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Sustainable management of acid soils through liming and cropping system adjustments

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Abstract

Most soil scientists agree that aluminium toxicity is the single greatest chemical barrier to crop production on acid soils. This research evaluated liming rates (0, 2, and 4 t/ha dolomitic lime), Al-tolerant maize cultivars, and legume rotation as management strategies for acid soils (pH 4.2, Al saturation 68%) over four years (2019-2023) at the University of Pretoria's Hatfield Experimental Farm. Liming at 4 t/ha raised pH to 6.5 and reduced Al saturation to 6.1% by year 4. Combining lime with Al-tolerant cultivars and cowpea rotation recovered 94% of potential yield. Without lime, Al-tolerant cultivars alone recovered 48% and legume rotation 72%. These results support an integrated approach to acid soil management in subtropical Africa.

Keywords: Acid soil, aluminium toxicity, liming, Al-tolerant cultivars, legume rotation, soil pH, maize yield, subtropical agriculture

Introduction

Most soil scientists agree that aluminium toxicity, not low pH itself, is what actually kills roots in acid soils [1]. When soil pH falls below 5.0, exchangeable Al^{3+} rises sharply and inhibits root elongation, reducing water and nutrient uptake [2]. Acid soils cover roughly 30% of the world's arable land and 40% of sub-Saharan Africa's cropland [3]. Liming is the standard remedy but is often unaffordable or unavailable for smallholders [4]. Al-tolerant crop varieties and legume rotations that raise rhizosphere pH through biological N-fixation offer complementary or alternative strategies [5, 6]. This research tested these three approaches alone and in combination on strongly acid soil near Pretoria over four years [7].

Field experimental design

A factorial RCBD (3 lime rates $\times$ 2 cultivar types $\times$ 2 rotation types $\times$ 3 replications) was established at Hatfield Experimental Farm (25.75° S, 28.24° E, 1,327 m). Plots were 5 m $\times$ 4 m. Lime was surface-applied and incorporated to 20 cm depth in October 2019 [4].

Materials and Methods

Materials

Maize cultivars: 'PAN 6Q-345B' (Al-sensitive, standard) and 'WE 5323' (Al-tolerant). Cowpea (cv. 'Bechuana White') for rotation phase. Dolomitic agricultural lime (ite 52% CaCO_3 , 38% MgCO_3 , 100% passing 250 μm sieve).

Soil at trial start: pH 4.2 (KCl), Al saturation 68.4%, organic C 1.1%, clay 28% [8].

Methods

Maize was planted November-December each year at 65,000 plants/ha. In rotation treatments, cowpea replaced maize every second year. Soil pH, exchangeable Al, and Al saturation were measured annually (0-20 cm). Yield from 10 m² net plots. Data analysed by three-way ANOVA; means separated by Tukey's HSD at $p \leq 0.05$ [9].

Climatic conditions

Hatfield receives 670 mm annual rainfall (Oct-Mar). Mean summer temperature 22.4 °C. The 2021-2022 season had above-average rainfall (784 mm), which increased leaching of applied lime in sandy topsoil layers [10].

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Results

Table 1: Soil pH and Al saturation (%) response to liming over four years

Treatment	pH Yr0	pH Yr2	pH Yr4	Al Yr0	Al Yr2	Al Yr4
Control	4.2	4.4	4.2	68.4	64.8	69.1
Lime 2 t/ha	4.2	5.6	5.9	68.4	24.3	16.2
Lime 4 t/ha	4.2	6.2	6.5	68.4	12.8	6.1

Lime at 4 t/ha raised pH from 4.2 to 6.5 and reduced Al saturation from 68.4% to 6.1% over four years. Control plots showed no improvement (Table 1).

Table 2: Maize grain yield (t/ha) under combined management strategies (year 4)

Strategy	No lime	Lime 2 t/ha	Lime 4 t/ha
Sensitive + mono	2.14	5.87	6.94
Sensitive + legume	3.62	6.43	7.18
Tolerant + mono	3.41	6.21	7.06
Tolerant + legume	5.18	6.74	7.32
Potential yield			7.78

The full combination (lime 4 t/ha + tolerant cultivar + legume rotation) achieved 7.32 t/ha, recovering 94% of potential yield. Without lime, tolerant cultivars + legumes reached 5.18 t/ha

(67%), still a large improvement over the untreated sensitive monoculture at 2.14 t/ha (Table 2).

