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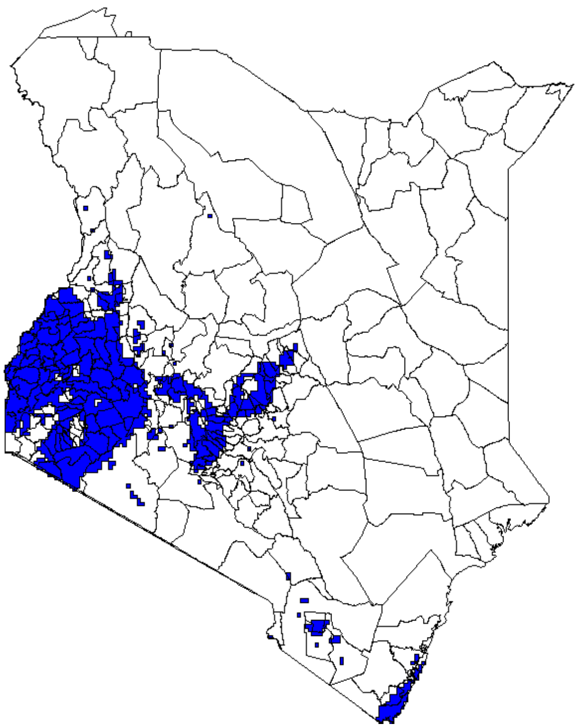
Acidic soils in Kenya: Constraints and remedial options



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Contents

Introduction

Acidic soils are have less than 7.0 pH values and cover about 13% (7.5 million hectares) of agricultural land of Kenya. Areas covered by acidic soils contribute significantly to the Kenyan economy through cash crop and dairy production. In the traditional ecological zone map of Kenya, areas with acidic soils are referred to as 'tea–dairy', 'coffee–tea' and 'main coffee' climatic zones (Jaetzold and Schmidt, 1982). This reflects the high potential for cash cropping and dairy keeping. Most soils in the humid tropics are characteristically acidic (Kamprath, 1984).

Acidic soils can be identified when a soil sample is analysed in any soil laboratory. In soil laboratories within the Kenya Agricultural Research Institute (KARI), acidic soils are classified further according to severity of acidity (Table 1).

Table 1. Grading of levels of soil acidity at the KARI–Kabete

Degree of acidity	pH range
Extremely acidic	<4.5
Strongly acidic	4.5-5.0
Moderately acidic	5.0-6.0
Slightly acidic	6.0-6.5
Near neutral	6.5-7.0

KARI–Kabete working manual

Crop tolerance to acidity

Different crops have various degrees of tolerance to acidity. Chillies, sweetpotatoes and irish potatoes are tolerant to acidity and can do well in soils with pH values below 5.5 (Plates 1 and 2). Most of the horticultural crops (onions, spinach, carrots, cabbages and cauliflower) do not tolerate acidity and can only grow well in soils with pH values above 6.0. Other crops like maize lie in the medium tolerance range and would do well in 5.5-6.0 pH values. Among the maize varieties, local cultivars like *Githigu* commonly found in central Kenya are adapted to the lower end of the tolerance range. Most of the flowers grown for export are sensitive to acidity. When crops are grown in soils with pH values below the lower limit, they give low yields and are of poor

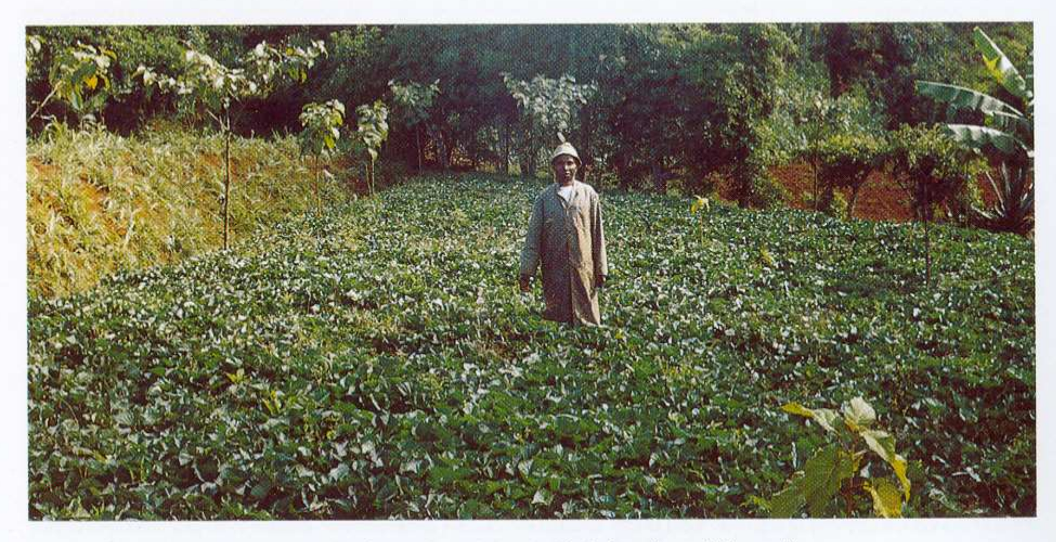

Plate 1. Irish potatoes thriving in acidic soils

Plate 2. Sweepotatoes thriving in acidic soils

quality. This can only be improved by applying inputs including fertiliser, lime, composts and manure—which would require additional labour and costs.

Research efforts and unresolved challenges

In recognition of the problems of caused by soil acidity, KARI has undertaken research work to develop affordable and sustainable methods of improving acidic soils. The Fertiliser Use Recommendation

Project (FURP) carried out trials between 1986 and 1991 and published area- and crop-specific fertiliser recommendations for various AEZ (KARI, 1994). These field trials were conducted in 65 locations in the high- and medium-potential areas (AEZ 1-4).

