1.5 Rates of Denitrification as Influenced by Irrigation

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ABSTRACT

The rate of denitrification, using the acetylene blockage method, was determined before and after irrigation at two sites; at Birsay on a clay-loam soil and at Outlook on a sandy soil. At Birsay, 110 kg N/ha as urea was applied 10 days before seeding and an additional 4 kg N/ha as ammonium phosphate at time of seeding. At Outlook, 50 kg N/ha as ammonium nitrate was applied just before seeding.

Before irrigation, the rate of denitrification at both sites was almost undetectable. A sharp increase in the rate, however, occurred at both sites within a few hours after irrigation (approximately 25 mm) and lasted for approximately 24 hrs and 12 hrs at Birsay and Outlook, respectively. At the time of maximum activity the losses of N (N_2O and N_2) were estimated to be 50 g ha^{-1} hr^{-1} and 3 g ha^{-1} hr^{-1} at Birsay and Outlook, respectively. The total amount of N lost per irrigation cycle due to denitrification at Birsay and Outlook were calculated to be 730 g ha^{-1} and 21 g ha^{-1}, respectively. The difference in the amount of N_2O evolution at the two sites is partially attributed to the difference in soil type. The water holding capacity at Outlook is lower as compared with the soil at Birsay. Subsequently, the degree of anaerobic conditions, a prerequisite for denitrification, will be less at Outlook.

A lag period of 20 hrs occurred between the application of water and the maximum evolution of N_2O of incubated soil cores. This was determined by analyzing incubated soil cores repeatedly over a period of 48 hrs. As the increase in denitrification at Birsay lasted for 24 hrs after the application of water, the maximum rate of denitrification did occur under those field conditions at Birsay. At Outlook, however, where the increase

in denitrification only lasted for 12 hrs, the maximum rate of denitrification was not obtained under the existing field conditions.

There were 10 irrigation and 7 precipitation events which caused denitrification. According to the percentage of the landform elements and its proper denitrification activity, the total N lost per year at Birsay was estimated to be 120 kg ha^{-1}.

INTRODUCTION

Denitrification is largely a biological process which converts NO_3 into N_2O and N_2 that are subsequently released to the atmosphere. Whereas N_2 is an inert gas and poses no known environmental risk, N_2O is considered a greenhouse gas and contributes to the destruction of the earth's protective ozone layer. As the increase in total denitrification activity is partly related to increase fertilizer-N use and biological N_2 fixation (Delwiche, 1979; Pratt et al., 1977) the evolution of N_2O from cultivated soils has been the subject of increased attention (Firestone, 1982; Sahrawat and Keeney, 1986).

Denitrification activity is highly variable under field conditions and rates between 0 and 223 kg N ha^{-1} have been reported (von Rheinbaben, 1990) and could cause losses of up to 73% of the applied fertilizer-N (Strebel et al., 1980; Ryden and Lund, 1980). Those large variabilities in denitrification activity *in situ* can partially be explained by differences in management. Sharp increases in N_2O fluxes have been observed after the additions of manure (Rolston et al., 1978) whereas in uncultivated land denitrification activity can be completely absent (Mosier et al., 1981) Some of the observed variability in denitrification activity can also be attributed to differences in the methodologies used to quantify N_2O fluxes (Hauck, 1986). Whereas all the unaccounted losses of applied ^{15}N have often been attributed to denitrification and would include all experimental errors (Tiedje et al., 1989), a more direct estimate, although not integrated over the whole season, of denitrification activity can be obtained by the use of the acetylene blockage technique (Yoshinari et al., 1977).

The objective of this study was to estimate denitrification in a large field setting using the acetylene blockage technique and compare the losses with those obtained from an adjacent ^{15}N-labelled fertilizer experiment.

MATERIALS AND METHODS

The major part of the field study was conducted in 1990 at Birsay, located in the Brown (aridic) soil zone of Southern Saskatchewan, Canada. The previous crop grown was fababean (*Vicia faba* L.) and the residue was incorporated in the fall of 1989. In May of 1990 the site received 100 kg N-urea ha^{-1} and was seeded into durum (*Triticum aestivum* L.) two weeks later. At time of seeding an additional 10 kg N ha^{-1} as ammonium phosphate was applied. Direct after the emergence of the seedlings, which occurred two weeks after seeding, and immediately after the first irrigation event a 200-m by 200-m area was selected in a representative section of the field and a sampling grid, composed of 144 sample sites and separated by a spacing of 10 m was selected. The sampling area was divided into four landform elements and 21 sampling sites were located on the landform element shoulders, 28 on footslopes, 44 on level-convex, and 51 on level-concave.

