Science of the Total Environment 481 (2014) 469–478

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

# Effects of calcite and magnesite application to a declining Masson pine forest on strongly acidified soil in Southwestern China

Yongmei Huang [a], Ronghua Kang [b], Xiaoxiao Ma [b], Yu Qi [a], Jan Mulder [c], Lei Duan [b,d,*]

[a] State Key Laboratory of Earth Surface and Resource Ecology, College of Resources Science and Technology, Beijing Normal University, Beijing 100875, PR China
[b] State Key Laboratory of Environmental Simulation and Pollution Control, School of Environment, Tsinghua University, Beijing 100084, PR China
[c] Department of Plant and Environmental Sciences, Norwegian University of Life Sciences, Box 5003, NO-1432 Ås, Norway
[d] Collaborative Innovation Centre for Regional Environmental Quality, Tsinghua University, Beijing 100084, China

## HIGHLIGHTS

- First long-term liming experiment for forests in China.
- Addition of $Ca^{2+}$ to forests may result in nutrient imbalance such as P deficiency.

## ARTICLE INFO

*Article history:*
Received 29 August 2013
Received in revised form 19 February 2014
Accepted 19 February 2014
Available online 12 March 2014

*Keywords:*
Acidification
Soil remediation
Liming
Calcite
Magnesite
Masson pine

## ABSTRACT

Liming of strongly acidified soil under a Masson pine (*Pinus massoniana* Lamb.) forest was studied through a seven-year field manipulation experiment at Tieshanping, Chongqing in Southwestern China. To distinguish between the individual effects of $Ca^{2+}$ and $Mg^{2+}$ addition, we separately applied calcite ($CaCO_3$) and magnesite ($MgCO_3$), rather than using dolomite [$CaMg(CO_3)_2$]. Both calcite and magnesite additions caused a significant increase in pH and a decrease in dissolved inorganic monomeric aluminium ($Al_i$) concentration of soil water. Ecological recovery included increases of herb biomass (both treatments) and Mg content in Masson pine needles (magnesite treatment only). However, the growth rate of Masson pine did not increase under either treatment, possibly because of nutrient imbalance due to phosphorus (P) deficiency or limited observation period. In China, acid deposition in forest ecosystems commonly coincides with large inputs of atmogenic $Ca^{2+}$, both enhancing $Mg^{2+}$ leaching. Calcite addition may further decrease the $Mg^{2+}$ availability in soil water, thereby exacerbating $Mg^{2+}$ deficiency in the acidified forest soils of southern and southwestern China. The effect of anthropogenic acidification of naturally acid forest soils on P availability needs further study.



## 1. Introduction

Acid deposition in China has been a serious environmental problem during the last several decades (Zhao and Sun, 1986; Larssen et al., 2006). Soil acidification, particularly in southern China (Larssen et al., 2006), was found to have severe impacts on tree growth and tree crown condition (Wang et al., 2007). Forest dieback since the early 1980's, attributed to acid rain, has also been reported for this area (Ma, 1991; Hao et al., 1998). Severe forest dieback occurring in central Europe in the mid-1980s was believed to be primarily due to direct, above-ground effects of air pollutants, rather than to indirect effects due to soil acidification (Ulrich et al., 1980; Gorham, 1989; Pitelka and Raynal, 1989). In contrast, forest decline in North America has been ascribed to indirect effects such as Al toxicity and depletion of soil base cations (mainly $Ca^{2+}$) in response to long-term soil acidification (Shortle and Smith, 1988; Bernier and Brazeau, 1988; Lawrence et al., 1995).

