SOILS DEVELOPED ON MAGARINI SANDS:

ACIDITY

EFFECTS OF LIMING AND FERTILIZING ON MAIZE PRODUCTION

EFFECTS OF LEACHING ON ACIDITY

A REPORT ON RESEARCH UNDERTAKEN IN 1982

IN THE TRAINING PROJECT IN PEDOLOGY, KILIFI AREA, KENYA

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IN THE TRAINING PROJECT IN PEDOLOGY, KILIFI AREA, KENYA

for the 3 months subjects

Tropical Soil Science and Soil Fertility

Tutors: Ing. H.W. Boxem; Prof. Dr Ir J. Bennema; Dr Ir W.G. Wielemaker; Ir W.A. Blokhuis; Ir H. Waaijenberg; Dr Ir B.H. Janssen

S. van LEEUWEN

November 1989

SUMMARY

<u>This research</u> was undertaken in the T.P.I.P.[1] for land evaluation of the Kilifi area (map sheet 198), Kenya, as a part of its soil research programme, and on behalf of 'Tropical Soil Science' and 'Soil Sience & Plant Nutrition'.
<u>Questions</u> existing before design of this research were:

- can locally found calcareous dunesand increase crop yields in this region, first yard-stick being the main staple crop maize (<u>Zea mays</u> L.)? (Later also the occurrence of lime leaching was questioned.)
- The second question concerned soil fertility: within the soil fertility research programme, more quantitative data were wanted on nutrient availability, and crop response to fertilizers for the two major soil units developed on Magarini sands.

First to find possibly **acid soils**, these sandy Oxisols were **surveyed** with as first result very strongly acid soils (pH 5.0) were found north of Kilifi Creek. Repetition in Wageningen of pH estimations in the same 'northern' samples proved first estimates were too low; new results were:
slightly acid soils (pH 6.4; s.d. 0.3) and extrapolation for soils south of Kilifi Creek gave neutral soils (pH 7.3; s.d. 0.5). Thus no risk of Al (and Mn) toxicity exists on these soils.
Nevertheless, partly based on the first estimates a **liming trial** was undertaken, **combined with** a **fertilizer trial**, both in 3 replicates, - on <u>two trial fields 'Sokoke' and 'Ngerenya'</u>, representing the two major mapping units of soils developed on Magarini sands UE111 and UE112.
The chosen maize variety was 'Coast Composite'.

Liming rates were '$CaCO_3$'[2] at 0, 1.14 and 2.32 ton.ha^{-1} for control, agricultural lime and calcareous dunesand respectively. The only relevant positive <u>liming effect</u> was increased Ca removal by stalks and leaves by 2 to 3 kg.ha^{-1} to nearly 7 resp. 11 kg.ha^{-1}.
The liming rate of calcareous dunesand deteriorated <u>soil structure</u> as it raised pH in the upper 15 cm to 7, around which sesquioxide charge changes from positive to neutral. (In order to preserve soil structure, any liming rate should not raise pH beyond 6.)
<u>Assessment of the liming materials</u> Calcareous dunesand is a quickly working liming material with neutral to somewhat positive effect on maize yields. An objection to its use could be that digging off dunes is ecologically contestable !
Agricultural lime characteristics and effects are opposite to those of calcareous dunesand and therefore this liming material should be investigated in greater depth in consecutive years.
From pH data positive indications of **lime leaching** on short term (one growing season) contradict negative ones on long term (after the leaching trial) and ultimately no proof of lime leaching exists.

Fertilizer rates were 50 resp. 30 kg.ha^{-1} of N (as CAN) resp. P (as TSP) combined to the treatments control, N, P, NP. The N fertilizer was applied in two halves.
<u>Growth</u> Especially in Sokoke, NP fertilizing furthered higher plants that matured earlier.

[1] Training Project In Pedology of the Agricultural University Wageningen, The Netherlands in cooperation with the Kenya Soil Survey (K.S.S.), Nairobi, Kenya.

[2] '$CaCO_3$' means the sum of compounds that show a liming reaction like $CaCO_3$, $MgCO_3$ and $Ca(OH)_2$.

Yields N fertilizing increased grain yields (12 % moisture) by 0.86 to 1.61 in Sokoke and by 1.13 $ton.ha^{-1}$ to 3.05 $ton.ha^{-1}$ in Ngerenya. NP interaction increased grain yields in Sokoke and tended hereto in Ngerenya by additionally 0.5 $ton.ha^{-1}$.
Removals and Recoveries N fertilizing raised P removal on both soils, but P fertilizing did not raise N removal. Thus N is the most limiting nutrient in these soils. From comparison with data from Walsh & Beaton (W&B) and Sanchez (S), it appears other limiting nutrients are P (W&B, and S), and possibly Mg (W&B) and Ca (S). NP interaction especially raised removals in Sokoke. Recoveries of NP fertilizing were much greater than those of single fertilizer applications.
Differences between the two trial fields are more striking than N fertilizer effects. Comparing mean field values $\frac{(0 + N + P + NP)}{4}$ and values from unfertilized plots, a conclusion is: fertilizing reduces relative field differences concerning yields and removals, and for growth characteristics even absolute field differences. Chemical soil characteristics like CEC, organic N contents and P-Olsen values are reflected in twice as high removals in Ngerenya (on UE112).
The rains and (N) fertilizer economics The extremely heavy rains (c. 80 % more than is normal during the period April-June) and thus leaching of N fertilizer, and the almost dry spell until three weeks after applying of the second half of the N fertilizer, reduced the recovery of N fertilizer. Depending on the (pre)seasonal amount of precipitation and its division over the decades, higher or lower recovery rates can be expected. - Economically only a single N fertilizer application of 50 $kg.ha^{-1}$ seems promising in the area covered by soil map unit UE112 with 1.52 as marginal rate of return on the Ngerenya field in 1982[3].
Probably only in some out of 10 years, the total amount of rain and its distribution will be so well that marginal rates of return will amount to 2 at which level fertilizers become recommendable to farmers. However under their common cultivation practices, fertilizing will be less paying than in the trials.
Fertilizer use may be more profitable if applied to higher priced crops like rice and grain legumes. Other management practices e.g. use of pesticides or herbicides[4] might be equally or more profitable.
Drought and erosion hazards The somewhat excessive drainage and limited amount of moisture storage (readily available water) cause combined with the erratic rainfall regime with dry decades during the growing season, a drought hazard which is partly reduced if mulching is applied, which farmers practise. Mulching also reduces erosion hazard and thus contributes to soil (fertility) conservation. (Unfortunately however, mulch of maize stalks and some grasses stimulates pest incidence.)

[3] SCHREURS (1984) however derived from data of de Bie's less representative sandy trial field on UE111, only single P fertilizing was comparably promising with 1.54 as marginal rate of return.

[4] and on Shales: tillage by tractor ploughing

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PREFACE

This report is a part of the research for land evaluation of the 'Kilifi area' which boundaries are marked by Map sheet 198 of the Survey of Kenya (Fig. 1.1). The Kenya Soil Survey (K.S.S.) maps agricultural areas in Kenya, which cover some 20 % of the country. The K.S.S. delegated the land evaluation including soil mapping of this area to, and cooperated with the Training Project in Pedology (T.P.I.P.). Over the years the T.P.I.P. included the Kisii project from September 1973 till March 1979, the Kilifi project from September 1979 to November 1982 and the Chuka project from March 1985 to August 1986. It was a project of the Agricultural University, Wageningen, The Netherlands. For more details on project and area I refer to the Kilifi report by BOXEM et al. (1987), (and the Preliminary Report no. 1 (FLOOR et al., 1980)) and van LEEUWEN (1988).
The research described in this report was undertaken for partial fulfilment of my three months subjects in Tropical Soil Science and Soil Fertility. - Locally I worked with Ing. H.W. Boxem (project manager) as tutor; also Ir H. Waaijenberg (research assistant on farming systems) gave advice. My tutors Dr B.H. Janssen (Department of Soils and Fertilizers, later: Department of Soil Science and Plant Nutrition) and Prof. Dr J. Bennema (Department of Tropical Soil Science) both visited the project; Janssen from March 20th till April 4th 1982, and Bennema from April 15th until May 7th in respectively the second and third month of this research.
Reasons for the below described research were Bennema's qualitative question whether the locally found calcareous dunesand could be utilized regionnally to raise crop yields on (slightly) acid soils. Further, more quantitative knowledge on fertilizer effects was needed for a proper land evaluation of the largest soil units developed on Magarini Sands (Janssen's question).
Unfortunately Prof. Bennema and Ing. Boxem passed away early 1985, the year in which part of this report was written. Therefore Dr W.G. Wielemaker who has 6 years of experience in Kenya, and after his departure for Costa Rica, Ir W.A. Blokhuis, became my tutors for Tropical Soil Science.
I worked in the Kilifi project as a post graduate student from February 1982 till September 21st 1982, partly for the research dealed with in this report, and partly on other subjects.

As 1982 was my first period in the tropics, I learnt much about my personal possibilities and restrictions at that time - as is usual in new environments. I liked many of my contacts with Kenyans. Also I liked the rythm of life and the climate. Among the new experiences were: my first research in surveys and field trials and working in a project: quite independant, sharing facilities; and working with local assistants, who were indispensable for communication with other Kenyan people and their manual skills e.g. handling the hoe (see Photo 0.1).

Photo 0.1. Assistants skills were indispensable (WO 51)!

I appreciated the visit of both my tutors Janssen and Bennema to the project. With them, the research got clearer scope and detail; further the work carried out already was critically evaluated. Their scientific controversy noticed before I departed for Kenya, remained. The research described in this report resulted from their ideas, and was set up to settle the matter.

A quite general experience of students is that tutors tend to overask their pupils. Ideas for research are uttered much quicklier by staff and also by students, than field and lab (and reporting) work can be finished. Probably, they plan the students work as if he has all the routine of a trained scientist. But a student doing his first research

may not work at professional pace. Moreover some scientists lack recent field and lab experience, and hence cannot plan scientific work of newcomers as these debutants would expect. - This resarch was planned to take 4 months, all in. Field work took 2 months, lab work took more, and reporting took many more months. As the ratio (reporting time : practical work) is estimated 1:1 for scientific research, reporting should have taken 5 to 6 months (given the extendedness of the planned research). In reality, the reporting lasted for over a year, partly due to my perfectionism which was overcome finally. And I kept in mind: "A task is a burden only when it has not been tackled." (Ngugi wa Th'iongo in "Devil on the cross").

