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The Effect of Wheat Straw, Corn Straw and Tobacco Residues on Denitrification Losses in a Field Planted with Wheat

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Abstract: A field experiment was conducted to determine the effects of different organic residues (OR) (e.g., wheat straw corn straw and tobacco residues) on nitrogen mineralization and denitrification loss (N_2O-N) using application rates recommended to local farmers. Nitrate and ammonium analyses were carried out on periodically collected soil samples. *In-situ* denitrification loss was determined using the acetylene inhibition technique (AIT). The results revealed that OR application increased N mineralization significantly. In the favorable conditions for nitrification and intensive mineralization period, NO_3^--N accumulation at 0-60 cm depth peaked at 163.0, 177.7 and 226.6 kg N ha^{-1} in plots with wheat straw, corn straw and tobacco waste, respectively. *In-situ* denitrification measurements showed that intensive mineralization, depending on temperature and humidity conditions, significantly increased denitrification losses. The denitrification values measured showed a variation between 7.58 and 17.40 kg N_2O-N ha^{-1}. The results also showed that the effect of organic substrates on N loss via denitrification was highly dependent on the type of organic substrate used, and the C/N ratio of the organic substrate played an important role in N loss by denitrification.

Key Words: Wheat straw, corn straw, tobacco waste, denitrification

Buğday Anızı, Mısır Sapı ve Tütün Atığının Buğday Vejetasyonu Altında Toprakta Denitrifikasyon Kaybına Etkisi

Özet: Bu çalışma, buğday anızı, mısır sapı ve tütün atığı gibi çeşitli organik artık ve atıkların uygulama koşullarında önerilen miktarlarının N-mineralizasyonu ve denitrifikasyon kaybına (N_2O-N) etkilerinin ortaya konması amacıyla yapılmıştır. Bu amaçla, belirli zaman aralıklarında alınan topraklarda nitrat ve amonyum analizleri ve tarla koşullarında Asetilen İnhibisyon Tekniği (AIT) ile denitrifikayon kaybı ölçümleri yapılmıştır. Sonuçlar, organik substrat uygulamalarının mineralizasyonu önemli derecede artırdığını göstermiştir. Mineralizasyon ve nitrifikasyonun yoğun olduğu dönemlerde ise buğday anızı uygulamasında 163,0 kg N/ha, mısır sapı uygulamasında 177,7 kg N/ha, tütün atığı uygulamasında 226,6 kg N/ha maksimum NO_3^--N değerleri elde edilmiştir (0-60 cm). *In-situ* denitrifikasyon ölçümleri, mineralizasyonun yoğun olmasının, sıcaklık ve toprak nemine bağlı olarak denitrifikasyonu önemli ölçüde artırdığını göstermiştir (uygulamalara göre değişmekle beraber 7,58-17,40 kg N_2O-N/ha). Sonuçlar ayrıca, toprağa ilave edilen organik substratların denitrifikasyonla meydana gelen N kaybına olan etkilerinin, ilave edilen organik substrata göre değiştiğini, organik substrat C/N oranının burada önemli rol oynadığını ortaya koymuştur.

Anahtar Sözcükler: Buğday anızı, mısır sapı, tütün atığı, denitrifikasyon

Introduction

The amount of organic matter in arable land is generally insufficient. In particular, high temperatures and monoculture cropping systems reduce the soil's organic matter content (Graham et al., 2002). Therefore, in recent years different types of organic materials have increasingly been applied to soils. Organic substrate applications not only increase the organic matter content of soil, but also enhance the soil's carbon and nitrogen contents and improve microbial biomass, microbial respiration and enzyme activities (Vigil et al., 1991). Data on the effects of various crop residues on microbial denitrification, mineralization and immobilization are limited (Schutter and Dick, 2002). The specific substrate C requirement for the dominant denitrifying microbes in denitrification is not well known (Beauchamp et al., 1989). In rice-wheat cropping systems the incorporation of wheat residues and green manures into soil under anaerobic conditions enhances soil respiration, CO_2 production and rate of denitrification (Aulakh et al., 2001). Although N-loss by denitrification occurs under anaerobic conditions, denitrification can, however, also occur under aerobic conditions as well as during intensive mineralization at micro site levels within the soil when the electron acceptor is rare (Ottow, 1992; Hutchinson et al., 1993). It is expected that in the sufficient nitrate content of soil (nitrate fertilization) the application of organic substrates encourages denitrification.

