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SEÇÃO II - QUÍMICA DO SOLO

DYNAMICS OF ^{14}C-LABELED GLUCOSE AND AMMONIUM IN SALINE ARABLE SOILS[1]

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SUMMARY

Organic matter dynamics and nutrient availability in saline agricultural soils of the State of Guanajuato might provide information for remediation strategies. ^{14}C labeled glucose with or without 200 mg kg^{-1} of NH_4^+-N soil was added to two clayey agricultural soils with different electrolytic conductivity (EC), i.e. 0.94 dS m^{-1} (low EC; LEC) and 6.72 dS m^{-1} (high EC; HEC), to investigate the effect of N availability and salt content on organic material decomposition. Inorganic N dynamics and production of CO_2 and $^{14}CO_2$ were monitored. Approximately 60 % of the glucose-^{14}C added to LEC soil evolved as $^{14}CO_2$, but only 20 % in HEC soil after the incubation period of 21 days. After one day, < 200 mg ^{14}C was extractable from LEC soil, but > 500 mg ^{14}C from HEC soil. No N mineralization occurred in the LEC and HEC soils and glucose addition reduced the concentrations of inorganic N in unamended soil and soil amended with NH_4^+-N. The NO_2^- and NO_3^- concentrations were on average higher in LEC than in HEC soil, with exception of NO_2^- in HEC amended with NH_4^+-N. It was concluded that increases in soil EC reduced mineralization of the easily decomposable C substrate and resulted in N-depleted soil.

Index terms: dynamics of inorganic N, emission of $^{14}CO_2$ and $^{12}CO_2$, saline soils.

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RESUMO: *DINÂMICA DE GLICOSE MARCADA COM ^{14}C E AMÔNIO EM SOLOS SALINOS*

Os conhecimentos sobre a dinâmica da matéria orgânica e disponibilidade de nutrientes em solos salinos podem ser úteis para nortear a adoção de estratégias de recuperação e manejo. O objetivo deste trabalho foi avaliar o efeito da condutividade elétrica (EC) e presença de N inorgânico na decomposição da matéria orgânica a dois solos salinos localizados em Guanajuato (México). Nesse sentido, glicose marcada com ^{14}C com ou sem amônio na dose de 200 mg kg^{-1} de N foi adicionada em dois tipos de solo com valores de condutividade elétrica de 0,94 dS m^{-1} (baixo EC; LEC) e 6,72 dS m^{-1} (alta EC; HEC). Amostras de solos foram incubadas durante 21 dias e, ao longo desse tempo, foram avaliadas as concentrações de N inorgânico e a produção de $^{12}CO_2$ e $^{14}CO_2$. Após o período de incubação, aproximadamente 60 % da glicose marcada com ^{14}C adicionado ao solo LEC evoluiu como $^{14}CO_2$, mas somente 20 % no solo HEC a evolução de $^{14}CO_2$ foi de apenas 20 %. Decorrido um dia de incubação, menos de 200 mg de ^{14}C foram extraídos do solo LEC, ao passo que no solo HEC foram extraídos mais de 500 mg de ^{14}C. Não ocorreu mineralização de N nos dois solos e a adição de glicose reduziu as concentrações de N inorgânico no solo controle e no solo que recebeu N-NH_4^+. As concentrações de NO_2^- e NO_3^- foram, em média, maiores no solo LEC do que no solo HEC, com exceção do teor de NO_2^-, que foi maior no HEC tratado com NH_4^+. O aumento da condutividade elétrica promoveu a redução da mineralização de substrato facilmente decomponível e a diminuição do teor de N no solo.

Termos de indexação: dinâmica de nitrogênio inorgânico, emissão de $^{12}CO_2$ e $^{14}CO_2$, solos salinos.