I am thankful for the many encouragements I received during reporting: critical comments by my tutors, most from Dr Janssen, the willingness of Dr Wielemaker and after him Ir Blokhuis, to become my new tutor for Tropical Soil Science, and the company of friends, especially Henk and Esther Cats who granted me typing facilities in their house. I thank Ineke Lammerse, Hans Rienks and Vincent van der Griendt for typing part of this report, and the Department of Soil Science and Plant Nutrition for granting text processing facilities and Frank du Moulin from the PC shop for trying to tackle some difficulties resulting from the imperfect Word Perfect 4.1 version. I thank Paul Chardon, Jan van der Wolf, Henk Weckseler and especially Heleen Kormelink for final text processing, and Ingrid Kamerbeek for being my encouraging comrade.

Also my thoughts go to Ing. Willem Boxem who passed away too young, and to Prof. Bennema. Last but not least I thank the lab assistants of the Department of Soil Science and Plant Nutrition, Arie, Eric, Egbert and Winnie, and field and lab assistants of the Kilifi project, Sammy, Onesmus, Joseph, Alfred, Katana, Kenneth, David and Benson, for their indispensable help.

Wageningen, November 1989. Sjoerd van Leeuwen

Photo 0.2. From left to right: some persons and their functions in the T.P.I.P.: Dr Ir T. de Meester (principal), Ing. H.W. Boxem (manager), and Prof Dr Ir J. Bennema (supervisor) (MK 1).

1 INTRODUCTION

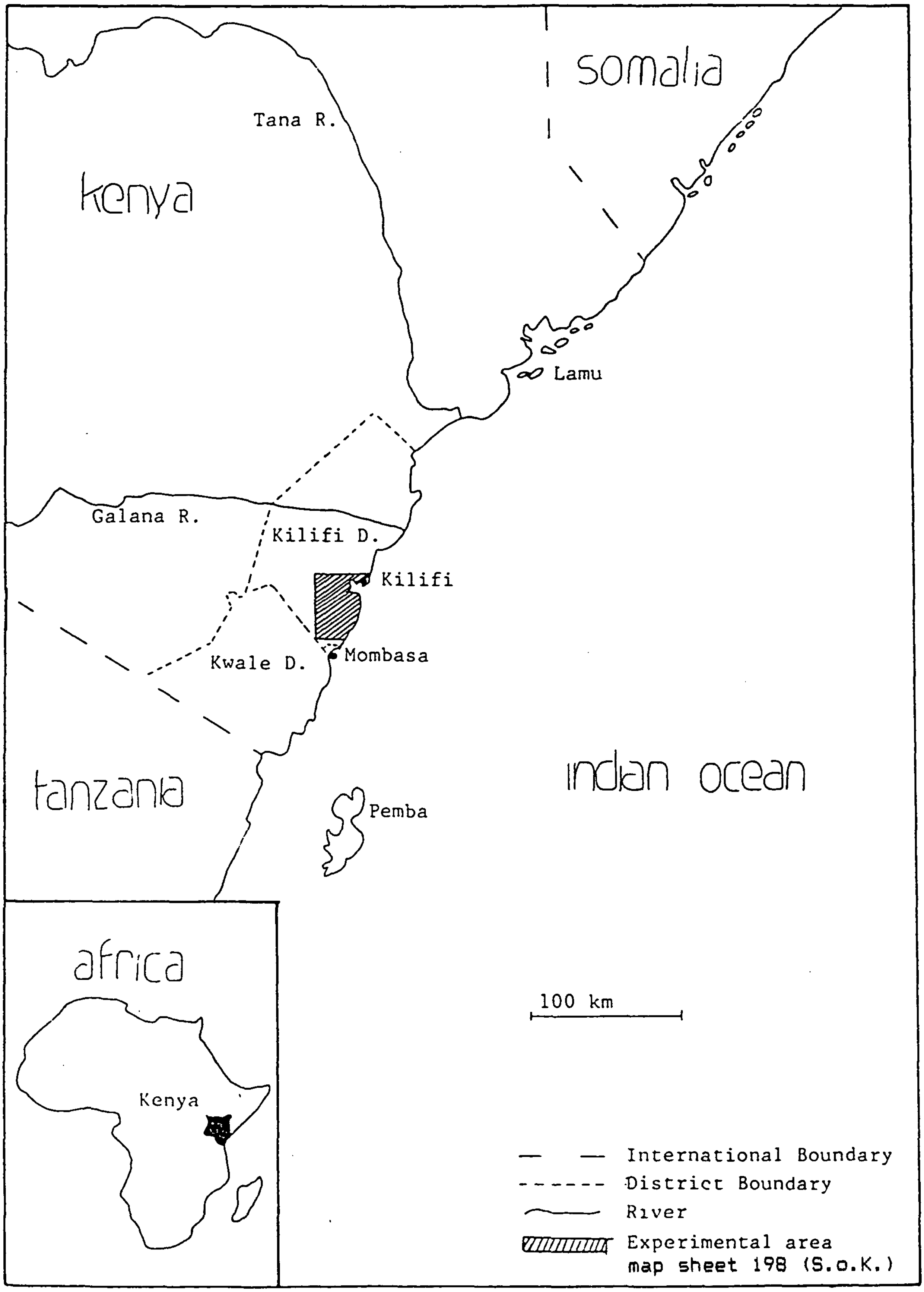
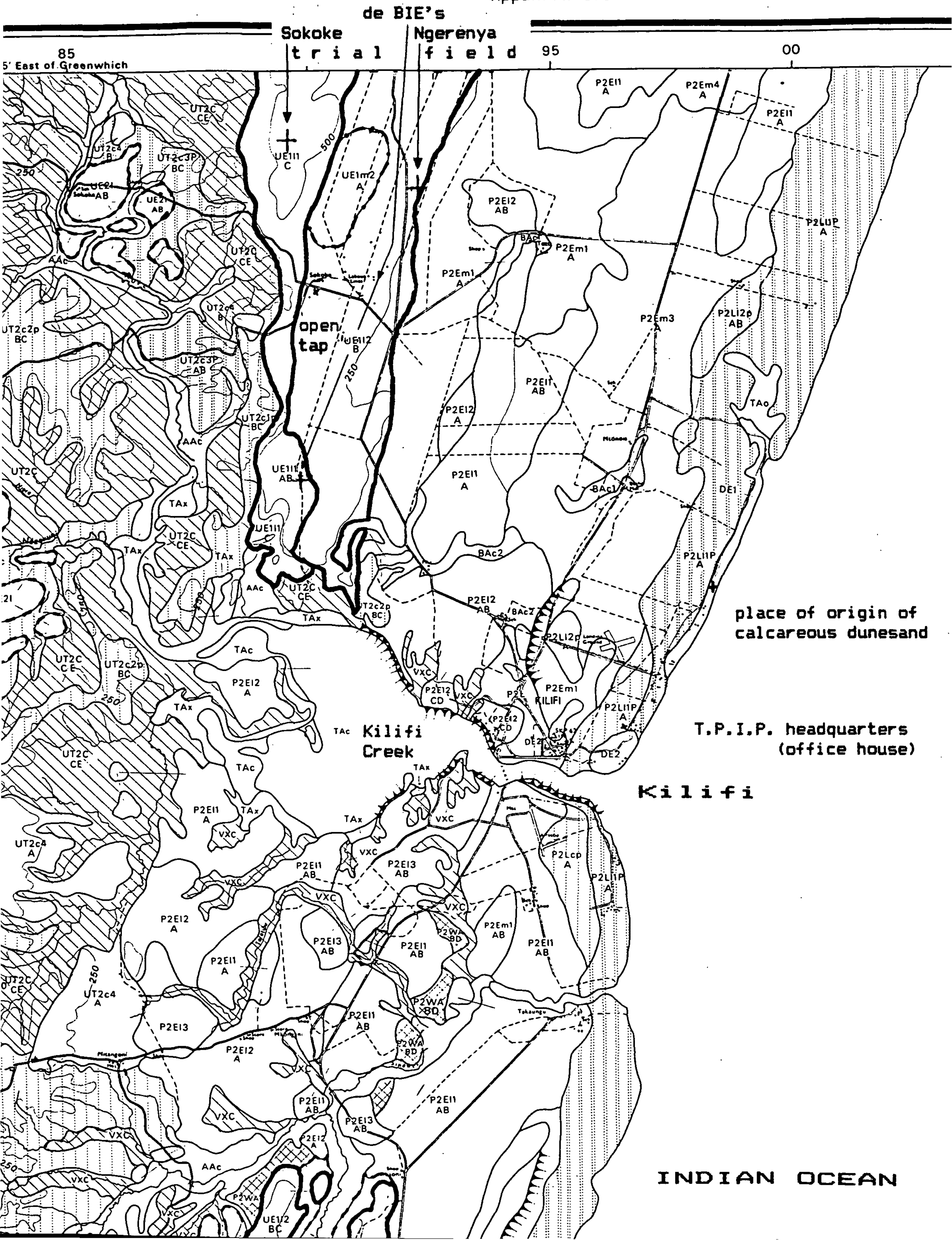


Figure 1.1. Location of Kilifi District and experimental area, map sheet 198 of the Survey of Kenya.

PART OF THE RECONNAISSANCE SOIL

AP OF THE KILIFI AREA

Figure 1.2.
Relevant spots for lime fertilizer trials and leaching trial on soils developed on Magarini sands, (after BOXEM et al., 1987: Appendix 1).



This research report deals with an acidity survey, a combined lime and fertilizer trial with Maize (_Zea mays_ L.) and a lime leaching trial, all carried out in 1982 in the Kilifi area, Kenya, on a sandy Oxisol. The research formed part of land evaluation for Map sheet 198 of the Survey of Kenya, also called 'Kilifi area' (see Figure 1.1).