The trials covered 28 soil sub-orders and 14 crops. In some of the 65 FURP locations, results obtained after 5 years of experimentation could not be conclusively used to give fertiliser recommendations. Twenty-three sites (29%) where the trials failed had acidic soils with less than 5.5 pH values and would require to be amended if maize was to be grown profitably (Plates 3 and 4) (Table 2). Nitisols, Acrisols and Ferralsols are the most common acidic soils. At 3 sites—Kavutiri in Embu District, Chehe in

Plate 3. Maize crop neglected due to soil acidity

Plate 4. Bean plants with acid-related malformations

Table 2. Distribution of FURP sites in the various pH ranges

pH range	No of sites[1]	(%)
<4.5	3	5
4.5-5.0	6	10
5.0-5.5	14	24
5.5-6.0	15	26
6.0-6.5	15	26
6.5-7.0	2	4
>7.0	3	5
Total	58	100

(FURP, 1987); [1]—Data was obtained from 58 out of the 65 sites

Table 3. FURP sites with pH values below 5.5

District	Sites	Elevation (m)	AEZ	pH	r/Eo	Soil type
Kisii	Otamba	1790	UM 1	5.25	0.92	Mollic Nitisols
	Kiamokama	2020	LH 1	4.63	0.98	Humic Nitisols
	NARS	1730	UM 1	4.75	1.18	Mollic Nitisols
S. Nyanza	Rongo	1440	LM 1	5.43	0.89	Humic Acrisols
Siaya	Ukwala	1200	LM 2	4.98	—	Orthic Acrisols
	Yala swamp	1160	LM 3	4.53		Humic Gleysols
Busia	Bukiri	1220	LM 3	5.38	0.80	Chromic Acrisols
Bungoma	Kamokoiwa	1710	UM 2	4.93	1.02	Rhodic Ferralsols
Kakamega	Mumias	1270	LM 1	4.25	0.94	Orthic Acrisols
	WARS	1520	UM 1	5.35	1.09	Mollic Nitisols
	Vihiga	1620	UM 1	5.22	1.03	Humic Nitisols
Kericho	Sosiot	1890	UM 1	5.13	1.12	Mollic Nitisols
Uasin Gishu	Moi TTC	2140	LH 3	5.38	0.64	Ferralic Cambisols
	Turbo	1850	UM 4	5.23	0.84	Chromic Acrisols
K/Marakwet	Bugar	2320	LH 2	5.27	0.88	Humic Nitisols
Baringo	Ravine	2100	LH 3	5.45	0.88	Chromic Luvisols
Muranga	Makuyu	1430	UM 4	5.25	0.57	Dystric Nitisols
	Kareti	1640	UM 2	5.68	1.24	Humic Nitisols
Nyeri	Muirungi	2080	LH 1	5.0	1.18	Ando-humic Nitisols
	Chehe	1920	LH 1	4.6	1.32	
Embu	Kavutiri	1700	UM 1	4.6	1.29	Ando-humic Nitsols
	RRC	1510	UM 2	5.45	1.10	Humic Nitisols
Meru	Kaguru	1460	UM 2	5.36	1.12	Humic Nitisols
	Tunyai	880	LM 4	5.43	0.57	Rhodic Ferralsol

(FURP, 1988)

Nyeri District and Mumias, formerly in Kakamega District, soils are extremely acidic. Location and other characteristics related to the sites with pH values below 5.5 are shown in Table 3.

Development of acidity

Soils developed on non-calcareous parent materials are inherently acidic. In humid regions soils become acidic naturally due to leaching of basic cations under high rainfall conditions. In addition, reclaimed swamps (peats) and soils fertilised with acidifying fertilisers can become acidic with time. Gleysols at Yala Swamp in the lake basin may be acidic due to peat in poorly drained conditions while most of the other areas are acidic due to leaching.

Further research

Due to the poor results obtained by FURP in the 1986-1991 field trials—and in recognition that no fertiliser recommendations were arrived at for many areas with acidic soils—laboratory and glasshouse studies with soil samples collected from Chehe (Nyeri District) in Central Province were carried out. This case study determined the most effective amendment option(s) for acidic soils that can be recommended to farmers. To achieve the purpose, 5 objectives were formulated thus—

- Determine the major soil fertility constraints in acidic soils with reference to maize
- Identify and compare the available options for amending acidic soils
- Determine the lime requirement of acidic soils for growing maize
- Determine the soil chemical changes that occur when soils are amended in various ways
- Develop and publish recommendations that can be adopted by farmers at Chehe

Materials and methods

Soil samples

Soil samples were collected in November 1997 from 2 farms with different management histories for glasshouse studies. One field had been under pasture and had not received any fertilisers for many years while the other had been cropped for many years without applying chemical fertilisers. Samples were collected from a 2 x 2-m surface to a depth of 20 cm. In addition, composite soil samples were collected from plots that had been fertilised in various ways for fertility evaluation and to compare results with samples intended for glasshouse studies. In the glasshouse, soil samples were spread evenly and air-dried for 2 weeks. Sub-samples were drawn for laboratory analysis and the rest was to form stock for various experiments.

Fertiliser materials

Farmyard manure (FYM) samples were collected from 2 heaps in farmers' fields at Chehe. All the fertiliser and amendment materials were bought from stockists in Nairobi. The materials were triple superphosphate (TSP), calcium ammonium nitrate (CAN), Mijingu rock phosphate (MRP) and 2 brands of lime; trade named agricultural lime and dolomite. Apart from TSP and CAN, all the other materials were analysed in the laboratory to determine the nutrient composition.

Socioeconomic information

Information on crop production and methods currently used to correct soil acidity was gathered through person to person interview of the farmers from whose farms the soil samples were collected. The information was used to short-list the available options.

Glasshouse experiments

The following studies were designed to generate outputs that would meet the objectives highlighted in above.

Comparison of different options of amending acidic soils: Nitrogen as CAN was blanket applied at 100 kg N ha^{-1} and P levels varied at 0, 22, 44, 66, 88 and 132 kg ha^{-1}. Four different forms of P application were compared—

- TSP (20% total P)
- MRP (13% total P)
- TSP + agricultural lime at 4 t ha-1
- TSP+ FYM at 5 t ha-1

The air-dry soil was weighed into 48 pots which can hold a maximum of 4-kg of soil each. The pots were then arranged in a 2-factor randomised complete block design of 2 replications (one replicate for each of the 2 farms) (Plate 5). Three maize seeds were sown after mixing all the treatments with the soil and thinned to 2 after emergence. The crop was watered continuously to field capacity—water holding at field capacity determined by saturating a weighed amount of air dry soil with water and

Plate 5. Greenhouse experimental set-up at KARI-Kabete

allowing it to drain overnight from a funnel with 200 mm filter paper—for 10 weeks when above ground biomass was harvested. Shoot harvest was then dried in the oven at 70 °C for 72 h, weighed and expressed as dry matter (DM) weight (g per pot). A residual crop was grown after collecting soil samples from each pot for laboratory analysis to determine chemical changes after application of treatments. Data collection for the residual crop was done as in the main crop and soil analysis in pots repeated after the 2nd crop. In each of the DM harvests, nutrient concentration in tissues was determined by the wet digestion method with H_2SO_4- Salicyclic- H_2O_2 (Okalebo *et al.*, 1993).

