The burden of acid soils for food security and agricultural development in sub-Saharan Africa

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Introduction

- Smallholder farming systems in sub-Saharan Africa are affected by a wide range of management and soil constraints

- Soil acidity encompasses a range of complex soil chemical and biological functions observed beyond soil pH (Sanchez, 2019).

- Lime is the most effective means to neutralize exchangeable Al in the topsoil and increase nutrient-use efficiency.

- Little research on soil acidity in sub-Saharan Africa since the 1980s.

- Renewed interest in countries like Ethiopia, Rwanda, and Tanzania as part of a broader agenda on soil health.

- Support of BMGF through the CIMMYT-led project ‘Guiding investments in acid soil management in East Africa” (GAIA)

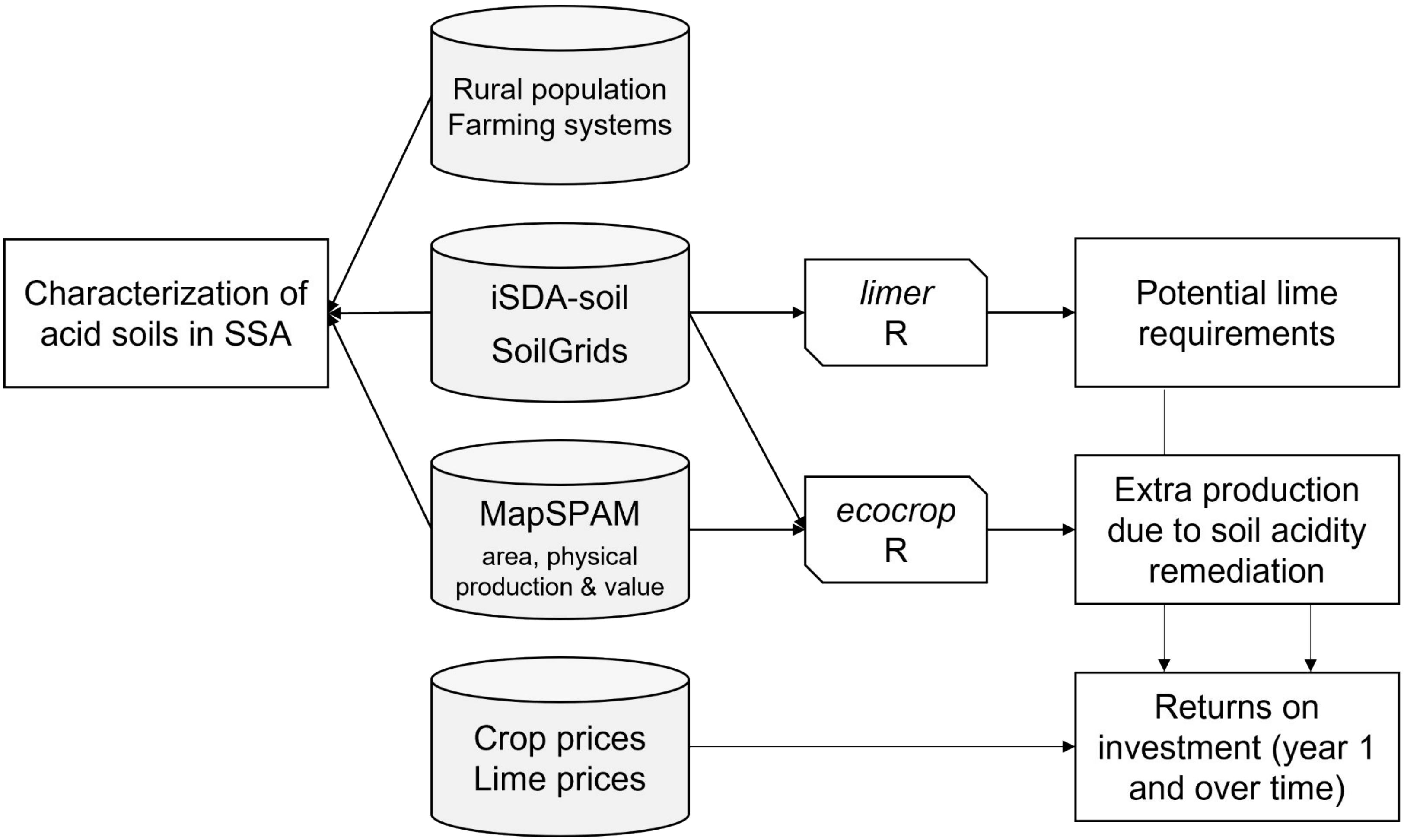
Objectives

1. Update the characterization of the magnitude and spatial distribution of acid soils in sub-Saharan Africa.

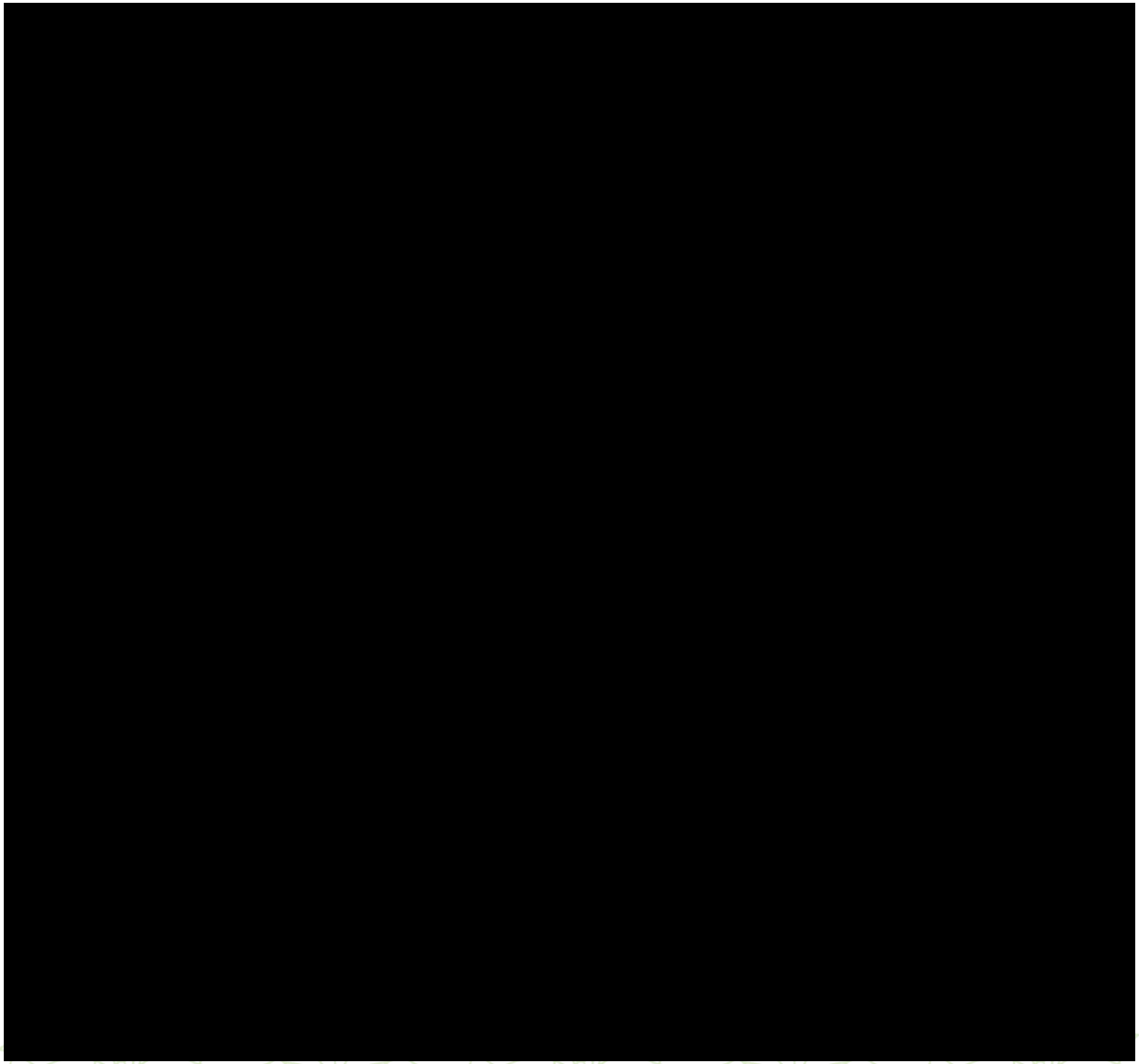
2. Estimate spatially-explicit lime rates and the potential demand for lime at country level.

3. Map returns-on-investment to liming under different yield response and lime price assumptions to target investments in acid soils.

Analytical framework



Characterization of acid soils in SSA



Key messages:

1) Topsoil pH mostly in the range between 5.0 – 6.5

2) Low pH is not equivalent to high Al^{3+} saturation (e.g., Ethiopia)