Two questions existed before this research was designed. A qualitative question was : can locally found calcareous dunesand (c. 70 % $CaCO_3$; see Figure 1.2) increase crop yields in this region, first yard-stick being maize? Later it was decided to add a test on the occurrence of lime leaching. - The second question concerned soil fertility: within the studies on the fertility of the Kilifi soils, more quantitative data were wanted on nutrient availability, and crop response to fertilizers, for the two major soil units developed on Magarini sands.

After a survey of the acidity status of soils developed on Magarini sands (soils being possibly acid), two trial fields were established in a slightly acid region of these soils to test the effect of liming, and fertilization with N and P on the yield of maize, the main staple crop in the area. Finally a leaching experiment was undertaken in small parts of one of the trial fields (to estimate the effect of rain on the long term residual effect of the applied lime).

Research on possible maize yield improvement was highly important, because maize is the main staple crop, and the coastal area at that time was supplying its inhabitants with only 40 to 50 % of the maize needed (WAAIJENBERG, thesis, in preparation), while the population growth was high (c. 4 % per year).

After this introduction follows a description of the physical environment (chapter 2). Chapter 3 gives a literature review. Chapter 4 provides detailed designs (as background information for this research). Chapter 5 describes methods and materials, and chapter 6 gives results, and discussions. Chapter 7 presents a synthesis and conclusions regarding

1) acidity and short and long term effect of liming on acidity and crop yields, and
2) effect of fertilizers on yields of maize grown on soils developed on Magarini sands.

The chapters 4, 5 and 6 are divided into the sections:

1 acidity survey 'Magarini sands',
2 liming trial (at NP level),
3 fertilizer trial,
4 leaching trial.

Trial fields and soil map units

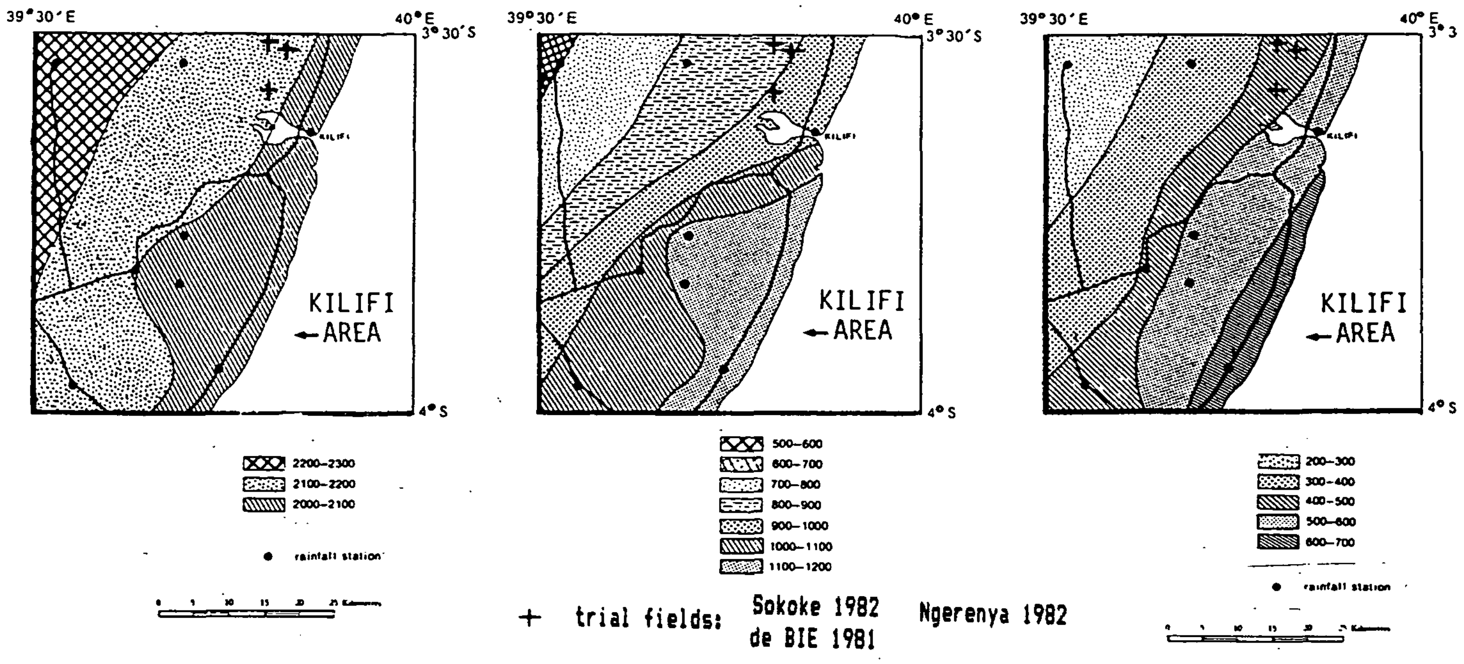
All trials were carried out on trial fields viz. the Sokoke and the Ngerenya field, and are often discussed in this order. The leaching trial took place at the Sokoke field only.

The Sokoke trial field is situated in map unit UE111, and the Ngerenya trial field in UE112. The codes UE111 and UE112 cover the main map units of soils developed on Magarini sands. Some of the trial field data perhaps are outside the central concept of these map units (pH).

Abbreviations

Within the report, cross-references are not worded fully as e.g. 'see chapter/paragraph 3.1', but shortly as 'see 3.1'.

'Soils developed on Magarini sands' are often abbreviated as 'Magarini sands'.



a) Average annual evapotranspiration (mm).

b) Average annual rainfall (mm).

c) Average rainfall (mm) during the period April-June.

Figure 2.1. Evaporation and rainfall in the Kilifi area - after BRAUN (MICHIEKA et al., 1978)

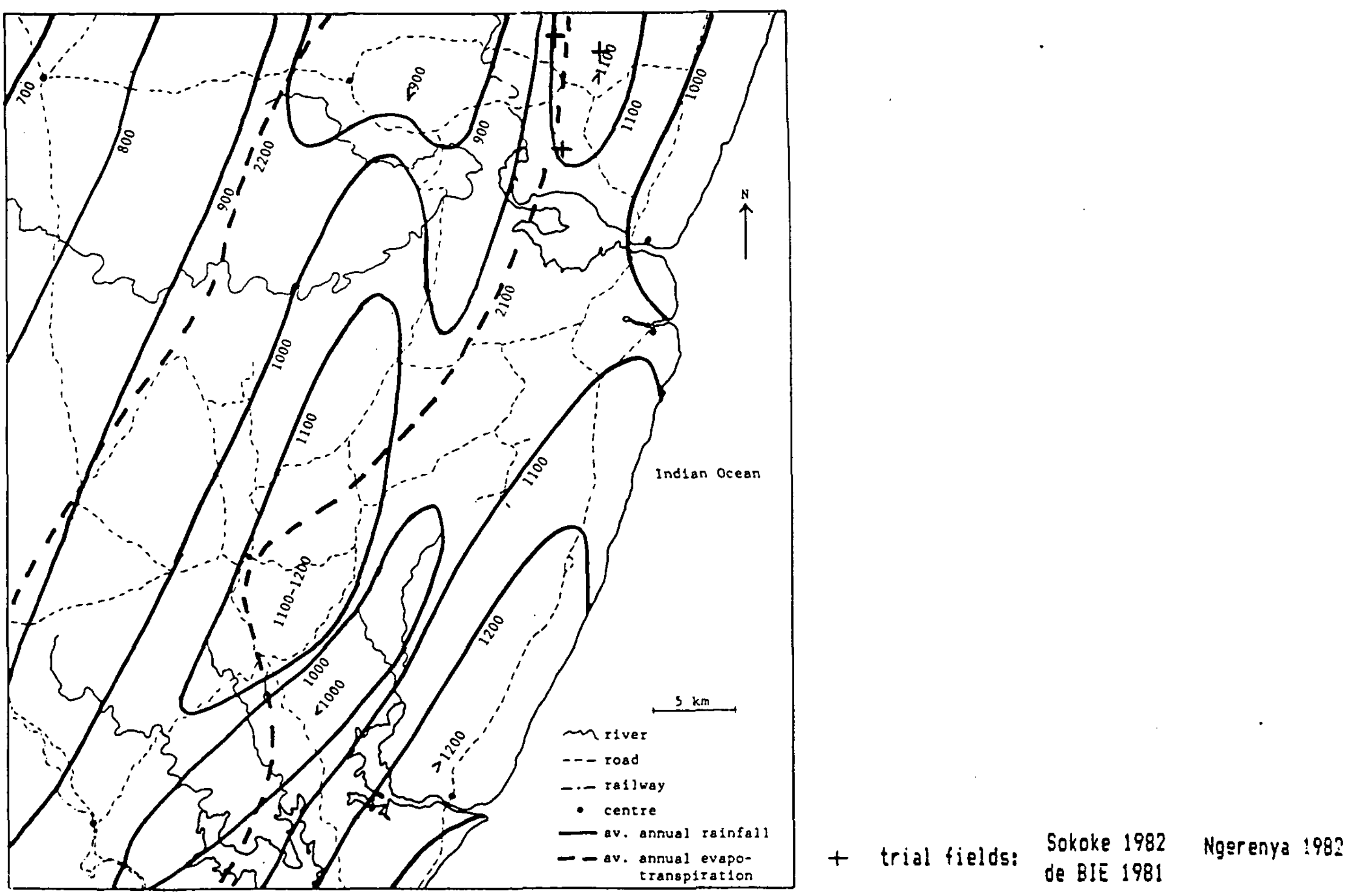


Figure 2.2. Approximate annual rainfall and potential evapotranspiration (mm) of the Kilifi area - after JAETZOLD & SCHMIDT, 1983 and BOXEM (1982, pers. comm.) in WAAIJENBERG (1986).

2 THE PHYSICAL ENVIRONMENT

2.1 CLIMATE

Chapter 2.1 presents literature data (2.1.1), whereas 2.1.2 deals with precipitation and its effects in 1982.

