallow)	30	61
ZW (Zero-till Wheat)	37	9
CW (Conventional till Wheat)	37	16

The pattern of denitrification throughout the sampling period is shown in Figure 1 for 1986 and Figure 2 for 1987. In 1986 the greatest denitrification losses occurred between May 29th and July 22nd. At this time all plots lost similar amounts of nitrogen through denitrification (30 kg/ha), but only the chemical fallow continued to experience significant denitrification until August 28th. This was attributed to the high surface moisture on the chemical fallow plot (42% v/v) relative to the tilled fallow (37% v/v) and the cropped plots (37 and 33% v/v for zero and conventional till respectively). Denitrification in 1987 did not peak until August and was largely confined to the fallow plots. This was a consequence of the dry spring. In 1987 there were no rainfall events greater than 10 mm between April 15th and July 10th and surface moisture contents were below 35% v/v. The lack of denitrification on the cropped plots in August was a result of plant water use; the surface moisture contents in these plots averaged 37% v/v.

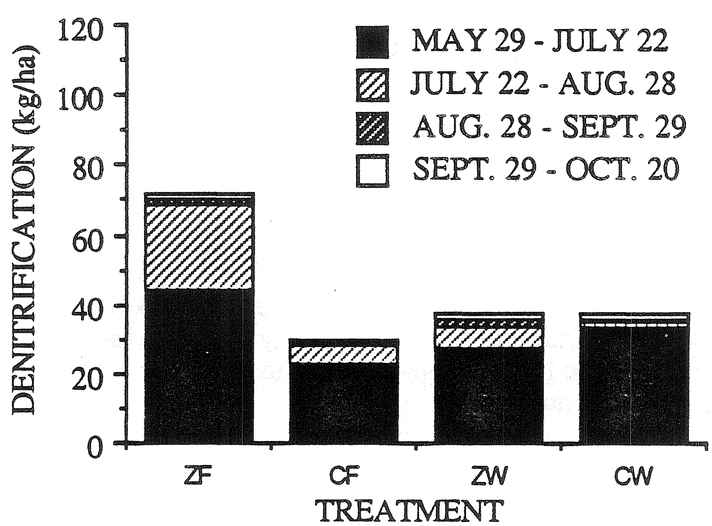

Figure 1. Temporal variation in denitrification in 1986 (see Table 1. for treatment names).

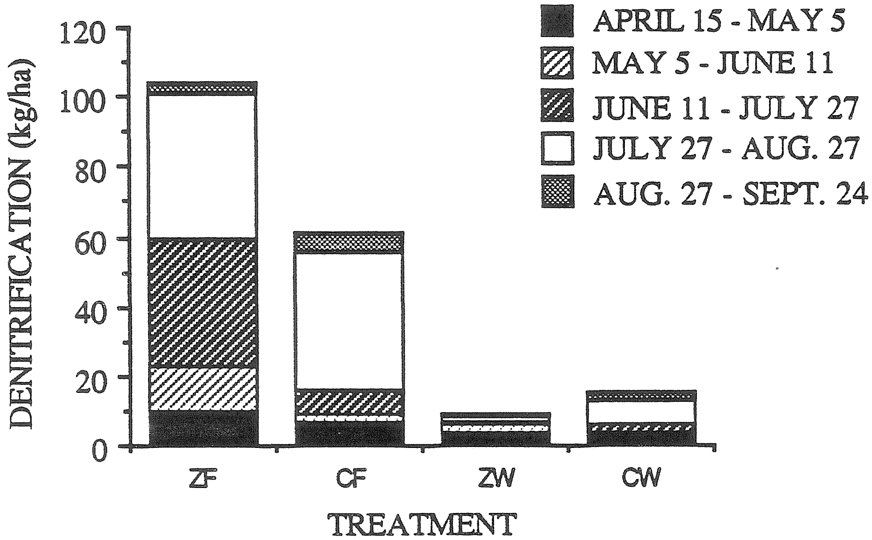

Figure 2. Temporal variation in denitrification in 1987 (see Table 1. for treatment names).

Volumetric water content (VWC) correlated well with denitrification (N-LOSS) and explained 26% of its variability. Gravimetric water content (GRAV), air porosity (AIRP),percentage of large aggregates (AGS), temperature (TEMP) and soil respiration (RESP) were also significantly correlated to denitrification. No relationship was found between denitrification and the substrate variables, soluble carbon (SOLC) and nitrate (NO3) which suggested that substrate levels were not limiting.

Two linear regression models were used to relate denitrification to soil properties. The model:

$$\ln \text{N-LOSS} = 0.147\ \text{VWC} + 0.088\ \text{TEMP} + 0.091\ \text{AGS} - 5.792$$

explained 46% of the variability in denitrification. In this model the VWC is an indicator of soil aeration status and moisture supply, TEMP is related to microbial activity and AGS is a measure of the suitability of the structure for anaerobic microsite formation. An alternative model:

$$\ln \text{N-LOSS} = 9.371\ \text{GRAV} - 0.057\ \text{AIRP} + 0.631 \ln \text{RESP} + 0.111\ \text{AGS} - 3.919$$

also includes the AGS term but has replaced VWC with AIRP and GRAV which represent aeration and moisture supply as separate parameters. RESP is used in place of temperature as an indicator of microbial activity. This model explains 44% of the variability.

The model fit can be improved by splitting the observations into depth categories (Table 2). The model for 2.5-10 cm depth is similar to the first model but the aggregate term is not significant. The best relationship is found at the 17.5-25 cm depth where substrate availability appears to influence denitrification. 89% of the variability is explained. The worst relationship occurs at the 10-17.5 cm depth where aggregate size is the only significant variable and only 28% of the variability is explained. It appears that there is some depth related factor that is not adequately characterized by the soil properties considered in this study. Some further improvement in model fit might be obtained by constructing a more mechanistic model.

Table 2. Model variables for the different depths.

Depth	Variables Significant in Model	% Variance Explained
2.5-10 cm	VWC, TEMP	49
10-17.5 cm	AGS	28
17.5-25 cm	GRAV, RESP, AGS, SOLC, NO3	89

CONCLUSIONS

Denitrification losses were estimated to range from as high as 104 kg/ha/yr from chemical fallow to 9 kg/ha/yr from zero till wheat. Fallow soils lost significantly more nitrogen through denitrification than cropped soils but there were no significant differences between conventionally and zero tilled plots in the crop year. Volumetric water content explained 26% of the variability in denitrification and the highest denitrification rates were observed following rains of greater than 10 mm. Air porosity, aggregate size, temperature and soil respiration were also related to denitrification and explained 45% of the variability when used along with moisture content in linear models. Substrate availability was adequate in the top 17.5 cm but was limiting denitrification in the 17.5-25 cm layer.

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