Soil cores were collected from the 144 grid-intersection points and collected within 3 hrs of the irrigation event which applied 25 mm of water through a central pivot system. Soil cores were collected in 10 cm × 40 mm i.d. aluminum cylinders, each of which was provided with 6 holes (7 mm in diameter) located in two rows along opposite sides of the cylinders. Each soil core was placed in a Mason jar (975 cm^3) and sealed with a lid that was equipped with a sampling port sealed with a rubber septum. Acetylene (C_2H_2) was injected (5% by volume) and incubated ambient temperature.

Denitrification activity was determined before and several times after the irrigation event in order to determine the period during which denitrification occurs.

Adjacent to the grid, in a small plot experiment 75 kg ha^{-1} of double ^{15}N-labelled ammonium nitrate (0.6177 atom % ^{15}N excess) was applied at time of seeding. At final harvest durum was harvested and soil samples were taken to a depth of 120 cm. Crop and soil was analyzed for total N and atom % ^{15}N.

At the Outlook site, only the small plot experiment with ^{15}N-labelled fertilizer was installed and the denitrification activity determined before and after irrigation. The land was seeded into springwheat.

RESULTS AND DISCUSSION

Denitrification was very variable and ranged from a low of 0 to a high of 20 kg N ha^{-1} day^{-1} (Fig. 1.5.1). The overall average of denitrification was 2.7 kg N ha^{-1} day^{-1}. The activity was not normally distributed with most of the denitrification activity occurring at