2.1.1 CLIMATE AND AGRO-ECOLOGICAL ZONATION (LITERATURE REVIEW)

Precipitation and potential evaporation

The mean precipitation during the period April - June ranges from 400 to 500 mm (see FLOOR et al., 1980, and by location of the trial fields in Figures 1.2 and 2.1). The average annual total ranges from 800 to 900 mm for the Sokoke field and about 900 mm for the Ngerenya field (see Figure 2.1 based on MICHIEKA et al., 1978). However, according to Figure 2.2 (based on JAETZOLD & SCHMIDT, 1983) the annual total amounts to about 1100 mm at the Sokoke trial field and between 1100 and 1200 mm at the Ngerenya field[1]. Annual evaporation amounts to 2100 - 2200 mm (MICHIEKA et al., 1978).

Agro-ecological zonation

The agro-ecological zonation by JAETZOLD and SCHMIDT (1983) emphasizes seasonal variation in rainfall and evapotranspiration. The basis of the determination of the zones is formed by temperature and moisture availability, and (also) taking into account "lengths of the growing period".

Table 2.1 presents the agro-ecological zones covering soils on Magarini sands. CL refers to Coastal Lowland zone; 4 and 3 refer to r/E_o (average annual rainfall/ average annual evapotranspiration) intervals 65-50 and 50-40. 60 % reliability means the given number of days will be surpassed in at least 6 out of 10 years.

The table shows the monomodal rainfall distribution pattern of the coastal zone; only one crop can be grown in the experimental area, for the growing period connected with the 2nd rains is too short.

Magarini sands north of Kilifi Creek (2100 ha) and the northern 120 ha south of this creek are situated in the ustic CL 4 m/s i zone, whereas the remaining greater part of these soils (4600 ha) lie in the CL 3 m/l i zone.

[1]) It remains unclear whose information is correct since MICHIEKA et al. (1978) is not available in the Agralin Library Catalogue.

Table 2.1. Agro-ecological zonation and 60 % probability of rainfall, and growing period for the coastal strip of the Kilifi Area[1].

Agro-ecological/ climatic zonation: Braun,	Jaetzold & Schmidt[2]	Rainfall recording site	Average annual rainfall(mm)	60 % - probability rainfall (mm): 1st rains	2nd rains[3]	growing period (days): 1st rains	2nd rains[3]	total[4]
III-I	CL 3 m/l i	Mtwapa Vipingo	1050-1230	400-800	50-130	155-175	< 40	-
IV-I	CL 4 m i	Kilifi D.O. Jibana Disp.	850-1100	320-600	50-130	135-155	< 40	-

1) source: JAETZOLD & SCHMIDT, 1983: 328, as cited by BOXEM et al., 1987: Table 5.
2) length of growing period (60 % probability).
m/l medium to long155-174 days
m medium 135-154 days
i intermediate rains (at least 5 decades 0.2 E_o, i.e. moisture conditions are above wilting point for most crops.
3) see text.
4) only added if rainfall continues at least for survival (0.2 E_o) of most long term crops.

Other climatic parameters (adapted from BOXEM et al.,1987)
The monsonal north- and south-eastern winds occasionally reach velocities that are hazardous to agriculture. Maize yield can be depressed because of lodging in the ripening stage.
Temperature is fairly constant throughout the year, and annually averaging around 26 °C.
Daylength is rather constant throughout the year. The number of sunshine hours also varies slightly: 7-8 hours per day on average.
High humidity (particularly along the coast) and cloudiness are factors that restrict the cultivation of certain crops and further hampers adequate insolation during parts of the years.

2.1.2 PRECIPITATION IN 1982 AND ITS EFFECTS AT THE TRIAL SITES

After the first light showers by the end of March, the bulk of the rains fell in April and May (see Figure 2.3). The trial fields were planted just after the first showers on April 1st and 2nd at the Sokoke and the Ngerenya field respectively (for location, see Figures 1.2 and 2.1). Harvest took place 4 months later on August 6th after a relatively dry spell.
Rains in 1982 were extremely heavy in Kenya's coastal strip. In the area of study, 800 mm of rain fell during only April, May and June (see Figure 2.3). This seasonal total of 1982 even approximates the annual total according to BRAUN (MICHIEKA et al., 1978).
In order to explain qualitatively to what extent these extremely heavy rains may have affected maize yields, the following can be said. Farmer

Mwango (Kilifi), who fertilized his crops well, grew a vigorous green maize crop, whereas generally maize crops in the Kilifi area were chlorotic. Thus the chemically poor nutrient status of the soils was the major yield reducing factor. The optimum rainfall during the first 5 weeks after sowing is about 200 mm (ACLAND, 1971, cited in 3.3). Until May 7th, 5 weeks after planting, about 400 mm precipitation was received (see Figure 2.3), thus probably precipitation was a minor yield reducing factor, although both soils were somewhat excessively drained (see Appendix 3). Besides, it is likely that rainfall leached N fertilizer.

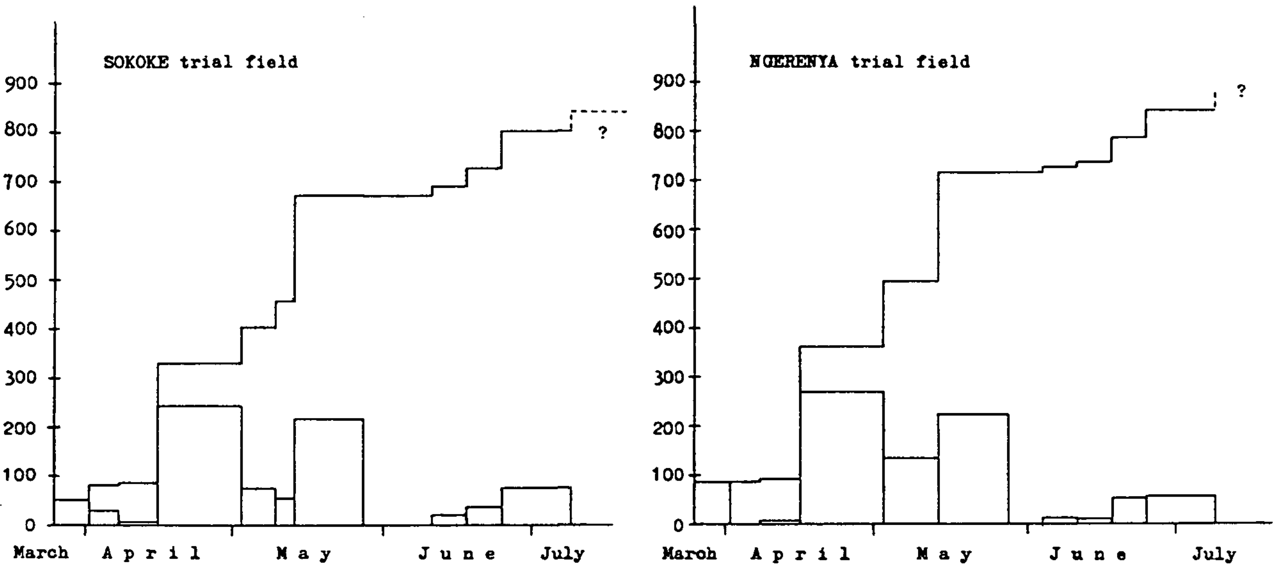


Figure 2.3. Precipitation data from trial fields on Magarini sands during the long rains of 1982 (mm); per interval and cumulative; first and last recording dates were March 26th (before onset), resp. July 9th (by the end of the rains).

2.2 SOILS

2.2.1 INTRODUCTION

Soils developed on Magarini sands

The investigated soils all belong to the Pingilikani upland, which occurs as two separate areas in the north eastern and in the eastern part of the Kilifi area, westward adjacent to the Lutsangani upland mainly comprising shales, and eastward to the Coastal Plains mainly consisting of Coastal sands. The altitude ranges between 100 and 200 m, relief is flat to undulating, dissection is slight to moderate. The parent material consists of medium grained unconsolidated sands (Magarini Formation). The major part of the Pingilikani upland has well-drained, very deep, mostly dusky red to red, sandy loams (map-unit UE1m1) and sandy clay loams to sandy clays (map-units UE111, UE112)

(adapted after BOXEM et al., 1987). The trial field lay in the north eastern part of the Pingilikani uplands with the Sokoke field upslope of the adjoining shales (see Fig. 4.1).
Classification of the soils was difficult due to lack of some laboratory data (see Appendix 3). The classifications are rhodic Ferralsols (FAO) and typic Haplustox (USDA) for profile pit 198/2-47 on the Sokoke trial field in map unit UE111, as well as for profile pit 198/2-46 on the Ngerenya trial field in map unit UE112.

<u>General description of both trial field soils (representative profile 198/2-47 on UE111 and 198/2-46 on UE112)</u>
Very deep, somewhat excessively drained dusky red (47) and dark reddish brown (46), very friable, sandy loam to sandy clay loam, uniform in appearance throughout their depths. Structure is weak throughout, and the whole profile is porous and rapidly permeable.
Both soil profiles have an oxic B horizon, above which in the upper c. 0.4 m sand content decreases and the silt clay fraction increases by 10 %. - Root distribution is normal. - Striking are the many rounded black manganese concretions. The chemical condition of both profiles is very poor (esp. in 47).

2.2.2 SOILS OF BOTH FIELDS PUT IN PERSPECTIVE - mutual comparison of trial field profiles and the profiles that are representative for the corresponding soil mapping units.

In this paragraph both trial fields are discussed, emphasizing mutual differences, and differences with map legend (App. 1) and representative profiles (App. 2).
Most soil data obtained from samples of both trial fields are given in Appendices 3 and 23; Appendix 2 presents all data of profiles representative for the corresponding soil mapping units. Table 2.2 facilitates a comparison of these data via a summing up.

Texture of the Ngerenya field profile (pit samples) is heavier than of representative profile 21 that is representative of the mapping unit, and in the topsoil somewhat heavier than in the Sokoke field. (This is reflected in corresponding CEC values, but not in bulk densities.) Both trial fields fit in the definitions given in the Legend to Map sheet 198 (App. 1), except for the layer of sandy loam of profile pit 198/2-46 (UE112) that is 25 cm too thin, and both soils are somewhat excessively drained, whereas the legend calls the soil units well drained.