Reducing atmospheric emissions likely decreases both direct and indirect effects of acid rain on forest ecosystems, and remains a main environmental priority. In addition, remediation of already acidified soils and restoration of degraded forest ecosystems is important to limit further ecological degradation and economic loss. Since the application of calcitic and/or dolomitic limestone increases the base saturation of soils and decreases concentrations of $H^+$ and toxic Al species in soil water, 'liming' is considered to be an effective tool for the rehabilitation of naturally or anthropogenically acidified ecosystems, and has been studied and practised for many years in Europe and North America (Hüttl and Zöttl, 1993; Lundström et al., 2003; Löfgren et al., 2009; Moore et al., 2012; Van der Perre et al., 2012). Elevated concentrations of $Al^{3+}$ by soil acidification were found to cause root damage and reduce the uptake of important nutrient cations such as

* Corresponding author at: State Key Laboratory of Environmental Simulation and Pollution Control, School of Environment, Tsinghua University, Beijing 100084, PR China. Tel.: +86 10 62771403; fax: +86 10 62773957.
*E-mail address:* lduan@tsinghua.edu.cn (L. Duan).

http://dx.doi.org/10.1016/j.scitotenv.2014.02.090
0048-9697/

magnesium ($Mg^{2+}$) in trees (Ulrich et al., 1980; Sverdrup et al., 1992; de Wit et al., 2010). The molar ratio of $Al^{3+}$ to base cation ($Ca^{2+}+Mg^{2+}+K^{+}$) (Al/BC) in soil water is commonly used as a risk indicator for forest decline due to acidification (Cronan and Grigal, 1995), and 1.0 is widely used as a critical limit in critical load assessments (Sverdrup et al., 1992). In contrast to expectations, however, lime applied to the soil surface has not always brought an overall improvement in forest growth. Most investigations in Europe have shown that liming does not significantly improve tree growth and tree vitality (Hüttl and Zöttl, 1993; Ljundström and Nihlgård, 1995; Hindar et al., 2003; Lundström et al., 2003; Røsberg et al., 2006), while some studies in North America (Long et al., 2011; Moore et al., 2012) and in Europe (van der Perre et al., 2012) have shown positive impacts. Further, there is no clear relation between elevated Al/BC and forest decline (de Wit, et al., 2010).

Although many studies have investigated liming treatments of forest soils in Europe and North America, the potential of surface liming to remediate acidified forest soils and increase forest growth has not been investigated in long-term experiments in China to our knowledge. In addition to the vegetation (and its sensitivity to acidification), soil, and climatic conditions, the composition of atmospheric deposition in China differs considerably from that in other countries. In particular, the atmospheric deposition of $Ca^{2+}$ is very high (although not as high as $SO_4^{2-}$ on an equivalent basis; Larssen and Carmichael, 2000; Larssen et al., 2011), due to large $Ca^{2+}$ emissions, from both natural (e.g. wind-blown dust) and anthropogenic sources (e.g. cement processing and coal combustion) (Zhao et al., 2011). Since $Ca^{2+}$ is an important acid-neutralizing component of soil, its atmospheric input provides unintentional liming of terrestrial ecosystems. Some studies have indicated that the application of $Ca^{2+}$ could decrease crown thinning, and increase growth rate and seedling density of sugar maple (Juice et al., 2006; Moore et al., 2012).

Here we present a seven-year field manipulation experiment in a Masson pine (*Pinus massoniana* Lamb.) dominated stand growing on highly acidified soil in Tieshanping, Chongqing in southwestern China. Masson pine forests, both natural and planted, are widely distributed in the humid subtropical areas of southern and southwestern China (Wu, 1980), and it has been suggested that Masson pine is very sensitive to soil acidification (Gao et al., 1992; Zhang et al., 1995; Wang et al., 2007). To distinguish between the individual effects of $Ca^{2+}$ and $Mg^{2+}$, we used high-purity $CaCO_3$ and $MgCO_3$, respectively, rather than dolomite [$CaMg(CO_3)_2$], which contains both $Ca^{2+}$ and $Mg^{2+}$ at a fixed ratio, and is commonly applied to acidified soils in Europe. The effect of $Mg^{2+}$ on tree growth is of particular importance because Mg is an important nutrient, and its deficiency has often been associated with poor tree growth on acidified soils (Horsley et al., 2000; de Wit et al., 2001, 2010). Soil $Mg^{2+}$ deficiency may be a major problem in acidified forest soils in China since long-term $Mg^{2+}$ leaching may have been aggravated by the large fluxes of atmogenic $Ca^{2+}$. The objective of the present study was to quantify the long-term responses of a widely-distributed subtropical forest on acid soil in China to different liming treatments. Based on the documented high $Al^{3+}$ concentration in soil water (Larssen et al., 2006) and severe forest defoliation (Wang et al., 2007), we hypothesized that in particular the magnesite treatment would improve the Mg status and overall health of the forest.