The aim of this study was to determine the effects of various plant residues, including wheat straw, corn straw and tobacco residue (residue from a cigarette factory), on the rate of denitrification loss measured by AIT in a field planted with wheat.

Materials and Methods

Field experiment

The experiment was carried out at the Research Station of Çukurova University in Adana/Turkey in the 1996-1997 cropping season. The plots (2.8 x 6 m) were arranged in a randomized complete block design in four replications. Treatments comprised control, wheat straw (4000 kg ha^{-1}), corn straw (7000 kg ha^{-1}) and tobacco waste (30,000 kg ha^{-1}). The carbon and nitrogen contents and C/N ratios of organic substrates applied to soil were 44.1%, 0.65% and 67.8 for wheat straw; 50.0%, 0.63% and 79.3 for corn straw and 48.6%, 2.26% and 21.5 for tobacco waste respectively. Some properties of the soils (0-20 cm) in the experimental site were as follows: total organic carbon content 0.79%, total N content 0.126%, $CaCO_3$ 35.4%, soil texture clay, total salt 0.086%, cation exchange capacity 23.9 me.100 g^{-1} and pH (H_2O) 7.70. Annual precipitation was 700 mm, and the range of temperatures was 25-35 °C in summer and 10-20 °C in winter at the research station.

Wheat and corn straw were applied by considering the balance fertilization with N [2 kg N/100 kg straw as $(NH_4)_2SO_4$]. Wheat seeds (*Triticum aestivum*, cv. Panda) were sown on 12.11.1996 following the incorporation of organic residues. Before wheat sowing, 60 kg N ha^{-1} and 60 kg P_2O_5 ha^{-1} as inorganic fertilizer (20-20) were applied to each plot. Applications of the second and third N fertilizers (to each plot 40 kg N ha^{-1} in the form of $CaNH_4NO_3$) were carried out on 31.01.1997 and 03.03.1997, respectively. Wheat was harvested on 03.06.1997 and grain yield was determined.

Chemical and Biological Analysis

Soil samples collected from 0-60 cm were analyzed for their nitrate and ammonium contents and other chemical analyses were performed in samples collected at 0-20 cm. Nitrate and ammonium were analyzed using the Na-salicylat methods (Fabig et al., 1978) and the Na-nitroprussid method (Deutsche Einheitsverfahren, 1983). The total carbon, total nitrogen, calcium carbonate ($CaCO_3$), texture, total salt and cation exchange capacity (CEC) of the soil samples were analyzed according to the methods of Lichterfelder (Schlichting and Blume, 1966), Kjeldahl (Bremner, 1965), Scheibler calcimeter (Schlichting and Blume, 1966), hydrometer (Bouyoucos, 1951), Wheatstone (U.S. Salinity Laboratory Staff, 1954) and ammonium acetate extraction (U.S. Salinity Laboratory Staff, 1954), respectively. pH was analyzed with a pH-meter (Schlichting and Blume, 1966) in a 1:1 soil to water ratio.

Measurement of total denitrification losses by C_2H_2 inhibition

Total denitrification losses were measured *in situ* using the acetylene inhibition technique (AIT) (Ottow et al., 1995). The N_2O concentration in each flask was determined by Electron Capture detector of gas chromatography (HP-5890, 2 m, 80-100 mesh, 1/8 inch steal poropak Q column; temperatures of detector 300 °C, injector 60 °C, oven 54 °C). N_2 was used as a carrier flow (Ottow et al., 1995). All results were statistically analyzed using MSTATC (Crop and Soil Sciences Department, Michigan State University, Version 1.2) software.

Results

Effect of Organic Residue (OR) Applications on Total Denitrification

The effects of wheat straw, corn straw and tobacco waste applications on total denitrification losses, and ammonium and nitrate contents are presented in Table 1. The highest denitrification losses occurred in the plots amended with chopped tobacco residues, followed by wheat and corn straw. The lowest denitrification losses were measured in the control plots without the addition

Table 1. Effects of different organic residues on N_2O loss (g N_2O-N/ha.day), NO^-_3-N and NH^+_4-N contents (kg/ha) of 0-60 cm soil depth along with soil moisture (%) and air temperature (°C).

