Nitrogen Mineralization from Root Residues of Subterranean Clover and Lucerne

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The XIX International Grassland Congress took place in São Pedro, São Paulo, Brazil from February 11 through February 21, 2001.

Proceedings published by Fundacao de Estudos Agrarios Luiz de Queiroz

ID # 20-02

NITROGEN MINERALIZATION FROM ROOT RESIDUES OF SUBTERRANEAN CLOVER AND LUCERNE

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Abstract

To understand why crops grown in the first or second year after lucerne (Medicago sativa L.) yielded less than crops grown after subterranean clover (Trifolium subterraneum L.) despite greater nitrogen (N) fixation by the lucerne, we studied the N mineralization patterns of their root residues in soil incubation assays. Fine roots of both species produced more mineral N than the control soil with no root residues. In contrast, coarse roots mineralized less N than the control soil. These differences in N mineralization were not explained by the physical size and therefore surface area differences between fine and coarse roots. Rather, the differences in N mineralization were explained by differences in the carbon to nitrogen ratio (C:N) of fine and coarse roots. Fine roots of both species had a C:N of about 11, while the C:N of coarse roots ranged from 28 to 37. Empirical evidence suggests that a mineralization / immobilization threshold occurs at a C:N of 20 to 30, and these results are in accordance with this interpretation. However, subterranean clover had mainly fine roots giving a weighted average C:N of 19 for the whole root system, while lucerne had mainly coarse roots giving an average C:N of 26, suggesting that root residues of subterranean clover result in a net mineralization of N while lucerne roots cause a net immobilization of N.

Keywords: carbon, clover, ley farming, lucerne, mineralization, nitrogen, root residues

Introduction

The use of self-regenerating annual pastures based on subterranean clover or annual medics (Medicago spp.) to provide the N for subsequent crops in short, regular rotations was considered to be a successful model of sustainability and profitability when ley-farming systems were first adopted in southern Australia in the 1940s and 1950s. More recently, there has been a trend towards longer and more intensive cropping phases which has resulted in the depletion of annual legume seed reserves and low or unreliable legume content in many pastures (Reeves and Ewing, 1993). This has occurred at a time when increasing crop yields have lead to an increased demand for N.

Since the mid-1990s there has been renewed interest in the use of lucerne in these ley-farming systems. In southeastern Australia, perennial pastures based on lucerne were found to provide consistently greater annual herbage production, had more stable legume contents and fixed about twice the N of subterranean clover-based pastures (Peoples et al., 1998). However, it has been observed that crops growing after lucerne yielded less than the same crops growing after subterranean clover in the first year or two of crop after pasture (Angus et al., 2000).

Since shoot residues of subterranean clover and lucerne both decompose readily (data not presented), we suspected that differences in the N mineralization of their root residues may help to explain why the greater N inputs by lucerne did not lead to higher crop yields. Our objective was to determine if root residues of subterranean clover and lucerne differed in N mineralization patterns, and if these patterns could be related to physical or chemical attributes of the roots.

Material and Methods

Plants of subterranean clover or lucerne were grown in PVC tubes (1.25 m tall × 0.10 m diameter) filled with coarse sand. The plants were well-nodulated and grown without N fertilizer but provided with non-limiting amounts of other nutrients. Plants were harvested after 20 weeks of growth, when the subterranean clover reached maturity. Plant shoots were cut from roots, and the root systems were carefully washed free of sand. Root systems were separated into size classes based on visual estimation. Subterranean clover roots were separated into coarse and fine root fractions, and lucerne roots were separated into coarse, medium and fine root fractions. These size classes were quantified *post hoc* by determining the specific root length of each root fraction (Table 1). The dry weight of each root fraction was determined and the proportion (by weight) of roots in each size class was calculated. Half of each root fraction was ground to a 1-mm particle size in a shear mill, and the other half was chopped into segments 15-mm long. The carbon (C) and N content of each root fraction was determined using an elemental analyzer (ANCA SL, Europa Scientific, Crewe, UK).

For N mineralization assays, a 0.75 g portion of root tissue was mixed with 270 g of a loamy, red-brown earth soil (total C=1.52%, total N=0.14%) wetted to field capacity (17.5% by weight). There was also a control treatment with no root residue added to the soil. The soil was packed to a bulk density of 1.4 g cm^{-3} in PVC rings 100 mm diameter by 25 mm thick, and each soil ring was inserted into a bag of low-density polyethylene, which allowed CO_2 exchange but inhibited water loss. There were 4 replicate soil rings of each treatment. The soil rings were incubated at 15 ^{o}C. Two soil cores, each 15-mm diameter, were taken from each ring at 0, 1, 2, 4 and 8 weeks of incubation. Mineral N was extracted from soil samples by shaking in a 2 M KCl solution for 1 hour. Filtered extracts were analyzed for NO_3^- and NH_4^+ using an ‘Alpkem’ autoanalyzer (Perstorp Analytical, Wilsonville OR, USA), and mineral N was calculated as the sum of NO_3^- and NH_4^+, expressed as mg of N per kg of dry soil.

Results and Discussion

The addition of fine roots of subterranean clover produced more mineral N than the control soil with no root residues (Fig. 1a). In contrast, soils to which coarse roots of subterranean clover were added mineralised less N than the control soil. This decrease in mineral N, termed immobilization, is the temporary tie-up of mineral N in organic matter. There was little difference in N mineralization caused by retaining the clover roots in segments or grinding them up.

Lucerne residues followed a pattern broadly similar to clover, with fine roots mineralizing more N than the control, while medium and coarse root fractions initially immobilized N (Fig. 1b). However, grinding medium and coarse root fractions of lucerne led to greater initial immobilization and less mineral N produced than the corresponding unground segments of these same fractions.

