FERTILITY EVALUATION OF MLINGANO AND KWAMDULU CATENA SOILS

A major thesis presented in partial fulfilment of requirements for the degree of master of science in soil and water management.

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1. INTRODUCTION:

Many tropical soils are known for their advanced stage of weathering, poor nutrient status and their acidic nature. In an attempt to improve the productivity of these soils, much work on fertility evaluation and fertilizer recommendations has been done in different parts of the world. Soil analysis, pot and field trials or a combination of these have been employed.

Field trials in most cases prove to be the best method as they are more close to the actual farming situation. However, field trials are costly and need much time to reach conclusive results. For instance National Soil Service (NSS) work on Mlingano catenary sequence in Tanga region of Tanzania needed 7 years of experimentation before it could get conclusive results on soil fertility and management requirements of the catena. Moreover, some fertilizer responses started to show up in the last years indicating the instability of soil fertility with time. Therefore there is a need to develop a method of fertility evaluation which will take less time but at the same time introducing minimum error. Topsoils have a great contribution to the fertility of the highly weathered tropical soils because they carry almost all of the organic matter and nutrients. Hence, if the use of topsoil in predicting soil fertility prove to be comparable to the results observed in field, pot trials or soil tests can be executed frequently to monitor fertility changes with time.

This study evaluated the effectiveness of the use of the topsoil in fertility assessment of tropical soils. Inherent fertility of the soils from the selected catenas was evaluated and then the response to fertilizers on these soils were studied using maize as a test crop. Maize response to fertilizers including growth rate, fresh, dry matter yield and nutrient uptake were studied in a pot trial and the results were compared with previous results obtained in the field. Finally, the following was investigated:

Whether the predicted yield from the topsoil by calculation using chemical characteristics or by pot trial are comparable to that obtained in the field.

Whether the position in the landscape can be used to predict crop response to fertilizers.

2. EXPERIMENTAL DESIGN

The experiment consisted of field studies and a pot trial. The field studies included characterization of study sites and detailed study of soil characteristics in profiles.

Two catenas, Mlingano and Kwamdulu were selected for this study. The location of the catenas is indicated in appendix 3. The catenas were selected because they have the same parent material and they have the same geological and pedological history. They have a similar climate and similar topographical features. Besides, their landscape positions are clearly defined and their land management practices are well known. The catenas have red acid soils on the crest which become less acid down the slope. On Mlingano catena the soils become brown down the slope while on Kwamdulu the soil colour is the same along the catena. The study concentrated on the crests and lower slopes to ensure that a clear difference between positions in the landscape is obtained.

The topsoil (0 -20cm) was collected randomly within each of the study sites and used for pot trial. The response to fertilizers N, P and K on these soils was tested using maize (Staha composite) as a test crop. In addition to fertilizers, the effect of lime was tested. Maize response to fertilizers and lime on soils of each site was tested using a completely randomized factorial design. In each case the treatments were tested in duplicates. Lime rates were based on the amount of exchangeable Al of the topsoil, while the choice of fertilizer treatments was based on previous field experiments. This made it possible to compare pot results to those from the field. Conversion from the fertilizer rates to the amount applied in pots was based on the weight of the fallow slice, which was supposed to be 2ton/ha.

The treatments are indicated in the following section.

3. MATERIALS AND METHODS:

3.1 Selection of sites

Two soil catenas with similar topographical features, parent material and agroecological zones were selected. The information on topographical features and parent material was obtained from survey report, Nation soil service (1988); De Pauw (1983) and the agroecological zone classification from the report by De Pauw, 1983.

The characteristics of soils in both crest and lower slope of the catenas were studied. Several auger holes of 40cm depth were made on each site for general characterization of the sites and also for guidance on where to make a pit.

3.2 Detailed study of the sites

One soil pit of up to 2 meters depth was made for each site. Description of profiles was done according to the guidelines for profile description (FAO, 1977). Soil colours were described in accordance to the Munsell colour chart (1975). A soil sample from each horizon was collected for analysis of the following characteristics; pH(H_2O), pH(KCL), Exchangeable bases, CEC, O.C, total nitrogen, available phosphate and partical size distribution.

3.3 Soil collection for the pot trial

Top soil material (0-20cm) was collected randomly from six different places on each site. Soil belonging to one site was mixed, air dried, ground and sieved through a 2mm sieve. The fine earth was mixed thoroughly and subsamples were taken for chemical analysis. This included pH, O.C, total nitrogen, exchangeable bases, CEC, exchangeable aluminium, available phosphate, iron and manganese.

3.4 Preparation of the pot trial

The field capacity of each soil was estimated by saturating 4kg of soil and leaving it to drain freely over night. 60 % of the soil moisture left after the drainage had ceased, was supposed to be an approximation of the field capacity.

The amount of lime to be applied to each soil was determined based on exchangeable aluminium of the soil. Lime rate used was 1.65 tons of $CaCO_3$ per hectare for every milliequivalent of exchangeable aluminium as suggested by Kamprath, 1970. Lime requirement of the soils was; 4.4g, 2.4g, 0, and 0 per pot of Kwamdulu crest, Kwamdulu lower slope, Mlingano crest and lower slope soils respectively. Due to the limited time, for a lime- soil reaction in the pots, a more soluble liming material was prefered. Analytical $CaCO_3$ was used in this pot trial.

Fertilizer rates used were based on the results of the previous fertilizer trials on Mlingano catena. Slightly higher rates was used. The rates were; 50, 20 and 20kg/ha of nitrogen, phosphate and potassium respectively. Urea was used as a source of nitrogen, triple super phosphate as source of phosphate and analytical potassium chloride as source of potassium.

3.5 Set up of the pot trial

The effect of nitrogen, phosphate, potassium fertilizers and lime on the productivity of the top soils of the crests and lower slopes of the two catenas was investigated. Maize was the test crop. A 2^3 and 2^4 factorial design were used for Mlingano and Kwamdulu respectively. Treatments were assigned randomly within each of the four soils in duplicate. The tested treatments were combinations of 2 levels of N, P and K fertilizers. For Kwamdulu catena the combination also included 2 levels of lime. The treatments tested are as indicated below;

Mlingano catena	Kwamdulu catena	
$N_0 P_0 K_0$	$N_0 P_0 K_0 L_0$	$N_0 P_0 K_0 L_1$
$N_1 P_0 K_0$	$N_1 P_0 K_0 L_0$	$N_1 P_0 K_0 L_1$
$N_0 P_1 K_0$	$N_0 P_1 K_0 L_0$	$N_0 P_1 K_0 L_1$
$N_0 P_0 K_1$	$N_0 P_0 K_1 L_0$	$N_0 P_0 K_1 L_1$
$N_1 P_1 K_0$	$N_1 P_1 K_0 L_0$	$N_1 P_1 K_0 L_1$
$N_1 P_0 K_1$	$N_1 P_0 K_1 L_0$	$N_1 P_0 K_1 L_1$
$N_0 P_1 K_1$	$N_0 P_1 K_1 L_0$	$N_0 P_1 K_1 L_1$
$N_1 P_1 K_1$	$N_1 P_1 K_1 L_0$	$N_1 P_1 K_1 L_1$

The subscript 0 denotes no application of the corresponding nutrient. The second level of application denoted by the subscript 1 stand for 100, 40 and 40mg/pot of N, P, and K respectively. For Kwamdulu catena, L_1 indicates 4400 and 2400mg of lime per pot on the crest and lower slope respectively.

Four kilograms of soil was moistened to 35 % of the field capacity and mixed thoroughly to ensure uniform moistening. The moist soil was divided into two. One portion was mixed with fertilizers or lime as per treatment. The other portion was again divided into two parts. One part was put at the bottom of the pot, followed by the fertilized soil and then the second part on top. This was done to ensure uniform distribution of fertilizers in the root zone and to avoid root damage due to a salt effect. The volume of the pots used in this trial was four litre. Four maize seeds were sown in each pot and then pots were irrigated to field capacity.

3.6 Running of the trial and data collection

The soil moisture was maintained at field capacity throughout the experimental duration. Rain water was used for irrigation. Pots were rotated daily to minimize positional variations. Five days after planting, germination percentage was recorded. Three days later, plants were thinned to two per pot. Frequent visual observations of plant performance were done during the experimental period. Plant heights were taken at the age of 12, 19, 31, 36 and 52 days.

3.7 Harvest

Fifty two days after germination, the above ground parts of the plants were harvested. Total length was measured and the shoots weighed. The shoots were washed in rain water, rinsed in demineralized water and afterwards oven dried at 60°C for four days. The weights of oven dried shoots were taken. Then the shoots were ground ready for chemical analysis.

After harvest, three pots were randomly selected from limed as well as nonelimed treatments for each of Kwamdulu crest and lower slope soils. Soil sample was taken from each of these pots for pH(H_2O) determination.

3.8 Methods used for soil analysis

pH(H_2O) and pH(Kcl) was determined in suspension of 1:2.5 soil to solution by the use of pH meter with a glass_calomel combination electrode.

Organic carbon was determined according to the Walkley_Black method

Total nitrogen was determined by digestion of soil samples in concentrated H_2SO_4 and distilled in boric acid as prescribed by the Kjeldahl procedure.

CEC was determined by the ammonium acetate method.

Exchangeable bases were extracted by neutral ammoniun acetate. In the extract, calcium and magnesium were determined by atomic absorption spectrometer and potassium and sodium by flame photometer.

Available phosphate was extracted by a mixture of 0.03M ammonium fluoride and 0.025M hydrochloric acid as instructed in the Bray1 method. Phosphate in the extract was determined colorimetrically using a blue ammonium molybdate method with ascorbic acid as a reducing agent.

Exchangeable aluminium was extracted by 1N KCL and obtained by titration with 0.005M hydrochloric acid in the presence of ammonium oxalate.

Phosphate retention was determined according to a method suggested by Blakemore _et al_. 1987.

Micronutrients were extracted by a mixture of 0.005M DTPA, 0.1M TEA and 0.01M CaCl at pH 7.3 then determined by AAS in the filtrate.

Particle size distribution; The soil was treated with 30 % H_2O_2 to oxidize the organic matter. Particles were dispersed by 4 % sodium hexametaphosphate. Water was added up to 1 liter. The mixture was homogenized by shaking and particles in suspension determined by hydrometer method.

3.9 Methods used in plant analysis

Ground plant samples were oven dried at 70°C and digested with a H_2SO_4 mixture at 350°C. Selenium was used as a catalyst. Nitrogen was first coupled to salicylic acid and subsequently reduced. The digest was used for the following determinations;

Nitrogen. Determined by a method based on the colour forming reaction of Berthelot, in which hypochlorite was used for oxidation and sodium nitroprusside as a catalyst.

Phosphate was determined colorimetrically by the blue ammonium molybdate method with ascorbic acid as a reducing agent.

Sodium and potassium were determined by flame emission spectrometry.

Calcium, magnesium and micronutrients were determined by atomic absorption spectrometer.

Procedures for soil analysis (ed.) by Van Reeuwijk was used for reference.

4. RESULTS

4.1 Site characterization:

Both Mlingano and Kwamdulu catenas are situated in semi-humid plains with the mean annual rainfall ranging from 600 to 1200mm, developed on intermediate metamorphic rocks, well drained, undulating to rolling plains with slope of 2 to 10 %, situated at low altitude, less than 750 M. (De Pauw, 1983).

The catenas are situated under the foot slope of Usambara mountain. They have convex slopes ranging between 0 and 13 %. The slope increases gradually from the crests to the foot slopes. Soils are red derived from gneissic parent material. The catenas have bimodal rainfall pattern, with long rains from March to May and short rains from September to November. Average annual rainfall is 1136 mm for Kwamdulu and 1150 mm for Mlingano. Mlingano catena is under maize cultivation whereas Kwamdulu is under sisal.

The soils of the catenas are deep. The solums are deeper than 1.5 m, with horizons having only slight differences either in colour, texture or structure. The boundaries between horizons are gradual or diffuse and smooth.

The soils have good physical properties. They are well drained, friable and moderately aggregated. However, the productivity of the soils is low at the crests and better at lower slopes as indicated by the crop yield (700 Kg/ha of maize on the crest as compared to 2,500 Kg/ha on the lower slope of Mlingano catena. Sisal leaf length of 94 cm on crest versus 106 cm on lower slope of Kwamdulu catena).

4.2 General description of soil properties of profiles:

The more detailed description is indicated in Appendix 1 and 2.

Kwamdulu crest

Kwamdulu crest have dark reddish brown topsoils. Soil colour changes gradually to dark red in the subsoil. The clay content increases gradually down the profile. Soils are strongly acid in topsoil, the pH increases gradually down the profile to moderately acid subsoil. This is due to the increase in bases (especially magnesium) with depth. Available P in the topsoil is slightly higher than in the subsoil. Generally, available P in the soil profile is low.

Kwamdulu lower slope

The soil colour changes gradually from dark reddish brown in the topsoils to dark red in subsoils. Topsoils are coarse in texture, while the subsoils are finer having twice as much clay as the topsoil. The soil reaction is slightly acid except at depth 10 -30 cm were it is strongly acid. This is also accompanied by the occurence of high exchangeable aluminium in this horizon. Like in Kwamdulu crest, exchangeable magnesium is increasing with depth. Available phosphate is low throughout the profile. There is a slight indication of phosphate accumulation in the subsoil (30-95 cm).

Mlingano crest:

Dark reddish brown topsoil changes gradually to dark red in the subsoil. Soils are friable, with clay content increasing gradually down the profile. Soil pH decreases with depth. The topsoil has a slightly acid reaction while the subsoil is very strongly acid. All nutrients decrease with soil depth. Available phosphate is low in the topsoil and very low in the subsoil, possibly due to fixation by aluminium or due to the decrease of organic matter.

Mlingano lower slope :

The soil colour is changing gradually from dark brown in topsoil to red in the subsoil. Topsoils are lighter textured than the subsoils in which clay accumulation was observed. The topsoil is neutral and the subsoil is slightly acid. Bases are higher in the topsoil and decrease with depth. Available phosphate is moderate in the topsoil and low in the subsoil.

4.3 Nutrient status of top (0 -20 cm) soil:

Table 1 shows chemical characteristics of the four soils used in the pot trial. Rating of nutrients is indicated in Table 2.

