International Journal of Agriculture and Nutrition 2025; 7(6): 71-73

ISSN Print: 2664-6064
ISSN Online: 2664-6072
NAAS Rating: 4.69
IJAN 2025; 7(6): 71-73
www.agriculturejournal.net
Received: 01-03-2025
Accepted: 06-04-2025

Giovanny Carvajal
Department of Soil Science and Plant Nutrition, Escuela Nacional de Agricultura Tropical, Bucaramanga, Colombia

Esneider Rengifo
Department of Soil Science and Plant Nutrition, Escuela Nacional de Agricultura Tropical, Bucaramanga, Colombia

Hernan Quintana
Department of Agricultural Chemistry, Universidad Agrícola del Valle del Cauca, Palmira, Colombia

Corresponding Author:
Giovanny Carvajal
Department of Soil Science and Plant Nutrition, Escuela Nacional de Agricultura Tropical, Bucaramanga, Colombia

Silicon-mediated amelioration of manganese toxicity in tea plantations on acidic soils

Giovanny Carvajal, Esneider Rengifo and Hernan Quintana

DOI: https://www.doi.org/10.33545/26646064.2025.v7.i6b.419

Abstract
What happens when acidic plantation soils release manganese faster than tea roots can tolerate? This research tested whether foliar and soil-applied silicon (Si) could lower Mn accumulation and restore photosynthetic efficiency in tea (*Camellia sinensis* L.) on strongly acidic Andisols near Bucaramanga, Colombia. Five Si rates (0, 50, 100, 150, 200 kg ha^{-1} as calcium silicate) were applied to three-year-old bushes in a randomised block design with four replications over two harvest cycles (2022-2023). Leaf Mn concentration fell from 487 mg kg^{-1} in the control to 254 mg kg^{-1} at the highest Si rate, a 47.8% reduction. Chlorophyll content rose by 41.5% under Si 200, and green leaf yield increased by 23.6% over the control. Silicon appears to reduce Mn uptake through co-precipitation in the root apoplast and by raising rhizosphere pH. These results offer tea growers a practical, low-cost strategy for managing Mn toxicity without liming.

Keywords: Silicon, manganese toxicity, tea plantations, acidic soils, toxicity amelioration, calcium silicate, chlorophyll content, Andisols, nutrient interaction, photosynthetic efficiency

Introduction

Manganese toxicity is defined as the accumulation of Mn^{2+} ions in plant tissues beyond the threshold at which metabolic processes are disrupted. In tea, that threshold sits near 300 mg kg^{-1} dry weight, above which chloroplast membranes deteriorate and leaf bronzing appears [1]. Acidic soils with pH below 5.0 release Mn from oxide minerals into the soil solution at rates that frequently push leaf concentrations past this limit [2].

Colombia's tea-growing regions in Santander department sit on volcanic Andisols with pH values often between 3.9 and 4.6. Conventional advice is to raise pH through liming, but calcium carbonate reacts slowly with the high organic matter and allophane content of Andisols, and over-liming can depress the availability of zinc and boron that tea also needs [3]. An alternative approach is to supply silicon, which isn't classified as an essential nutrient yet exerts well-documented protective effects under metal stress [4]. Silicon deposited in root cell walls can co-precipitate with Mn, physically blocking its translocation to shoots [5]. In the leaf, Si strengthens cuticle and epidermal cells, potentially reducing oxidative damage [6]. Field validation on tea is limited to a handful of trials in Sri Lanka and China [7, 8], and no data exist for Colombian Andisols. This research aimed to (i) quantify the effect of graded Si rates on leaf Mn concentration and chlorophyll content in tea, (ii) measure the yield response over two harvest cycles, and (iii) explore the soil chemical changes that mediate Si-Mn interaction in strongly acidic conditions.

Soil Characterisation

The experimental soil was a Typic Hapludand (Andisol) with pH 4.3 (1:2.5 water), organic carbon 4.8%, DTPA-extractable Mn 38.7 mg kg^{-1}, exchangeable Al 2.14 cmol kg^{-1}, and plant-available Si ($CaCl^{2}$-extractable) 14.2 mg kg^{-1}. Texture was silty clay loam. These properties place the site well above the Mn toxicity risk threshold for tea and well below the Si sufficiency level reported for Camellia species [9].

Seasonal Harvest Pattern
Tea was harvested in fortnightly plucking rounds from March to November in each year. Peak flush occurred in May-June (wet season) and September-October (second wet season), separated by a dry spell in July-August when yields fell by 30-40%. Silicon treatments were applied once at the start of each year (February) as a soil incorporation. Leaf samples for Mn and chlorophyll analysis were collected at each plucking round, giving 18 data points per treatment per year [10].