Date		Days	Soil moisture	Air temp.	control			wheat			corn			tobacco		
					N_2O-N	NO_3-N	NH_4-N	N_2O-N	NO_3-N	NH_4-N	N_2O-N	NO_3-N	NH_4-N	N_2O-N	NO_3-N	NH_4-N
1996	N 06	5	18	32	20.5	31.0	18.1	34.1	124.3	25.1	34.2	161.7	53.3	55.3	169.6	19.8
	N 13	12	19	26	21.5	30.9	123.3	0.6	129.4	214.1	23.5	70.5	185.6	36.1	124.7	224.2
	N 22	21	19	22	12.1	76.0	27.7	14.6	155.2	29.7	15.8	166.2	30.0	40.2	179.4	62.4
	N 28	27	20	21	22.4	31.8	61.2	17.2	88.4	58.0	5.0	115.2	84.3	25.3	158.9	101.8
	D 11	40	24	21	14.3	92.2	43.1	25.8	163.0	30.7	36.2	164.0	46.0	85.0	166.5	40.9
	D 19	48	28	16	29.9	30.3	68.1	29.8	100.2	49.0	24.2	177.7	41.0	76.7	185.4	148.0
1997	J 02	62	28	19	21.9	35.2	38.7	22.3	47.6	44.6	20.9	67.1	44.8	62.8	226.5	41.1
	J 20	80	30	13	35.8	3.1	20.4	30.9	3.1	18.6	24.2	7.5	22.2	44.6	31.0	21.6
	J 30	90	23	9	27.3	16.8	69.7	23.9	24.4	47.5	17.6	16.5	54.3	27.0	59.8	48.1
	F 18	109	23	16	19.4	35.8	28.5	28.3	34.9	21.3	20.6	22.4	20.5	56.3	145.9	23.2
	M 10	129	26	15	31.1	42.7	24.6	66.0	36.3	33.8	45.9	53.1	20.2	67.4	65.2	25.8
	A 01	151	27	22	23.8	106.8	46.6	33.9	97.0	24.0	24.1	84.4	23.5	34.6	238.5	25.3
	A 17	167	31	17	13.6	18.1	25.4	14.4	20.8	33.5	13.8	19.8	28.2	60.7	73.0	38.4
	A 30	180	25	17	16.9	13.1	35.5	4.4	31.7	36.0	3.6	32.3	38.6	33.4	161.8	32.1
	M 20	200	19	32	4.9	16.4	34.6	5.1	23.4	39.2	2.0	27.8	39.1	9.8	200.0	36.9

of organic residues. Wheat and corn straw did not differ greatly in their effect on denitrification. The highest N_2O-N losses (34 g ha^{-1} day^{-1} in wheat and corn straw, 55 g ha^{-1} day^{-1} in tobacco waste) were determined as a result of balance fertilization with nitrogen applied to plots following OR applications. Mineralization values were high towards the end of December 1996 due to OR application, while the lowest NH_4^+ and NO_3^- contents in the soil were measured on 20.01.1997.

Particularly high losses in denitrification were found in plots treated with tobacco waste, possibly due to high mineralization (Table 1). The ammonium and nitrate contents of soil treated with tobacco waste were higher until January 1997 compared to the following periods. However, N-loss by denitrification was not lower; it was even higher until January 1997 than in the period following January 1997 (Table 1). It seems likely that the factors other than Nmin affect denitrification.

The effects of organic C and N from the OR applications on the average level of denitrification loss, the percentage of N_2O-N loss of the total N applied and wheat seed yield are presented in Table 2.

Average N_2O-N losses caused by denitrification were 17.4, 7.6, 8.6 and 7.7 kg ha^{-1} $year^{-1}$ for the tobacco waste, corn straw, wheat straw and control treatments, respectively. As presented in Table 2, the effects on denitrification losses were significant in tobacco waste plots; however, no significant differences were obtained between the other residue treatments. N_2O fluxes were found to be closely related to the amount of nitrogen applied. Among the treatments the lowest percentage (2.1%) of denitrification was found with tobacco residue treatment, and the highest was in the control plots (5.5%) (Table 2). The results obtained indicated that for the Çukurova region there is no clear relationship between the denitrification rate and the amount of available N and C; however, organic residue applications were effective in decreasing denitrification losses. Among the organic residues used, tobacco waste had the largest effect on wheat grain yield. There were no significant (P = 95%) differences between the other organic residues except for tobacco waste. The higher increases in grain yield in plots treated with tobacco waste seem to be directly related to the N content of the soil. Tobacco residue supplied the soil with the highest amount of N and this was reflected in a high grain yield (Table 2).