TABLE 1: CHEMICAL CHARACTERISTICS OF SOILS USED IN POT TRIAL

SOIL no.	pH H2O	pH Kcl	Ca	Mg	Na (Exch. cations)	K (Exch. cations)	Sum (Exch. cations)	CEC	BS
					meq/100g				%
K1	4.6	3.9	1.1	0.6	0.1	0.1	1.9	9.1	21.0
K2	4.9	4.1	2.0	1.1	0.1	0.6	3.8	8.5	44.0
M1	6.4	5.9	7.8	3.0	0.1	1.1	11.8	12.2	96.0
M2	6.8	6.0	11.6	4.2	0.1	1.8	17.6	16.4	100.0

SOIL no.	org. matter C %	org. matter N	P_Bray mg/Kg	Cu (DTPA extraction one to 5 extr.)	Zn (DTPA extraction one to 5 extr.)	Fe (DTPA extraction one to 5 extr.)	Mn (DTPA extraction one to 5 extr.)	exch. Al (Kcl extr.) meq/100	P-sorp %
				ppm					
K1	1.5	0.1	4.33	5	3	35	173	1.32	29
K2	1.2	0.14	3.66	4	2	37	134	0.68	23
M1	2.1	0.24	4.9	7	5	10	122	0.0	18
M2	2.3	0.24	8.6	6	4	14	76	0.0	15

KEY:
- K1 Kwamdulu crest soil
- K2 Kwamdulu lower slope soil
- M1 Mlingano crest soil
- M2 Mlingano lower slope soil

TABLE 2: RATING OF SOIL CHEMICAL PROPERTIES

SOIL	RATING				
		------- exch. cations -----------			
	soil reaction	Ca	Mg	K	Al
Kwamdulu crest	strongly acid	v.low	low	low	low
Kwamdulu lower slope	strongly acid	low	moderate	high	low
Mlingano crest	slightly acid	moderate	high	v.high	v.low
Mlingano lower slope	neutral	high	high	v.high	v.low

SOIL	Org.matter	Av.P	CEC	Bs	Mn
Kwamdulu crest	moderate	low	low	low	high
Kwamdulu lower slope	moderate	low	low	moderate	
Mlingano crest	high	moderate	moderate	high	
Mlingano lower slope	high	moderate	moderate	high	

Generally, nutrient status of the soils is higher in the lower slopes than at the crests. Soil pH and base status is higher at lower slopes for both Mlingano and Kwamdulu. For Mlingano, organic matter content, available phosphate and CEC are also higher at the lower slope. This is not the case in Kwamdulu, where the crest soils have higher organic matter, available phosphate, CEC and micronutrients than the soils at the lower slopes. The data shows Mlingano catena to be more fertile than Kwamdulu catena. This could be due to differences in management practices. Kwamdulu catena is under sisal, a deep rooted crop with high requirement of potassium and calcium. Mlingano on the other hand, is under maize cultivation, a crop with high requirement of nitrogen and P. Another reason could be the effect of fertilizers. Mlingano area has been under research for a long time, could be the area with a recent history of being nonfertilized was once under fertilizer trials.

4.4 Nutrient supply by the soils:

The nutrient supply by unfertilized soils to the test crop are indicated in Table 3. Table 3 also shows values estimated for potential supply of nutrients by the soils as calculated from soil chemical properties (available P, O.C, pH, and Exch K) as instructed in QUEFTS method (Janssen <u>et al</u> 1989a).

TABLE 3: THE AMOUNT OF NUTRIENTS SUPPLIED BY NONE FERTILIZED SOILS TO THE PLANTS

SOIL	NUTRIENT	CONTENT %	CONTENT ppm	ACTUAL UPTAKE mg/pot	ACTUAL UPTAKE RATING	CALCULATED POTENTIAL SUPPLY Kg/ha	CALCULATED POTENTIAL SUPPLY mg/pot
Mlingano crest	N	3.14		330	optimum	126.1	252
	P	0.2		22	low	9	18
	K	6.08		628	high	105.6	211
	Ca	2.26		250	high		
	Mg	0.36		40	high		
	Fe		129	1.4	optimum		
	Mn		71	0.7	optimum		
Mlingano lower slope	N	1.64		235	optimum	148.6	297
	P	0.23		33	optimum	9.8	20
	K	4.71		676	high	131.1	262
	Ca	2.19		314	high		
	Mg	0.27		39	optimum		
	Fe		147	2.1	optimum		
	Mn		37	0.5	optimum		
Kwamdulu crest	N	2.74		85	optimum	42.2	84
	P	0.19		6	low	2.3	4
	K	3.57		111	high	24.4	49
	Ca	3.65		113	high		
	Mg	0.53		16	high		
	Fe		100	0.3	optimum		
	Mn		1079	3.3	toxic		
Kwamdulu lower slope	N	2.54		74	optimum	38.8	78
	P	0.11		3	deficient	3.5	7
	K	4.75		138	high	168.8	338
	Ca	3.61		105	high		
	Mg	0.41		12	high		
	Fe		66	0.2	optimum		
	Mn		313	0.9	optimum		

It was observed that potential nutrient supply obtained by calculation, especially that of potassium and of nitrogen was very low when compared to the actual uptake. Even the uptake from unfertilized soils was already far higher than the calculated potential supply. This discrepancy could be caused by a pot effect. Quefts was developed based on field data. The use of data from pots gives a higher uptake because in pots plant roots are exposed to small volume of soil, hence a much more intensive extraction of nutrients by plants occurs. In field condition roots extend to larger volume of soil leading to little nutrient extraction per unit volume.

4.5 Fertility assesment for maize:

Rating of nutrient contents in plant tissue from unfertilized soils is shown in Table 3.

Criteria used in rating of nutrient content in the soils and plant tissue are indicated in Appendix 4.

Mlingano catena soils

At the lower slope nutrients were supplied in sufficient amount. The supply of potassium and calcium was more than optimum. At the crest, most of the nutrients were supplied in sufficient amount. The supply of potassium, calcium and magnesium was higher than optimum whereas that of phosphate was below optimum.

Kwamdulu catena soils

Crest soils supplied low phosphate and very high manganese. The supply of phosphate in the lower slope soil was in the deficiency range while potassium and calcium supply was beyond the optimum range.

4.6 Effect of N, P and K fertilizers on plant growth:

The fertilizers had no significant effect on germination percentage as by this time seedlings used the nutrient reserve in the seed. Also this indicates the absence of a salt effect on seed germination.

At the early growth stage no difference was observed in plant performance. To explain this is the low nutrient requirement and the nutrient reserve in the seeds. With time nutrient demand increased and the nutrient reserve in seeds was exhausted. Some plants started to be weak and developed a purple colour on their midrib and leaf blade, indicating phosphate deficiency. On Mlingano crest soils these symptoms were observed in plants with K and NK treatments. The symptoms were absent in plants on soils of Mlingano lower slope. On both crest and lower slope soils of Kwamdulu catena, the symptoms were observed in most pots irrespective of treatments. This observation indicates that fertilizer treatments at the applied rate was not sufficient to overcome phosphate deficiency.

The effect of fertilizer treatments on plant height is indicated in Table 4.

At early stage of growth, fertilizer effect on plant height was insignificant in all of the four soils. As plants grew the effect of phosphate on both Kwamdulu crest and lower slope soils became evident. Plants in P- treated soils grew throughout the experimental period. On soils without phosphate treatment, plants showed a stunted growth in a period between the age of 3 and 5 weeks. After this period plants resumed growth but at significantly lower rate than those in P- treated soils (see Figure 1 & 2).

TABLE 4A: TREATMENT EFFECT ON PLANT HEIGHT ON MLINGANO CREST

TREATMENTS			(Days after germination)				
N	P	K	12	19	31	36	52
	mg/Pot				cm		
0	0	0	40	59	84	105	254
100	0	0	43	60	88	104	249
0	40	0	44	61	92	108	256
0	0	40	40	58	88	109	243
100	40	0	46	64	93	105	263
100	0	40	44	60	88	103	259
0	40	40	47	67	96	107	250
100	40	40	49	69	98	112	265
		sx	4.10	3.73	3.37	3.41	9.43
		cv	8.2	8.6	6.1	4.1	5.3
		n	2	2	2	2	2

TABLE 4B: TREATMENT EFFECT ON PLANT HEIGHT ON MLINGANO LOWER SLOPE

TREATMENTS			(Days after germination)				
N	P	K	12	19	31	36	52
	mg/pot				cm		
0	0	0	49	70	106	120	269
100	0	0	43	62	98	113	257
0	40	0	44	68	104	116	268
0	0	40	47	67	100	112	251
100	40	0	45	66	98	111	250
100	0	40	43	61	98	110	255
0	40	40	46	66	101	113	250
100	40	40	49	71	104	115	271
		sx	2.17	3.09	4.46	5.01	7.30
		cv	6.7	7.1	4.6	4.5	4.0
		n	2	2	2	2	2

TABLE 4C: TREATMENT EFFECT ON PLANT HEIGHT ON KWAMDULU CREST SOIL

TREATMENTS				(days after germination)				
N	P	K	Lime	12	19	31	36	52
mg/Pot				cm				
0	0	0	0	43	54	57	58	144
100	0	0	0	41	57	62	64	158
0	40	0	0	47	65	80	89	215
0	0	40	0	39	56	60	61	146
100	40	0	0	43	59	70	77	206
100	0	40	0	45	59	63	64	143
0	40	40	0	41	58	66	74	193
100	40	40	0	42	59	73	82	201
0	0	0	4400	44	63	70	74	177
100	0	0	4400	44	60	64	69	171
0	40	0	4400	43	60	86	92	214
0	0	40	4400	46	63	67	71	176
100	40	0	4400	48	66	88	101	236
100	0	40	4400	43	57	63	69	179
0	40	40	4400	46	62	81	88	202
100	40	40	4400	44	67	84	94	217

TABLE 4D: TREATMENT EFFECT ON PLANT HEIGHT ON KWAMDULU LOWER SLOPE

TREATMENTS				(days after germination)				
N	P	K	Lime	12	19	31	36	52
mg/Pot				cm				
0	0	0	0	43	57	63	65	149
100	0	0	0	43	54	61	62	134
0	40	0	0	46	61	78	87	213
0	0	40	0	45	60	65	66	150
100	40	0	0	48	62	80	91	216
100	0	40	0	42	52	57	58	136
0	40	40	0	47	65	81	90	215
100	40	40	0	43	62	82	91	221
0	0	0	2400	50	64	72	74	165
100	0	0	2400	45	60	65	67	139
0	40	0	2400	43	60	73	87	230
0	0	40	2400	46	60	68	68	149
100	40	0	2400	44	57	76	89	224
100	0	40	2400	48	59	62	67	150
0	40	40	2400	45	62	76	86	228
100	40	40	2400	45	62	74	84	208
			sx	2.32	2.23	2.95	2.83	5.95
			cv	7.2	6.8	11.8	15.6	4.6
			n	2	2	2	2	2

Fig.1 KWAMDULU CREST

P effect on plant growth

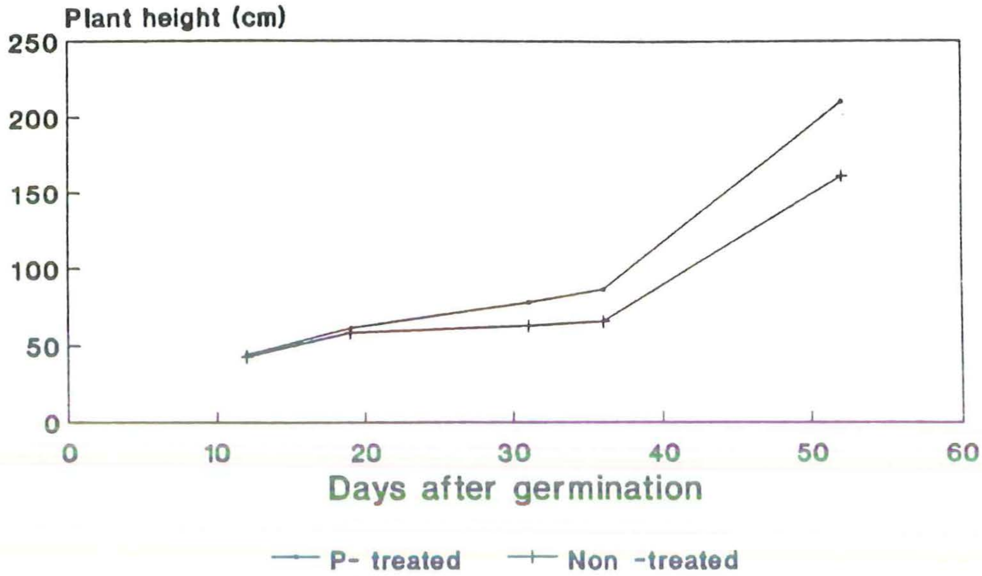
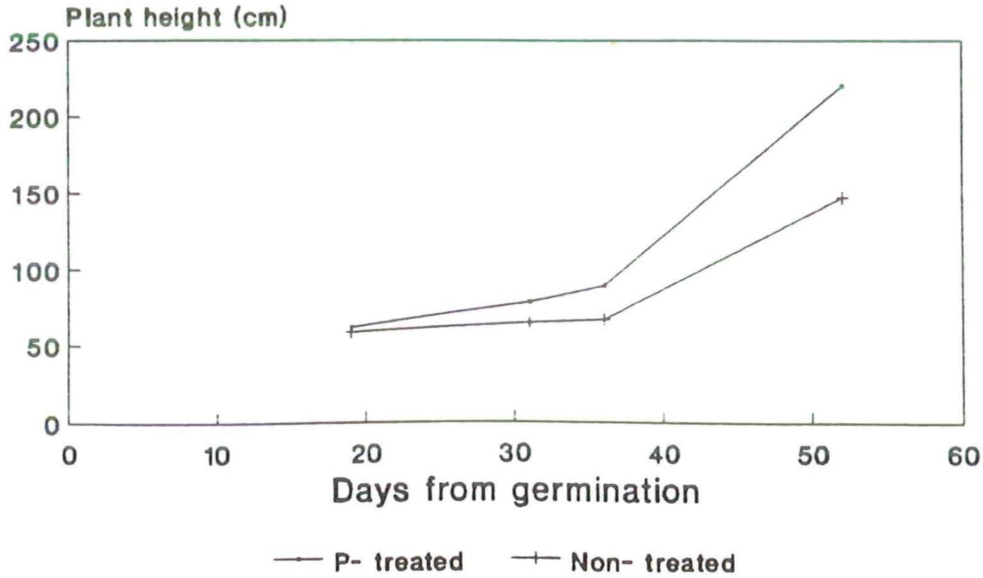
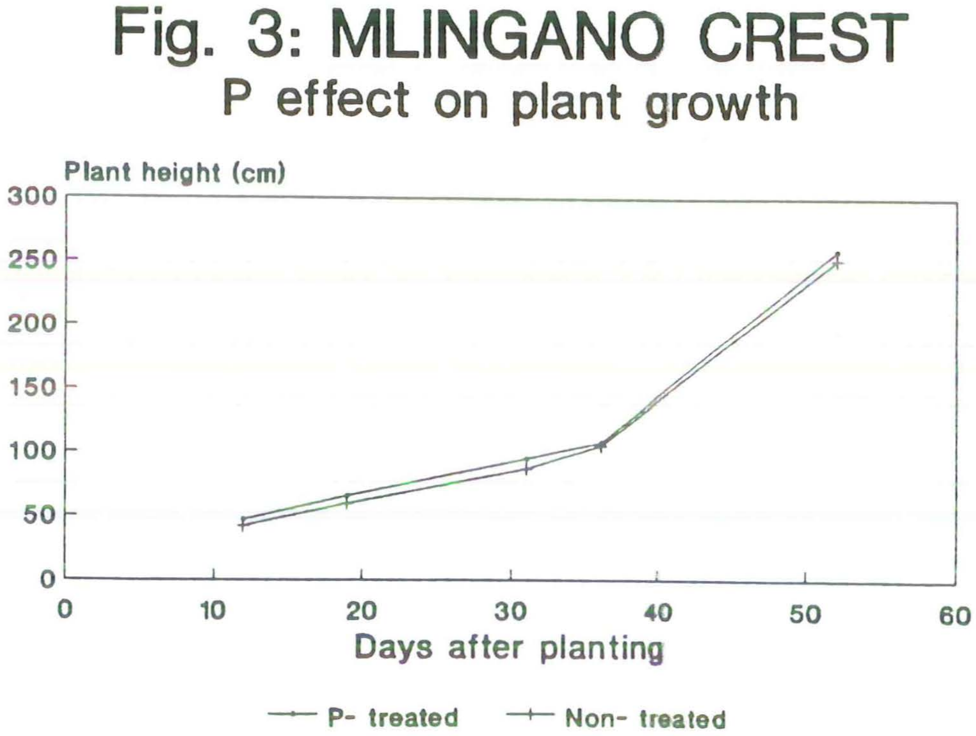