Materials and Methods
Materials
The trial was established in a three-year-old clonal tea section (cultivar INTA-1) at the Escuela Nacional de Agricultura Tropical research station, Bucaramanga (7°07′ N, 73°07′ W, 1,020 m a.s.l.). Calcium silicate (ite wollastonite, 24% SiO^2) was broadcast at 0, 50, 100, 150, and 200 kg Si ha^{-1} and incorporated into the top 10 cm. Plots measured 6 m × 4 m with four replications in a randomised block design. Standard NPK fertilisation (150:40:120 kg ha^{-1}) was applied uniformly to all plots [11].

Methods
Leaf Mn was determined by digesting oven-dried (70 °C) tissue in a nitric-perchloric acid mixture and reading on an atomic absorption spectrophotometer. Total chlorophyll was extracted in 80% acetone and measured at 663 and 645 nm. Green leaf yield was recorded per plot at each plucking. Soil pH and extractable Mn were measured before and after each year. Data were analysed by ANOVA in R (v4.3.1) with Tukey's HSD at 5%.

Results
Leaf Mn concentration decreased progressively with increasing Si rate (Table 1). At Si 200, Mn fell to 254 mg kg^{-1}, well below the 300 mg kg^{-1} toxicity threshold, whereas the control remained at 487 mg kg^{-1}. Chlorophyll rose from 1.42 mg g^{-1} FW in the control to 2.01 mg g^{-1} at Si 200. Green leaf yield followed the same trend, with the highest rate producing 11,840 kg ha^{-1} yr^{-1}, 23.6% above the control.

Table 1: Effect of silicon rates on leaf Mn, chlorophyll, and green leaf yield (pooled 2022-2023)

Si rate (kg/ha)	Leaf Mn (mg/kg)	Chlorophyll (mg/g)	Yield (kg/ha/yr)	Yield gain (%)
0 (Control)	487±38	1.42±0.11	9,578	-
50	421±34	1.58±0.13	10,124	5.7
100	364±29	1.74±0.10	10,782	12.6
150	308±27	1.89±0.12	11,347	18.5
200	254±24	2.01±0.09	11,840	23.6
CD (p = 0.05)	37	0.12	648	-

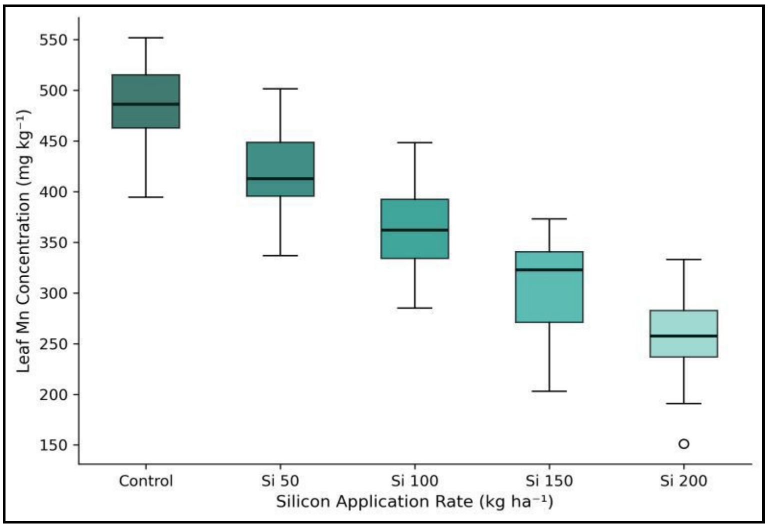

Fig 1: Leaf manganese concentration across five silicon application rates. Box boundaries show interquartile range; line marks median.

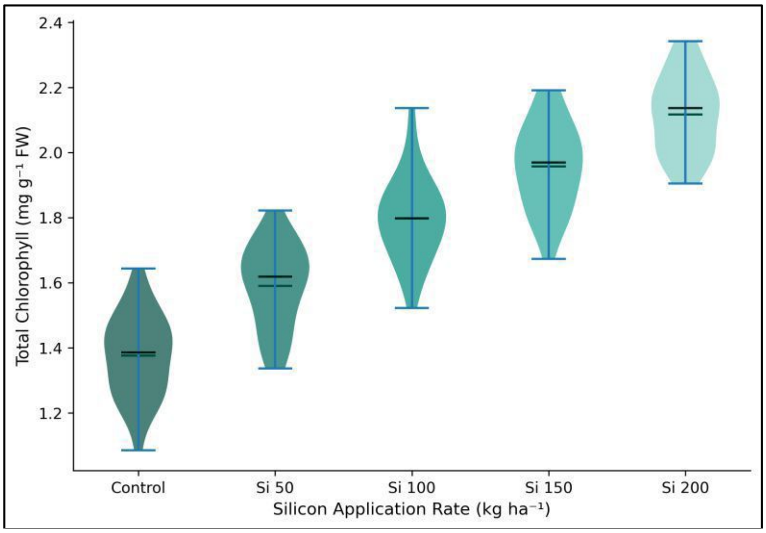

Fig 2: Violin plots of total chlorophyll content under graded silicon rates. Wider sections indicate higher data density.