Lime requirement studies: Air-dry soil was weighed into pots that can hold up to 4 kg of soil each and fertilised with 100 kg ha^{-1} of N from CAN and 44 kg P from TSP. Agricultural lime was added at 0, 2, 4, 6, 8, 10, 14, 16 and 20 t ha^{-1}. The pots were arranged in 3 blocks (3 replicates) and treated equally (Plate 6). After thorough mixing, maize crop was planted and data collected explained above.

Results and discussions

Laboratory analytical results for soils sampled from 3 differently managed plots are shown in Table 4. Soils from Chehe were extremely acidic, had high exchangeable acidity, low amounts of exchangeable cations Ca and Mg, and low extractable P. The soils had high organic

Table 4. Laboratory analytical results for Chehe soils

Soil parameter	Under grass	Cropped but not fertilised	Cropped and fertilised	Comments
PH_{H2O}	3.6	4.1	3.8	Extremely acidic
Na (meq/100 g soil)	0.40	0.48	0.54	—
K ,,	0.49	0.67	0.74	Okay, grass a strong miner
Ca ,,	0.74	1.30	1.20	Low, grass a strong miner
Mg ,,	0.38	0.92	0.90	Low, grass a strong miner
Ca/K ratio	1.51	1.94	1.62	Low, need more Ca
Ca/Mg ratio	1.95	1.42	1.33	Low, need more Ca
Mg/K	0.78	1.37	1.22	Low, need more Mg
Mn ,,	0.55	0.52	0.60	Okay
Hp ,,	3.05	2.35	2.70	Very high
P (ppm Meh)	1.00	2.00	2.00	Very low
Tot N (%)	0.21	0.23	0.32	Okay
Org C%	3.82	3.17	3.90	Very high
C/N ratio	18.2	13.8	12.0	—
Fe (ppm)	124.5	130.7	46.7	Very high
Cu (ppm	3.79	7.31	2.11	Very high
Zn (ppm)	11.60	14.7	0.98	Very high

matter content, sufficient levels of trace elements Fe, Zn and Cu and adequate levels of exchangeable element K.

Acidic soils develop as a consequence of excessive leaching of basic cations, mainly Ca, Mg and K in climatic conditions characterised by excessive rainfall (r) relative to evapotranspiration (Eo). In the case of Chehe, this ratio of r/Eo was 1.30 and is characteristically humid (FURP, 1987). According to Mehlich (1964), ratios of Mg:K in healthy soils should be 4:1 and 10:1 for Ca:K, implying that K levels are too high which can cause Ca and Mg deficiency (Haby *et al.*, 1990). Deficiencies, particularly of Mg are widely reported and has resulted in such ailments as grass tetany (hypomagnesaemia) in ruminant animals feeding on grass with K induced Mg deficiency (Haby *et al.*, 1990).

In low pH conditions, there is usually high concentration of Al^{3+} in the soil solution. Al^{3+} binds with orthophosphate ions ($H_2PO_4^-$, HPO_4^{-2}) and forms insoluble compounds resulting in low levels of extractable P. Excessive Al^{3+} concentrations cause low yields of non-acidic tolerant crops (Pearce and Sumner (1997), Evans and Kamprath, (1970). Besides the depressed P availability (P-fixation), high Al^{3+} concentrations are toxic to non-tolerant crops where it particularly affects the development of the root system that lowers the uptake of water and plant nutrients. Marschner (1990) reports that in pH values <4.0, the carrier system of K uptake is impaired resulting in loss of K from the roots (efflux) that is higher than influx.

Many soil advisory laboratories only determine the Total Exchangeable Acidity (TEA), also expressed as Hp which for soil samples analysed from Chehe (FURP, 1987) are related to the exchangeable Al (Fig. 1). Besides Al, TEA also incorporates H^+ ions originating particularly from organic acids derived from soil organic matter. Al takes a bigger share of TEA as TEA increases in soils (Table 5).

High organic matter lowers the amount of exchangeable Al in soil solution. Exchangeable Al^{3+} complexes with organic acids that result

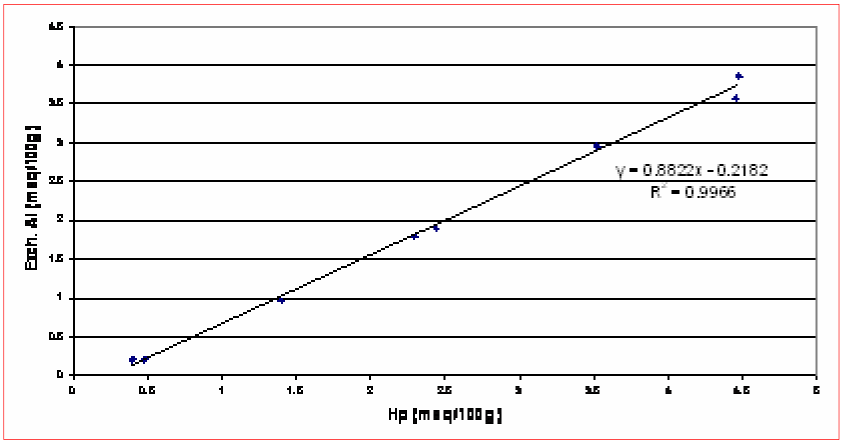

Fig. 1. Relationship between exch. Al and Hp

Table 5. Proportion of exchangeable Al in total exchangeable acidity for soils from Chehe

Sample numbers	H + Al $_{\text{KCl (meq/100g)}}$	Al $_{\text{KCl (meq/100g)}}$	Al (%)
A	0.40	0.20	50.0
B	0.48	0.20	41.7
E	1.40	0.96	68.6
F	2.30	1.78	77.4
C	2.44	1.90	77.9
D	3.52	2.96	84.1
G	4.46	3.58	80.3
H	4.48	3.86	86.2

(FURP, 1987)

from mineralisation of organic matter thus lowering concentration of exchangeable Al^{3+} in soil solution. In addition, organic ligands complex with trace elements and improve on their availability. This may explain the high levels of Fe, Cu, Zn and Mn in the soils (Table 4). Accumulation of soil organic matter (SOM) is possibly due to low rates of mineralisation resulting from inactivity of the micro- organisms necessary for mineralisation due to either low pH or low temperatures in AEZ LH1 (Table 3).