INTRODUCTION

Nowadays, there is an environmental and economic need to understand the role and destiny of N in different ecosystems. Nitrogen cycling is mostly controlled by biological activity and at the same time biological processes are affected by climate and physicochemical soil characteristics. In some extreme environments, such as saline soils, the high electrolytic conductivity (EC) inhibits microbial activity and organic matter decomposition and thus affects N cycling (Johnston & Guenzi, 1963; McCormick & Wolf, 1980; Bandyopadhyay & Bandyopadhyay, 1983; Zahran, 1997; Pathak & Rao, 1998). For instance, mineralization of maize and glucose were inhibited in alkaline saline soils with EC > 10 dS m^{-1} and large amounts of NH_4^+ and NO_3^- were immobilized within short periods of time, reducing N availability (Conde et al., 2005). Additionally, high concentrations of nitrite (NO_2^-) were accumulated in these soils when an easily decomposable substrate plus NO_3^- were added (Vega-Jarquin et al., 2003). Pathak & Rao (1998) reported that ammonification and nitrification were inhibited by high salt concentrations and that, particularly the latter, was very sensitive to the presence of salts.

High concentrations of soluble salts in soil have a negative effect on plant growth in different aspects (Aguirre, 1993; Zahran, 1997). In the first place, high concentrations of specific ions such as Na^+ are toxic to plants and cause physiologic disorders. Secondly, the presence of salts decreases water root uptake (Bohn et al., 1979; Aguirre, 1993; Pankhurts et al., 2001; Atlas & Bartha, 2002; Bernstein & Kafkafi, 1996; Haynes & Rietz, 2003). And thirdly, certain ions have a negative effect on the solubility of other ions and on microbial biomass activity, e.g., protein synthesis and respiration (Giambiagi & Lodeiro, 1989; Aguirre, 1993; Atlas & Bartha, 2002; Sardhina et al., 2003).

Plant growth and crop yields have decreased in some parts of the State of Guanajuato, Mexico, due to the excessive amounts of salts in the soil, and some parts have become uncultivable. The salt in soil increases since crops are irrigated with saline effluents and by inadequate soil practices. The Agriculture Department of the State of Guanajuato has started a project to investigate how increased salinity affects nutrient availability in the soil and how the addition of organic material might restore soil fertility. As part of this project, the effect of increased salinity on dynamics of inorganic N (NH_4^+, NO_2^-, NO_3^-) and organic material were investigated. Two agricultural soils with different electrolytic conductivity (EC), i.e. 0.94 dS m^{-1} (low EC; LEC) and 6.72 dS m^{-1} (high EC; HEC) were amended with or without ^{14}C-labeled glucose and with or without $(NH_4)_2SO_4$. The ^{14}C-labeled glucose is routinely used to determine effects of soil characteristics on mineralization of organic material (Saggar et al., 1999). The objective of this study was to investigate the effect of EC and inorganic N on the decomposition of organic matter in two soils of Guanajuato State, Mexico.

MATERIALS AND METHODS

Sampling site

The sampling sites are located in Cuerámaro (HEC soil) and San Francisco del Rincón (LEC soil), State of Guanajuato, Mexico, at 1,726 and 1,804 m asl, with a mean annual temperature of 20.3 and 19.4 °C; and precipitation of 981 and 967 mm, respectively (Terrones-Rincón et al., 2000). Soils in the area originating from aluvio-coluvial deposits are clayey-loamy to clayey-sandy. The soil structure is granular in the top soil and organic matter contents range from 14 to 52 g kg^{-1} dry soil; EC in saturation extracts ranges from 0.9 to 6.7 dS m^{-1}. The cation exchange capacity (CEC) in soils ranges from 34.8 to 40.5 $cmol_c$ kg^{-1} dry soil while exchangeable Ca^{2+} from 66 to 90 mg kg^{-1}, Mg^{2+} from 17 to 26 mg kg^{-1}, Na^+ from 82 to 163 mg kg^{-1}, K^+ from 15.6 to 19.6 mg kg^{-1}, and extractable P from 23 to 32 mg kg^{-1}. CO_3^{2-} in the exchangeable saturation extract ranges from 15 to 24 mg kg^{-1}, Cl^- from 82 to 93 mg kg^{-1} and SO_4^{2-} from 230 to 289 mg kg^{-1} (Castellanos-Ramos et al., 2000). Approximately 17 % of the study area is irrigated. The natural vegetation consists of species that can be used for cattle raising, such as *Bouteloua chasei, Muhlenbergia* spp., *Prosopis* spp., *Camedrioteucrium chamaedrys*, *Bothriochloa* spp., *Buchloe dactyloides*, *Aristida divaricata, Liendilla lanuda*, *Bouteloua curtipendula*, *Acacia* spp., *Opuntia* spp., and *Uncaria tomentosa.*

Two agricultural soils with different EC were sampled (Table 1). In each one, three plots of approximately 400 m^2 were defined from which 30 soil samples were collected by augering the top 0–15 cm layer. The 30 soil samples from each plot were pooled separately and characterized for a total of six soil samples, i.e., soil from two fields and three plots.