3) Acid soils largely occur in high rainfall areas

4) Very acidic soils tend to have a low cropland presence

Sources:
iSDA-soil, SoilGrid, CHIRPS, GeoSurvey

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Characterization of acid soils in SSA

Key messages:

1) Most farming systems and crops in cropland with pH between 5.5 and 6.5
2) Farming systems in low pH cropland have few cereal crops
3) Commodities (coffee, tea, etc.) and perennial crops mostly found in cropland with low pH
4) Cereals and legumes mostly found in cropland with high pH
5) Results based on Al^{3+} saturation confirm those of pH

Spatially-explicit lime requirements

Kamprath (1970) based on exchangeable acidity

Cochrane et al. (1980) based on crop-specific target Al saturation

Exchangeable Aluminum As a Criterion for Liming Leached Mineral Soils[1]

E. J. KAMPRATH[2]

ABSTRACT

Lime rates equivalent to the amount of exchangeable Al reacted primarily with the exchangeable Al and reduced the Al saturation of the effective CEC to less than 30%. Lime rates greater than the equivalent amount of exchangeable Al resulted in appreciable amounts of nonexchangeable acidity being neutralized. Below pH 5.4 the buffer capacity of the soils was primarily due to exchangeable Al. Lime applications based on the exchangeable Al extracted with a neutral unbuffered salt appear to be a realistic approach for Ultisols and Oxisols.