Management influences the nutrient composition of soils in various ways. Soils under grass are more acidic, have high Fe, Hp and organic C%. On the other hand, they are low in K, Ca, Mg, P and N. This data suggests a higher rate of nutrient uptake under grass due to the continuous removal of biomass through grazing. Fertilisation with inorganic, organic or both types of fertilisers increases the level of K, P, N and organic C% but results in reduced levels of trace elements Fe, Cu and Zn. Trace elements are not routinely applied in food crops and high yields may result in excessive mining and deficiency. Non- fertilised soils have high Ca, Mg, P, Fe, Cu and Zn, possibly because they produce less, resulting in less mining of nutrients.

Table 6. Laboratory analytical results for MRP, dolomite and agricultural lime

Material description	Total nutrient content (%)		
	CaO	MgO	P_2O_5
MRP	28.4	2.1	28.3
Dolomite	47.5	18.5	—
Agric. lime	38.4	19.2	—

Laboratory analytical data for MRP, agricultural lime and manure

Table 6 shows the analytical results for MRP, dolomite and agricultural lime. In Kenya, there is no standard for liming materials and farmers would go for ground chalk or limestone from deposits close to their locality. In the UK, it is a legal requirement to state the CaO or $CaCO_3$ content in lime and the granular size (Simson, 1986). Dolomite refers to a magnesian limestone with at least 3% Mg (5% MgO). The pure dolomite has a formula $CaCO_3.MgCO_3$ which contains by weight 54.3% $CaCO_3$ (30% CaO) and 45.7% $MgCO_3$ (22.5% MgO). The materials available in Nairobi were rich in CaO but slightly poor in MgO to qualify for pure

Table 7. Laboratory analytical report for manure from Chehe

Fertility index	Farmer 1	Farmer 2	Mean	Content (kg ha^{-1} from 5 t of FYM)
pH	7.9	8.1	7.9	—
Tot N (%)	1.81	2.29	2.0	90
Org C (%)	3.44	6.50	5.0	—
C/N ratio	1.90	2.80	2.3	-
P (%)	0.10	0.15	0.12	6
K (%)	0.93	0.90	0.91	40
Ca (%)	0.07	0.10	0.08	4
Mg (%)	0.13	0.17	0.18	7
Fe (%)	5.4	5.43	5.41	240
Mn (%)	0.15	0.15	0.15	7
Zn (%)	0.05	0.06	0.05	2
Na (%)	1.15	1.05	1.10	50

dolomite. Both however qualify for magnesian limestones (MgO > 5%). Since both Ca and Mg are deficient in Chehe soils, either of the materials can be used as an ameliorant but agricultural lime was used in the experiment because it is readily associated with agriculture.

Table 7 shows the analytical results for manure samples from Chehe. The manure was of high quality and easily mineralisable due to low C/N ratio. Alkalinity in manure is desirable in neutralising the exchangeable acidity in soils. Assuming 10% moisture content in air dry manure, 5 t of the manure will give 4.5 t DM, 90 kg total N, 6 kg P and 40 kg K ha^{-1}. The manure is a good source of N and K but a poor source of P. The nutrient release profile for the manure was not determined.

Information from interview

Farmers at Chehe applied large quantities of phosphatic fertilisers but the benefits realised were low. Only soluble forms of P were being used, with diammonium phosphate (DAP) being the most common planting fertiliser. Other varieties of mixed fertilisers of N:P_2O:K_2O grades including 20:20:0, 17:17:17 were widely used. Farmers also used the fertiliser 25:5:5 + 5S to topdress. Though not consciously, FYM was widely used to ameliorate the acidic soils.

Available options

From literature and other sources, soil acidity can be effectively neutralised by either liming or application of FYM. Calcium and Mg can be sourced from dolomitic limestones while P can be sourced from readily soluble sources (including superphosphates) or slowly soluble forms (including rock phosphates). Farmers had tried different combinations of inputs to improve the soils that led to the comparing of 4 options in this experiment. The options are—

- Application of high rates of soluble phosphate including TSP
- Application of a soluble P mixed with lime at planting
- Application of a soluble P mixed with FYM at planting
- Application of a less soluble P including MRP

Since P appeared in all the options, different rates of P in TSP and MRP were applied

Pot experiments

Dry matter yields

Yields increased with increasing P-levels up to a maximum yield of about 37.5 g per pot beyond which the differences were small (Table 8; Fig. 2). TSP + Lime option attained the maxima at 44 kg P ha^{-1} but all the others attained the maximum at 66 kg P ha^{-1}. There is hence a 50% saving on P requirements after liming to achieve similar yields. Application of more than 66 kg P ha^{-1} gave no further increase in DM yields possibly because either the genetic potential had been achieved or another limiting nutrient was in control.