Fig.2: KWAMDULU SLOPE

P effect on plant growth



Unlike Kwamdulu soils, in Mlingano soils no stunted growth was observed. On crest soils, plant growth in pots without P treatment was lagging behind those in P-treated pots. Nevertheless, the difference was significant only for the first 4 weeks (Figure 3).



There was no significant difference in plant growth between P- treated and non treated Mlingano lower slope soils. A slight negative NK interaction on plant growth was observed in both Kwamdulu and Mlingano lower slope soils.

4.7 Effect of lime on plant growth:

Lime effect on plant growth was significant on Kwamdulu crest soils (Figure 4).

On Kwamdulu lower slope soils lime effect was not significant. Figure 5 shows a negative lime - P interaction on these soils. This implies that application of P with no lime was sufficient.

Fig.4: KWAMDULU CREST
Lime effect on plant growth

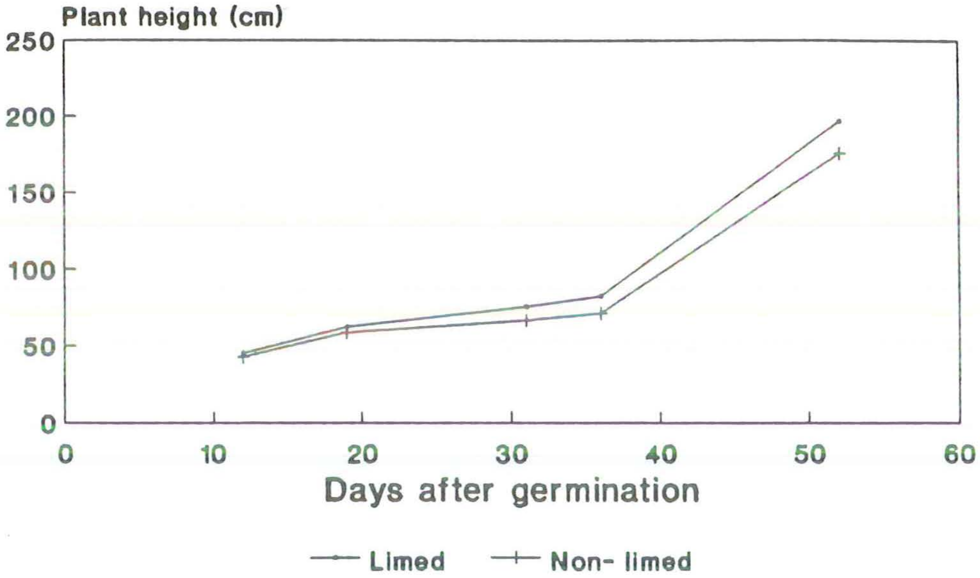


Fig. 5: KWAMDULU SLOPE
Effect of P and lime on plant growth

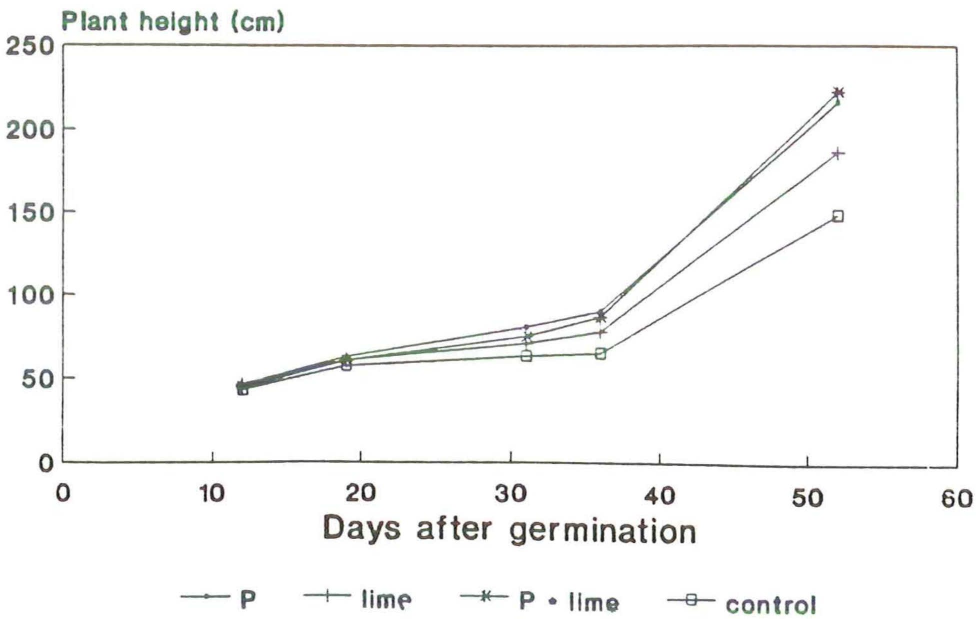


TABLE 5: FERTILIZER EFFECT ON FRESH AND DRY MATTER YIELD ON MLINGANO SOILS

TREATMENTS			CREST		LOWER SLOPE	
N	P	K	Fresh wt.	Dry wt.	Fresh wt.	Dry wt.
mg/pot			g/pot			
0	0	0	148.6	11.1	173	14.4
100	0	0	143.4	10.2	189	13.2
0	40	0	155.2	12.4	171.9	15.4
0	0	40	129.6	10.3	167	14.4
100	40	0	156.5	12	181.2	15.2
100	0	40	130	9.4	183.2	14.6
0	40	40	158.4	13.2	173.2	15.4
100	40	40	133.4	13.1	211.6	14.3
		sx	10.27	1.07	12.3	1.04
		cv	9.8	13.2	9.7	10.0
		n	2	2	2	2

4.8 The effect of N, P and K fertilizers on fresh and dry matter yield:

Mlingano

Fertilizer effect on fresh and dry matter yield is indicated in Table 5.

The effect of fertilizers on lower slope soils was a slight increase in fresh weight of the crop. The increase due to nitrogen application was significant at 10 % level while that of phosphate and potassium was not significant. The fertilizer effect on dry matter yield was not significant.

On crest soils the fresh weight as well as dry matter yield were significantly increased by phosphate application. The effect of nitrogen and potassium on crest soil was insignificant. The application of nitrogen, potassium or a combination of the two without phospate application tended to decrease fresh and dry matter yield. This observation shows that the two nutrients are not limiting at the present level of nutrients in these soils. The soil data in Table 1 also are in agreement with this observation. Unless the main limiting factor is corrected, no efficient utilization of other nutrients is expected. Instead addition of these nutrients into the soil will increase the crop demand of the most limiting nutrient.

Kwamdulu

Fertilizer effect on fresh and dry matter yield is shown in Table 6.

TABLE 6: TREATMENT EFFECT ON FRESH AND DRY MATTER YIELD ON KWAMDULU SOILS

TREATMENTS N	P	K	Lime	CREST Fresh	Dry wt.	LOWER SLOPE Fresh	Dry wt.
mg/pot				g/pot			
0	0	0	0	33.3	3.1	25.8	2.9
100	0	0	0	33.2	2.5	26.4	2.6
0	40	0	0	62.5	6	78.6	7.6
0	0	40	0	27.2	2.4	30.2	3
100	40	0	0	54.4	5.2	87.5	7.7
100	0	40	0	27.4	2.5	23.7	2.4
0	40	40	0	57.6	5.2	81.2	7.8
100	40	40	0	65	6.3	102.8	8.4
0	0	0	L	43.6	3.2	33.4	3.6
100	0	0	L	43	3.8	25.8	2.7
0	40	0	L	76.1	7.2	87.4	7.8
0	0	40	L	44.7	4.2	30.1	3.2
100	40	0	L	92.4	8.8	90	8
100	0	40	L	43.2	3.4	33.8	3.2
0	40	40	L	70.6	7.4	88.4	7.4
100	40	40	L	85.6	8.2	77.7	6.8
			sx	4.94	0.57	5.24	0.3
			cv	13.1	16.4	12.8	7.9
			n	2	2	2	2

Fertilizer application on both crest and lower slope soils increased the fresh and dry matter yield. The increase due to phosphate application was significant whereas that of nitrogen and potassium was not significant. The increase due to phosphate was higher than that in Mlingano crest soil. This was expected since available P in Kwamdulu soils was much lower than that in both Mlingano soils. Like on Mlingano crest, the application of nitrogen, potassium or their combination without phosphate had a tendency to decrease yield on both Kwamdulu crest and lower slope. Like in Mlingano crest P appeared to be the most limiting nutrient.

4.9 The effect of lime on fresh and dry matter yield:

Lime effect on Kwamdulu lower slope was not significant. Yet the interaction between lime and NP or NPK was siginificant at 10 percent level (Table 6). On Kwamdulu crest soils a significant increase in fresh and dry matter yield was obtained from lime treatment. This positive effect of lime on crest soils could be due to the improvement of the calcium status of the soil. Improvement of phosphate availability by precipitation of aluminium which otherwise fixes this nutrient is another explanation. The differences in response to lime between Kwamdulu crest and lower slope is explained by the differences in exchangeable calcium, exchangeable aluminium and manganese content (Table 1) in these soils. The lack of yield response to lime on Kwamdulu lower slope could be due to precipitation of phosphate by lime or a little amount of exchangeable aluminium initially in these soils (Table 1).

TABLE 7A: TREATMENT EFFECT ON NUTRIENT UPTAKE BY MAIZE ON MLINGANO CREST SOIL

TREATMENTS			UPTAKE						
N	P	K	N	P	K	Ca	Mg	Mn	Fe
			mg/Pot						
0	0	0	377	22	628	250	40	0.72	1.4
100	0	0	299	17	595	166	42	0.52	0.8
0	40	0	275	25	642	228	40	0.54	1.9
0	0	40	289	21	595	205	42	0.6	0.5
100	40	0	349	23	698	285	49	0.75	1
100	0	40	282	17	553	242	43	0.57	0.9
0	40	40	320	28	649	242	43	0.75	1.3
100	40	40	627	41	732	341	52	0.83	1.7

TABLE 7B: TREATMENT EFFECT ON NUTRIENT UPTAKE BY MAIZE ON MLINGANO LOWER SLOPE SOIL

TREATMENTS			UPTAKE						
N	P	K	N	P	K	Ca	Mg	Mn	Fe
			mg/Pot						
0	0	0	235	33	676	314	39	0.53	2.1
100	0	0	312	35	740	222	41	0.49	1.3
0	40	0	237	38	762	256	40	0.55	1
0	0	40	253	35	828	433	39	0.46	1
100	40	0	349	40	795	311	52	0.6	1.5
100	0	40	285	35	856	288	48	0.44	1.2
0	40	40	237	35	715	263	43	0.69	1.3
100	40	40	300	41	709	259	44	0.49	1.7

TABLE 8A: TREATMENT EFFECT ON NUTRIENT UPTAKE BY MAIZE ON KWAMDULU CREST SOIL

TREATMENTS				UPTAKE						
N	P	K	Lime	N	P	K	Ca	Mg	Mn	Fe
				mg/Pot						
0	0	0	0	85	6	111	113	16	3.3	0.31
100	0	0	0	69	5	91	91	13	3.5	0.21
0	40	0	0	119	11	135	218	30	5.3	0.7
0	0	40	0	64	4	103	94	10	2.8	0.59
100	40	0	0	154	12	124	193	31	6.5	0.44
100	0	40	0	70	4	103	99	11	3.9	0.45
0	40	40	0	125	11	161	180	22	4.3	0.68
100	40	40	0	165	13	152	236	30	7.5	0.57
0	0	0	4400	83	6	100	161	21	1.2	0.32
100	0	0	4400	107	6	110	226	23	1.5	0.38
0	40	0	4400	133	11	137	250	37	2.6	0.71
0	0	40	4400	105	6	147	154	19	1.4	0.56
100	40	0	4400	216	15	139	337	55	3.1	0.81
100	0	40	4400	101	6	123	134	17	1.4	0.28
0	40	40	4400	126	10	155	210	22	1.5	0.54
100	40	40	4400	188	13	149	307	49	3.1	0.6

TABLE 8B: TREATMENT EFFECT ON NUTRIENT UPTAKE BY MAIZE ON KWAMDULU LOWER SLOPE

TREATMENTS				UPTAKE						
N	P	K	Lime	N	P	K	Ca	Mg	Mn	Fe
				mg/Pot						
0	0	0	0	74	3	138	105	12	0.9	0.19
100	0	0	0	78	3	113	78	10	0.8	0.26
0	40	0	0	145	11	405	151	19	1.3	0.51
0	0	40	0	75	3	148	80	10	1	0.25
100	40	0	0	200	12	409	140	21	1.5	0.94
100	0	40	0	74	3	120	72	11	0.9	0.44
0	40	40	0	128	10	398	166	20	1.3	0.57
100	40	40	0	176	12	441	184	25	1.9	0.71
0	0	0	2400	79	4	198	146	13	0.8	0.43
100	40	0	2400	199	15	450	346	30	1.1	0.8
100	40	40	2400	183	12	361	228	25	1.1	0.7

4.10 The effect of N, P and K fertilizers on nutrient uptake:

The effect of fertilizer treatments on nutrient uptake is shown in Table 7 & 8.