Aerobic incubation

The soil samples were passed through a 5 mm sieve and placed in drums containing a beaker with 100 mL distilled H_2O to avoid desiccation. One contained 100 mL 1 mol L^{-1} NaOH solution to trap any CO_2 evolved for six days.

Sixty soil sub-samples (30 g) from each field and plot were filled in 120 mL glass flasks. Fifteen sub-samples were amended with a solution containing ^{14}C-labeled glucose (approximately 1.48 MBq kg^{-1}), 15 with ^{14}C-labeled glucose plus $(NH_4)_2SO_4$, 15 with $(NH_4)_2SO_4$ and the others were treated with an equal amount of distilled H_2O. The amount of water added resulted in a soil moisture content of approximately 50 % WHC, and the amounts of C and N added as glucose and NH_4^+ were approximately 1,000 mg kg^{-1} C and 200 mg kg^{-1} N. Three flasks were chosen at random from each treatment. Soil was extracted (30 g) for inorganic N and ^{14}C with 120 mL 0.5 mol L^{-1} K_2SO_4 solution to provide zero time samples. The samples were shaken for 30 min, filtered through Whatman No 42 paper® and stored until analysis at -20 °C (Jenkinson & Powlson, 1976).

The glass flasks were placed in 945 mL glass jars with 10 mL distilled H_2O. One contained a vessel with 20 mL 1 mol L^{-1} NaOH solution to trap CO_2 evolved and another a vessel with 20 mL 2 % H_3BO_3 solution to trap volatilized NH_3. The jars were sealed airtight and stored in the dark for 21 days at 22 ± 1 °C. After 1, 3, 7 and 21 days, three jars selected at random from each treatment were opened, and the vessels containing NaOH and H_3BO_3 were removed. An aliquot of 0.2 mL 1 mol L^{-1} NaOH solution was taken and analyzed for ^{14}C activity. The remaining NaOH and H_3BO_3 solution was titrated with appropriate concentrations of H_2SO_4 to determine CO_2 and NH_3 trapped, respectively. The soil was removed from the three flasks and 30 g was extracted with 120 mL 0.5 mol L^{-1} K_2SO_4 solution. The samples were shaken for 30 min and filtered through Whatman N° 42 paper® and the inorganic and organic N and ^{14}C were measured as described for zero time samples (Conde et al., 2005).

Chemical analysis

The pH was measured in 1:2.5 soil/H_2O suspension using a glass electrode (Thomas, 1996). Total C was determined by oxidation with potassium dichromate

Table 1. Soil characteristics

Soil	Conductivity	pH_{H_2O}	WHC[1]	Carbon		Total		Particle size distribution			Textural Classification
				Organic	Inorganic	N	P[2]	Clay	Silt	Sand	
	dS m^{-1}			g kg^{-1} dry soil							
LEC soil	0.94	7.7	850	12.0	0.04	1.14	0.032	404	307	289	Clay
HEC soil	6.72	7.4	838	9.2	1.26	0.98	0.023	416	240	344	Clay

[1] WHC: water holding capacity. [2] Total P was measured by *aqua regia* digestion with sodium carbonate fusion (Crosland et al., 1995).

($K_2Cr_2O_7$) and titration of excess dichromate with $(NH_4)_2FeSO_4$ (Kalembasa & Jenkinson, 1973), and inorganic C by adding 5 mL 1 mol L^{-1} HCl solution to 1 g air-dried soil and trapping CO_2 evolved in 20 mL 1 mol L^{-1} NaOH. Total N was measured by the Kjeldhal method using concentrated H_2SO_4, K_2SO_4 and HgO to digest the sample (Bremner, 1996), soil particle size distribution by the hydrometer method as described by Gee & Bauder (1986) and CEC with the barium acetate method (Jackson et al., 1986).