Table 8. Dry matter yields of maize (g per pot) harvested at 10 weeks

Source of P	0	22	44	66	88	132
TSP	22.0	25.6	30.6	36.4	36.3	39.9
RP	21.8	30.4	31.6	36.7	38.5	37.1
TSP + lime	31.3	34.4	37.1	36.9	36.9	39.4
TSP + FYM	24.1	33.7	35.1	38.1	37.8	36.4

At every level of P application, DM yields were highest for TSP +L > TSP + FYM > RP > TSP. This pattern reflects decreasing capabilities to supply the deficient nutrients, Ca, Mg and P and ability to neutralise acidity. Lime alone (in PO treatment) can achieve more than 80% of the maximum yields and no response is expected from further investment in fertilisers (Walmsley, 1971) (Fig. 3). In this treatment, lime increased yields by 43% while FYM increased yields by 10%. There is a possibility that after liming or manuring, fixed P was made increasingly available due to the neutralisation of Al^{3+} with increased pH. Dolomitic limestones also contain sufficient amounts of Ca and Mg that results in increased yields. Liming alone (no P) gave a higher yield than P alone from TSP at 44 kg P ha^{-1}. It was not possible to determine how sustainable such a practice can be.

Rock phosphate performed better than TSP at every level of P application. This observation is of significance as P in locally available MRP is cheaper than the P in super-phosphates. Superiority of MPR is associated with its liming power due to the high CaO content and its nutritive value due to the content of Ca and traces of Mg.

Choice of what option to adopt will depend on many factors including crop response to application, purchase and transportation costs, availability of input in local market, environmental friendliness and the residual effects. Informal discussions with local marketing agents pointed to the fact that it is not cost-effective to transport lime and sell it at the current rate of KES 180 for a 50-kg bag. This may require intervention from government to have lime made available at highly subsidised rates as happened in the UK after the 2nd world war (Simpson, 1986). Marketing of MRP, the only slowly soluble P source in the market is not well established and farmers may not be able to get the material in their locality. Manure is also too bulky, variable in quality and sometimes very scarce at farm level.

Results obtained, the status quo and recommendations

Farmers from Chehe plant maize with compound fertiliser 20:20:0 at a P application rate of 35 kg ha^{-1} and topdress with either CAN or fertiliser 25:5:5 + 5S intended for tea. From the tea fertiliser, an extra 9 kg is topdressed to make up to a total of 44 kg P ha^{-1}. From the results in this experiment (Figs. 2 and 3), the same yield level can be achieved by applying half the P rate (22 kg ha^{-1}) but in form of MPR. Higher yields can be realised if the farmers apply lime only at 4 t ha^{-1} or better still, half the

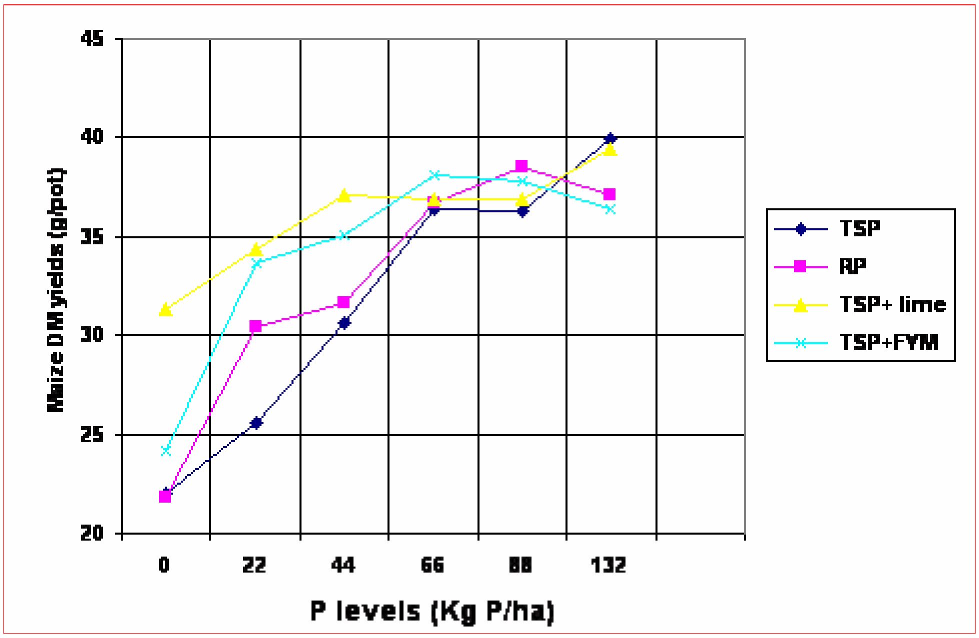

Fig. 2. Change in maize yields with increasing P levels

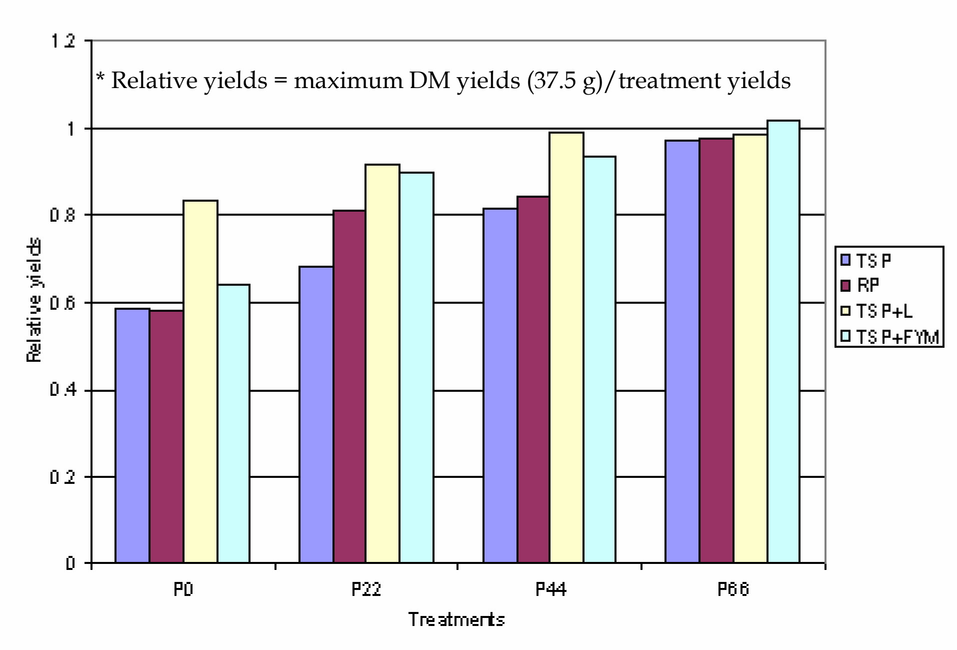

Fig. 3. Variation of relative* DM yields for maize with treatments

current rate of P in form of super-phosphates but mix with either 5 t ha^{-1} of FYM or 4 t ha^{-1} of agricultural lime. It is difficult to make a prescription at this point due to the limitations highlighted earlier that are associated with each of the options. Forty-four kilogrammes of P ha^{-1} in TSP has a market value of KES 6 160 (USD 80) when compared to an equivalent amount from MRP that would cost KES 2 700 (USD 36), yet the yields realised are not significantly different.