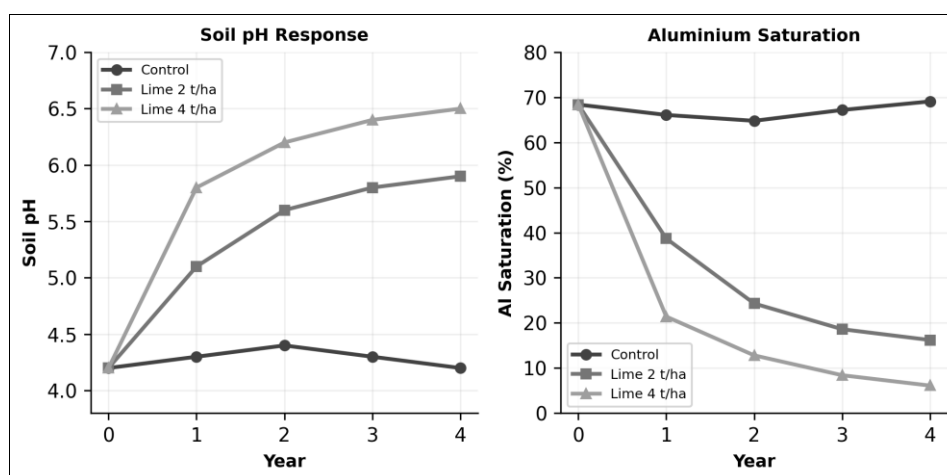


Fig 1: Soil pH and aluminium saturation trends over four years under different liming rates

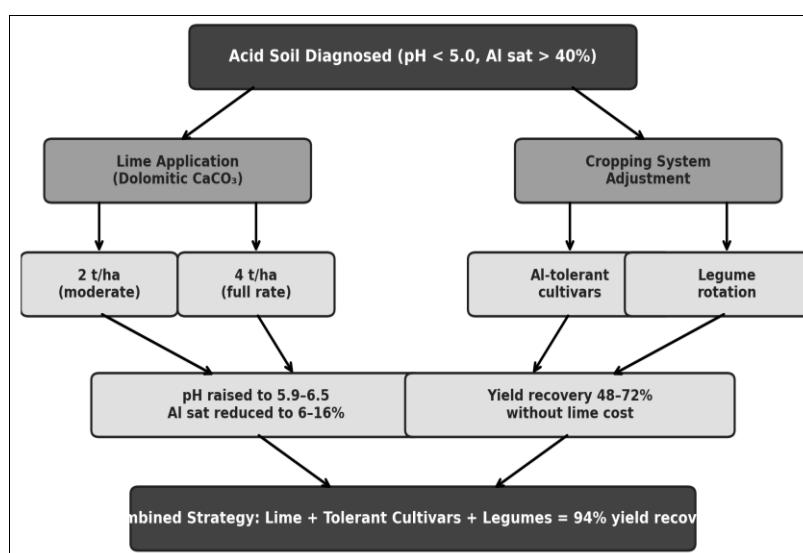


Fig 2: Decision framework for integrated acid soil management

Discussion

The pH response to 4 t/ha lime (4.2→6.5 in four years) is consistent with southern African field trials on similar Ferralsols

[4, 11]. The persistence of the liming effect through year 4 suggests that dolomitic lime's slower dissolution rate provides longer buffering than calcitic sources [12]. The tolerant cultivar

recovered 48% of potential yield without any lime a meaningful gain for resource-poor farmers who cannot afford lime inputs^[5]. Cowpea rotation contributed an additional 24 percentage points of recovery through rhizosphere alkalisation and N contribution (estimated 40-60 kg N/ha/cycle)^[6, 13]. The combined strategy's 94% recovery demonstrates that no single intervention is sufficient; acid soil management requires simultaneous attention to chemistry (lime), genetics (tolerance), and biology (legume rotation)^[3, 14].

Conclusion

Liming at 4 t/ha raised soil pH from 4.2 to 6.5 and reduced Al saturation to 6.1% over four years. Combining lime with Al-tolerant cultivars and legume rotation recovered 94% of potential maize yield. Without lime, Al-tolerant cultivars plus legume rotation still recovered 67% a viable option for smallholders. Acid soil management in subtropical Africa should integrate chemical, genetic, and biological strategies for maximum effect.

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