The NH_4^+, NO_2^- and NO_3^- in the 0.5 mol L^{-1} K_2SO_4 extracts were measured colorimetrically with an automatic Skalar San plus System (the Netherlands). The ^{14}C in the extracts was measured with a scintillation counter (Beckman LS6000SC, USA). The CO_2 in the 1 mol L^{-1} NaOH was determined by titration with 0.1 mol L^{-1} HCl (Jenkinson & Powlson, 1976). The WHC was measured in soil samples water-saturated in a funnel and left to stand overnight and defined by weight differences (Conde et al., 2005).

Statistical analysis

The cumulative production of $^{12}CO_2$ and $^{14}CO_2$ was regressed on elapsed time using a linear model forced to pass through the origin, but allowing different slopes (production rates) for each treatment. This approach was supported by the theoretical considerations that no $^{12}CO_2$ and $^{14}CO_2$ was produced at time zero and a control (flask without soil) accounted for atmospheric $^{12}CO_2$ and $^{14}CO_2$.

The data of soil characteristics, concentration of NH_4^+, NO_2^- and NO_3^-, and extractable ^{14}C were subjected to one-way analysis of variance using PROC GLM (SAS, 1989) to test for significant differences between treatments with Tukey's Studentized Range test. Significant differences between treatments for $^{12}CO_2$ and $^{14}CO_2$ production were determined using PROC MIXED (SAS, 1989).

RESULTS

Extractable ^{14}C and production of $^{14}CO_2$

The CO_2 production rate was significantly higher in LEC soil amended with NH_4^+ than in the unamended soil, but lower than in soil amended with ^{14}C labeled glucose or ^{14}C labeled glucose plus NH_4^+ ($p < 0.05$) (Figure 1a, Table 2). The CO_2 production rate was significantly higher in HEC soil amended with ^{14}C labeled glucose or NH_4^+ than in the unamended soil, but lower than in soil amended with ^{14}C labeled glucose plus NH_4^+ ($p < 0.05$) (Figure 1b, Table 2). The CO_2 production rate was 1.3 times and significantly higher in LEC soil than in HEC soil (mean of all treatments) ($p < 0.05$).

The production of $^{14}CO_2$ was greater in LEC soil amended with glucose than in soil amended with glucose plus NH_4^+ (Figure 1c, Table 2). The production of $^{14}CO_2$ was lower in HEC soil amended with glucose than in soil amended with glucose plus ammonium soil (Figure 1d, Table 2). The $^{14}CO_2$ production rate was 1.4 times and significantly higher in LEC soil than in HEC soil (mean of all treatments) ($p < 0.05$).

The amount of extractable ^{14}C was similar in LEC soil amended with glucose and glucose plus NH_4^+ over time (Figure 1e). A sharp drop was detected after the first day and a flattening out afterwards. Based on the concentration of ^{14}C in the soil extracts, approximately 150 mg C of the added glucose could not be detected one hour after its application in LEC soil and 100 mg glucose-C in HEC soil. Less than 10 mg kg^{-1} ^{14}C soil was measured after 21 days. The extractable ^{14}C decreased more slowly in HEC soil than in LEC soil and the residual concentration of ^{14}C was > 68 mg kg^{-1} ^{14}C in soil amended with glucose plus NH_4^+ after 21 days (Figure 1f). The extractable ^{14}C decreased faster in HEC soil amended with glucose plus NH_4^+ than in soil amended with glucose and the