Bulk density of the Sokoke field is higher than on the other field corresponding with low organic C, while the representative profiles show the contrary.

Photo 2.1 shows the 'Sokoke' soil (on UE111).

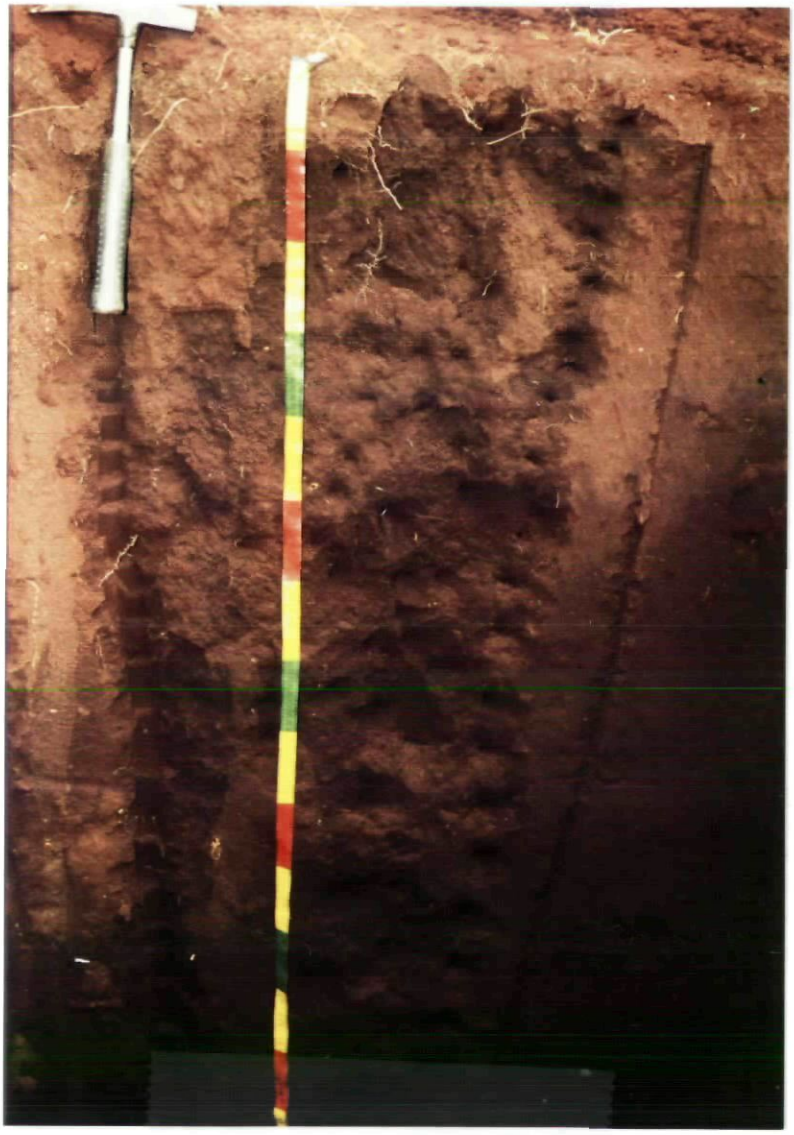


Photo 2.1. Soil profile pit 198/2-47 at the Sokoke trial field (KN 9).

Footnotes Table 2.2

1) Data from representative profiles are mostly found every other line and are connected with dots.
2) Data for 0-20 cm obtained in Wageningen are based on many (pH), duplo (org. C and N, P-Olsen) and single (CEC & exch. bases) measurements. pH determinations were done with many separate control plot samples. Duplo and single determinations were done with mixed samples from control plots. The CEC-AgTu method has an internal duplo, but no standard samples were included in this determination.
3) trial field profile pit data derived from 'distinguishing depths' mentioned in paragraph 5.3 and used in App. 3 and 23.
4) see footnote 2) and Fig. 2.4. Moisture storage is connected with pF range 2.3-3.7. Per profile cumulative data till 30 resp. 80 cm depth. Basic pF data can be found in App. 2,3 (and 23).

Table 2.2. Summed up soil data of trial fields and representative profiles[1].

Mapping unit	**UE111**				**UE112**			
Trial field profile	198/2-47 Sokoke				198/2-46 Ngerenya			
Soil classification FAO	rhodic Ferralsol				rhodic Ferralsol			
USDA	typic Haplustox				typic Haplustox			
Representative profile	*20 (198/4-41)*				21 (198/2-3)			
Soil classification FAO	chromic Luvisol				rhodic Ferralsol			
USDA	"rhodoxic" Paleustalf				typic Haplustox			
Lab location	Wag.[2]	Nairobi (NAL)			Wag.[2]	Nairobi (NAL)		
Horizon		Ap	Au	B		Ap	Au	B
Depth (cm)	0-20	0-6	6-60/80	60/80-170	0-20	0-25	25-80	80-200
$pH-H_2O$ (1:2½ v/v)	5.6	4.9	4.9	5.0	5.8			
	6.5		6.6 ...	6.4 5.7				
pH-KCl (1:2½ v/v)	4.6	3.6	3.7	4.1	5.0			
	5.1		5.3 ...	5.2 5.0				
EC ($ms.cm^{-1}$)	0.04	0.02	0.06					
	0.03		0.03 .	0.04 0.04				
$CaCO_3$ (%)	n.d.							
	n.d.							
C ($g.kg^{-1}$ soil)	5.1	2.3	1.2	0.6	9.7			
	0.4		0.2 ...	0.1 0.1				
N (,,)	0.45				0.69			
	n.d.							
C/N	11.3				14.1			
P-Olsen ($mg.kg^{-1}$)	2.8				2.3			
	3		2	1 1				
CEC $\frac{(mmol(+))}{100\ g}$, pH 8,2		4.1	4.3	4.3				
pH7.0	2.5		1.3	1.5 1.5				
AgTu	3.3				4.3			
Exch. Ca (,,)	1.60	0.85	1.45	1.85	2.66			
(,,)	0.9		0.8 ...	0.8 0.6				
Mg (,,)	0.46	0.64	0.20	0.68	0.72			
(,,)	0.3		0.2 ...	0.2 0.2				
K (,,)	0.16	0.25	0.18	0.25	0.16			
(,,)	0.5		0.3 ...	0.2 0.2				
Na (,,)	0.004	tr.	tr.	tr.	0.002			
	0.1		tr.	0.1 0.1				
Sum of bases	2.22	1.74	1.83	2.78	3.54			
	1.8		1.3 ...	1.3 1.1				
Base sat %, pH 8.2		42	43	65				
pH 7.0	72		100	81 73				
AgTu	67				82			
<u>Texture</u>, limited pretreatment:		K I L I F I				K I L I F I		
Sand % 2.0-0.05 mm		80	78	70		78	63	67
	84		76	72 74	84	....	83 82 ...	76 77
Silt % 0.05-0.002 mm		0	2	2		1.3	9	14
	2		2	0 2	5	USDA	3 3 ...	17 18
Clay % 0.002-0 mm		20	20	28		21	28	19
	14		22	28 24	11	....	14 15	7 5
Texture class		SCL/SL	SCL/SL	SCL		SCL	SCL	SL
,, ,, [3]		SL	SL/SCL	SCL		SL	SCL	SCL
	SL		SCL ..	SCL SCL	LS		LS/SL ...	SL SL
Bulk density[3]	1.44	1.43	1.47	1.53	1.33	1.34	1.40	1.47
	1.38		1.34	1.52 1.52	1.62	1.53	1.58 .	1.56 1.64
Moisture storage[4]	22.4		69.8		15.9		57.6	
(mm)	21.7		62.5		36.8		112.9	

Footnotes are given on the foregoing page.

Moisture availability during the growing season.

Potential moisture storage

In WIELEMAKER and BOXEM (1982), 0-80 cm depth is chosen as rooting depth class for maize[2]. Except for this layer, moisture storage capacity is also computed for 0-30 and 30-80 cm depth. The upper layer is most important for the crop(s), especially after sowing, but may dry up later on in the growing season. Then the layer from 30 to 80 cm depth should contain the minimally required water. Figure 2.4 illustrates part of the situation once more.

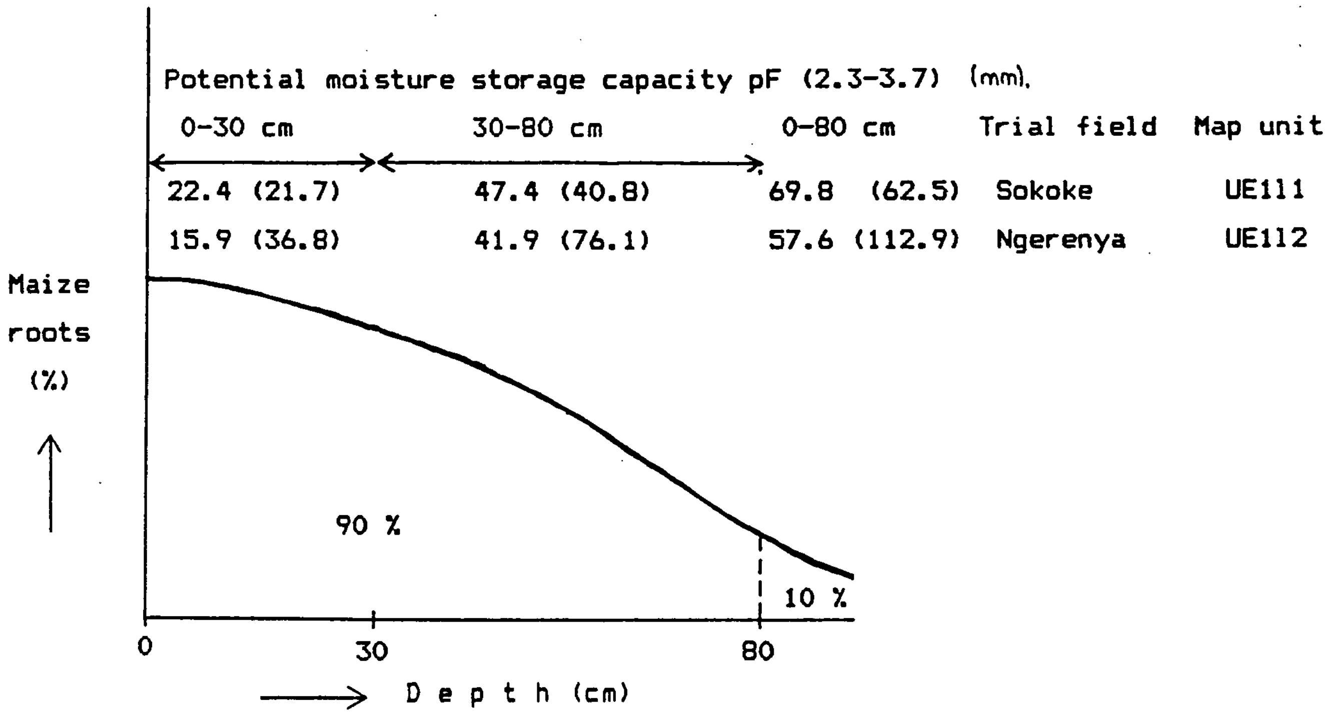


Figure 2.4. Imaginary maize rooting pattern during the second half of the growing season, and moisture storage (mm) on the trial fields and in parenthesis representative profiles.