Nevertheless, the big differences in N mineralization between fine roots and medium or coarse roots was not explained by the physical size of the roots. Grinding to remove surface area differences among root fractions had no effect on eliminating the large differences between the mineralization of fine and medium or coarse root fractions of both species (Fig. 1a and 1b).

The differences in N mineralization can be explained by differences in the C:N of the different root fractions (Table 1). Fine roots of both species had greater N concentrations, giving C:N values of about 11. Coarse or medium roots had lower N concentrations, giving C:N values ranging from 28 to 37. Empirical evidence suggests that a mineralization /

immobilization threshold occurs at a C:N of 20 to 30 (Aber and Mellilo, 1991), and our results are consistent with this interpretation.

Considering the root system as a whole, arithmetically combining the root fractions in Figs. 1a and 1b suggests that root residues of subterranean clover result in a net mineralization of N while lucerne roots cause a net immobilization of N (Fig. 1c). This is because subterranean clover had mainly fine roots (Table 1), giving a weighted average C:N of 19, while lucerne had mainly coarse and medium roots giving an average C:N of 26. However, this interpretation ignores possible spatial and interaction effects between root fractions with different C:N values decomposing *in situ* in the soil.

These results together with field observations suggest that the supply of plant available N for the first crops sown after lucerne may be lower than after subterranean clover pasture. However, it is likely that the greater organic N reserves combined with the slow mineralization of lucerne root residues would result in N benefits to more subsequent crops (perhaps 3-5), than for just one or two crops, as typically occurs after subterranean clover pastures. Improved knowledge of the decomposition and N mineralization dynamics of the different plant residues in pasture-crop rotations, such as the results presented here, will enable the development of more profitable and sustainable farming systems.

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Table 1 - Percent nitrogen (%N) and carbon (%C), carbon to nitrogen ratio (C:N), specific root length (SRL) and proportion by weight of different root fractions of subterranean clover and lucerne.

Species	Root fraction	%N	%C	C:N	SRL ($m\ g^{-1}$)	Proportion ($w\ w^{-1}$)
Subterranean clover	fine	3.4	37.8	11.3	53.19	0.70
	coarse	1.1	40.6	37.0	9.76	0.30
Lucerne	fine	3.7	40.7	10.9	60.61	0.15
	medium	1.4	37.8	27.7	5.70	0.26
	coarse	1.3	37.7	29.3	0.63	0.59

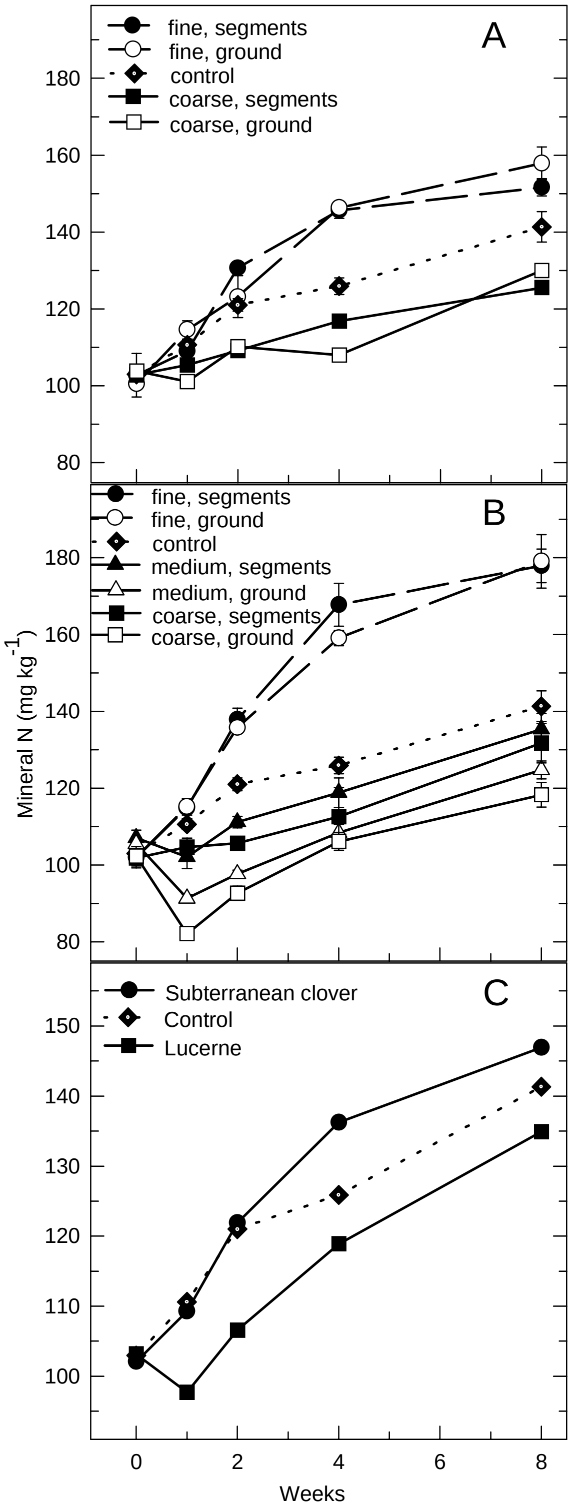

Figure 1 - Mineral nitrogen (N) in soil incubated with: A) no roots (control), or fine and coarse root fractions, either ground or in segments, of subterranean clover, B) no roots (control), or fine, medium and coarse root fractions, either ground or in segments, of lucerne, C) no roots (control), or a weighted average of the root fractions for subterranean clover and lucerne.