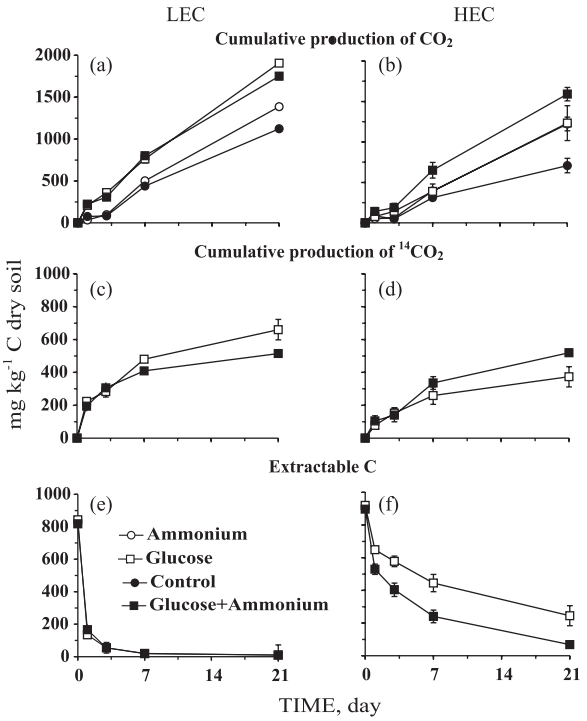

Figure 1. Cumulative production of $^{12}CO_{20}$ in (a) LEC soil and (b) HEC soil, cumulative production of $^{14}CO_2$ in (c) LEC soil and d) HEC soil and extractable ^{14}C in (e) LEC soil and (f) HEC soil unamended (●) or amended with 200 mg kg^{-1} NH_4^+-N dry soil (○), 1,000 mg kg^{-1} ^{14}C-labeled glucose C dry soil (□) or with 200 mg kg^{-1} NH_4^+-N dry soil plus 1,000 mg kg^{-1} ^{14}C-labeled glucose C dry soil (■) incubated aerobically at 22 ± 2 °C for 21 days. Bars are ± 1 STD and each point is the mean of n = 9.

residual concentration was also higher in the latter, i.e., 245 mg kg^{-1}. ^{14}C. The amount of extractable ^{14}C was significantly higher in HEC than in LEC soil (mean of all treatments) ($p < 0.05$) (Table 2).

the maximum was lower, reached after seven days. The mean NO_2^- concentration was similar in LEC and HEC soil (mean of all treatments) ($p < 0.05$) (Table 2).

Table 2. The $^{12}CO_2$ and $^{14}CO_2$ production rate, the mean extractable ^{14}C (mg kg^{-1} C soil), mean amount of NH_3 volatilized and the mean concentration of NH_4^+, NO_2^- and NO_3^- in LEC and HEC soil

	LEC soil	HEC soil	SEE[1] ($p < 0.05$)
$^{12}CO_2$ production rate (mg kg^{-1} day^{-1} C)[2]	73.8 A[3]	56.7 B	2.3
$^{14}CO_2$ production rate (mg kg^{-1} day^{-1} C)	16.5 A	12.0 B	1.9
			LSD[4] ($p < 0.05$)
Extractable ^{14}C (mg kg^{-1} C soil)	106.5 B	248.8 A	65.6
Mean concentration of NH_3 (mg kg^{-1} N soil)	0.6 A	1.2 A	0.6
Mean concentration of NH_4^+ (mg kg^{-1} N soil)	41.7 A	40.3 A	11.4
Mean concentration of NO_2^- (mg kg^{-1} N soil)	2.2 A	1.6 B	0.6
Mean concentration of NO_3^- (mg kg^{-1} N soil)	40.2 A	19.3 B	6.4

[1] SEE: standard error of the estimate ($p < 0.05$). [2] Mean of the four treatments. [3] Values with the same letter are not significantly different from each other ($p < 0.05$). [4] LSD: Least significant difference ($p < 0.05$).

Inorganic N

The emissions of NH_3 from both soils < 4 mg kg^{-1} N soil and treatment had no significant effect on the mean NH_3 concentrations volatilized from both the LEC soil and HEC soils (Table 2). The mean amount of NH_3 volatilized was similar for LEC soil and HEC soil (mean of all treatments) ($p < 0.05$).

The NH_4^+ concentrations in the unamended LEC soil and HEC soil remained < 4 mg kg^{-1} NH_4^+-N and glucose addition decreased these values < 0.2 mg kg^{-1} NH_4^+-N (Figure 2a,b). The concentration of NH_4^+ was lower in soil amended with glucose plus NH_4^+ than in soil amended with NH_4^+ alone (Table 2). The mean concentrations of NH_4^+ were similar in both soils (mean of all treatments) ($p < 0.05$).

