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Effect of calco-magnesian amendment on the mineral weathering abilities of bacterial communities in acidic and silicate-rich soils

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A B S T R A C T

Liming of forest ecosystem is recognized to increase nutrients availability in soil and water and to enhance the biomass and bacterial activities in soil. However, little studies have investigated on change induced on bacterial ability to alter silicate mineral after soil liming. Thus, this study is carried out in experimental conditions using podzol collected in the winter (2007), spring and summer (2008) in small forest catchments in Vosges Mountains amended in 2003 by dolostone and limestone. Bacterial communities, extracted from various horizons of these soils amended or not, were put in contact with a phyllosilicate (phlogopite as sole source of Mg and Fe) in miniaturized bioassays in aerobic conditions. A weathering phenotype was determined through the quantification of (i) protons and organic acids released in assay solution by bacteria (ii) iron leached from phlogopite lattice into solution by bacteria and (iii) the carbon source consumption (i.e. glucose). These results were then compared to empirical model based on chemical leaching experiments realized in the same conditions in order to simulate the processes involved. In parallel, the carbon source utilization patterns of bacteria were investigated in order to discriminate the bacterial communities from amended and non-amended soil horizons. The results indicate that (1) the total bacterial biomass was unaffected by the Ca–Mg amendment, whereas the cultivable bacterial biomass increased after the amendment, and (2) the weathering and the carbon source utilization patterns of bacterial communities differs from one soil horizon to another and among soil types. The metabolic profiles analyzed indicated significant differences in organic C substrate usage depending on season and Ca–Mg amendment. Bacterial communities, extracted from the amended soil, are enable greater iron leaching compared to those found in the control soil, suggesting a greater release of organic acids and/or a more highly chelating organic acid release. The process developed by bacteria to alter the phillosilicate is complexolysis. We conclude that the Ca–Mg amendment had a positive effect on the functional richness of bacterial communities extracted from soil and on their potential to weather minerals that was present after several years.

1. Introduction

Several decades of acidic atmospheric depositions have acidified ecosystems in the Northern hemisphere. This has lead to several negative impacts on soils and surface water quality together with forest decline (Landmann and Bonneau, 1995). Despite the global reduction of SO_4^{2-} and NO_3^- atmospheric emissions, acidification continues in forest ecosystems grown on siliceous rocks poor in base cations allowing the development of naturally acidic soils such as podzol. In podzolic soils, the low proportion of available soil nutrients (Mg, Ca, K…) compared to protons and aluminium explains the very low saturation rate of these soils (Maitat et al., 2000). In addition, bound forms of aluminium serve as the main buffer system, reducing their ability to neutralize acids. This process leads to forest decline since 1985 in the North Eastern France (Poszwa et al., 2003). To remedy it, policies of forest managements recommend the liming of forest ecosystems. Several studies have shown that liming can significantly improve the chemical and biological qualities of soils by an increase of the pH and base cation content (Mg, Ca, K) in soil and in the leaves and needles of trees (Angeli, 2006 and Baudoin, 2007). Moreover, liming induced major changes in soil microorganism activity and increased the bacterial biomass producing higher microbial activity (Macdonald and Paton, 1979; Neale et al., 1997 and Rosenberg et al., 2003). Few studies have been dedicated on the effect of liming on the mineral weathering ability of bacteria

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under these new conditions (Uroz et al., 2011). However, it is recognized since several decades that soil bacteria are excellent agent of mineral weathering (Berthelin, 1983; Robert and Berthelin, 1986; Leyval et al., 1990; Drever and Stillings, 1997; Barker et al., 1998). These studies demonstrated that bacteria can accelerate elemental release from silicate minerals. These processes were performed by the production of protons and/or of low-molecular organic molecules (siderophores and organic acids) and by colonization of mineral surfaces (Ullman et al., 1996; Liermann et al., 2000; Valsami-Jones and McEldowney, 2000; Rogers and Bennett, 2004). Nevertheless, these studies do not provide information if a change in living conditions, such as a significant input of nutrients, have an impact on mineral weathering abilities of bacteria.

This study was focused on the effect of liming in the bacterial processes involved in weathering of silicate minerals in order to highlight an adaptation and a change in the bacterial processes due to the change of environmental conditions. For this, a series of laboratory experiments were conducted with bacterial communities isolated from limed and untreated forest soils of the sandstone catchments located in the Vosges Mountains (NE of France). These bacteria were put in contact with a phyllosilicate; then parameters of bacterial growth and silicate weathering were measured. The results were analyzed using an empirical model. In parallel, the carbon source utilization patterns of bacteria were investigated in order to discriminate the bacterial communities from amended and non-amended soil horizons.