Due to lower bulk density on UE112, the moisture storage capacity of the Ngerenya field (198/2-46) is lower than on the Sokoke field. This profile 198/2-46 has only half the moisture storage capacity of representative profile 21. Thus in this respect, the Ngerenya field is not representative for the map-unit.

Appendix 23 shows all measured moisture contents from samples of both trial fields in the period May (14^{th}) - July 9^{th} (-September) and soil

[2] Maize roots may have extended to greater depths (see 5.3) but the upper soil layers are anyway most important on these somewhat excessively drained, chemically poor soils. Further the heavy rains caused shallow rooting. (Continuous availability of sufficient moisture near the soil surface during the first 6 weeks of crop growth stimulated the crop to establish a superficial rooting pattern.)

Table 2.3. Moisture storage in the long rains of 1982 (vol. %, or mm.(0.1 m^{-1})).

Date / Depth (m)	Sokoke pms[b]	14/5	28/5	11/6	25/6	9/7	6/8	Ngerenya pms[b]	6/5[a]	14/5	28/5	11/6	25/6	9/7	3/8[a]
0.0-0.1	**6.7**	7.6	3.1	- 7.5	16.2	11.4	0.7	**5.6**	8.3	12.7	9.0	- 2.8	17.0	18.7	8.9
0.1-0.2	**7.5**	5.0	3.1	- 7.5	13.2	7.4	-0.7	**5.3**	3.7	9.0	4.6	- 4.6	11.9	10.6	4.1
0.2-0.3	**8.2**	3.4	4.9	- 8.9	9.6	13.7	3.1	**5.0**	2.3	6.1	5.7	- 4.7	9.8	10.4	2.8
0.3-0.4	**8.7**	2.0	3.9	- 6.0	-0.8	4.2	-1.4	**6.3**	4.0	6.5	4.5	- 4.0	6.6	9.2	3.4
0.4-0.5	**9.2**	1.4	2.0	- 5.7	0.2	5.4	-0.6	**7.7**	4.1	6.0	4.8	- 2.4	4.9	8.3	4.4
0.5-0.6	**9.7**	4.6	1.0	- 5.0	2.2	22.0	7.9	**9.2**	3.9	6.7	4.3	- 2.5	4.9	7.6	4.5
0.6-0.7	**9.8**	2.3	0.8	- 4.4	-1.3	2.9	-1.4	**9.2**	3.4	6.7	4.3	- 2.3	2.8	6.5	4.1
0.7-0.8	**10.0**	2.2	0.8	- 4.1	-2.0	2.2	-1.6	**9.3**	3.2	7.1	4.0	- 1.7	8.4	10.9	4.5
Sum per layer															
0.0-0.3	**22.4**	16.0	11.1	-23.9	39.0	32.5	3.1	**15.9**	14.3	27.8	19.3	-12.1	38.7	39.7	15.8
0.3-0.8	**47.4**	12.5	8.5	-25.2	-1.7	36.7	2.9	**41.7**	18.6	33.0	21.9	-12.9	27.6	42.5	20.9
0.0-0.8	**69.8**	28.5	19.6	-49.1	37.3	69.2	6.0	**57.6**	32.9	57.6	41.2	-25.0	57.6	57.6	36.7
surplus										3.2			8.7	24.6	
Moisture storage for .. days[c]															
0.0-0.8	**11.6**	4.8	3.3	- 8.2	6.2	11.5	1.0	**9.6**	5.5	9.6	6.9	- 4.2	9.6	9.6	6.1
mean and st.dev. per field		3.1 s.d. 6.6								6.2 s.d. 4.9					

a) based on data from BOXEM's moisture research (unpublished).
b) potential (or maximum) moisture storage.
c) data for the layer 0-80 (preceding line) divided by 6, 6 mm being the average daily evapo(transpi)ration in this zone with 2100-2200 mm annual evapo(transpi)ration (see Fig. 2.1 and 2.2).

moisture contents at pF 2.3 and 3.7 (vol. %). Stored moisture (see Table 2.3) was derived from comparing actual moisture content with this pF interval for the mentioned layer 0-80 cm depth.

From the annual evapo(transpi)ration between 2100 and 2200 mm follows a daily average of 6 mm.

The very heavy long rains of 1982 mainly precipitated from end March to mid May (670 resp. 715 of the totally recorded 800 and 840 mm on the Sokoke resp. Ngerenya field). In this period no water shortage occurred on Magarini sands.

Whereas the Sokoke soil has a higher potential moisture storage (pms) capacity, the Ngerenya soil had always higher moisture contents. From moisture data on May 14th obtained just after the last heavy rains, it appears these rains built up some storage of moisture in the rooting zone: for 5 and 10 days in the Sokoke and Ngerenya field respectively. On the Ngerenya field surplusses of stored water occurred on this May 14th, on June 25th and especially on July 9th. On the contrary water shortage (pF>3.7) was found on June 11th, especially on the Sokoke field. On this day the crop on the Sokoke field showed obvious drought symptoms:

plants with drooping and curled leaves on plots with O and P fertilizer treatments, a direct cause being the corresponding with small plants, low developed root system. By this time the crop on the Ngerenya field and on NP (and N) plots on the Sokoke field was in the silking stage that forms part of the pollination period from tasselling to blister kernel stages, which is the most sensitive stage for maize yield reduction by drought (ACLAND, 1971, and DOORENBOS and PRUITT, 1977, both cited in 3.3). The on both fields again commencing rains by the end of the tasselling stage probably prevented bad pollination.

In 1982 water availability was quite well till the end of the growing season, except on June 11^{th}. The water deficit around this date in the middle of this exceptionally wet rainy season however indicates drought is not only a hazard but common experience in this area with erratic rains.

Fertility assessment

The other characteristics mentioned in Table 2.2 are discussed for topsoil (0-20 cm) only, because this layer supplies most nutrients for crop growth.

For the Kilifi area the fertility assessment has been carried out according to two systems (cited from BOXEM et al., 1987):

- the Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS), a modification of the Kisii system (GUIKING et al., 1982, JANSSEN et al., 1986);
- the Fertility Capability Classification (FCC; BUOL et al., 1975).

Below follows the fertility assessment of both trial fields according to these systems.

During writing this report, no fertility data were at hand of profile 198/2-46 on UE112 (except for 0-20 cm obtained in Wageningen; results rest with the NAL, Nairobi) and its representative profile 21 (not determined). Therefore data from UE111 will be discussed more extendedly.

QUEFTS (Quantitative Evaluation of the Fertility of Tropical Soils)

The expected nutrient uptake for N, P and K ($kg.ha^{-1}$) and maize yield levels ($kg.ha^{-1}$) are 35 6 50 1300 for D3 and 10 3 20 400 for E3 (BOXEM et al., 1987: Table 12). These yields and uptake levels can only be obtained under good crop husbandry (see BOXEM et al., 1987) as during this research.

A recenter version of QUEFTS (see 3.3, JANSSEN et al., in press) does not classify soil fertilities, but based on chemical soil data (or experimental data) it facilitates estimation of N, P and K uptakes and grain yields (of maize).

Diagnostic properties are pH-H_2O, org. C, P-Olsen and exch. K; additional properties in the computer model are org. N and total P, and experimental recovery data. (Estimates from experimental (uptake and recovery) data are discussed in 6.3.3).

Table 2.4. Ranking of values of diagnostic properties of topsoil (0-20 cm) in terms of nutrient availability in relation to other soil properties for the soils of both trial fields (source: BOXEM et al., 1987:112, Table 10).

Diagnostic property	Range of values	Other conditions	Nutrient availability class
organic carbon[1)] ($g.kg^{-1}$)	9-17 < 9	pH-H_2O > 5.5	3 4
P-Olsen[2)] ($mg.kg^{-1}$ P)	≤ 3	org. C ≤ 17	4
exchangeable K ($mmol.kg^{-1}$ K)	< 2	org. C ≤ 28	4

1) Organic N can be used instead of organic C; the relationship is organic N = 0.1 x organic C. Many soils, however, have a C/N ratio which exceeds 10.
2) For P-Mehlich the corresponding range ($mg.kg^{-1}$ P) is: ≤ 9.

Table 2.5. Trial field properties (0-20 cm) relevant to QUEFTS.

Map unit	Profile pit 198/2-	Diagnostic properties org.C ($g.kg^{-1}$)	P-Olsen ($mg.kg^{-1}$)	exch.K ($mmol.kg^{-1}$)	pH-H_2O (-)	Additional properties CEC(AgTu) ($mmol.kg^{-1}$)	P-total ($mg.kg^{-1}$)	Combinations of nutrition avail. class[a)] N	P	K	Fert. class[b)]
UE111	47	5.1	2.8	1.6	5.6	33	n.d.	4	4	4	E3
UE112	46	9.7	2.3	1.6	5.8	43	n.d.	3	4	4	D3 (?)

a) see Table 2.4.
b) see BOXEM et al. 1987: Table 11 (and 12).