Additional Key Words for Indexing: nonexchangeable acidity, lime rates.

AT THE present time most lime recommendations are based on the amount of lime required to bring a soil to a given pH. A number of buffer methods have been developed to determine the lime requirement (5). The beneficial effects of a pH near neutrality on availability of soil phosphorus, molybdenum, calcium, and magnesium, and increased activity of microorganisms have been given as reasons for liming a soil to a given pH. However, with present day fertilization practices it is doubtful whether these beneficial effects on nutrient availability are as important as when the supply of nutrients was restricted to the native soil supply (7).

Investigations during the past 15 years on the role of Al in soil acidity have resulted in changes in concepts about acid soils (5). Numerous studies in recent years have shown that exchangeable Al is generally the predominant cation in the leached soils of the southeastern USA and of tropical regions when the soil pH is 5 or less (4, 14, 17). Aluminum in the soil solution has been identified as a factor responsible for poor growth in many acid soils (12, 19). Therefore, another approach to liming of acid soils is the addition of lime to neutralize Al and to supply Ca and Mg.

The Al extracted with a neutral unbuffered salt is considered to be exchangeable (3, 13). Studies with a wide range of soils showed that water-soluble Al was related to Al extracted with 1N KCl (2). Nye et al. (16) found that Al is held quite tightly in comparison to other cations and that in soils with low salt contents appreciable amounts of Al are not found in the soil solution until the Al saturation is greater than 60%. However, as the salt content increases, which would be the case with heavily fertilized soils, the amount of Al in the soil solution is increased (9). Therefore, in heavily fertilized soils a relatively low Al saturation may be required to avoid detrimental effects.

Based on these and other considerations, Coleman et al. (4) suggested that lime rates should logically be based on the acidity extracted with a neutral unbuffered salt. The present investigation was conducted to examine this approach for determining the lime requirement. The objectives were (i) to determine the forms of acidity neutralized

An equation for liming acid mineral soils to compensate crop aluminium tolerance

T. T. COCHRANE, J. G. SALINAS and P. A. SANCHEZ

Centro Internacional de Agricultura Tropical, Apartado Aéreo 67–13, Cali, Colombia

Liming recommendations for acid mineral soils based on the neutralization of aluminium have been used since the mid-nineteen-sixties. However, crops vary in their tolerance to Al, the degree of which may be expressed in terms of the percentage Al saturation of the effective cation exchange capacity. Consequently, it is necessary only to apply enough lime to decrease the Al saturation percentage to levels that do not affect production. To facilitate estimation of liming needs, an equation was developed:

$$\text{mequiv. Ca/100 g soil required for liming} = 1{\cdot}5\ [Al - RAS(Al + Ca + Mg)/100]$$

The values for the elements on the right side of the equation are expressed in terms of mequiv./100 g soil in the original exchange complex of the unlimed soil. *RAS* = required percentage Al saturation. When the estimated lime requirement is greater than the chemical lime equivalent of the exchangeable Al, replacement of the factor 1·5 with 2·0 gives closer agreement with measured data. The equation can be used to estimate approximate field liming requirements in tons of lime/ha by multiplying the right side of the equation by the apparent specific gravity of the soil. It requires no special soil analyses, only a 1 N KCl extraction for the determination of exchangeable Al, Ca and Mg. The use of the equation could lead to considerable savings in the use of lime.