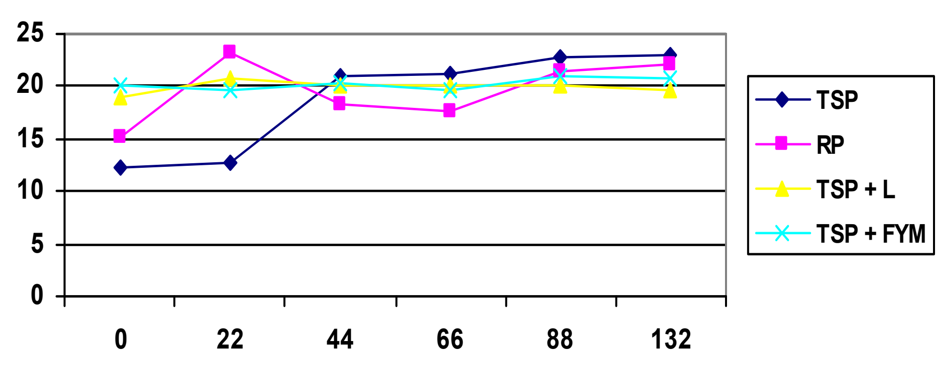

Fig. 4. Variation of DM yields with increasing P levels on residual crop

Dry matter yields of residual crop

Dry-matter yield data for the residual crop is shown in Figure 4. Apart from TSP, where DM yields increased with increasing P rates applied in season 1 by 70% (from 12.3-21.0 g per pot), other treatments in season 1 did not affect the residual crop significantly. Although TSP performed worst in season 1, the P fixed season one can be used in subsequent crops unlike other treatments where the residual effect is limited.

The overall mean DM yields were lower in season 2 than in season 1 by about 40% from 33.7-19.7 g per pot and a relative mean yield of 0.58. Drop in yield was possibly due to exhaustion of nutrients through uptake in initial crop. Residual yield correlated positively with initial yield and can be defined by the equation

$$Y_r = -4.6 + 0.69\,Y_i,\ r^2 = 0.79$$

indicating that where high yields had been obtained in the 1st season, the fertility status had been raised to a sustainable level. A unique case is that of limed and manured pots where effects of season 1 were completely suppressed. Thus, in every level of P application, losses through uptake balanced out with gains through fertilisers. The soil is hence well buffered as far as nutrients are concerned

Nutrient concentration in plant tissue

When the DM was analysed for nutrient content, concentrations were correlated with P levels and application forms. Nitrogen content in plant tissues varied from 0.89%-1.33% and a mean of 1.08%. Concentration declined exponentially with increasing P rates and DM yields, with a regression equation of the type

$$N = 1.2497e^{-0.0026\,P} \text{ and } r^2 = 0.808$$

Mean N levels for the various P-sources were not significantly different. Considering that N was not a limiting factor in the soil, the low N concentration at high DM yields can be attributed to a reduced uptake efficiency due to a 2nd limiting nutrient. There are also possibilities of a luxurious N uptake in cases of low biomass yields as happens when N fertiliser is applied in excessive rates.

Phosphate concentration in the tissues averaged 0.09% and did not vary significantly with increasing P levels or DM yields. It can be assumed that P availability was not limited under the circumstances and a constant proportion of P to DM was maintained. Potassium levels were 2.09-2.51% and a mean value of 2.19% DM. Concentration correlated negatively with P levels and DM yields with a correlation equation

$$K = 2.3753-0.0032 P, r^2 = 0.683$$

Since K was not applied as a fertiliser, concentration was lower from high yielding pots because of dilution with increased biomass. There is a possibility of K levels in the plant tissues affecting N use efficiency and the growth rate (Kemmler and Hobt, 1986). Nitrogen and K are the likely nutrients that limited maize growth at high P application levels. Potassium concentration did not vary with different P sources significantly. Other nutrients—Ca and Mg—did not vary significantly in plant tissues.

Change in nutrient concentration in soils after treatments and seasons

Soil samples were analysed after harvest and macronutrient concentrations compared with concentrations before treatments were applied. In all the treatments, pH and P values went progressively higher with seasons while all the other nutrients (except Mg in TSP + L treatment) went down (Fig. 5). The behaviour of P in the soil and soil test values obtained at the start of a season should be studied further. It appears that after prolonged drying of some of these soils, P is transformed into compounds that cannot be solubilised by the extracting solution (Mehlich 1) resulting in erroneous results. After wetting of the soil however, as happens after the 1st rains, P availability improves through solubilisation of the same compounds. This is also observed in the field where the early crop shows the characteristic purple colour due to deficiencies but which disappear with time even where no P fertiliser is applied. The rise in pH can be associated with changes in Ca^{++} and H_2PO4^- balance in soil solution. Solubilisation of P would mean that there is more H_2PO4^- relative to Ca^{++} because Ca^{++} has been leached or taken up by the crop (Fig. 5). By anion exchange, there is a net excess of OH^- ions resulting in a rise in pH (Reeve and Sumner, 1970). Negative nutrient balances in 2 successive seasons irrespective of options employed shows that it takes time before the after-effects of acidification are corrected (Table 9). The superiority of lime and manure can be attributed to the improved status of exchangeable cations Ca, Mg and K (Table 10).