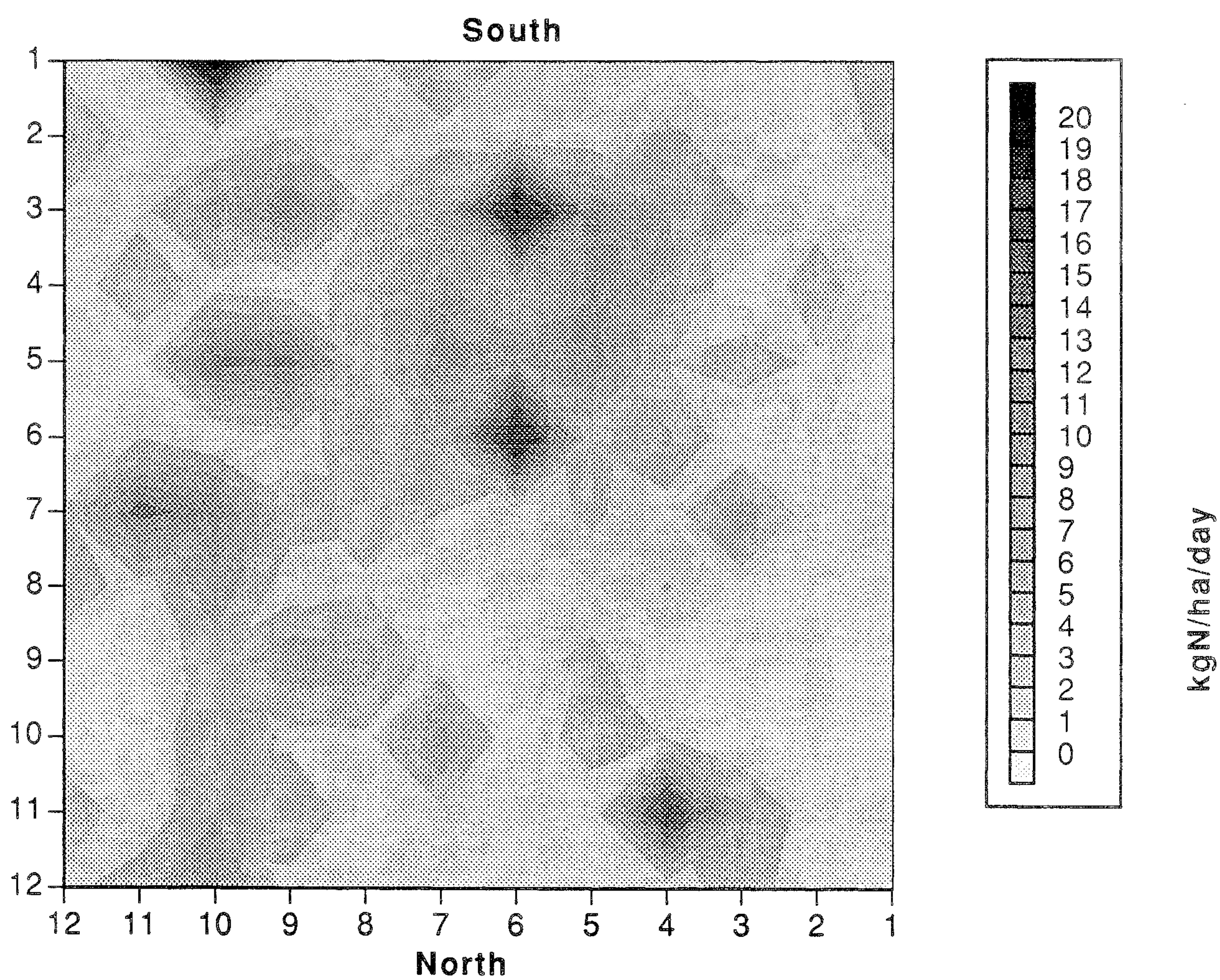

Figure 1.5.1 Spatial pattern of denitrification activity at Birsay

low levels. A distinct significant pattern in denitrification in the landscape, however, was observed and the highest activity was found in the level-concave and level-convex land form elements; the lowest denitrification activity in the shoulders and footslope land form positions (Table 1.5.1). The denitrification activity in the level-concave was about 3.5 times higher than calculated for the shoulders.

Table 1.5.1 Rate of denitrification at the various landform elements

Landform element	% of area	Denitrification* $\mu g\ N_2O\ ha^{-1}\ day^{-1}$
Shoulders	14.6	1.11 a
Footslopes	19.4	2.19 bc
Level-convex	30.6	2.46 b
Level-concave	35.4	3.97 c

* Means with same letter indicate no significant difference (LSD α >0.05) on log transformed data.

A lag period of 20 hrs was observed before the maximum rate of N_2O evolution was observed of acetylene incubated soil cores (Fig. 1.5.2). This would indicate that the microbial population which converts nitrate into N_2O requires a certain period of time before it can switch from O_2 as an electron donor to NO_3 as the new electron donor.

The denitrification activity before irrigation was zero at both locations but increased dramatically after the irrigation event (Fig. 1.5.3). The decline in N_2O evolution coincided with a decrease in soil moisture content (Fig. 1.5.4). However, at Birsay denitrification activity lasted for less than 30 hrs and a sharp decline was already observed