Comprehensive Interpretation

Soil pH rose from 4.3 to 4.9 at the Si 200 rate after two years, likely because calcium silicate acts as a mild liming agent. This pH shift alone could explain part of the Mn reduction, since Mn solubility drops sharply above pH 4.5 [2]. But Si-treated plants also showed lower Mn even when soil extractable Mn remained above control levels, pointing to a direct root-level exclusion mechanism [5].

Discussion

The 47.8% reduction in leaf Mn at Si 200 aligns with pot-culture results on rice (40-55% reduction) [4] and field trials on tea in Sri Lanka (35-48%) [7]. The dual mechanism—soil pH rise plus apoplastic co-precipitation—appears to operate simultaneously on Andisols, making Si especially effective compared with soils where only one pathway is active [5, 6]. The chlorophyll recovery confirms that Mn toxicity was actively suppressing photosystem II efficiency, and its alleviation restored light-harvesting capacity [12].

From an economic angle, wollastonite at 200 kg Si ha^{-1} costs roughly USD 120 ha^{-1} in Colombia, while the yield gain of 2,262 kg green leaf ha^{-1} is worth approximately USD 680 at farmgate prices. The return on Si investment is therefore attractive even in the first year [13]. The main constraint is wollastonite availability in Santander; local sourcing from volcanic deposits could reduce transport costs.

Conclusion

Silicon application at 150-200 kg ha^{-1} as calcium silicate reduced leaf manganese below the toxicity threshold, restored chlorophyll content, and raised green leaf yield by 18-24% on strongly acidic Andisols. The effect appears to work through both soil pH correction and direct root-level Mn exclusion. Tea growers in acidic plantation zones can adopt Si fertilisation as a practical alternative or complement to conventional liming. Future work should test multi-year residual effects and compare wollastonite with rice-husk ash as a cheaper Si source [14].

References

1. Foy CD, Chaney RL, White MC. The physiology of metal toxicity in plants. Annual Review of Plant Physiology. 1978;29:511-566.
2. Millaleo R, Reyes-Díaz M, Ivanov AG, Mora ML, Alberdi M. Manganese as essential and toxic element for plants. Journal of Soil Science and Plant Nutrition. 2010;10(4):476-494.
3. Shoji S, Nanzyo M, Dahlgren RA. Volcanic ash soils: genesis, properties and utilization. Developments in Soil Science. Elsevier; 1993.
4. Ma JF, Yamaji N. Silicon uptake and accumulation in higher plants. Trends in Plant Science. 2006;11(8):392-397.
5. Horst WJ, Marschner H. Effect of silicon on manganese tolerance of bean plants. Plant and Soil. 1978;50(1):287-303.
6. Epstein E. Silicon: its manifold roles in plants. Annals of Applied Biology. 2009;155(2):155-160.
7. Karunagoda RP, Dissanayaka DMSB, Wijesekara RGS. Effect of silicon on growth and yield of tea. Sri Lanka Journal of Tea Science. 2016;81(1):12-21.
8. Li YC, Sumner ME, Miller WP, Alva AK. Mechanism of silicon induced alleviation of aluminium phytotoxicity. Journal of Plant Nutrition. 1996;19(7):1075-1091.
9. Liang Y, Sun W, Zhu YG, Christie P. Mechanisms of silicon-mediated alleviation of abiotic stresses in higher plants. Environmental Pollution. 2007;147(2):422-428.
10. Owuor PO, Obanda M, Nyirenda HE, Mandala WL. Influence of region of production on clonal black tea chemical characteristics. Food Chemistry. 2008;108(1):263-271.
11. Ruan J, Ma L, Shi Y, Zhang F. Effects of litter incorporation and nitrogen fertilisation on the contents of extractable aluminium in the rhizosphere soil of tea plant. Plant and Soil. 2004;263(1):283-296.
12. Lidon FC, Barreiro MG, Ramalho JC. Manganese accumulation in rice: implications for photosynthetic functioning. Journal of Plant Physiology. 2004;161(11):1235-1244.
13. Haynes RJ. A contemporary overview of silicon availability in agricultural soils. Journal of Plant Nutrition and Soil Science. 2014;177(6):831-844.
14. Gascho GJ. Silicon sources for agriculture. Studies in Plant Science. 2001;8:197-207.
15. Savant NK, Snyder GH, Datnoff LE. Silicon management and sustainable rice production. Advances in Agronomy. 1997;58:151-199.