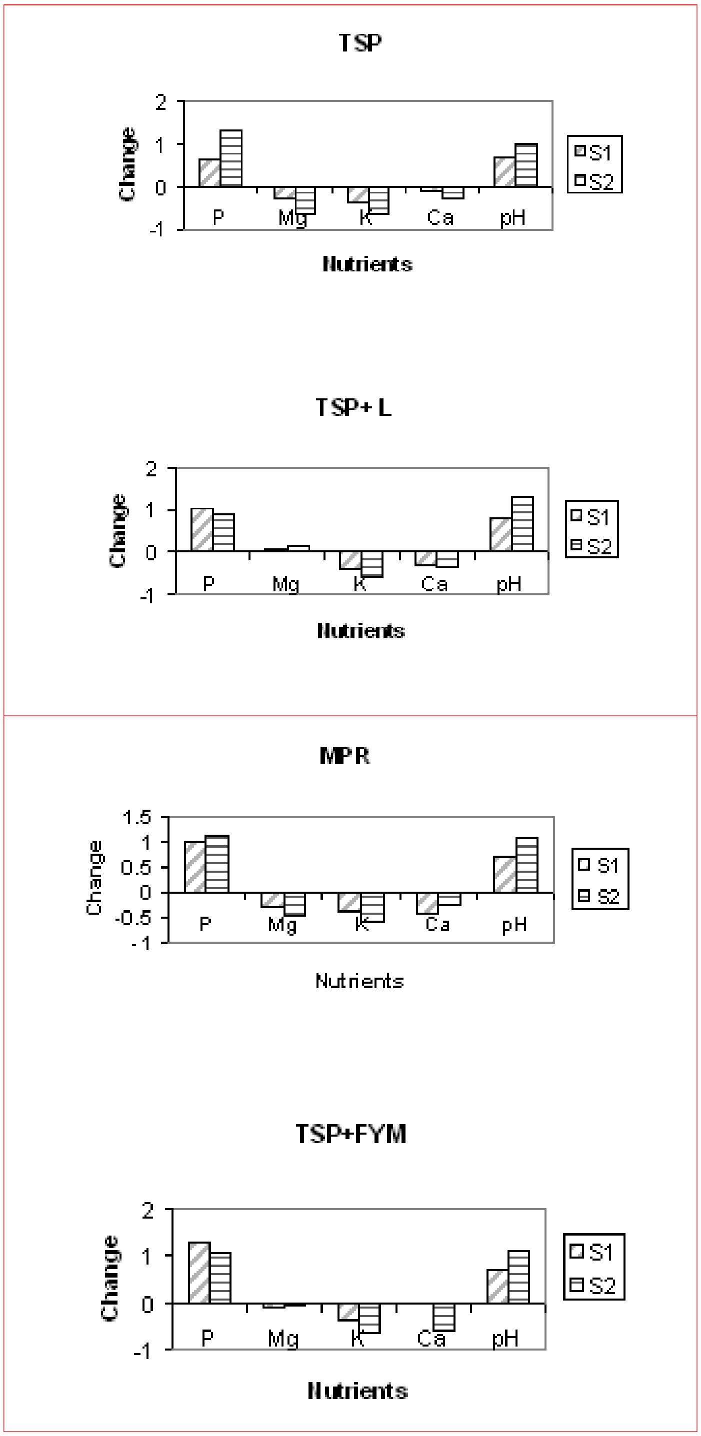

Fig. 5. Seasonal changes in pH and other nutrients with different treatments

Table 9. Sum of cations Ca + Mg + K in soils after 2 seasons

Treatments	Sum of cations (Ca + Mg + K) in meq/100 g soil		
	Before	season 1	season 2
TSP	2.25	1.67	1.24
RP	2.25	1.36	1.30
TSP + Lime	2.25	1.34	2.06
TSP + FYM	2.25	1.69	1.62

Table 10. Effect of increasing levels of lime on maize DM yields, soil pH and exch. acidity

Lime levels (t ha^{-1})	DM yields (g per pot)	Soil pH	Exch acidity (Hp)
0	18.1	4.6	1.7
2	27.5	4.6	1.9
4	35.5	4.6	1.9
6	34.8	4.7	2.1
8	34.3	5.1	1.6
10	36.5	5.2	1.5
14	33.4	5.1	1.4
16	34.9	5.3	1.0
20	38.2	5.1	1.0

Plate 6. Maize response from lime and manure

Lime requirement studies: There is extensive literature showing that the most common method of ameliorating acidic soils is by liming. In the olden days, liming of acidic soils was aimed at raising the soil pH to about 6.5 which is ideal for most crops. Due to high buffering power of particularly the soils rich in organic matter, the lime requirements were too high and uneconomical. Too much liming also created other problems like micronutrient deficiencies and P deficiency. Modern liming technology aims at adding that amount of lime which just neutralises the exchangeable Al^{3+} to avoid toxicity. According to Kamprath (1984), liming is recommended if Al^{3+} saturation of the exchange complex is higher than 60%. According to Mehlich (1964), crops with a moderate tolerance to soil acidity can do with a moderate TEA provided that the sum of Ca^{2+} and Mg^{2+} is higher than Hp. The formula used to determine lime requirement is

Lime requirement (meq $CaCO_3$ */100 g soil) = 2 x exchangeable* Al^{3+} *(meq/100 g)*

For example, the calculation for lime requirements for the Chehe soil with a Hp averaging 2.7 meq/100 g would be

- a Hp of 2.70 will give Al^{3+} saturation of 2.16374 meq/100 g
- Lime requirement in $CaCO_3$ equivalent = 2 x 2.16374, = 4.32748 meq/100 g
- 1 equivalent of $CaCO_3$ = 50 g and 4.32748 meq would weigh 0.216374 g/100 g soil

Assuming that 2 000 000 kg of soil per hectare, lime requirement will be 4.3 t ha^{-1}