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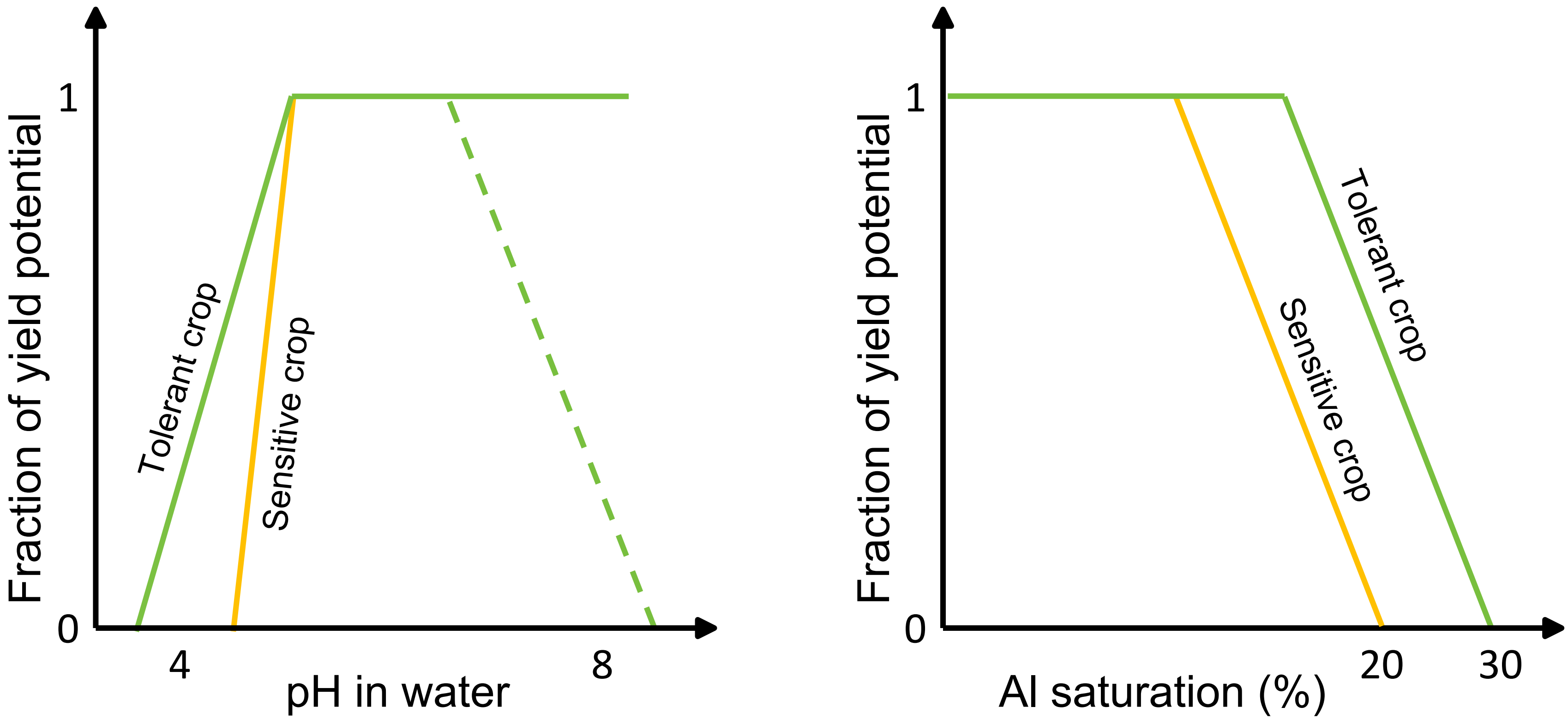
Spatially-explicit lime requirements

Key messages:

1) High lime requirements in coastal W Africa, SW Ethiopia, E African highlands, Katanga eco-region, KwaZulu Natal, and Madagascar highlands.
2) Most lime needed in areas with pH below 5.5, but considerable ‘demand’ also in areas with pH between 5.5 – 6.0
3) Consistent estimates across different lime recommendation methods

Crop yield response to soil acidity

Crop type-specific (cereal, legume, RTB, commodities) "suitability" based on pH and Al saturation using EcoCrop model with actual production data from SPAM.



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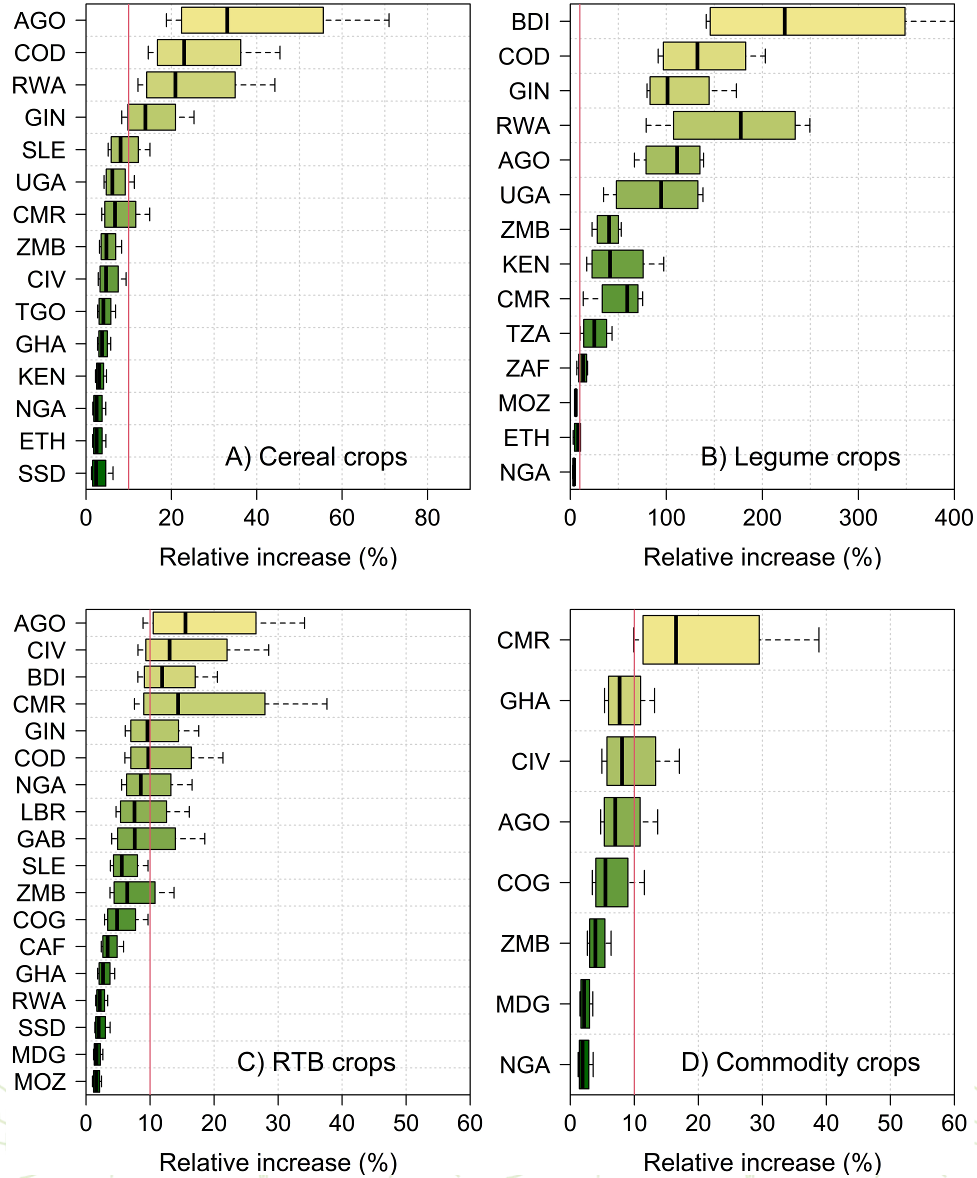
Extra crop production on acid soils