## 2. Materials and methods

### 2.1. Experiment location and design

A field manipulation experiment was carried out in a Masson pine (*P. massoniana* Lamb.) stand planted in 1962 following the clear cutting of a natural Masson pine forest at Tieshanping (106°41.24′E, 29°37.42′ N). Tieshanping is located about 25 km northeast of the centre of Chongqing City, at an elevation of about 450 m above sea level (Fig. 1). The soil is locally called yellow earth (corresponding to a Haplic Acrisol in FAO; Surhone et al., 2010), with a thin (<1 cm) O horizon and pH about 4. The annual mean temperature and precipitation were 18.2 °C and 1105 mm, respectively, from 1971 to 2000 (Meteorological Station of Chongqing). The stand is homogeneous, dominated by Masson pine and some associated species such as *Cunninghamia lanceolata* (Lamb.) Hook. and *Eurya groffi* Merr. The stand density is about 800 stem $ha^{-1}$. Dominant species of ground vegetation are *Camellia oleifera* Abel, *Randia cochinchinensis* (Lour.) Merr., and *Loropetalum chinense* (R. Br.) Oliver in the underbrush layer; *Dicranopteris pedata* (Houtt.) Nakaike, *Woodwardia japonica* (L. F.) Sm., *Dryopteris*

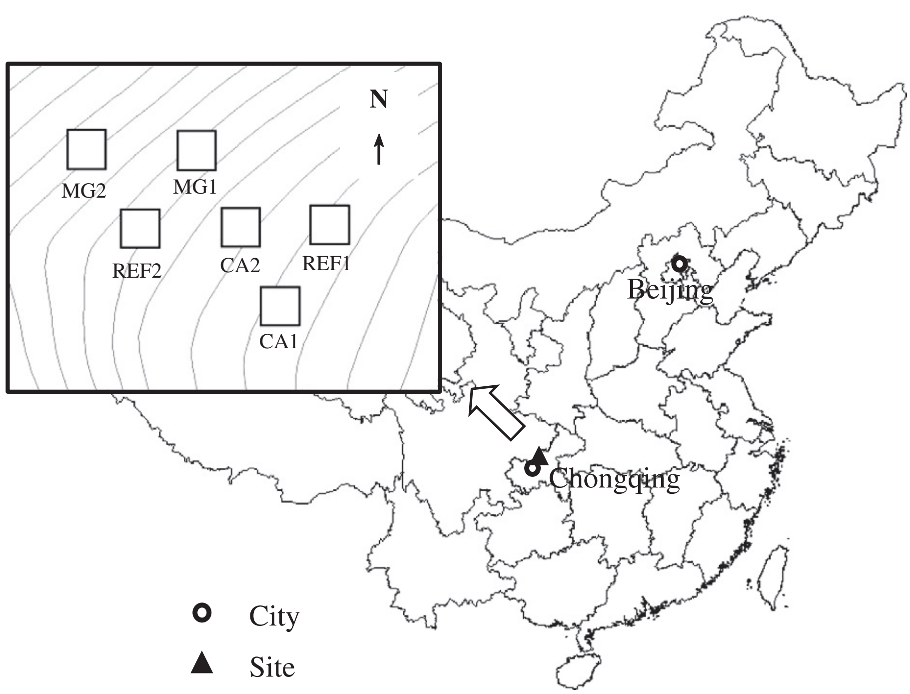


**Fig. 1.** Location of the experimental site and schematic presentation of sampling plots. Squares on the inset figure represent sampling plots. Contour interval of the contour map is 1 m.