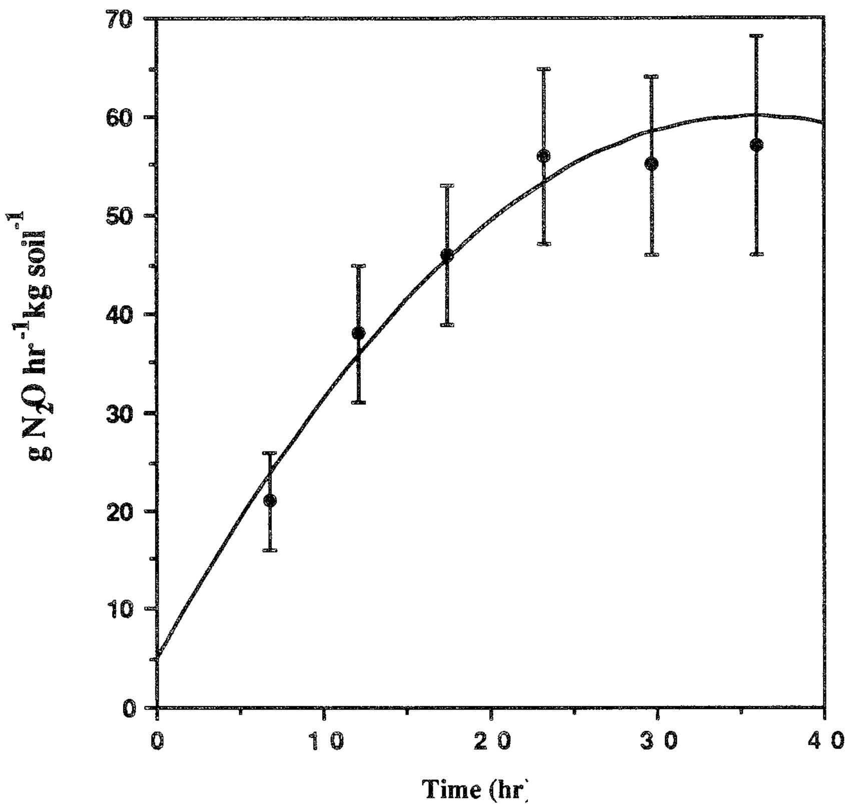

Figure 1.5.2 Hourly rate of N_2O evolution as affected by time of incubation

20 hours after the irrigation event. At Outlook, the rate of denitrification was small and only lasted less then 10 hrs. Taking the percentage and the rate of N_2O evolution at the different landscape elements taken into consideration (Table 1.5.1), a loss of 6.6 kg N cycle^{-1} at Birsay would have occurred. No detailed survey mapping was conducted at the Outlook site and no such detailed estimate could be made. At the Birsay site, irrigation was carried out 10 times and there were 7 precipitation events which would have induced denitrification activity. This would suggest that the total loss on denitrification during the growing season would amount to 122 kg N ha^{-1}.