Key messages:

1) Results of a sensitivity analysis to EcoCrop parameters controlling yield response to exch. acidity
2) Greatest yield response to exch. acidity for legumes, followed by cereals, and by other crops
3) Increases in cereal production most promising in Angola, DRC, and Rwanda
4) Increases in legume production most promising E Africa, and parts of W Africa
5) Only marginal relative increases in the production of RTBs and commodity crops

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Returns-on-investment to liming

(*preliminary results*)

Background information:

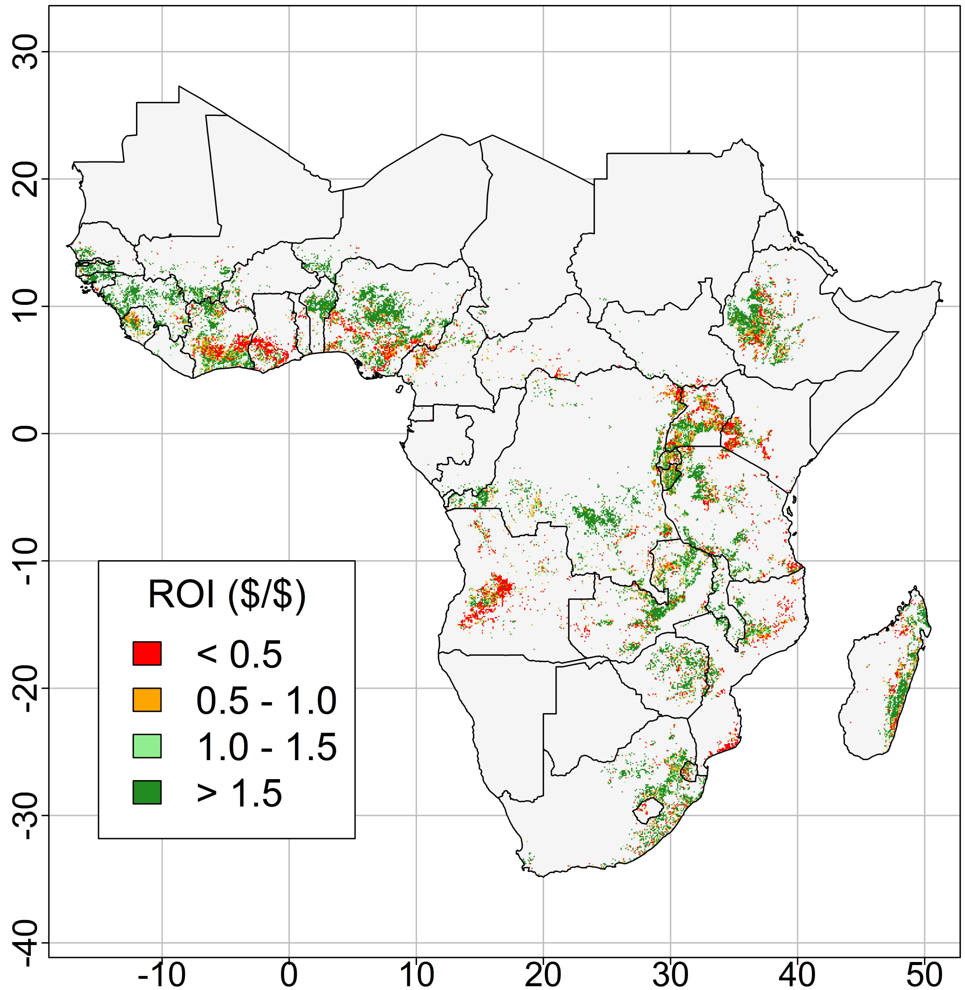
- ✓ Crop yield response to pH
- ✓ Crop prices based on average FAO prices across SSA
- ✓ Lime requirements based on Kamprath (1970)
- ✓ Lime price = 100 US$/t
- ✓ ROI = sum of returns from extra production of all crops in a pixel divided by lime requirements in that pixel times the lime price