Nitrogen fertilizer

Mlingano lower slope

Application of nitrogen showed a slight decrease in calcium uptake. Manganese uptake was not affected and the uptake of other nutrients was slightly increased. Less effect due to nitrogen application was expected, as the soils already had high amount of nitrogen and organic matter (Table 1 and 2).

Mlingano crest

Nitrogen treatment in the absence of phosphate resulted in a slight uptake decrease of all nutrients with the exception of magnesium whose uptake was almost unchanged. This observation indicates that nitrogen is not the most limiting nutrient in these soils. Janssen et al (1989a) pointed out that plants can not utilize fully the nutrients supplied to it unless other factors are not limiting its growth. Therefore, application of nitrogen without correcting the major limiting nutrients created nutrient imbalance which in turn depressed nutrient uptake by plants. Nitrogen application together with phosphate fertilizer resulted in an increased uptake of all nutrients (Table 7). Yet the increase in nutrient uptake due to nitrogen treatment was generally low. Little nutrient uptake after nitrogen application can be explained by the soil data in Table 1 and nutrient rating in Table 2. High amount of organic matter in these soils supplied sufficient amount of nitrogen, hence additional nitrogen brought only a slight change in the nutrition of the plants.

Kwamdulu lower slope

Calcium uptake was slightly increased by nitrogen application. The uptake of the other nutrients was almost unaffected by nitrogen treatment. Very little effect of nitrogen to nutrient uptake while the soils have only moderate amount of organic matter was not expected. However, this could be explained by the observation that phosphate was still limiting in these soils even after the application of phosphate treatment (see section 3.6).

Kwamdulu crest

Like for Mlingano crest, no benefit was obtained by applying nitrogen alone. The main effect of nitrogen was to increase nutrient uptake, potassium being the exception. Potassium uptake was slightly reduced.

Phosphate fertilizer

Mlingano lower slope

The application of phosphate had a slight increase in phosphate, nitrogen, magnesium and manganese uptake. Potassium uptake was increased while calcium and iron uptake was almost not affected. The result indicates that P in these soils is not very much limiting.

Mlingano crest

A slight increase in P, potassium and iron uptake was observed when P was applied alone. The uptake of other nutrients was not affected. The slight increase of phosphate, potassium and iron by P treatment is explained by provision of the most limiting nutrient P. Addition of phosphate to the soil increased the amount of P available for plant uptake. This in turn improved root growth hence enabled the plant roots to extract more nutrients from the soil. When phosphate was applied together with nitrogen and potassium fertilizers, the uptake of all nutrients was increased substantially. This could be the result of combined effect of nutrient availability and the ability of roots to come in contact with these nutrients. Nitrogen, potassium and phosphate application increased nutrient availability while root contact was increased through improved root growth by phosphate.

Kwamdulu lower slope

The uptake of all nutrients was increased by P treatment on these soils. Like on Mlingano crest, phosphate effect on nutrient uptake was increased by application of nitrogen and potassium fertilizers.

Kwamdulu crest

Phosphate treatment increased the uptake of all nutrients. This observation reveals that phosphate is the most limiting nutrient in these soils. The observation is in agreement with the data on soil available P (Table 1 and 2) and fertility assesment for maize (Table 3). As already explained, the application of P fertilizer improved P status of the soils and the uptake of nutrients was increased accordingly. Like in Mlingano and Kwamdulu crest soils, the effect of phosphate on nutrient uptake was increase by nitrogen and potassium. Nevertheless, the effect of phosphate fertilizer on nutrient uptake on these soils was less than the effect on soils of Kwamdulu lower slope. The difference in available P between these two soils (Tables 1, 2 and 3) account for this observation.

Potassium fertilizer

Mlingano lower slope

Potassium treatment showed some increase in macronutrient uptake. This could indicate potassium to be among the limiting nutrients. However, soil data and potassium content in plants from unfertilized soil (Table 3) indicate sufficient potassium in these soils.

Mlingano crest

Potassium fertilization increased the uptake of P and slightly that of nitrogen, calcium, magnesium and manganese. Potassium uptake and iron uptake was not affected.

Kwamdulu lower slope

On Kwamdulu lower slope, potassium application slightly increased the uptake of potassium, magnesium, manganese and iron. The uptake of phosphate was not affected by potassium fertilization. A little depression in the uptake of nitrogen and calcium uptake by potassium fertilization was observed.

Kwamdulu crest

Potassium application improved the uptake of manganese, potassium and iron while the uptake of calcium, magnesium, phosphate and nitrogen was slightly depressed. One reason for depression of these nutrients could be the competition between these nutrients and potassium for adsorption sites on the roots. However, this is not in agreement with soil data in which potassium is only 5 % of exchangeable bases. Insufficiency of phosphate even after fertilization (section 3.6) could be the reason for the negative effect of potassium application on the uptake of these nutrients.

4.11 The effect of lime on nutrient uptake:

Kwamdulu crest

The application of lime had no effect on nitrogen, phosphate, potassium or iron uptake but increased the uptake of calcium and to a lesser extent that of magnesium. The uptake of manganese was reduced. Lime was expected to increase phosphate availability by precipitating aluminium hence reducing P fixation (Mengel and Kirkby, 1987). However this effect was not revealed on these soils. Possibly, there was not much P in the fixed form (see Table 1) or the amount of lime applied was not enough to free the fixed phosphate.

When lime was applied together with nitrogen, potassium and phosphate fertilizers, lime increased the uptake of nitrogen, potassium, calcium and magnesium. The uptake of manganese was reduced to a greater extent (Table 8). The increase in calcium uptake was expected since more calcium was added to the soils by lime. Liming raised the pH of the soils from 4.6 to 5.6. Normally solubility of manganese decreases as pH increases(Lindsay,1972). Therefore, liming decreased manganese solubility through its effect on pH hence reducing manganese available for plant uptake. Reduction of manganese was reported to be among the benefits of liming by Pierre et al, 1967.

A previous study done by Sims and Ellis (1983), on the effect of liming an Ultisol indicated the amount of exchangeable magnesium and potassium to decrease with liming. This is due to the fact that calcium ions substitute these cations on the exchange sites. The exchanged cations are released into the soil solution where they can be taken up by plants or leached out of the root zone. This exchange phenomenon accounts for the increase in magnesium and potassium uptake on limed soils of this experiment in which no leaching was allowed.

Lime and fertilizer application creates favourable conditions of pH and nutrients for mineralization of organic matter by microorganisms. Mineralization of organic matter could explain the increase in nitrogen uptake observed in treatments where lime and fertilizers were combined.

Kwamdulu lower slope

Lime application in the absence of fertilizers had no effect on phosphate, nitrogen and manganese uptake but the uptake of calcium, potassium and iron was increased. The explanation for increase in magnesium and potassium uptake is as in Kwamdulu crest. The lack of effect on P uptake after liming could be due to low value of P in these soils. The soils contain 3.7ppm available P and about 23% P is sorbed. This indicates that only a small amount of P was made available by liming. Another reason could be the precipitation of P as calcium phosphate.

When applied with fertilizers, lime increased the uptake of potassium, calcium and magnesium. Also phosphate uptake was increased but to a small extent while the uptake of manganese was reduced.

4.12 The effect of nutrient uptake on dry matter yield:

Generally dry matter yield increased as uptake increased except for Mlingano lower slope soils. However, the amount of dry matter increment appeared to depend on the kind of nutrient, treatment and the soils.

P uptake

Figure 6 shows the effect of P uptake on dry matter yield.

A good correlation between P uptake and dry matter yield was observed in all soils with the exception of Mlingano lower slope soil. The correlation coefficient of individual soils appeared to follow the trend of soil available P. The coefficients were in the order of Kwamdulu lower slope (r=0.99);Kwamdulu crest (r =0.97); Mlingano crest(r =0.83) and Mlingano lower slope (r =0.29).

Lime was observed to increase the slope of the graph in Kwamdulu crest soils (Figure 7).

This indicates that with lime more dry matter was obtained at a given P uptake increment than in no lime treatment. This was not the case in Kwamdulu lower slope soils. On Kwamdulu lower slope soils lime tended to decrease the slope of the graph, indicating that high P uptake was accompanied by a slight increase in dry matter yield.

Fig. 6: PHOSPHATE
yield vs phosphate uptake

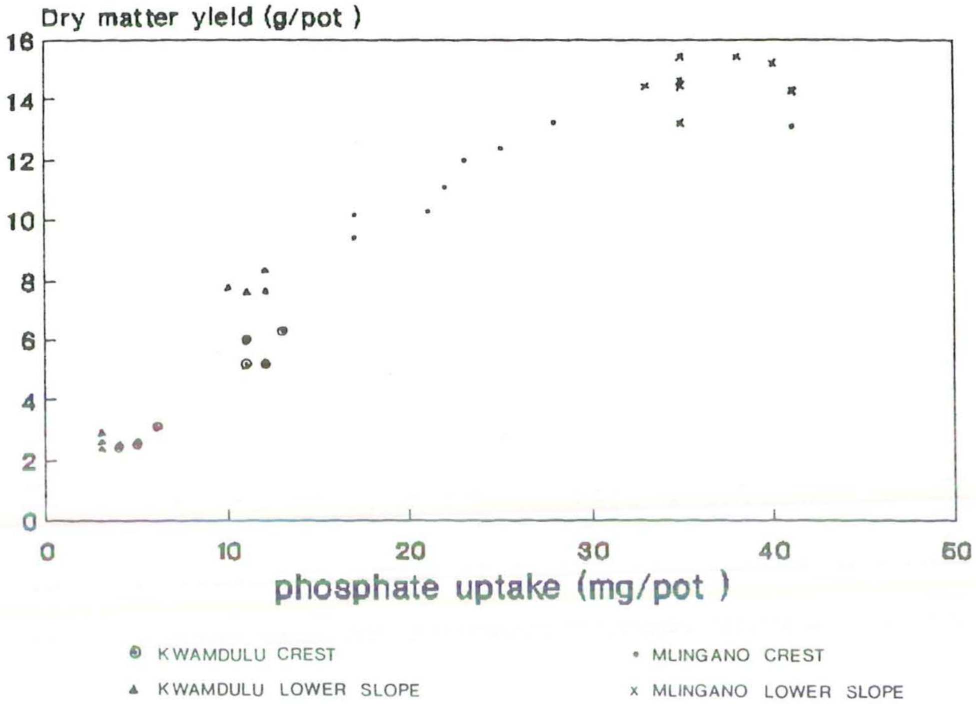
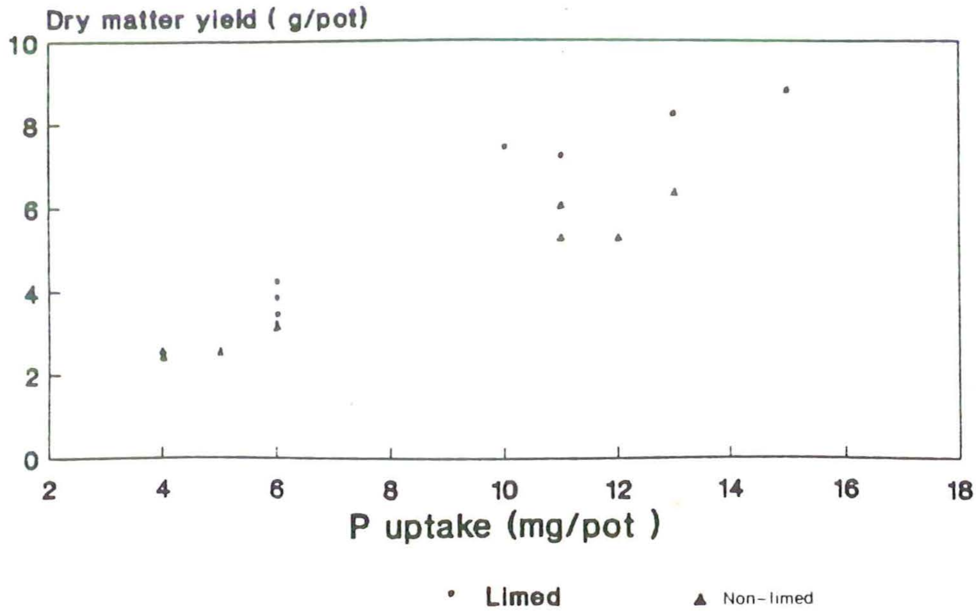