<u>FCC (Fertility Capability Classification)</u>

According to the FCC both soils are classified as S(L)ek

S = sandy topsoils: loamy sand and sand,

(L) = inplaces overlying loamy subsoil: <35 % clay but not (loamy) sand,

e = (low cation exchange capacity): a.o. CEC < 100 $mmol.kg^{-1}$ soil at pH 8.2, and

k = (low K reserves): a.o. exchangeable K < 2 $mmol.kg^{-1}$.

In the Kilifi report, UE soils are generally classified as E2 and S(L)ek, which classes adjoin D3 and E3. Both trial fields on UE11 had lower P availability (P4) than UE soils in general (P3). UE112 had a higher organic C level (9.7 mg/kg soil; N3 > 8) than generally occurring on UE (N4), but lower than 0.1 x 8 ($mg.kg^{-1}$) organic N, wherefore this soil could be reclassified D3/E3 with (expected) NPK uptakes and yields of 22.5, 3, 20 and 850 $kg.ha^{-1}$.

Compared with the FCC classification of soils on UE, these trial fields had somewhat heavier topsoils, than the general S(L). Both soils discussed before are low fertility soils.

Some additional remarks on pH, organic C and N, CEC and the sum of exchangeable bases are:

pH values of the Sokoke field are about 1 unit lower than in representive profile (r.p.) 20, but very probably not restricting crop production. - In the tropics 4 to 8 % of organic matter mineralizes per year (JANSSEN, 1978). Normally organic N contents (determined as 'total N') vary from 0.2 to 4 $g.kg^{-1}$ soil (IBID). Following quotations are from LANDON (1984). METSON (1961) mentions an N content (Kjeldahl) < 0.1 % = 1 $g.kg^{-1}$ soil very low. Thus, the obtained low N contents (0.45 and 0.69 $g.kg^{-1}$ soil) together with the found organic C levels produce relatively high C/N ratios.

In the tropics, C/N ratio is normally slightly lower than 10:1, and according to LEIGHTY and SHOREY (1930) varying from 35:1 to 3:1.) Mulching may have reduced organic N in the soil. Further, the relatively high C/N ratios found on both trial fields are probably due to burning, which causes volatilization of N and hence (possibly) low mineralization rates. Within the very low N contents, the one of Sokoke is lowest, possibly by the longer uninterrupted use of this field (see history, App. 4).

Also P-Olsen is found to be very low on both trial fields.

Both soils have a very low CEC (below 50 $mmol(+).kg^{-1}$ soil) especially on UE111. Moreover the sum of exchangeable bases of the field on UE111 is only 0.6 times as high as on the other field. This also coheres with the longer uninterrupted use of the field on UE111 (see App.4). On unmanured plots yields on the UE111 and UE112 fields can be expected to relate as 0.6 : 1.

3 LITERATURE

3.1 PHYSICAL AND CHEMICAL PROPERTIES OF OXISOLS (AFTER LEGGER, 1987)

Some physical properties: structure and aggregate stability (parts of paragraph 3.2.1 in LEGGER, 1987; some basic knowledge on the coherence of soil characteristics with (changing) pH)

Small but stable, aggregates are characteristic of Oxisols but also occur in Ultisols. These aggregates are usually smaller than 1 mm and, depending on their size, are called pseudo sand or pseudo silt.

The stability of aggregates explains the generally good physical properties of Oxisols and many Ultisols, such as a high permeability, a high infiltration rate, a low erodibility and wide limits of workability.

In most climates with pronounced dry and wet seasons, the alteration in moisture conditions causes periodic changes in the pH and hence in the surface charge and structure stability (see chapter 3.3.1).

The aggregation of the clay fraction is caused by:

- packing of the kaolin minerals, strengthened by sesquioxide-coatings,
- by crystalline forms of sesquioxides,
- and perhaps, and in that case to a lesser extent, by humus.

The forces between the sesquioxides and the clay minerals consist of hydrogen bridges and electrostatic bonding. Below pH 7 Fe(III) oxides and Al oxides have a positive surface charge and above pH 4 kaolinite has a negative charge. So, between pH values of 7 and 4, electric attraction forces exist between these minerals (SANCHEZ, 1976; EL-SWAIFY, 1980; WAMBEKE, 1974) (for more details on charge characteristics is refered to LEGGER, 1987: chapter 3.3.1).

Oxisols with a low iron content, low pH and high Al saturation, as in many sediments in Surinam and Brazil (Xanthic Ferralsols in the FAO legend) have a low structure stability, especially if they have high sand contents.

In Oxisols with larger amounts of iron oxides in the clay fraction (and pH higher than 5.0 or 5.5; S.v.L.) structure is more stable because of the stronger cementation by the iron oxides, i.e. more positive and more negative charges at the zero point of charge. (For neither of the trial fields a z.p.c. is known (S.v.L.)). This results into small but stable aggregates, in extreme cases leading to the formation of pseudosand structural elements as mentioned at the beginning of this paragraph. Above 5 % free iron oxides however, the stability does not increase any further (SANCHEZ, 1976).

Some chemical properties: charge characteristics, pHo, ZPNC (based on paragraph 3.3.1 in Legger, 1987)
Oxisols consist of mixed systems of permanent (2:1 clay minerals) and variable (a.o. sesquioxides) charge. 2:1 clay minerals are permanently negatively charged due to ion substitutions. This is reflected in CEC's exceeding AEC's and pH-H_2O values exceeding pH-KCl values. Sesquioxides are charged dependant on pH, due to amphoteric properties (see Figure 4 in LEGGER, 1987).
At pHo, no variable charge exists. Below pHo, close to the Zero Point of Net Charge (ZPNC) sesquioxides are positively charged and attracted by the negatively charged clay minerals, resulting in a stable soil structure; the colloids in a soil solution will flocculate: aggregates will be formed and soil structure will improve. Above the ZPNC, the net charge of the soil is negative; below the ZPNC positive. The further away from the ZPNC the more colloidal soil particles will peptise, resulting in a decrease in aggregate stability and in the quality of the soil structure. (Particles - and also clays and sesquioxides - are less attracted to each other as their charge becomes higher and of the same sign.) For this reason charge characteristics of soil constituents have to be considered when discussing e.g. liming and soil stability.

3.2 MAIZE AND SOIL ACIDITY

3.2.1 ACIDITY CHARACTERISTICS OF MAIZE

Main authors on this topic are ABRUÑA et al. (1974) as cited by PEARSON (1975) and SANCHEZ (1976). The trial fields on Magarini sands were Oxisols, and part of PEARSON's and SANCHEZ's data were obtained from their research on 3 Puerto Rican Oxisols, with pH-H_2O varying from 4.2 to 4.8 before liming.
On 3 Puerto Rican Oxisols, they found maximum maize yields with 10-18 % Al saturation (ABRUÑA et al., 1974, in PEARSON, 1975: Fig.11); on the same Oxisols maximum maize yields were depending on the Oxisol found in the pH-H_2O range 4.8-5.4 (as cited by PEARSON, 1975). Below 70 % base saturation and correspondingly from 30 % Al saturation, maize yield drops below 90 % of the maximum yield (as cited by SANCHEZ (1976)).
JANSSEN (1978) classifies maize as preferring neutral to slightly acid environments, which according to the SOIL SURVEY STAFF (1952) should be understood as a pH-H_2O ranging from 6.1 to 7.3 (see Table 3.1).

Table 3.1. <u>Terms to use for ranges in pH</u> (source: SOIL SURVEY STAFF, 1952).

Extremely acid	Below 4.5	Neutral	6.6-7.3
Very strongly acid	4.5-5.0	Mildly alkaline	7.4-7.8
Strongly acid	5.1-5.5	Moderately alkaline	7.9-8.4
Medium acid	5.6-6.0	Strongly alkaline	8.5-9.0
Slightly acid	6.1-6.5	Very strongly alkaline	9.1 and higher

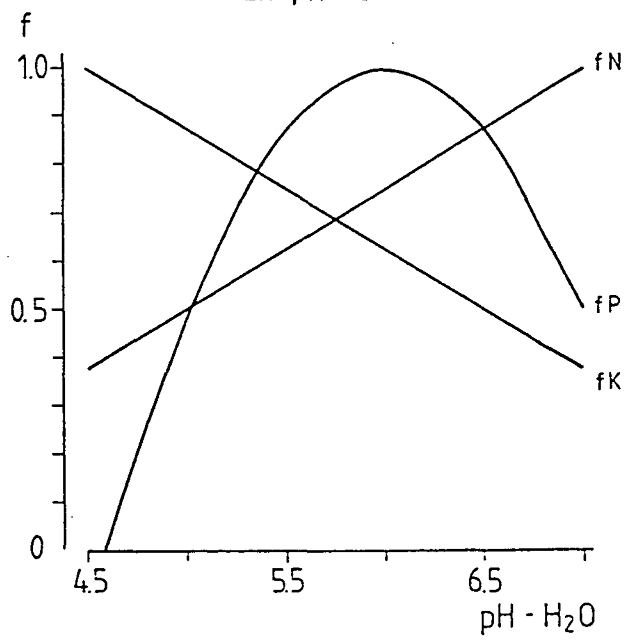
Therefore within the Oxisols developed on Magarini sands only subsoils (25 -45 cm) may have hindered growth of the crop. However, according to ten HAVE (1976) suitable pH values range from 5 to 8 (strongly acid to mildly alkaline). Thus, whether maize production will be reduced on these Oxisols north of Kilifi Creek, may largely depend upon the chosen variety and its tolerance.
Regarding <u>other annual crops</u>, beans might not do well on these soils North of Kilifi Creek, because the crop prefers neutral to mildly alkaline soils (JANSSEN, 1978:195).
<u>Concluding</u> on soil acidity and the acidity preferences of maize, liming effect on maize production is doubtful.