The pattern of NO_2^- concentrations in the unamended LEC soil and soil enriched with NH_4^+ was similar, i.e., a small decrease over time, with concentrations < 2 mg kg^{-1} N (Figure 2c). The NO_2^- concentration in the glucose-amended soil also decreased over time, though the values were higher than in the unamended soil and soil enriched with NH_4^+. In the glucose-amended soil plus NH_4^+, the NO_2^- concentrations increased sharply to > 7 mg kg^{-1} NO_2^- N on day 1 and 3 and then decreased sharply to < 2 mg kg^{-1} NO_2^- N. The NO_2^- concentrations in the unamended HEC soil and soil enriched with glucose showed a similar pattern, i.e. a small decrease over time, with concentrations < 2 mg kg^{-1} N (Figure 2d). The NO_2^- concentrations in the glucose-amended plus NH_4^+ increased to a maximum of 5 mg NO_2^- N after three days, and then decreased. In the NH_4^+-amended soil, the concentrations of NO_2^- showed a similar pattern as in glucose plus NH_4^+ amended soil, but

The NO_3^- concentration did not change significantly over time in unamended LEC, but decreased in the glucose-amended soil ($p < 0.05$)

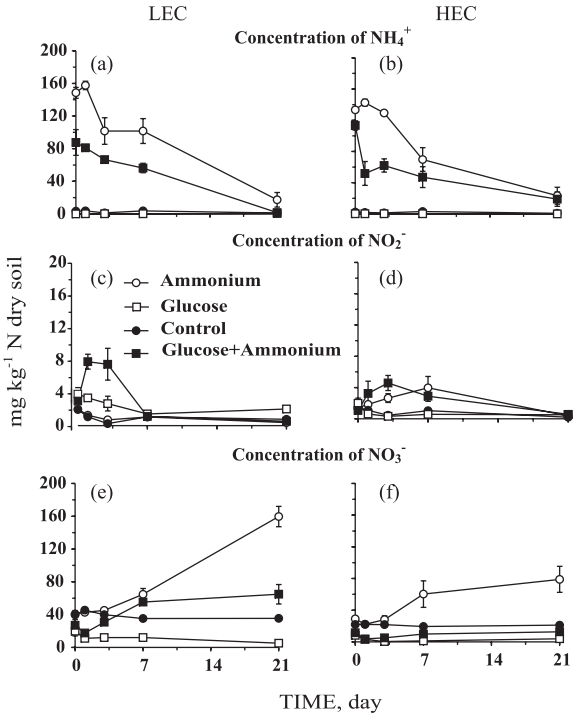

Figure 2. Concentration of NH_4^+ in (a) LEC soil and (b) HEC soil, concentration of NO_2^- in (c) LEC soil and (d) HEC soil and concentration of NO_3^- in (e) LEC soil and (f) HEC soil. Legends to the figure are given in figure 1.

(Figure 2e). In the NH_4^+ plus glucose and NH_4^+ amended soil, NO_3^- increased over time with the highest increase found in the NH_4^+ amended soil. The NO_3^- concentration did not change significantly over time in the unamended HEC soil, the glucose and glucose plus NH_4^+-amended soil, but increased in the NH_4^+-amended soil ($p < 0.05$) (Figure 2f). The mean concentration of NO_3^- was lower in HEC soil than in LEC soil (mean of all treatments) ($p < 0.05$) (Table 2).

DISCUSSION

Concentration of extractable ^{14}C

After one day, < 200 mg ^{14}C was extractable from LEC, but > 500 mg ^{14}C from HEC soil. After one day, 20 % of the added glucose was mineralized to $^{14}CO_2$, with an efficiency of 60 % for C (Payne, 1970), so only 53 % of the glucose was mineralized although 80 % could not be detected in the soil. Part of the ^{14}C-labeled glucose was taken up by the microorganisms in LEC soil without being metabolized. A similar lag was observed in HEC soil. Approximately 10 % of the added glucose was mineralized to $^{14}CO_2$, at an efficiency of 60 % for C, so only 27 % of the glucose was mineralized although 50 % could not be accounted for in HEC soil. The lag between glucose uptake and utilization for biosynthesis has often been reported (Payne & Wiebe, 1978; Bremer & van Kessel, 1990; Bremer & Kuikman, 1994). It indicates, as stated by Coody et al. (1986), that CO_2 evolution is a poor indicator of glucose uptake rates by soil microbes.