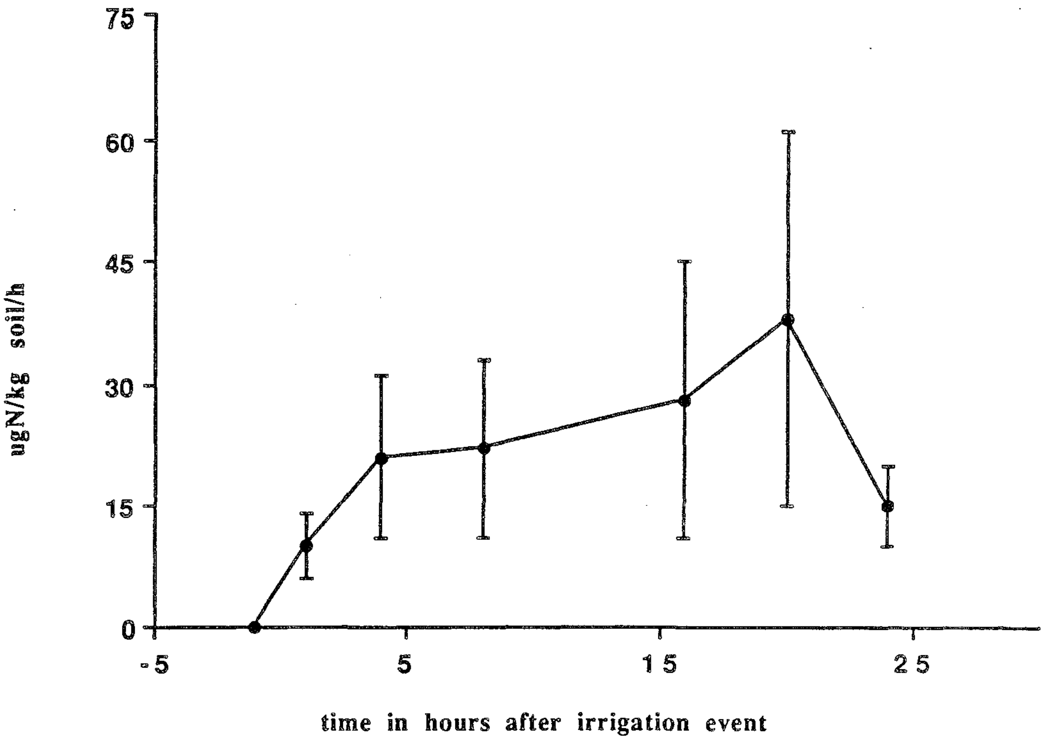

Figure 1.5.3 Evolution of N_2O before and after irrigation at Birsay

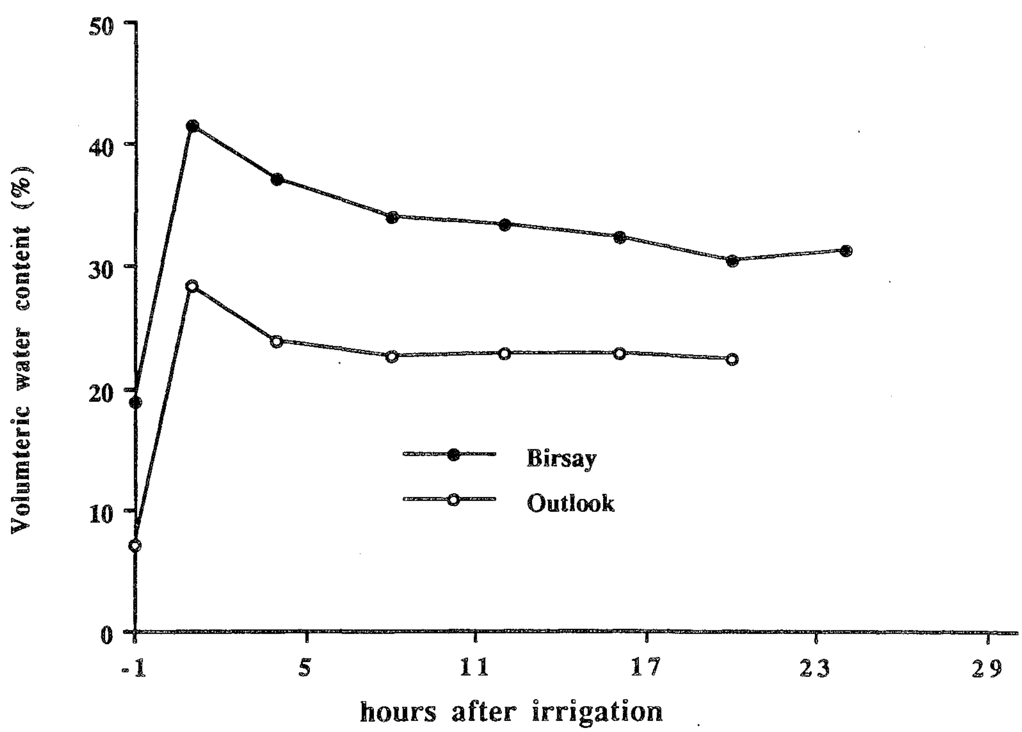

Figure 1.5.4 Volumetric water content before and after irrigation

The % recovery of ^{15}N in the straw and grain amounted to 22.1 and 16.1 at Outlook and Birsay, respectively (Table 1.5.2). Almost identical amounts of ^{15}N-fertilizer were recovered at both sites in the soil, i.e. approximately 41%. Most of the ^{15}N fertilizer was recovered from the top 0-15 cm of soil, the recovery declined in the 15-30 cm soil depth but increased again in the 30-60 cm soil depth and further declined at lower depths. One possible explanation about this pattern of ^{15}N recovery in the soil might be the immobilization of ^{15}N in the top 15 cm by the microbial biomass which tends to be higher in the top layer of soil. Less immobilization occurred in the 15-30 cm soil depth and the crop took up the labelled fertilizer. At lower depths the effect of leaching started to appear and this induced higher levels of labelled ^{15}N in the 30-60 cm soil layer.

Table 1.5.2 Recovery and losses of ^{15}N fertilizer at Birsay and Outlook

Site	Fertilizer recovered (%)										
	Crop			Soil (cm)							
	Grain	Straw	Total	0-15	15-30	30-60	60-90	90-120	Total 0-120	Soil + crop	Unaccounted
Birsay	29.0	14.1	43.1	16.6	0.9	15.7	5.3	2.4	40.9	83.9	16.1
Outlook	26.7	9.3	36.1	21.6	4.9	9.3	4.8	1.6	41.9	77.9	22.1

Although the percent of unrecovered ^{15}N-fertilizer is approximately equal at both sites, 16 and 22% at Birsay and Outlook, respectively, the rate of N_2O evolution at Birsay was found to be significant higher as compared with Outlook. The assumption often made that all the non recovered ^{15}N fertilizer is lost to denitrification may not always be valid.

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