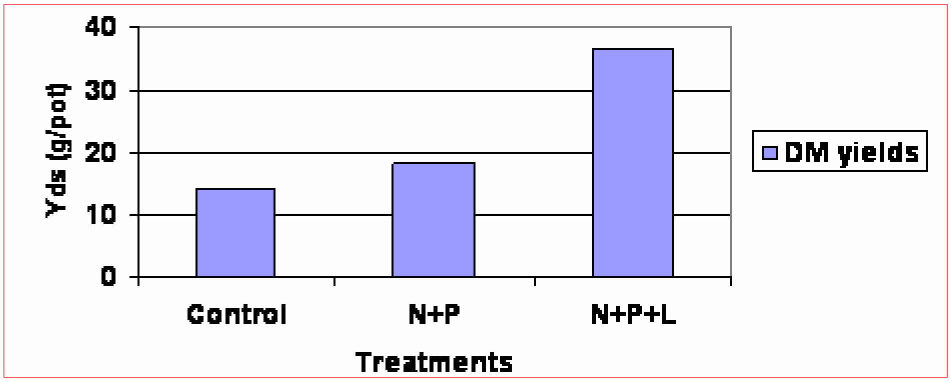

Fig. 6. Effect of lime on a maize crop fertilized with N and P

A 2nd method of determining lime requirement is by applying increasing rates of lime to a given quantity of soil and selecting the level that gives highest yield. Change in DM yields with increasing levels of lime is shown in Table 10 and figures 6 and 7. Application of 100 kg of each N and P_2O_5 ha^{-1} increased DM yields by 28% from 14.04-18.07 g per pot (Fig. 6). Liming increased DM yields further to a maximum of about 37.5 g per pot at a liming rate of 4 t ha^{-1} (Fig. 6). Dry matter yields were positively correlated to the levels of lime ($r^2 = 0.74$). Liming resulted in rise of pH of the soils from 4.4-5.3 and reduced exchangeable acidity that went down to 1.0 cmol kg^{-1} (Fig. 7).

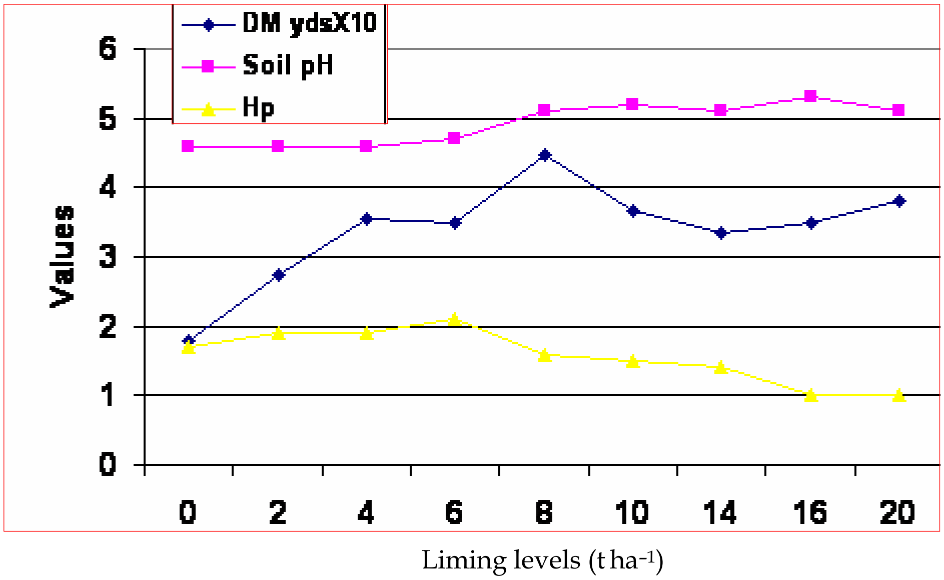

Fig. 7. Effect on increasing levels of lime on maize yields, soil pH and exch. acidity

Conclusions

These findings agree with reports from Reeve and Sumner (1970) that acidic soils have a low pH, low P, low base status, high P fixation and Al toxicity. The outputs expected from this greenhouse work were met to a large extent. Most of the limitations were identified, 4 options of ameliorating them identified and compared and optional solutions found. It was not possible to prescribe any of the options because some have low chances of adoption due to external factors that are more socioeconomical than agronomic. There is a big opportunity for state intervention so that lime is made easily accessible to farmers. Bulk buying by farmer groups will benefit from economies of scale where lime is ferried in trucks and shared out in the villages. Packaging of lime in 50-kg bags is unrealistic for a material applied in tonnes and where the market value of quantities packaged is lower than the bag and labour that go with it. In the meantime, KARI will strive to calibrate soils from different regions that have different buffer power and hence lime requirements. Composting and other technologies that can be used to produce alternatives to FYM to stem the trend of declining availability at farm level should be encouraged. The current practice of using superphosphates at planting is both expensive and inefficient. At all levels of P application, MPR performed better than the TSP due to its high CaO content which limes and supplies needed Ca to the soil. Sourcing P from MPR reduced the P requirement from 44-22 kg ha^{-1}, yet the cost of P in MPR is cheaper than the same P in TSP by 60%. The results presented here should be tested on-farm using participatory Learning And Research (PLAR) (Plate 7).

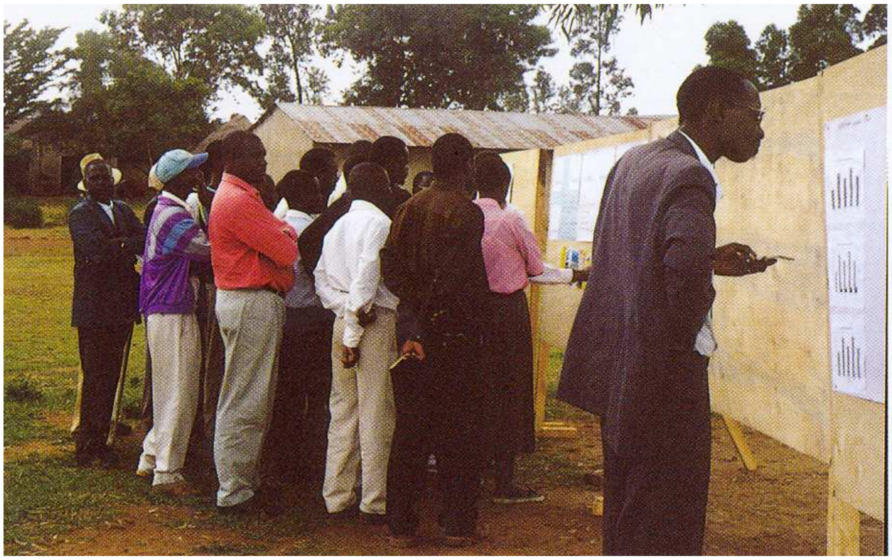

Plate 7. Farmers' training during a field day

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