The NH_4^+ addition reduced the amount of extractable ^{14}C and thus stimulated decomposition of ^{14}C-labeled glucose. Saline soils are often N depleted and the addition of NO_3^- or NH_4^+ to glucose-amended soil increases CO_2 production and a priming effect (as explained below) may also be observed (Conde et al., 2005).

$^{12}CO_2$ and $^{14}CO_2$ production

Approximately 9.4 % of the soil organic matter C was mineralized within 21 days in LEC and 7.7 % in HEC soil. The percentage of organic C mineralized was lowest in the HEC soil. This suggests that salts decreased microbial activity. The decrease in CO_2 production, however, was lower than reported by Pathak & Rao (1998), who found that when EC increased from 1.1 dS m^{-1} to 96.7 dS m^{-1}, the CO_2 respiration decreased from 2.1 to 0.9 g kg^{-1} CO_2-C in *Sesbania*-amended soil after 90 days. However, they added salts to soil (NaCl and $CaCl_2$) to increase EC whereas the high EC in the HEC soil was the result of a slow salt increase due to irrigation. The microorganisms in the soils used by Pathak & Rao (1998) were not adapted to high salt contents and this might have strongly inhibited their activity. Salt addition to non-saline soils would require the adaptation of microorganisms to osmostic and/or specific ion stress and would therefore inhibit their activity more strongly.

Approximately 60 % of the glucose-^{14}C added to LEC soil was evolved as $^{14}CO_2$ and 50 % in LEC soil amended with glucose plus NH_4^+. The percentage of mineralized glucose-C in the LEC soil was similar to values reported in literature. Bremer & Kuikman (1994) found that approximately 60 % glucose was mineralized in a sandy loam soil and silt loam soil after 35 days when ≥ 576 mg kg^{-1} of glucose C soil had been added.

The amount of glucose-^{14}C mineralized was only 37 % in HEC soil. The higher EC in HEC than in LEC soil presumably explained the lower amount of glucose ^{14}C respired to $^{14}CO_2$, although the effect of other soil characteristics on glucose decomposition can not be ruled out. Clay content has often been found to affect the decomposition of organic material fertilization (Sørensen, 1981; van Veen et al., 1985; Amato & Ladd, 1992) as does the pH (Saggar et al., 1999), but pH and clay were similar in both soils. The specific surface area of the clay, and the nature rather than the amount of the clay mineral has also been found to affect the decomposition of organic material (Saggar et al., 1996; Torn et al., 1997), but this effect is presumably more important in the long term than in short-term laboratory incubation experiments. Considering the above, it appears that EC was the factor that explained most of the reduction in mineralization of glucose added.

Compared to the unamended soil, the application of glucose increased CO_2 production to 784 mg kg^{-1} C in LEC soil and to 525 mg kg^{-1} C in HEC soil after 21 days, but the amount of $^{14}CO_2$ produced was only 660 and 374 mg kg^{-1} C in LEC soil and HEC soil, respectively. The accelerated decomposition of unlabeled soil organic matter following the addition of organic material has often been referred to as a "priming effect", and has been a matter of controversy for many years (Brookes et al., 1990). However, the conditions for an apparent priming effect, such as non-uniformly labeled substrate or a great substrate addition, are absent in this experiment and the bicarbonate in the soil solution could not explain the differences either, as they were similar in both soils, i.e., 0.26 $cmol_c$ kg^{-1} HCO_3^-. Brookes et al. (1990) described situations where a true priming effect is mainly caused by an increased turnover of microbial cell C (after glucose addition) or by an increased decomposition of native soil organic matter (after addition of rye-grass). In the first situation, the new microbial biomass partly replaces the native, resulting in a greater production of unlabeled CO_2. In the second, the new microbial biomass is added to the already present native biomass and the increase in CO_2 production results from an increased contact between the native soil organic matter and enzymes produced by a more active microbial population.