Following the rainy season, soil humidity increased by about 10-15% w/w. Favorable humidity conditions and temperature levels increased mineralization, and consequently the ammonium-N and nitrate-N contents of soils were also enhanced. Mineralization and thus NH_4^+-N

Table 2. The effects of organic carbon and nitrogen on wheat grain yield and denitrification losses from the plots at the experimental site during 1996-1997 [1)].

Applications	Added amount of org. residues kg ha^{-1} (= kg C ha^{-1})	Added mineral and organic N kg ha^{-1}	Grain yield kg ha^{-1}	Mean N_2O-N losses g ha^{-1} day^{-1}	N_2O-N fluxes in % of total added N
Control	-	140	5060 B[2)]	21.0 B	5.5 A
Wheat straw	4000 (1762)	246	5020 B	23.4 B	3.5 B
Corn straw	7000 (3499)	324	5580 B	20.8 B	2.3 C
Residue tobacco	30000 (14577)	818	8430 A	47.7 A	2.1 C

[1)] The experimental plots were planted with wheat.
[2)] Different letters show significant differences at the 95% probability level.

and NO_3^--N contents of the soil dropped with the decreasing temperature after the beginning of January. However, in this period, the decrease in denitrification loss was not significantly relevant to the NO_3^--N and NH_4^+-N contents of the soil. Denitrification was not corrupted, but decreased in the relatively low air temperature (10-15 °C). In the case of tobacco waste, mineralization was more intensive compared to other OR applications. Therefore, the N loss caused by denitrification was much higher in tobacco waste treatments than that of the OR application in almost all periods. With OR application, different NH_4^+, NO_3^- and N_2O peaks occurred. The diversity of the peaks could be explained by the different C and N contents (Table 2) and thus with different C/N ratios of OR. The NO_3^- peaks were relevant to the N_2O peaks. The corn and wheat straw applications showed fewer and smaller NH_4^+, NO_3^- and N_2O peaks when compared to the tobacco waste application. Mineralization and denitrification were high in all plots treated by OR when compared to the control (without OR application) plots. Finally, a balanced C/N ratio is of great importance for optimizing the yield and minimizing denitrification losses and N-leaching in soils. In particular, organic substances showing high mineralization would increase mineral N content of soil and contribute to soil fertility.

Discussion

In the Çukurova region, where generally a wheat-corn or wheat-soybean cropping system is followed, plant residues are burned, causing the degradation of organic matter. Recently, farmers in Turkey have increased their use of organic wastes and green manure to improve and sustain soil quality. This practice is widely recommended to compensate for the deficient mineral nutrients in soils, improve soil physical structures and allow energy conservation of soils. Such positive effects of organic residues on soil quality have been repeatedly shown in different countries (Palm et al., 2001; Kumar et al., 1999). The amount of OR applied to the soil is a generally recommended amount to the farmer, or it is the amount remaining in the field after harvesting (Table 2). As found in the present study, OR application to soil enhanced the C and N contents of the soil, microbial biomass, soil respiration and dehydrogenase activity as well as mineralization (Roose and Barthes, 2001; De Neergard et al., 2002). NH_4^+-N and NO_3^--N may be converted to gaseous products by the denitrifying micro flora at adequate soil humidity and air temperature in spite of both being available for the growing crop. The results revealed that denitrification losses increased following mineral fertilization, and the amount of NO_3^--N significantly increased with increasing soil humidity and temperature. In field experiments, Simarmata et al. (1991) showed that the highest denitrification losses occurred in plots without organic straw application and just after mineral fertilization. They found a close relationship between soil nitrate contents and denitrification losses. Recently, Hao et al. (2001) demonstrated that N_2O emission can be minimized by N fertilization and retention of straw in soil. Confirming these results we showed that OR application reduced denitrification losses as a percentage of total N (Table 2).

The results obtained in this study showed the importance of the balance between C and N in soil for sustaining optimum yield and reduced N-loss by denitrification (Table 2). The effect of organic residues on N loss by denitrification is dependent on the type of residue, being highest with tobacco residues. There is a great need for controlling the rate of organic residue application because of its increasing effect on the accumulation of NO_3^- in the soil and the possible contamination of ground water.

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