Next steps:

Disaggregate analysis per crop

Explore different price scenarios

Estimate ROI based on response to Al saturation



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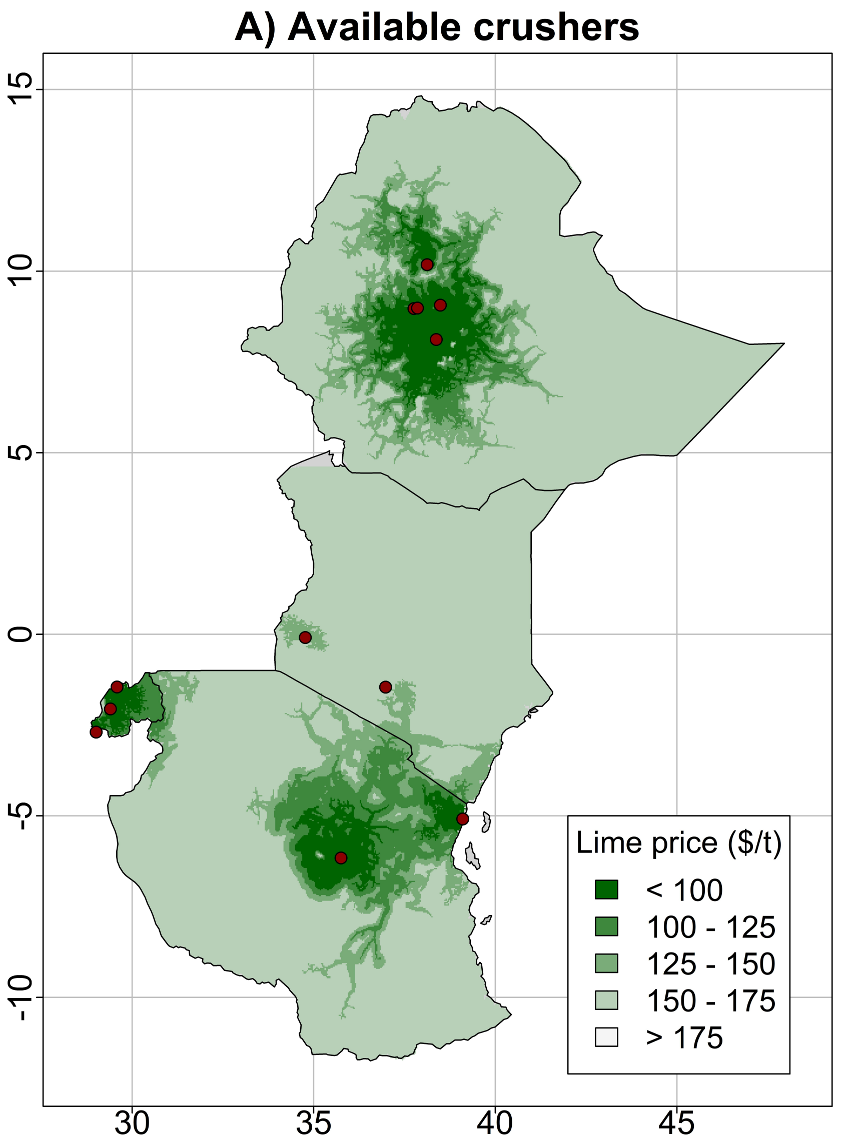
Spatially-explicit market assessment

Lime price calculation:
Quarry-gate price
+ Transportation costs
+ Packaging costs

Method used:
Non-linear transport cost-distance model and major road network

Scenarios:
1. Current crusher locations
2. Current cement factories
3. Available lime deposits

Next steps:
Acid cropland and rural population covered with different lime prices