2. Materials and methods

2.1. Site description

The study was conducted in the Vosges Mountains in the Senones watersheds located in northeastern France (Fig. 1). The Senones watersheds are composed of three small catchments drained by three acidic streams ("Basse des Escaliers", "Courbeligne" and "Gentil Sapin"). The Basse des Escaliers catchments was limed using a dolomite application, and the Gentil Sapin was used as the control catchment.

The Basse des Escaliers catchment was chosen as a limed catchment due to its relative similarity with the control catchment. These catchments are composed of a large upper plateau, steep slopes lower in the catchments. With altitudes ranging between 600 and 1000 m, these sites are characterized by a mountain climate with mean annual precipitation of 1000 mm and mean annual temperature of 5 °C. Vegetation on the slope of the catchments is composed of a mixture of Norway spruce (*Picea abies L.*), European beech (*Fagus sylvatica*) and silver fir (*Abies alba* Mill) stands. The landscape on the plateau corresponds to a moor with patch of young trees (spruce and fir). The understory dominates the summits of these catchments and is mainly composed of hair grass (*Deschampsia flexuosa*) and calluna (*Calluna vulgaris* L.). The plateau where the sampling occurred five years after the Ca and Mg amendment could therefore be considered a moor.

The parental material corresponds to the "Vosgian sandstone" or the upper part of the middle Buntsandstein layer (upper Trias)

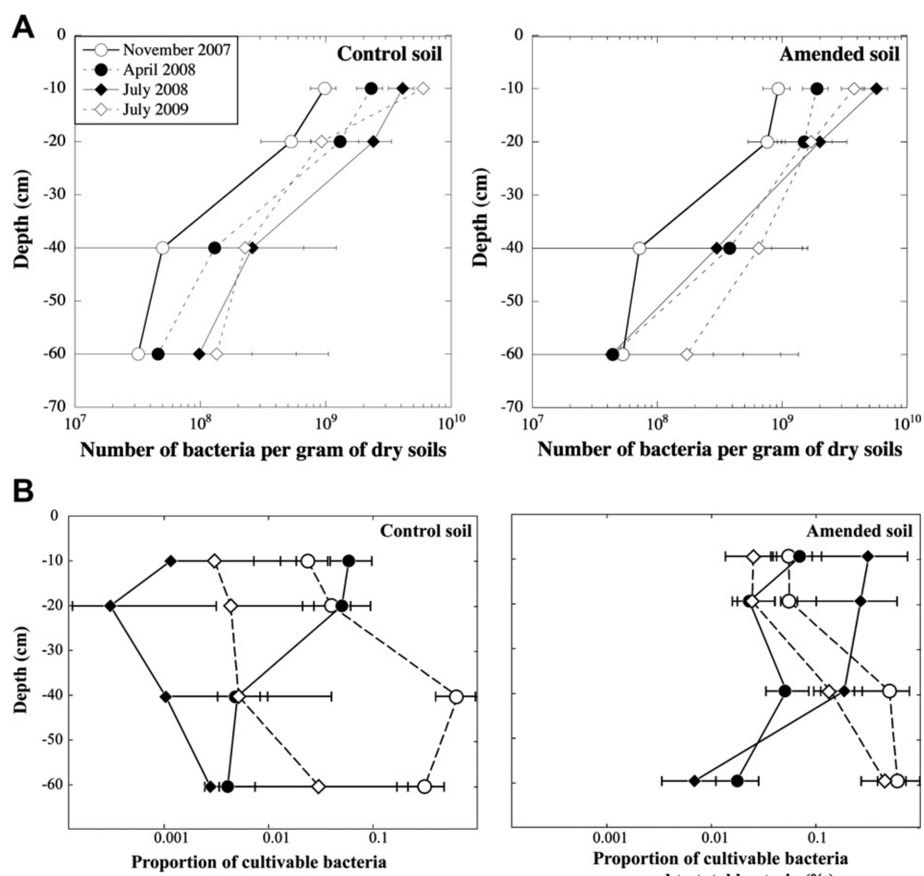

Fig. 1. (A) Number of total bacteria per gram of dry soils for the control and the amended soils; (B) Proportion of cultivable bacteria compared to total bacteria (per mil) for the control and the amended soils. Each point corresponds to the mean and the standard deviation of 24 replicates.