Fig.7: KWAMDULU CREST
Lime effect on P uptake and yield



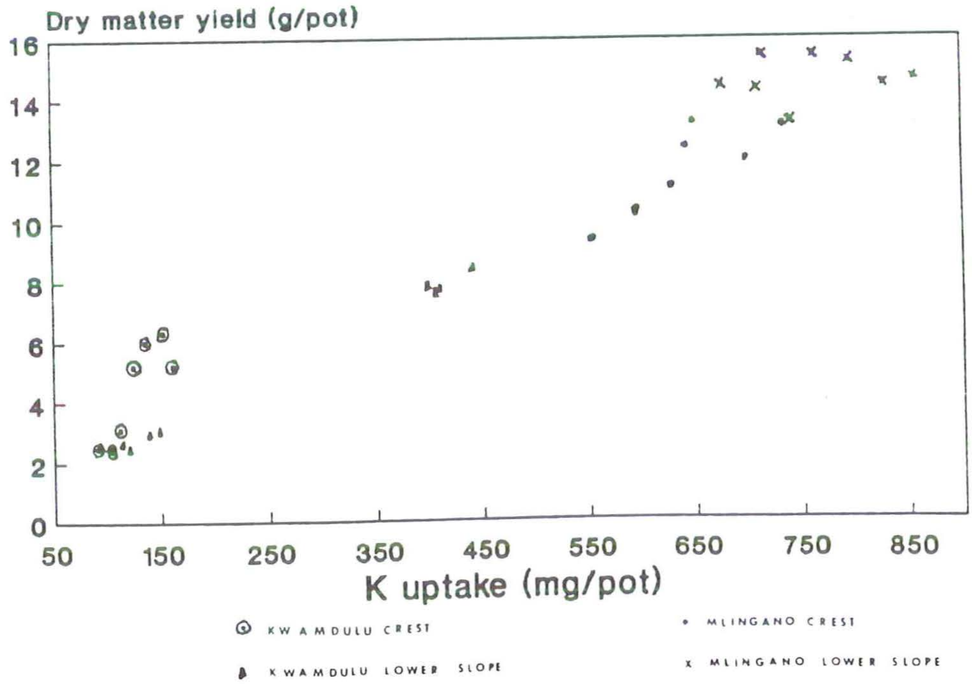
K uptake

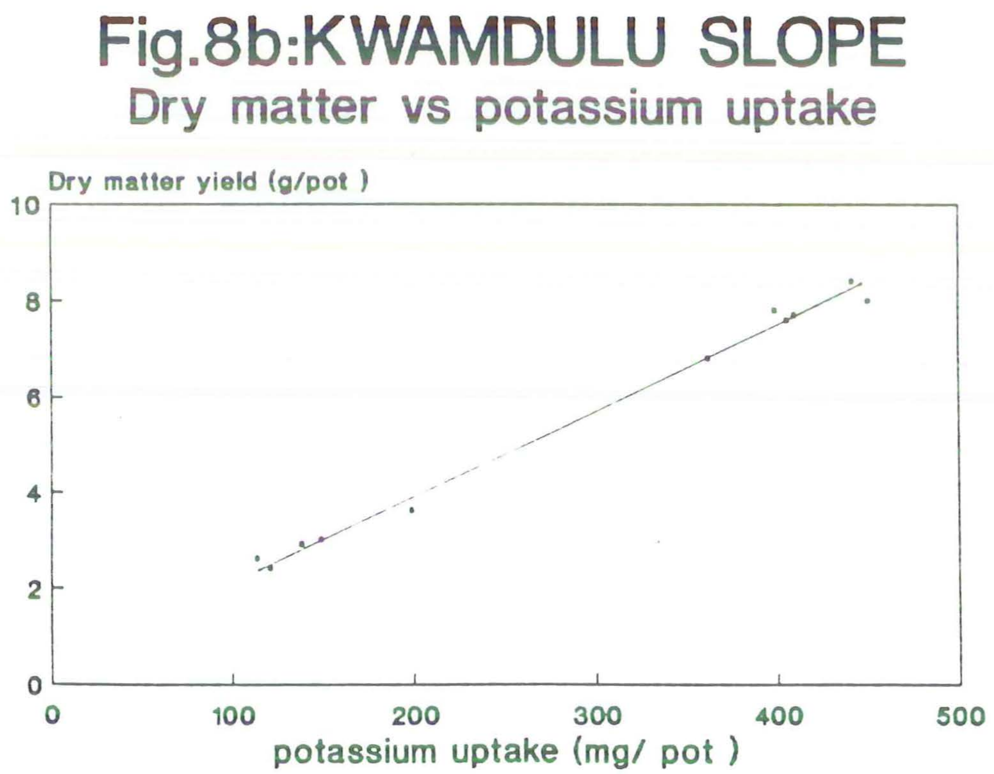
The effect of K uptake on dry matter yield is indicated in Figure 8.

Only Kwamdulu lower slope soils showed a good correlation between potassium uptake and dry matter yield (r =0.999). Crest soils of Mlingano and Kwamdulu showed a good dry matter response to potassium uptake only at a low level of uptake. Potassium and dry matter yield were no longer correlated at uptake above 640 mg/pot on Mlingano crest soils. Likewise, poor correlation between potassium uptake and dry matter yield was observed on Kwamdulu crest soils when potassium uptake exceeded 130 mg/pot (Figure 8). This means that at these levels of uptake another factor other than potassium becomes limiting. In case of Kwamdulu crest this limiting factor seem to be P since the results indicate that the applied amount was not enough to correct the deficiency of this nutrient in these soils (section 3.6). Dry matter yield on Mlingano lower slope was not correlated with potassium uptake (r =0.113).

Fig. 8A: POTASSIUM

Dry matter yield vs K uptake

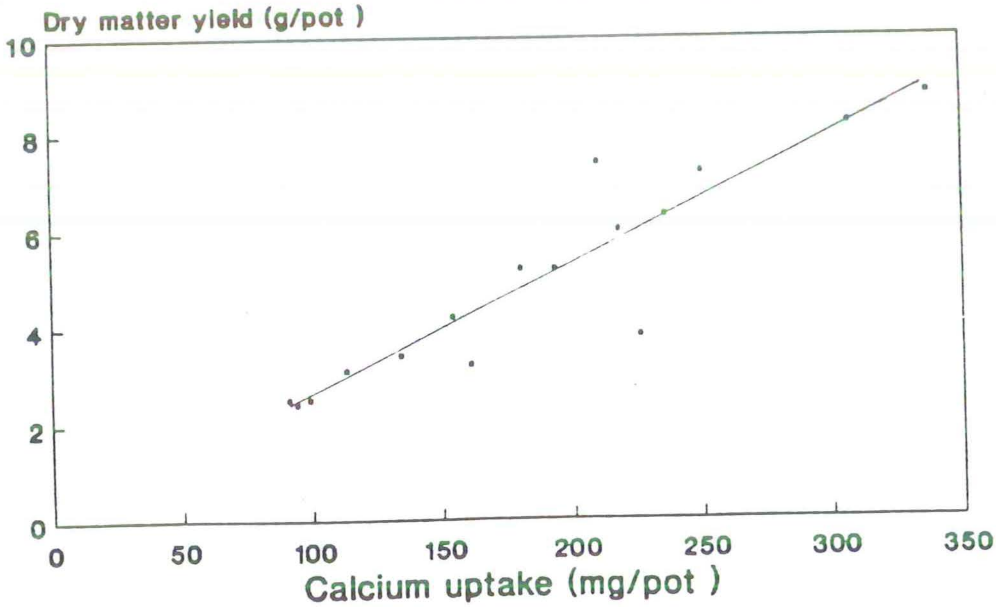




Ca uptake

Calcium uptake was well correlated with dry matter yield on Kwamdulu soils. Crest soils (r =0.996) and lower slope (r=0.956). The observation shows that calcium is among the limiting nutrients. This is in agreement with the nutrient rating in table 2. Mlingano crest soils showed a relatively poor correlation (r =0.676) while no correlation was observed on Mlingano lower slope soils. It was observed that the correlation coefficient between calcium uptake and dry matter increased as soil exchangeable calcium decreased.

Fig.9: KWAMDULU CREST
Yield vs Calcium uptake



Mn uptake

Manganese uptake on Mlingano soils was almost constant for all treatments. Generally the increase in dry matter yield on both Mlingano soils appeared to be independent of an increase in manganese uptake. Some dry matter increase due to a high manganese uptake was observed on both Kwamdulu crest and lower slope soils. The response was higher on lower slope than on crest soils. Kwamdulu crest soils showed a positive response in dry matter yield to manganese uptake and had the highest manganese content in plant tissues. However, the soil gave the lowest dry matter yield of the four soils.

5. DISCUSSION:

In this discussion little attention will be given to the micronutrients. It is well known that the quantity of micronutrients present in most soils exceeds crop requirement. However, their availability can be a limiting factor. Their availability is affected by the soil pH and organic matter. In this study it was observed that the availability of micronutrients in the four soils was sufficient (see Table 1,2 and 3). This observation complies with the concept that fine textured acid soils are rarely deficient in micronutrients,instead they can have micronutrient toxicity.In this study no other indication of micronutrient toxicity was observed apart from that of manganese on Kwamdulu crest soils. Therefore, much attention will be given to macronutrients.

5.1 Nutrient availability as related to soil chemical properties

When soil chemical properties and nutrient uptake from non- fertilized soils were compared, a strong relationship was obtained. The uptake of phosphate was greately determined by the values of P-Bray 1, O.C and pH(H_2O). The correlation coefficients were 0.93, 0.95 and 0.95 respectively. These three factors were highly correlated as well,the highest coefficient was obtained between pH and O.C. This observation indicates that soil pH and O.C values could be used interchangeably to predict phosphate availability to crops in these soils. The importance of pH and O.C in prediction of phosphate supply by the soil was also observed in Kenya by Wielemaker and Boxem (1982) and that of O.C in Uganda by Foster (1981).

Soil pH and O.C was also observed to be important in nitrogen uptake. Nevertheless, the correlation coefficients between these parameters and nitrogen uptake are 0.89 and 0.88 respectively. These coefficients are lower than those obtained for phosphate uptake. Besides, a high coefficient is obtained with total N % values (r=0.99). The uptake of potassium is related to pH (r=0.99), O.C (r=0.95) and exchangeable K (r=0.92). The amount of bases in the soils and their uptake were according to expectation. They were highly determined by the soil pH, the correlation coefficients being 0.98 and 0.96 respectively.

From the preceding sections it was observed that phosphate is the most limiting nutrient in the studied soils excluding that from Mlingano lower slope. Furthermore, it was observed that the uptake of all nutrients as well as their efficient utilization in plants was greatly determined by phosphate availability. Hence, the factors which affect the availability of phosphate to plants could give a clue on the fertility status of a soil. For nitrogen, it was observed that its availability was explained better by total N % values. These observation indicate that O.C, pH and total N % can be used efficiently for fertility prediction.

5.2 The influence of soil properties on crop response to fertilizers:

The results were according to expectation. The drymatter response to fertilization increased as the soil became nutritionaly poorer. In this trial only phosphate fertilization appeared to have a significant effect on drymatter yield. The influence of soil properties on crop response to fertilizers was evaluted based on the percentage increase in drymatter. The relationship between drymatter response to phosphate and the selected soil properties is shown in Figure 10.

The drymatter response to phosphate fertilization was well related to soil pH, O.C and total N % also to a lesser extent to P-Bray 1. This observation is similar to that in the previous section on phosphate uptake. Hence phosphate uptake could be used efficiently to predict drymatter yield. From section 4.1 and this section, it was observed that Organic matter had a strong effect on crop response to fertilizer phosphate. The results emphasize the importance of organic matter in these highly weathered soils. In addition to its large contribution to plant nutrition, organic matter positively influences the soil environment through its effects on biological activity, water retention, buffering capacity, contribution to the CEC and soil structure, all of which are important for plant growth.