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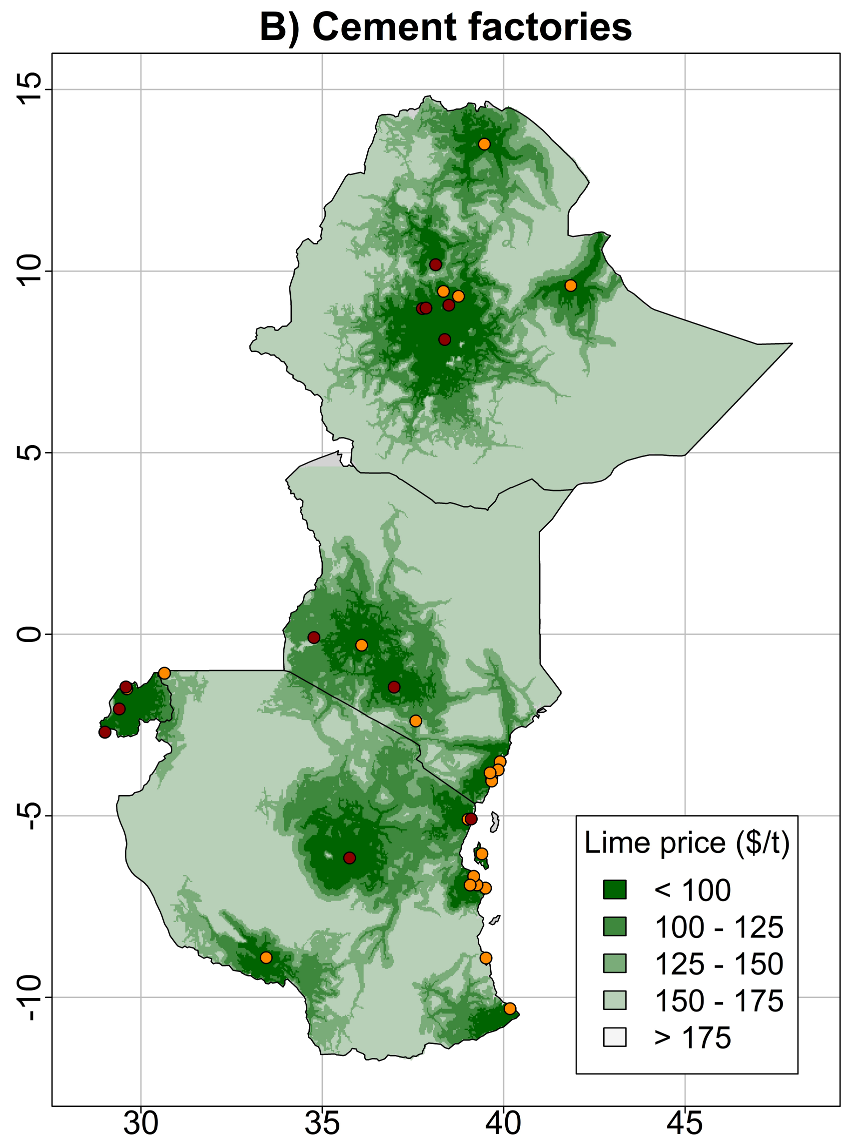