Compared to the soil amended with NH_4^+, the application of glucose plus NH_4^+ increased the CO_2 production to 364 mg kg^{-1} C in LEC soil and to 369 mg kg^{-1} C in HEC soil after 21 days, but the amount of $^{14}CO_2$ produced was 515 and 520 mg kg^{-1} C for LEC soil and HEC soil, respectively. As such, the addition of NH_4^+ to the glucose-amended soil induced a negative priming effect. The addition of different substances to the soils might cause not only an acceleration of mineralization or positive priming effect, but also a reduction or a negative priming effect. A negative priming effect has often been reported for N, e.g. N immobilization and a temporal N unavailability, but less often for C. It is difficult to indicate which mechanisms might contribute to a negative priming effect, but Kuzyakov et al. (2000) stated that when a negative priming effect occurs the microbial biomass switches from metabolizing soil organic matter to easily available C sources, stimulated by NH_4^+. Another possibility is that the addition of an easily decomposable substrate plus NH_4^+ induced the growth of an active glucose-decomposing population that inhibits the activity of a passive population decomposing soil organic matter. It might also be that the addition of NH_4^+ itself inhibited microbial activity by the formation of NH_3. NH_3 is toxic and known to inhibit microbial activity.

Inorganic N

The factors that normally most affect NH_3 volatilization are concentrations of NH_4^+, pH and water content (Kirchmann & Witter, 1989). Both soils had similar water contents, pH and mean NH_4^+ concentrations so the mean amounts of NH_3 volatilized were similar (Table 2).

It has often been reported that nitrification and especially oxidation of NO_2^- to NO_3^- is inhibited by high salt concentrations (Darrah et al., 1987; Low et al., 1997; Pathak & Rao, 1998). However, in the experiment reported here the mean NH_4^+ and NO_2^- concentrations were similar so it appeared that the nitrification process was not inhibited.

The concentration of inorganic N (sum of NH_4^+, NO_2^- and NO_3^-) decreased over time in HEC soil amended with NH_4^+, but not in LEC soil (Figure 3). The amount of N lost through NH_3 volatilization was similar in both soils so HEC was N-depleted, but not the LEC soil. Additionally, the concentration of inorganic N in HEC amended with glucose plus NH_4^+ was lower than in LEC soil, i.e. N immobilization was higher in HEC than in LEC soil.

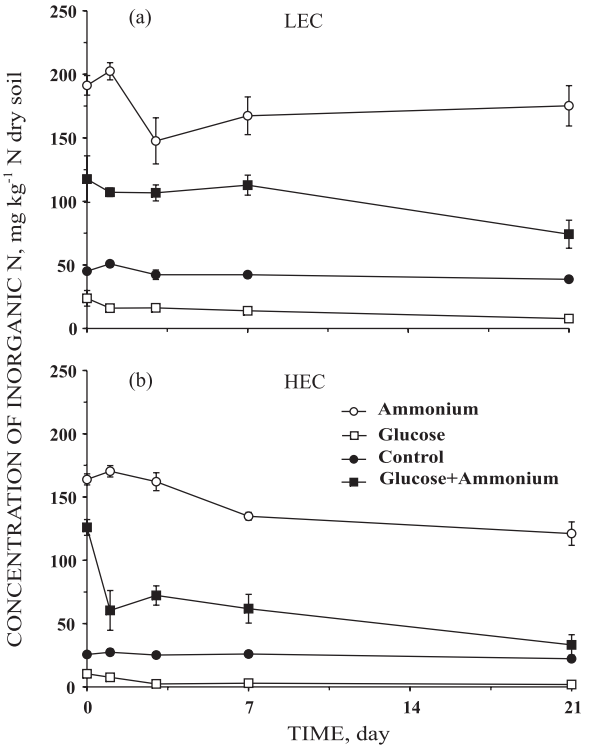

Figure 3. Concentration of inorganic N (NH_4^+, NO_2^- and NO_3^-) in (a) LEC soil and (b) HEC soil. Legends to the figure are given in figure 1.

CONCLUSIONS

1. Organic matter decomposition and N mineralization were most affected in the HEC soil.

2. In HEC soil, the addition of NH_4^+ led to N immobilization.

3. NH_4^+ and NO_2^- oxidation was not inhibited in the HEC as it was in the LEC soil.

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