Fig.10a: pH

Response to P vs pH

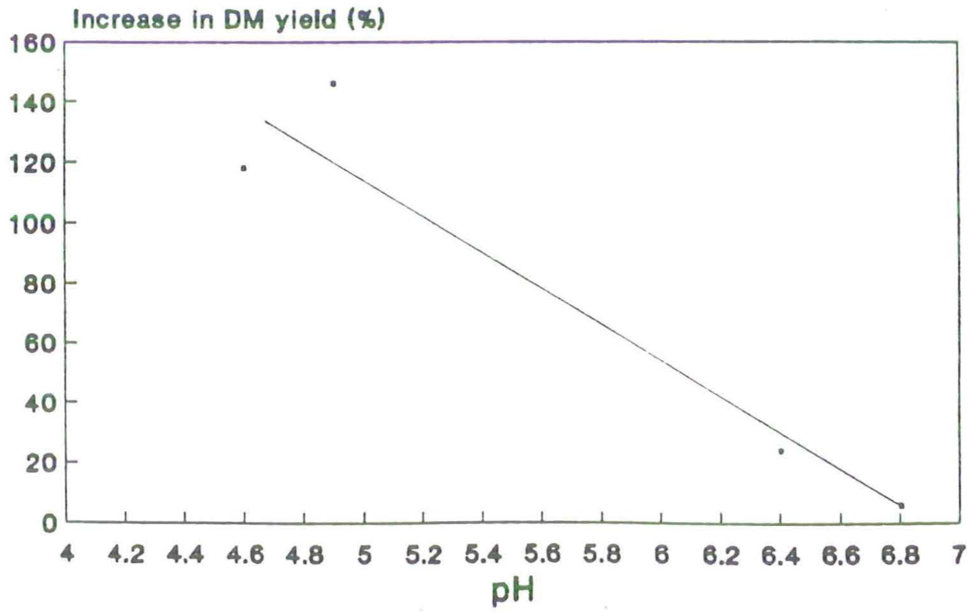


Fig.10b: ORGANIC CARBON
Response to P vs O.C

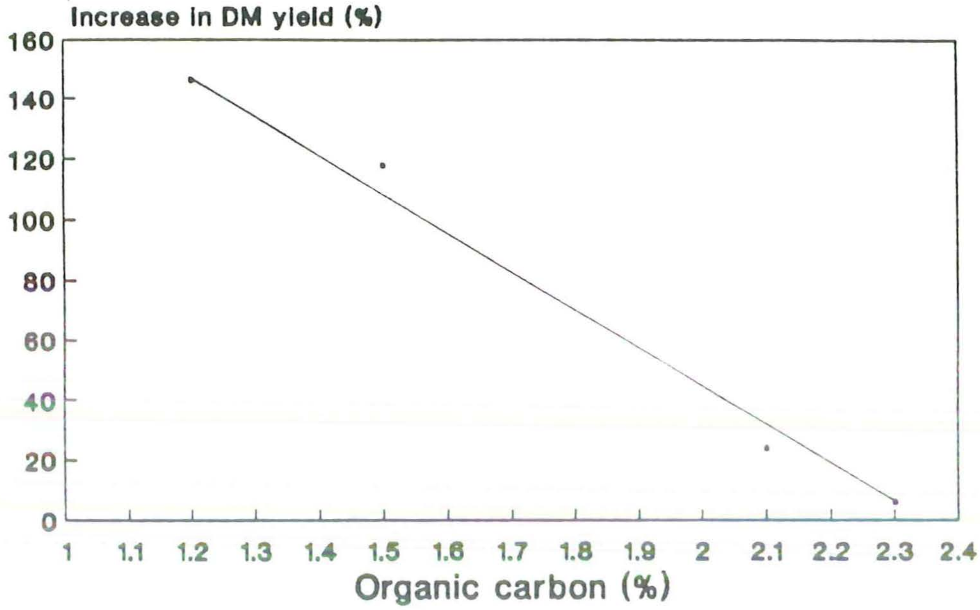


Fig.10c: AVAILABLE P
Response to P vs Av. P

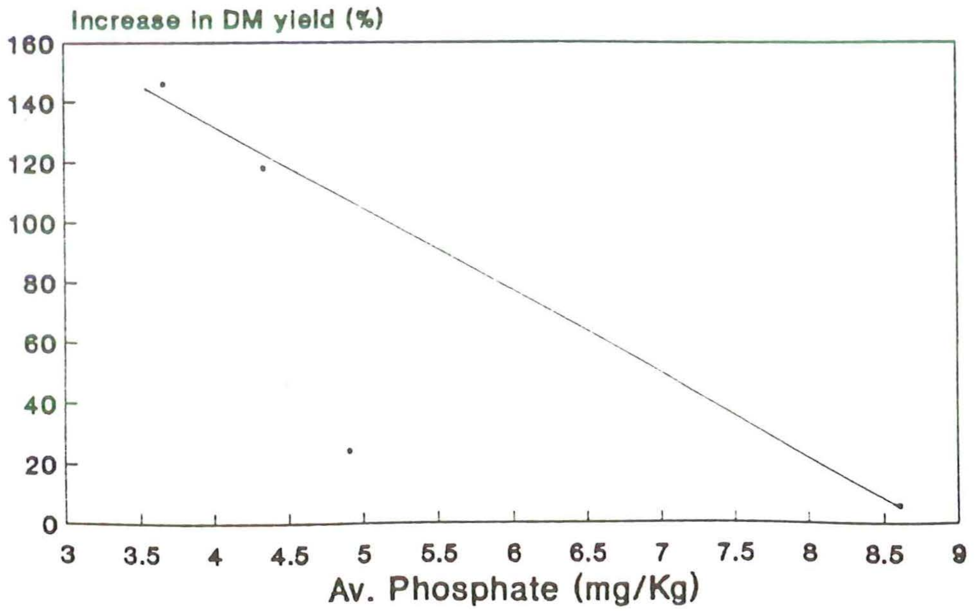
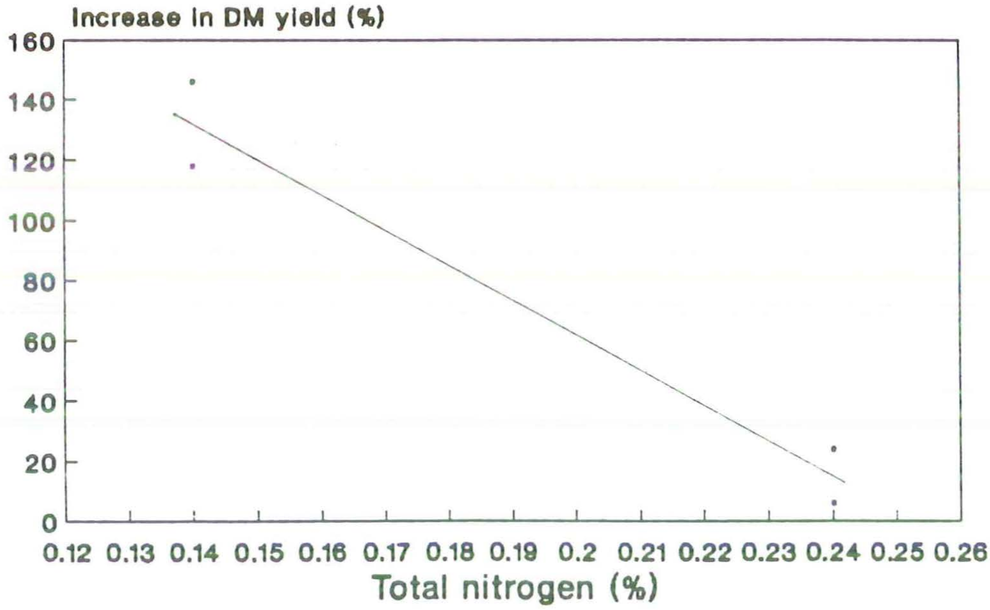


Fig.10d: TOTAL N
Response to P vs total N



5.3 Comparison of nutrient uptake with the calculated potential supply:

It was observed that the soil parameters found to be the main determinant of macronutrients supply and crop response in this trial were comparable to those used in the QUEFTS method for yield estimation (Janssen et al., 1989a). Since in both cases these parameters were obtained as the properties of the top soil, an attempt was done to test whether QUEFTS method can be applied to these soils. Comparison of the nutrient uptake and the potential supply calculated from soil O.C, pH, available P and exchangeable K using QUEFTS method was done (Figure 11).

Fig.11a: N UPTAKE
Measured vs calculated values

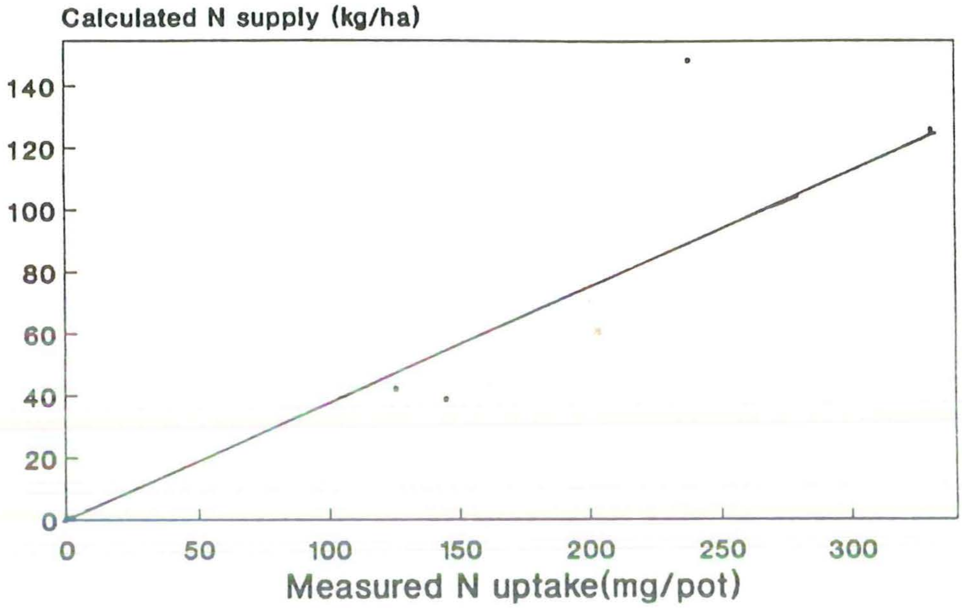


Fig.11b: P UPTAKE
Measured vs calculated values

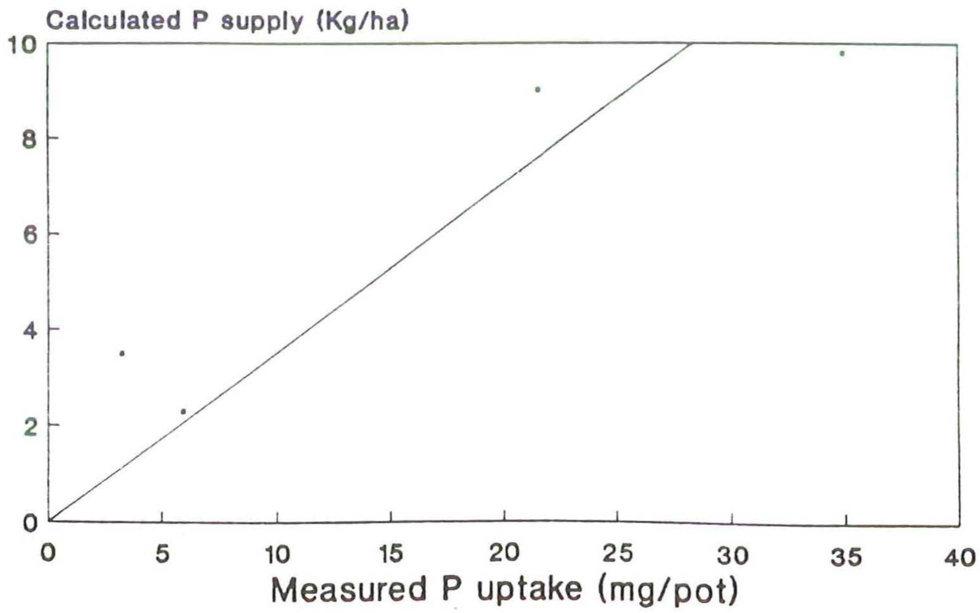
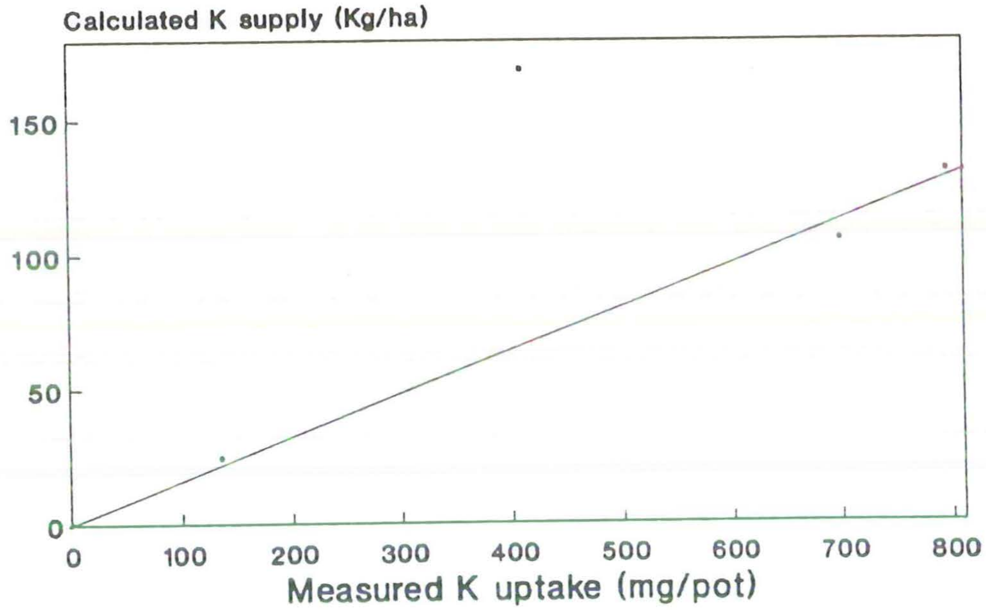


Fig.11c: K UPTAKE

Measured vs calculated values



The highest uptake value from any treatment in which the nutrient under consideration was not applied was used in drawing Figure 11. In section 3.4 it was observed that the calculated potential supply values by QUEFTS method underestimated the actual nutrient supplying power of these soils. The reason was attributed to the difference in root intensity between pot and field conditions. However, Figure 11 shows that there is a certain relationship between the observed maximum uptake and calculated potential supply. A similar relationship was observed for nitrogen and phosphate. The ratio of 1 kg/ha potential supply and 3 mg/pot maximum uptake was observed for these two nutrients. In each case Mlingano lower slope soil seemed to deviate from this relationship. With potassium, it was observed that such a relationship could be obtained on Kwamdulu lower slope soil. Otherwise, for the rest of the soils the ratio between calculated potential supply and actual uptake was very low (1 kg/ha to 6 mg/pot) indicating that the calculated value was too low to explain the actual uptake in these soils. In addition to uptake comparison, the yield obtained (by NSS, 1989) from the field (table 9) was compared with the calculated yield by QUEFTS.

TABLE 9: YIELD (Kg/ha) FROM NON - FERTILIZED PLOT OF MLINGANO CATENA AND THE CALCULATED YIELD BY QUEFTS METHOD

	Crest	Lower slope
Mean yield in years with good rainfall distribution	1050	5225
Highest yield of 7 years	1110	5780
Mean of 7 years	615	3400
yield in 7th year	620	2720
calculated yield	4315	4799
Highest value of fertilized plots	2170	4225

Source: Soil fertility report F5 (NSS 1989) calculated yield being the exception.

5.4 Calculated yield as compared to the actual yield:

Table 9 shows the yield from Mlingano catena and the calculated yield by QUEFTS. Unlike in the pots where QUEFTS method underestimated the actual nutrient supplying power of the soil, in the field, yield calculated by QUEFTS was far higher than the actual yield obtained from Mlingano crest. It even exceeded the highest mean value of the fertilized plots. Since this field is under standard management practices, the only external factor which could limit yield is the climate, especially the amount of rain and its distribution during the growing season. However, even when considering the yield obtained during the years with good rainfall distribution, still the actual yield was lower. In case of the Mlingano lower slope, the calculated yield value was close to the actual yield particularly for the yields obtained in the years with good rainfall distribution. The difference between the two soils can be explained by the way in which nutrients are distributed in the profile of these soils. In Mlingano crest soil, the fairly fertile topsoil is overlying a nutritionally poor subsoil. Whereas in Mlingano lower slope, the fertility decreases progressively down the profile (see appendix 2). In the other words, the topsoil chemical properties and subsoil properties are more interrelated in Mlingano lower slope than in Mlingano crest soils. The observation is comparable to that of Wielemaker and Boxem (1982) on Kisii area, in which rating of soil fertility based on top soil properties was only adequate for soil developed from underlying rock and whose topsoil and subsoil were interrelated.

The profiles of both Kwamdulu crest and lower slope show not much difference between the topsoil fertility and that in subsoil. It might be expected that the topsoil properties could adequatelly be used to predict the productivity of these soil. However, the lack of maize yield data from this soil is a setback in the testing of this supposition. Furthermore, inadequacy in field-yield data made it impossible to make any quantified evaluation.

5.5 Crop response to fertilizers in pots as compared to that obtained in field.

Crop response to fertilizers in pots and in field were similar in that both cases a higher response was observed in the crest soils. This was expected since Mlingano crest soils are nutritionally poorer than those on the lower slope (see appendix 2). Yet, the nature of the response between field and pot trials was quite different. In pots nitrogen fertilization was not significant. Crop response to nitrogen in the field was pronounced, the highest being on the crest soil which amounted up to 182 percent.

The response on the lower slope was only 15 percent (NSS report 1989). This difference could be attributed to the efficiency with which the nitrogen is used in each case. In pots conditions like moisture, temperature and nutrients are more conducive to microbial activities than in the field. Hence the rate of organic matter mineralization in pots can be higher than in the field and in turn provide more nitrogen to the crop.

Furthermore, the condition of no leaching in this pot prevented losses of soil nitrogen through leaching. Such response can be expected under the field conditions when the soil has adequate organic matter content, other nutrients not limiting and when extensive leaching does not occur. An example of such conditions is the one observed on maize by Nguyen van Nguu(1987) on an Ultisol.

The report that in Mlingano field a high response due to nitrogen occured at low application (NSS 1989), could indicate that nitrogen fertilization is just enough to compensate for leaching losses.

The apparent nitrogen recovery in this trial was 74 and 71 percent for Mlingano crest and lower slope respectively. These values are higher than 30- 50 percent, which are the generally reported values for practical farming. The reason is the lack of nitrogen losses through leaching in this pot trial. A similar recovery value (70%) was reported by Jones (1973) on maize under no leaching condition when nitrogen was applied before sowing. Such high recovery values indicate low nitrogen supply by the soils (Janssen et al 1989 a). From the nitrogen recovery values obtained in this trial, it might be deduced that the nitrogen fertilization improved nitrogen nutrition status of the crop. Nevertheless, this improvement in nitrogen uptake was not reflected in the dry matter production, thus indicating that nitrogen taken up by the plant was not efficiently metabolized. The observation is in agreement with the conclusion made by Kayode and Ogboola (1986) that high nutrient levels do not necessarily result in high yield. Insufficient nitrogen metabolization in plants occurs under the condition of water stress (Boxman at al. 1985; Nnoham and Odurukwe, 1987) or inadequency of phosphate or potassium (Mengely and Kirkby,1987). In this pot trial optimum amount of water and nutrients were provided, it is difficult to explain why the improvement in nitrogen uptake was not accompanied by an increase in dry matter yield. One might suspect that the applied levels of phosphate and potassium were not adequate for sufficient nitrogen utilization by the crop. But this is contradicted by the the field observation in which response to nitrogen was observed while phosphate and potassium seemed to have only little effect on yield (NSS,1989).