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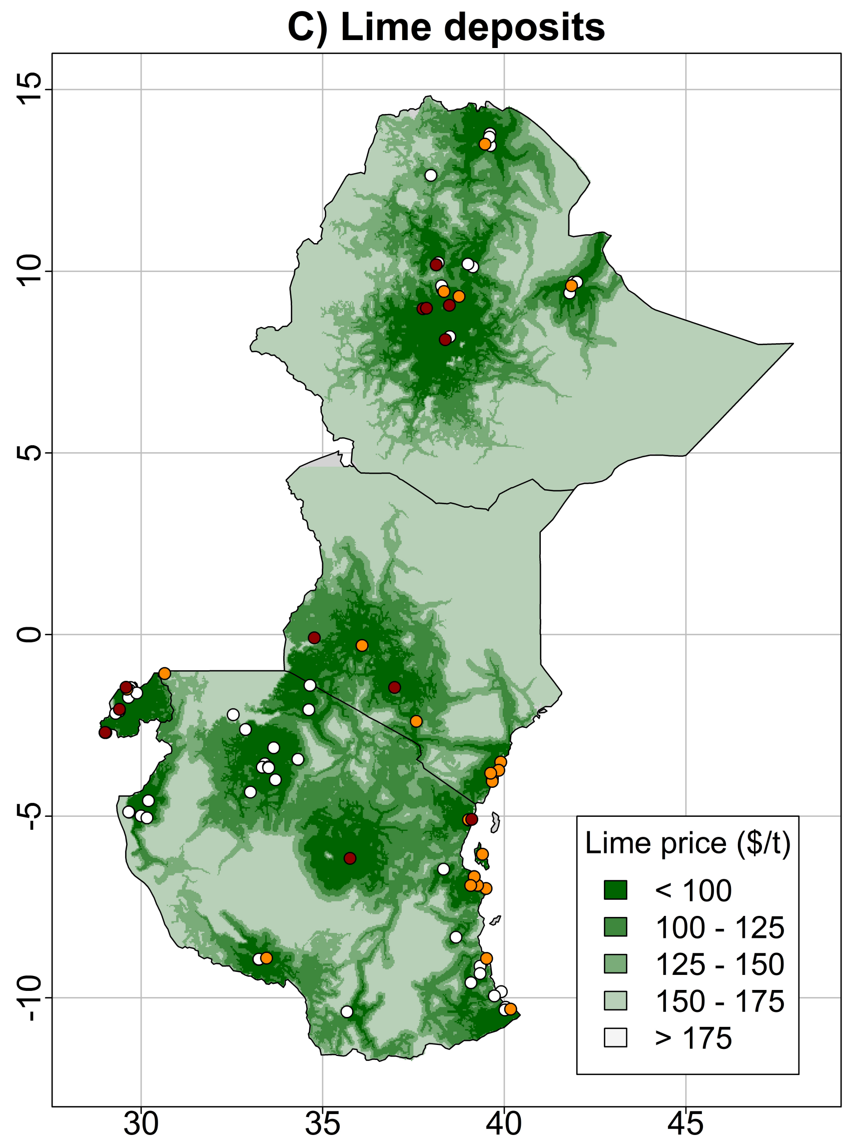
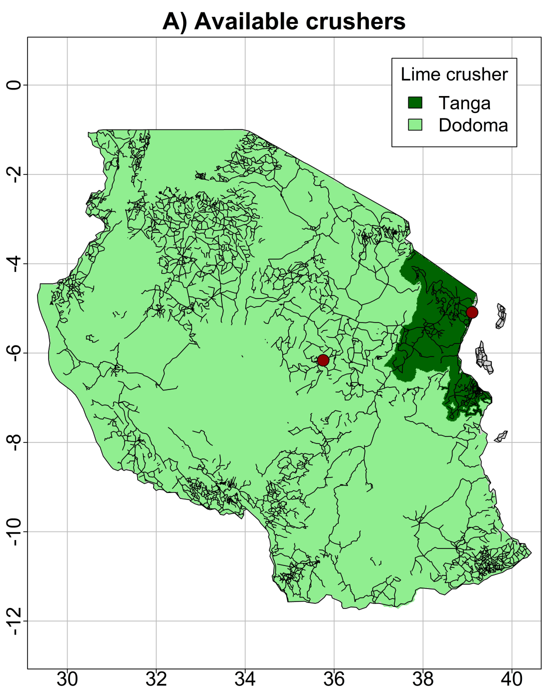
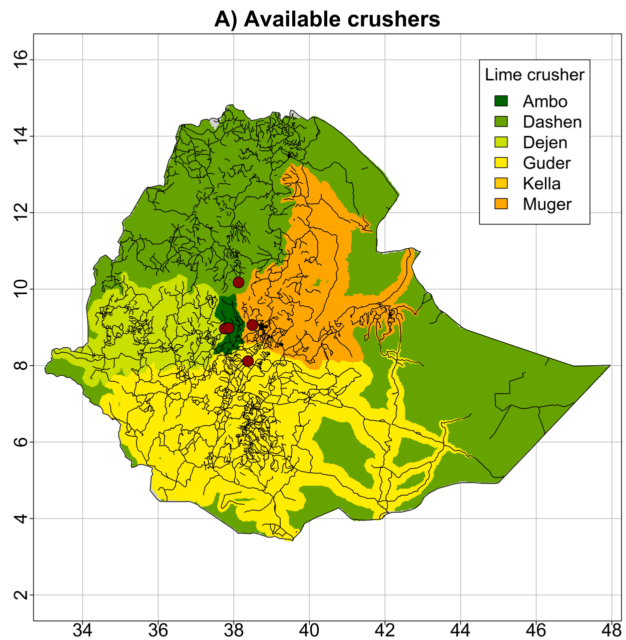
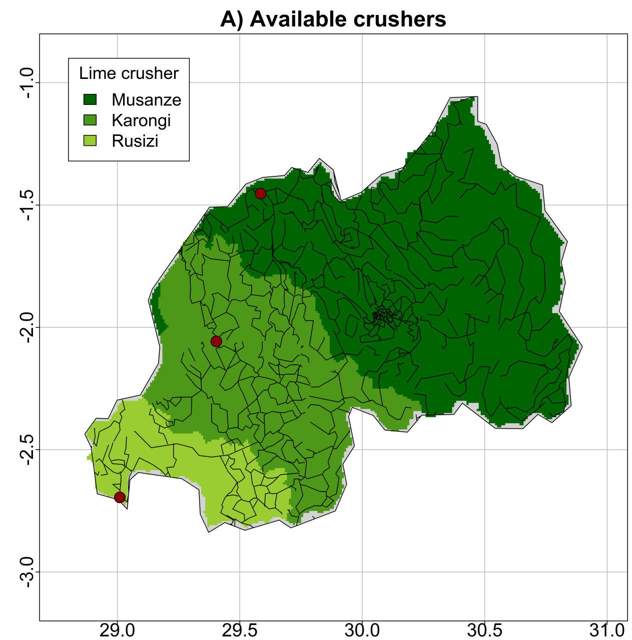


Spatially-explicit market assessment

Areas supplied with lime by current crushers at minimal cost







**Kenya not shown due to a single crusher currently providing ag lime

Knowledge gaps

1. Inconclusive evidence from secondary data (OAF, GIZ, etc.) on **yield response** to liming across the region
2. Fragmented evidence for the role of **alternatives to lime** (e.g., manure) to manage acid soils in SSA
3. Lack of understanding of **long-term effects** of liming and alternatives on soil properties and yield response
4. Missing lime **prices** on-farm and across agro-dealers
5. Aggregated benefits/externalities of remediating acid soils **beyond current cropland**

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Key messages

1. Regions with acid soils are dominated by farming systems with RTBs and perennial crops rather than cereal and legume crops.

2. Nearly 15 million people across the 4 GAIA countries live in regions with soils having a pH < 5.5.

3. Soil acidity remediation in the 4 GAIA countries requires between 50 and 96 million tones of lime.

4. Liming is a profitable investment in parts of Western Ethiopia, South-Central Rwanda, and 'pockets' of Tanzania (but not in Kenya).

5. Broadening lime suppliers to cement factories and lime deposits can decrease lime costs in Tanzania, Ethiopia, and Kenya (not in Rwanda).

Thank you for your interest!

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