Crop response to phosphate application between pot and field trial was comparable only for the lower slope in which no response was observed. On the crest the response to phosphate was different. In pots the effect due to phosphate fertilization was significant, amounting to 24 % yield increase as compared to no-P treatments. In the field Phosphate effect was not significant. As already mentioned, the root density in pots is higher then that in field. In addition to the complete depletion, phosphate availability is increased by the rhizosphere effect. In pots a large proportion of the soil volume is influenced by the rhizospere. The influence of rhizosphere on phosphate availability has been reported by several authors (Barber and Martin,1976; Brewster <u>et al</u>,1976; Nye,1977; Moghimi <u>et al</u>,1978). Phosphate recovery value of 26 % was obtained in pots. This value is within the phosphate recovery range of 10 -30 % reported for tropical soils by Baligar and Bennet (1986).

The lack of crop response to phosphate fertilization on Mlingano crest field was thought to be phosphate supply through mineralization of organic matter or phosphate fixation by the soil (NSS, 1989).

The results of this pot trial gave the indication that mineralization of organic phosphate can not fully explain the lack of response to phosphate in the field. Since only the topsoil was used in pot trial, it might be expected that the influence of organic matter on phosphate availability should be higher in pots than in the field. This means that no response to phosphate could be expected in pots. However, this was not the case. One might think that the length of growing period in pots was too short to allow considerable organic phosphate mineralization as compared to that in field. The highest phosphate requirement of a crop is in the early growth stage (Mengel and Kirkby 1987). Hence the difference in period during which the soil is under a crop will have little effect in this aspect. The lack of response to phosphate in the field might be attributed to phosphate fixation. However, the extent of phosphate sorption in the topsoil was not high enough to make all of the phosphate fertilizer unavailable (see Table 1). Possibly, in the field most of phosphate is fixed in the subsoil, which is more acid than topsoil (see Appendix 2).

The response to potassium in both pots and field was not significant. These results are comparable to that observed by Motonya (1980) on Kenyan red and brown sandy clay soils. The reason for the lack of response to potassium on Mlingano soils is the high amount of this nutrient in these soils (Tables 1 and 2). The observation confer with those obtained by Van Keulen and Van Heemst (1982); Baligar and Bennett (1986) that most tropical soils have a sufficient potassium supplying capacity. The nature of the test crop also plays a role. Cereals are well known for their low response to potassium (Schön <u>et al</u>, 1976; Baligar and Bennett, 1986).

Generally, it was observed that response to fertilizers in pots was comparable to that of the field only for Mlingano lower slope. For Mlingano crest the responses were different, revealing that the subsoil of this soil has a pronounced effect on the response of the crop to fertilizers, particularly phosphate.

The comparison of crop response to fertilizers between pots and field trial was done using grain yield from field and dry matter yield from the pots. This was done on the assumption that dry matter yield and grain yield are well correlated. The availability of yield data from the field was limited. Only means from the main effect of nitrogen were available. For this reason it was difficult to make any quantified comparison of response in pots and that in the field.

5.6 The influence of the location in the landscape on soil properties and response to fertilizers.

The data on soil properties show that the crest soils have lesser bases than the lower slopes and thus are more acidic. This was according to expectation. Crest soils are remnants of a former erosion surface of considerable age and are very deeply weathered. On the other hand, lower slope soils, due to their position in the landscape, are less weathered as they have been enriched with bases and other materials from the upper slopes.

On Mlingano catena, organic matter, available phosphate and CEC are higher in lower slope soils than in crest soils. The reason for this observation is the difference in weathering intensity between crest and lower slope soils. The nutrients and pH of the lower slope soils favour vegetation growth which inturn add more organic matter in these soils.

On Kwamdulu catena the situation is different. Organic matter, available phosphate and CEC are higher on the crest, indicating that on this catena organic matter decomposition is higher on the lower slope than on crest soils. It is difficult to explain this trend. The explanation could be the effect of exchangeable aluminium and low pH of the crest soils on the microorganisms. High aluminium content and low pH slow down the activity of microorganisms which are responsible for organic matter decomposition. But then one might expect the same trend on Mlingano catena where pH on the crest is lower than on lower slope soils. Moreover, each catena is under uniform management practices hence the variation in organic matter is not attributable to management practices. This observation could indicate that not necessarily soils on the lower slopes of catenas have higher organic matter content than the crests. However, the data are too few to reach a definite conclusion. More catenas need to be evaluated.

As already mentioned, only crop response to phosphate on the catenas was significant. It was observed that the response to phosphate was more related to soil organic matter than any other soil characteristic. This made the trend in response to phosphate fertilizer in the two soil catenas to be different. On Mlingano higher response was observed on the crest whereas higher response on Kwamdulu was obtained from the lower slope soils.

From the previous sections it was observed that no significant response to either nitrogen or potassium was obtained in this pot trial. Further observation showed that although the dry matter yield in N- treatments were slightly lower than in no- N treatments on both catenas, the response on crest soils was slightly better than on lower slopes. The dry matter yield from nitrogen treated Mlingano crest soils was lower than that in no-N by the amount equivalent to 5.2 % absolute control yield, while that on the lower slope was lower by 5.6%. Likewise, yield from nitrogen treated Kwamdulu crest was lower than that in no-N treatments by 1.5% and that on the lower slope was 1.7 % absolute control yield, lower than that in no-N treatments. The difference in response to nitrogen between crest and lower slope is small. However, it gives a clue on the expected nitrogen response trend in the field. In field condition where a considerable amount of soil nitrogen is lost through leaching, the higher response to nitrogen and larger difference in response between crest and lower slope soils can be expected.

Like for phosphate, response to potassium did not depend on the location of the soils on the catenas. The response was almost the same within the catena. On Mlingano catena the yield from potassium treated crest soils was higher than that in no-K treatment by 0.7% absolute control yield, while on the lower slope was lower by 0.9%. The response on Kwamdulu soils was a little higher than that on Mlingano catena soils. The yield from potassium treated crest soils was lower than that from no-K treatments by 3.3% absolute control yield while on the lower slope was higher by 6.9%. This observation indicates the possibility of obtaining a response to potassium in the field of Kwamdulu lower slope.

The results showed phosphate to be the most limiting nutrient on the studied soils, Mlingano lower slope being the exception. Furthermore, it was observed that the limitation due to phosphate was more pronounced in soils of Kwamdulu than Mlingano. It was also observed that the applied amount of phosphate fertilizer on Kwamdulu soils was not enough to correct P-deficiency (see section 3.6). Since the uptake and utilization of other nutrients are determined by the supply of a deficient nutrient, insuficient supply of phosphate in both of Kwamdulu soils could account for the lack of response to nitrogen and potassium in these soils. Besides phosphate, calcium was observed to be a limiting nutrient on Kwamdulu crest soils. On the lower slope, potassium was identified as a next limiting nutrient. This assessment was deduced from the yield-uptake relationship (Figures 8 and 9). A linear relationship between yield and the uptake of these nutrients was obtained. According to Van Keulen and Van Heemst (1982), this kind of relationship is an indication of limitation of these nutrients. In sections 3.13 and 3.14 it was observed that lime had not much effect on phosphate uptake on Kwamdulu crest soils but increased the efficiency of phosphate utilization by a crop. Calcium limitation could explain better a high dry matter response to lime on these soils than the improvement in phosphate availability by lime.

In section 3.12 it was observed that potassium fertilization had a tendency to depress calcium and magnesium uptake on Kwamdulu crest soils. This could account for the lack of response to potassium on these soils. On Kwamdulu lower slope, the response to potassium was very little and not significant. This is contradicting the observation that potassium is limiting in these soils. Possibly, a good response to potassium could be obtained if higher amount of phosphate than that used in this trial was applied.

6. CONCLUSION

From the preceding sectons it was observed that the dry matter yield trend was in line with the chemical properties of the topsoil. The drymatter yield and the response to fertilizers in pots followed the same trend as reported from the field experiments by NSS. Also the yield predicted by the QUEFTS method using chemical characteristics of the topsoil followed the same trend as that reported from the field. However, the predicted yield from the topsoil exceeded the yield obtained from the field on Mlingano crest. On Mlingano lower slope where the properties of the topsoil and subsoil were not much different, a better prediction of yield and fertilizer response using topsoil was obtained. The fertility and response to fertilizers on the studied catenas was not influenced by the position in the landscape.

The results of this study can not lead to a sound conclusion since the data on yield from field experiments and number of catenas are not sufficient. However this study showed an indication of the following;

Fertility of these soils are highly determined by soil organic matter, pH, N %, available P and to the lesser extent exchangeable K.

The availability of nutrients to the crop on these soils is controlled by the availability of P which was determined to be the major limiting nutrient.

Topsoil can be used effectively to predict yield and response to fertilizers only on soils whose chemical properties do not vary very much between the top and the subsoil.

Yield and crop response to fertilizers are determined better by the soil properties than by the location on the landscape.

No response to K fertilization on maize can be obtained at the present fertility status of these soils and at the used rates of P.

More investigations in which more catenas and field data will be used are recommended to confirm the observations of this study.

7. SUMMARY

This experiment was set up to evalute the fertility status of crests and lower slopes of the two catenas. The catenas, Mlingano and Kwamdulu are under the foot slope of the Usambara mountain, in Tanga region, Tanzania. The soils are derived from gneiss and they belong to the Muheza series. The soils were classified according to FAO- UNESCO system as Rhodic Ferralsols on crests of both catenas and Chromic Luvisols and Haplic Acrisols on the lower slope of Mlingano and Kwamdulu respectively. Crest soils are redder and more acidic than the lower slope soils.

A pot trial was set up using top soils of the crests and the lower slopes of these catenas. Maize was used as a test crop. The aim of this trial was to assess the effectiveness of using topsoil properties in fertility evaluation, and also to assess the influence of position in the landscape on crop response to fertilizers.

The ability of the soils to provide a test crop with nutrients together with the crop response to fertilizers on these soils were studied. Parameters used in the assessment included plant height, fresh and dry matter yields and nutrient uptake by the crop. The data obtained from the absolute control were used to assess the inherent fertility of the soils. In addition, they were used to assess the extent of crop response to fertilizers on the studied soils.

Crest soils of both catenas were more acid and hence had less bases than the lower slope soils. Mlingano crest soils were nutritionaly poorer than the lower slope soils. Kwamdulu crest soils were poorer in bases and micronutrients but had higher amount of available P, organic matter and CEC than the lower slope soils.

In the pot trial no difference in plant growth was observed at early growth stages. With time plants started to show some response to P. The response to P was higher on soils of Kwamdulu catena than on that of Mlingano. The plant growth on no-P treated Kwamdulu soils was very much retarded. On Mlingano catena, plant growth on lower slope soils was almost not affected by fertilization while those on crest soils showed a significant response to P. Plants on no-P treated crest soils had a lower growth rate than those on P treated soils. At the later stages of growth the growth differences were reduced for all the soils. Despite of the high response to P on Kwamdulu catena soils, plants in both P- treated and in no-P treatments showed symptoms of P deficiency. N and K effect on plant growth was not significant on all four soils. The fresh weight as well as dry matter yield had a significant response to P fertilization on all of the soils except that on Mlingano lower slope soils. Dry matter yield was well correlated with P uptake excluding that on Mlingano lower slope soils. Phosphate increased the uptake of all of the nutrients studied on all of the soils. The effect of N and K on nutrient uptake was little. A slight tendency of K fertilization to depress the uptake of Mg and Ca was observed on Kwamdulu catena soils.

Among the soil chemical properties, pH, O.C and % N were observed to be the major determinants of the fertility of the studied soils. In addition P-Bray 1 and exchangeable K seemed to explain soil fertility but to a lesser extent. Nutrient supplying power of the soils estimated using these chemical properties was not equal to the actual supplying power in the pots, however, both followed the same trend. The yield estimated from the chemical properties increased down the slope, a trend similar to that reported from field trial. Yet this estimate greatly exceeded the actual yield on soils of Mlingano crest.

Crop response to fertilizers in pots was comparable to that in the field as in both cases more response was obtained on the crest soils than on the lower slopes. Unlike in field, no significant response to N was observed in pots. While in pots a significant response to P was observed, no significant P effect was reported from the field. However, the response to P on Mlingano lower slope soils in pots as well as in field was not significant.

The organic matter content was observed to be the main determining factor of soil fertility and crop response to fertilizers. It was observed that the position of a soil in the landscape can be used effectively in predicting the crop response to fertilizer only if the organic matter content increases down the slope. Otherwise, the location of a soil in the landscape on its own is not a good indicator.

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Appendix. 1

PROFILE DESCRIPTION

Mlingano crest

High catagory classification (FAO) :	Rhodic ferralsol
Physiographic position:	Peneplain
Topograph of surroundings:	Undulating
Microtopograph:	None
Slope grade:	2 %
Land use:	Cultivation of maize
Parent material:	Gneiss
Drainage:	Well
Flooding:	None
Climate:	Tropical
Moisture condition in the soil :	Slightly moist in the subsoil
Depth of the phreatic level:	>200m
Stoniness/rockness:	None
Crust formation:	None
Erosion sheet:	None

Horizon: Ap 0-14cm

Dark reddish brown (2.5YR 3/4)dry, dark reddish brown (2.5YR 2.5/4)moist; clay;hard dry; friable moist; sticky and plastic when wet; moderate medium granular and moderate fine subangular blocky; many very fine, common fine pores; many very fine and many fine roots; gradual smooth boundary to:

Horison: BA 14-26cm

Dark reddish brown (2.5YR 2.5/4)dry, dark reddish brown (2.5YR 2.5/4) moist; clay; hard dry, friable moist, sticky and plastic when wet; moderate fine and medium subangular blocky; many fine pores; common very fine roots; gradual smooth boundary to:

Horison: Bws1 26-56cm

Dusky red (10YR 3/4) moist; clay; very friable moist, sticky and plastic when wet; moderate fine angular and subangular blocky; common fine pores; few very fine roots; gradual smooth boundary to:

Mlingano lower slope

Higher catagory classification:	Chromic luvisols
Physiographic position:	Lower slope
Topography of surroundings:	Undurating
Microtopography:	None
Slope grade:	8 %
Land use:	Maize, cultivation
Parent material:	Gneiss
Drainage:	Well

Flooding:	None
Climate:	Tropical
Moisture condition in soil:	Dry
Depth of phreatic level:	>200cm
Stonenness/ rockness:	None
Crust formation:	None
Erosion sheet:	None

Horison: AP1 0-15cm

Dark brown (7.5YR 4/2)dry, dark brown (7.5YR 3/2) moist; sandy clay; slightly hard dry, friable moist, sticky and plastic when wet; strong medium granular, moderate medium subangular blocky; many fine, many medium pores; many fine, many medium, few coarse roots; clear smooth boundary to:

Horison: AP2 15-29cm

Dark brown (7.5YR 4/2) dry, dark brown (7.5YR 3/2) moist; sandy clay; hard dry, friable moist, sticky plastic when wet; moderate medium and coarse sub angular blocky; many very fine, many medium pores; many fine, few medium roots; clear smooth boundary to:

Horison: Bt1 29-60cm

Dark red (2.5YR 3/6) dry, dark reddish brown (2.5YR 3/4) moist; clay; slightly hard dry, friable moist, sticky and plastic when wet; weak to moderate subangular blocky; few medium pores; few very fine roots; gradual smooth boundary to:

Horison: Bt2 60-100cm

Red (2.5YR 4/6) dry, dark red (2.5YR 3/6)moist; clay; slightly hard dry, friable moist, sticky and plastic when wet; weak medium angular blocky breaking into moderate fine angular blocky; many fine and very fine, few medium pores; few very fine roots; broken thin clay cutans; few medium weathering rock; diffuse smooth boundary to :

Horizon: B 100-150cm

Red (2.5YR 4/6)dry, dark red (2.5YR 3/6)moist; clay; slightly hard dry, friable moist, sticky and plastic when wet; weak fine angular blocky; many fine and many very fine, few coarse pores; few very fine roots; partchy thin clay cutans; very few gravel

Kamdulu crest

Higher catagory classification:	Rhodic Ferralsols
Physiographic position:	Peneplain on crest
Topography of surroundings:	Rolling land
Microtopography:	None
Slope grade:	2 %
Land use:	Sisal cultivation
Parent material:	Gneiss
Drainage:	Well drained
Flooding:	None
Climate:	Tropical
Moisture condition:	Moist
Depth of phreatic table:	>200cm
Stoniness/rockness:	None

Crust formation:	None
Erosion:	None

Horizon: Ap1 0-10cm

Dark reddish brown (2.5YR 3/4) moist; sandy clay; very friable moist, sticky and plastic when wet; moderate to strong very fine crumb and subangular blocky; many fine, many medium pores; many fine, common medium, few coarse roots; clear smooth boundary to:

Horizon: Ap2 10-28cm

Dark reddish brown (2.5YR 3/4)moist; clay; friable moist, sticky and plastic when wet; moderate fine subangular blocky; many fine, few medium and few coarse pores; common fine, few medium roots; clear smooth boundry to:

Horizon: Bws1 28-45cm

Dark red (2.5YR 3/6) moist; clay; friable moist, sticky and plastic when wet; moderate fine subangular blocky; many fine, few medium pores; few fine, few medium roots; few shiny ped faces; gradual smooth boundary to:

Horizon: Bws2 45-65cm

Dark red (2.5YR 3/6)moist; clay; friable moist, sticky and plastic when wet; somewhat weak medium subangular blocky; many fine, few medium pores; few fine, few medium roots; few shiny ped faces; gradual smooth boundary to:

Horizon: Bws3 65-125cm

Dark red (2.5YR 3/6) moist; clay; very friable moist, sticky and plastic when wet; weak fine subuangular blocky breaking into very fine crumb; few coarse, few medium and many fine pores; few fine and very few medium roots; diffuse smooth boundary to:

Horizon: Bws4 125-190cm

Dark red(2.5YR 3/6)moist; clay; friable moist, sticky and plastic when wet; weak coarse subangular blocky breacking into very fine subangular blocky; few medium and many very fine pores; very few fine roots.

Kwamdulu lower slope

Higher catagory classification:	Haplic Acrisols
Physiographic position:	Lower slope
Topography of surroundings:	Rolling land
Microtopography:	None
Slope grade:	10 %
Land use:	Sisal cultivation
Parent material:	Gneiss
Drainage:	Well drained
Flooding:	None
Climate:	Tropical
Moisture condition in the soil:	Moist
Depth of phreatic level:	>200cm
Stoniness/rockness:	None
Crust formation:	None
Erosion sheet:	None

Horizon: Ap1 0-10cm

Dark reddish brown (5YR 3/4) moist; sandy clay; friable moist, slightly sticky when wet; moderate fine, strong very fine granular; many medium, many fine pores; many fine and few medium roots; clear smooth boundary to:

Horizon: Ap2 10-30cm

Dark reddish brown (2.5YR 3/4) moist; sandy clay loam; friable moist, sticky slightly plastic when wet; moderate fine subangular blocky; common fine, few medium pores; common fine, few medium roots; clear smooth boundary to:

Horizon: Bt1 30-55cm

Dark reddish brown to dark red (2.5YR 3/5) moist;clay; friable to firm moist, sticky and plastic when wet; moderate fine subangular blocky; common fine, few medium and few coarse pores; few fine, few medium roots; gradual smooth boundary to:

Horizon: Bt2 55-95cm

Dark red(2.5YR 3/6) moist; clay; firm moist, sticky slightly plastic when wet; moderate medium subangular blocky; common fine, common medium pores; few fine, few medium roots; diffuse smooth boundary to:

Horizon: Bt3 95-130cm

Dark red (2.5YR 3/6) moist; clay; firm moist, sticky and slightly plastic when wet; somewhat weak medium subangular blocky; common fine, few medium pores; few fine, few medium roots; clear smooth boundary to:

Horizon: BC1 130-170cm

Dark red (2.5YR 3/6) moist; clay; friable moist, sticky and slightly plastic when wet; somewhat weak medium subangular blocky; few gravel; common fine, few medium pores; very few fine roots; clear smooth boundary to:

Horizon: BC2 170-180cm

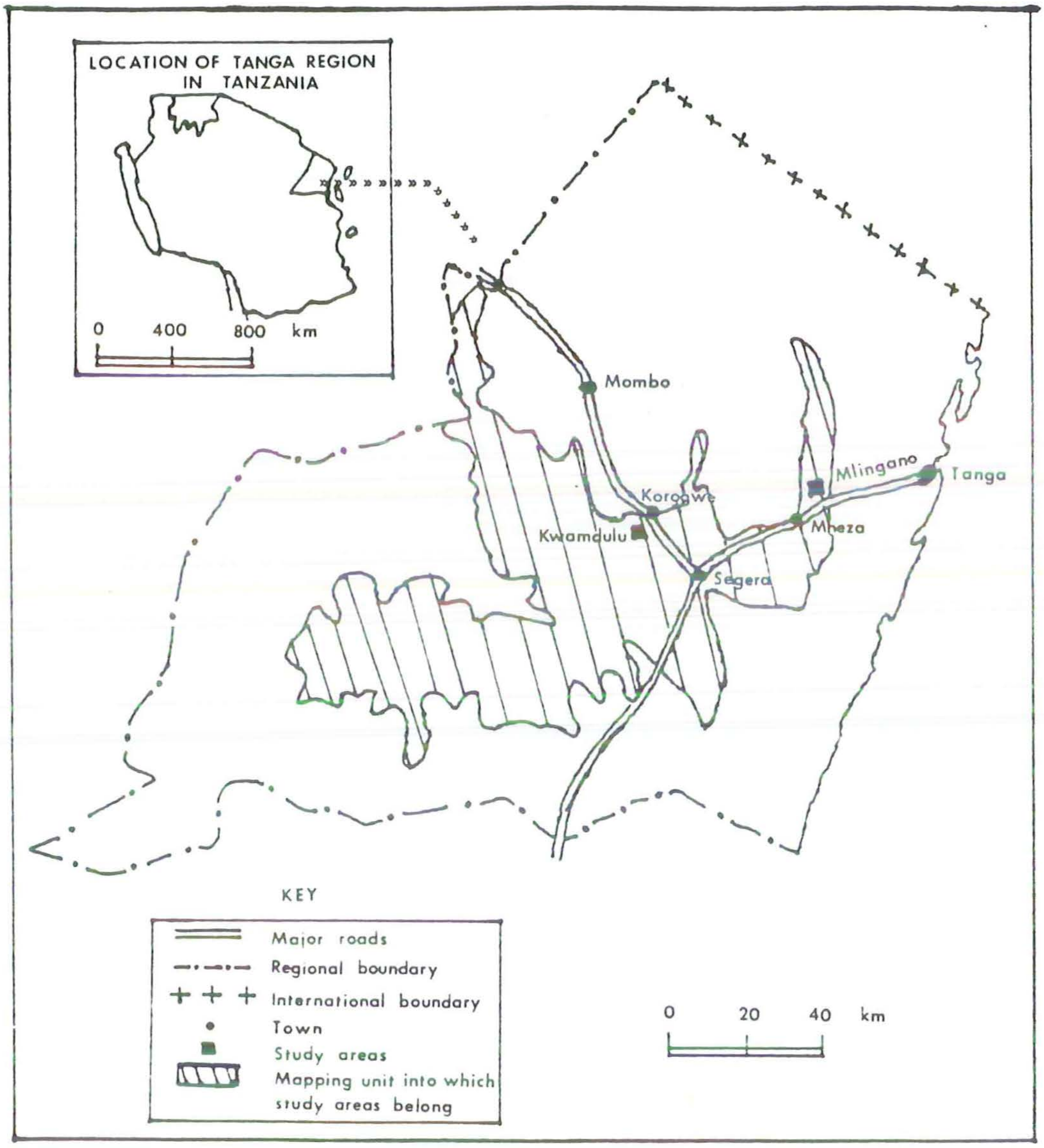
Dark red (2.5YR 3/6)moist; clay; friable moist, sticky slightly plastic when wet; somewhat weak fine and very fine subangular blocky; many very fine gravel.

Appendix 2.

CHEMICAL CHARACTERISTICS OF THE SOIL PROFILES

soil depth cm	pH H2O	pH KCl	Ca	Mg	exch. bases Na meq/100 g	K	CEC	Org. C	matter N %	Av. P mg/Kg
KWAMDULU CREST										
0-10	5.3	4.0	0.9	0.9	0.1	0.02	10.6	1.8	0.16	6.0
10-28	5.2	4.1	0.5	0.3	0.0	0.02	9.2	0.9	0.11	7.4
28-45	5.4	4.0	0.5	0.5	0.1	0.05	6.8	0.4	0.06	6.7
45-65	5.5	4.0	0.4	0.7	0.0	0.04	5.8	0.6	0.06	6.3
65-125	5.7	4.1	0.2	1.2	0.0	0.04	6.2	0.4	0.05	5.6
125-190	6.0	4.7	0.2	1.3	0.1	0.03	6.5	0.2	0.03	5.2
KWAMDULU LOWER SLOPE										
0-10	6.0	4.7	1.9	1.3	0.1	1.00	10.1	1.7	0.14	3.9
10-30	5.2	4.0	1.7	1.0	0.1	0.61	10.2	1.2	0.08	4.6
30-55	6.1	4.7	2.2	1.2	0.0	0.39	8.6	1.0	0.06	5.8
55-95	6.4	4.8	1.9	1.6	0.1	0.49	8.2	0.4	0.05	5.4
95-130	6.2	4.6	0.5	2.0	0.1	0.93	7.7	0.3	0.05	4.6
130-170	6.1	4.5	0.6	2.2	0.1	0.90	6.2	0.4	0.05	4.2
170-180	6.2	4.6	0.5	2.4	0.1	0.89	5.6	0.3	0.04	4.4
MLINGANO CREST										
0-14	6.5	5.8	6.0	2.8	0.2	1.0	12.6	1.9	0.15	6.8
14-26	6.1	5.4	3.8	1.0	0.2	0.5	9.4	0.6	0.08	0.8
26-50	5.0	4.3	1.7	0.8	0.1	0.2	8.6	0.3	0.04	1.0
56-80	4.7	4.1	0.9	0.4	0.1	0.1	9.9	0.3	0.03	0.7
80-120	4.9	4.1	1.0	0.4	0.1	0.1	11.0	0.4	0.04	0.8
MLINGANO LOWER SLOPE										
0-15	6.7	6.0	10.8	2.6	0.1	0.90	17.9	2.3	0.20	8.4
15-29	6.1	5.4	11.6	2.4	0.1	0.35	15.8	2.3	0.17	7.7
29-60	5.2	4.5	4.1	2.9	0.1	0.04	11.9	0.4	0.05	2.1
60-100	5.4	4.8	5.6	1.2	0.1	0.03	11.8	0.4	0.03	4.2
100-150	5.9	5.0	4.0	0.8	0.1	0.03	9.4	0.4	0.04	2.8

Appendix 3: LOCATION OF THE STUDY AREAS



APPENDIX 4:

CRITERIA USED IN RATING SOIL FERTILITY PARAMETERS

	v. low	low	moderate	high	v. high	
Organic matter (%)	< 1	1 - 2	2 -4	4 -6		+
CEC (meq/100g)	< 6	6 - 12	12 -25	25 -40	>40	+
Exch. Ca (meq/100g)	< 2	2 - 5	5 -10	10 -20	>20	*
Exch. Mg (meq/100g)	< 0.2	0.2 -1	1 -3	3 -6	>6	*
Exch. K (meq/100g)	< 0.1	0.1 -0.2	0.2 -0.4	0.4 -0.8	>0.8	+
Base saturation (%)	< 20	20 -40	40 -60	60 -80	>80	+
Al saturation (%)			<20	20 -60	>60	**
Av. P - Bray 1 (ppm)	< 3	<7	7 -20	>20		***

KEY:

- * Rated according to Taylor and Pohmen, 1970.
- ** Rated according to Sanchez, 1976
- *** Rated according to Page et al, 1982
- \+ Rated according to NSS 1987

CRITERIA USED IN RATING NUTRIENT CONTENT IN PLANT TISSUE

		deficient	low	intermediate	high
	N			2.7 -3.5	
	P	0.11	0.17	0.25	
In %	K	0.58		0.74 -1.47	
	Ca	0.18 -0.32		0.38 -0.43	
	Mg			0.23 -0.35	
	Mn			20 -500	
in ppm	Fe			56 -178	> 100
	Zn	<15		> 15	

According to Chapman, 1966