Table 3.2. pH values corresponding with optimum availability of plant nutrients[1].

N	6-8	Fe	4½-6
P	6-7	Mn	4½-6
K	7		
Ca	7-8½	Bo Zn Cu	5 -7
Mg	7-8½	Mb	7 -8½

1) Source: JANSSEN, 1978.

Figure 3.1. Relative availability of N, P and K dependent on pH[1].



1) Source: JANSSEN et al., in press, figure 1.

3.2.2 EFFECTS OF PH AND LIMING ON SOIL FERTILITY

The effect of pH on soil fertility is usually indirect, via its influence on the availability of nutrients, microbiological activity and soil structure (JANSSEN, 1978).

pH affects availability of plant nutrients. pH's for optimum nutrient availabilities are given in Table 3.2 based on JANSSEN (1978). For the major nutrients N, P and K Figure 3.1 presents relative availabilities according to QUEFTS (JANSSEN et al., in press).

pH-H_2O ranges of the trial fields 'Sokoke' and 'Ngerenya' were medium acid to neutral, viz. 5.6-6.9, resp. 5.8-6.8 (see Table 6.9), the lower ranges corresponding with the unlimed plots. Within these ranges liming may have increased the availability of Ca, Mg and Mb, and decreased Fe and Mn availability (after JANSSEN, 1978).

Following quotations are more specific for cereals in general and maize in particular.

Following quotations are from PEARSON (1975). According to Abruña et al.(1974) no risk of Al toxicity exists at pH-H_2O 5.4 and above on Puerto Rican Ultisols and Oxisols (Fig. 3.2). However van RAIJ et al. (1977), found no risk of Al toxicity at pH-H_2O 6.2 and above (Table 3.3). (Probably these contradictory data played a role when liming critiria were appointed.)

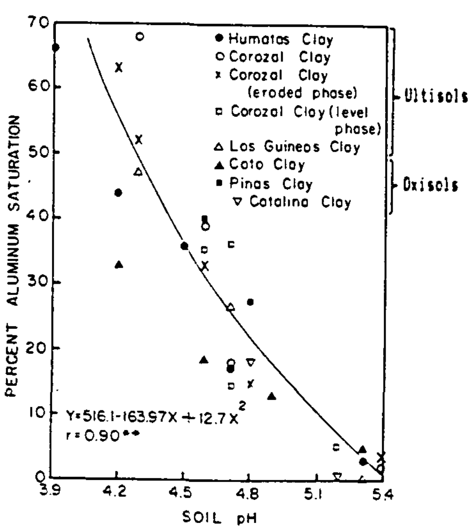


Figure 3.2.
Changes in Al saturation percentage with pH in several Puerto Rican Ultisols and Oxisols (Abruña et al., 1974).

Table 3.3. Effect of liming on soil characteristics of a Dark Red Latosol, sandy phase of Sao Simao, Sao Paulo, Brazil. Lime (38% CaO and 27% MgO) was applied in October 1973.

Lime applied ton·ha⁻¹	Date of sampling	pH	Ca + Mg	Al	Aluminum saturation %
			me·(100 g)⁻¹ soil		
0	12/19-73	4.9	0.6	1.1	65
1.5		5.4	1.6	0.4	20
3.0		6.1	2.8	0.2	7
4.5		6.2	3.0	0	0
	10/1975	4.7	0.6	1.0	63
		5.4	1.9	0.3	16
		5.9	2.9	0	0
		6.3	3.8	0	0

B. van RAIJ et al., 1977.

MARIN (1968) cautioned against overliming and stated that micronutrient deficiencies, particularly of Mn and Fe, can be induced a.o. in some cereals. FOX and PLUCKNETT (1964) stressed the danger of overliming some Hawaiian soils, from the standpoint of both depressed P uptake and possible induced Zn deficiency in some crops. They reported that chlorosis resulting from Zn deficiency appeared at around pH 7 and reached serious proportions around 7.4.

On the other hand SPAIN et al. (1974) in field screening tests on an Oxisol in the Columbian Llanos Orientales, observed that most of the acid tolerant crop species were surprisingly tolerant to high rates of lime, and reported no overliming injury to a.o. maize (up to 16 ton. ha^{-1}).

The results summarized above seem to indicate that the overliming hazard is not reliably predictable. Yield depressions occurred most in pot tests, where the entire root system was confined in the limed zone (PEARSON, 1975). - In case overliming took place on the trial fields in the Kilifi area, still part of the maize roots utilized the unlimed zone below 15 cm depth.

3.3 MAIZE AND MOISTURE AVAILABILITY

<u>Critical periods for soil water stress for maize</u> I: from ACLAND, 1971, II: from DOORENBOS and PRUITT, 1977. Maize yields are negligible when evapotranspiration (ET) is severely restricted during the tasselling stage. In decreasing order of importance the critical periods are the

- pollination period from tasselling to blister kernel stages,
- period prior to tasselling,
- grain filling periods.

The pollination period is very critical if no prior water stress occurred.

3.4 EVALUATION OF HARVEST DATA

Yields and nutrient uptakes are mainly compared and assessed with estimates obtained with the QUEFTS computer model, but also with data from SANCHEZ (1976) and JANSSEN (1978).

In QUEFTS (Quantitative Evaluation of the Fertility of Tropical Soils) the definition of fertility is restricted to the capacity of a soil to provide plants with nutrients. The QUEFTS model provides a fertility classification predicting a maize (grain) yield estimate and belonging N, P and K uptakes. These estimates are based on four diagnostic top soil (0-20 cm) properties - (organic C ($g.kg^{-1}$), P-Olsen ($mg.kg^{-1}$) exchangeable K ($mmol.kg^{-1}$) and pH-H_2O - and two additional properties- (CEC at pH 8.2 ($mmol.kg^{-1}$) and P-total ($mg.kg^{-1}$). Alternatively however these estimates can be derived from experimental N, P and K uptake data obtained from unfertilized maize (see JANSSEN et al., in press). Both ways of obtaining maize yields and uptakes from the QUEFTS model require nutrient recoveries as well.

Table 3.4 presents some data on nutrient uptakes and maize yields from SANCHEZ (1976) and JANSSEN (1978). Table 3.5 gives the expected range of nutrient concentrations in mature grains (after WALSH & BEATON, 1973), with which nutrient contents (see 6.2 and 6.3) are compared in order to assess these data.

Table 3.4. Nutrient removal by maize (from SANCHEZ, 1976 and JANSSEN, 1978).

		Yield 2)	N u t r i e n t ($kg.ha^{-1}$) 1)							
Source	Part	($ton.ha^{-1}$)	N	P	K	Ca	Mg	Mn	Fe	B
Sanchez (1976)	Grain	1.0	25	6	15	3.0	2.0			
	Stover	1.5	15	3	18	4.5	3.0			
	Total	2.5	40	9	33	7.5	5.0			
	Grain	4.0	63	12	30	8.0	6.0			
	Stover	4.0	37	6	38	10.0	8.0			
	Total	8.0	100	18	68	18.0	14.0			
JANSSEN (1978)	Total		80-120	20-30	100-150	20-50	20-30	>1.0	0.90-1.50	0.10-0.45

1) atomic mass (M) 14 31 39 40 24.5
(needed for computation of nutrient contents from SANCHEZ's data).
2) yields on a dry weight basis.

Table 3.5. The normal expected range in element concentration for grains at maturity (derived from table 4 in WALSH & BEATON, 1973).

	% of dry weight	$mmol.kg^{-1}$
N	1.0 - 2.5	714 -1,786
P	0.2 - 0.6	65 -194
K	0.2 - 0.4	51 -103
Ca	0.01- 0.02	2½ - 5.0
Mg	0.09- 0.20	37 - 82
Mn	5 -15 $mg.kg^{-1}$	(91 -273) $\times 10^{-3}$

JANSSEN (1978) states Mn deficiency and toxicity occur below 20, and beyond 500 - 1000 $mg.kg^{-1}$ respectively.

3.5 SOME BACKGROUND TO ASSESSMENT OF THE LEACHING TRIAL

Definition The hydraulic conductivity (or permeability) of a soil, K, in $cm.hr^{-1}$ or $m.day^{-1}$, defines the volume of water which will pass through unit cross-sectional area of a soil in unit time, given a unit difference in water potential.

Due to rapid draining of the larger pores there is a rapid decrease in K with decrease in water content in unsaturated soils. When the water content is reduced to the field capacity moisture content, K commonly decreases to 1/100 or 1/1000 of its value at saturation.

4 DESIGN

Two questions existed before this research was designed. Bennema's qualitative question was: can locally found calcareous dunesand (c. 70 % $CaCO_3$) increase crop yields in this region (first yard-stick being maize yields)? The second question concerned soil fertility: within the studies on the fertility of the Kilifi soils, data were wanted on nutrient availability and crop response to fertilizers for the two major soil units developed on Magarini sands.

The study consisted of four parts:

1. a survey of the acidity of soils developed on Magarini sands;
2. a liming trial;
3. a fertilizer trial;
4. a leaching trial.

The liming and fertilizer trials were combined. The trials were conducted on two locations, representative for the legend units UE111 and UE112, being the largest units developed on Magarini sands.

4.1 ACIDITY SURVEY 'MAGARINI SANDS'

In this survey soils were considered acid if pH-H_2O was (below) 4.8 or pH-KCl was (below) 4.0 (pH-H_2O 4.8 is very strongly acid (see p.19, Table 3.1)). Among the possibly acid soils are the red soils with low organic matter content, developed on Magarini sands. It was decided to limit the acidity survey to these soils. Within the land area of the Kilifi mapsheet (200,000 ha) they cover approximately 7,000 ha or 3½ % distributed over an area of 4,700 ha south of Kilifi Creek and one north of Kilifi Creek of c. 2,100 ha (see Figure 4.1, given as a separate annex at the back of this report). North of the mapsheet the northern Magarini area still extends further. Planned was to sample the whole Magarini sands area within the mapsheet, taking about one composite soil sample per 100 ha (= 1 km^2), in order to compile a pH-map of the Magarini sands. Such a map could indicate whether or not soil acidity of Magarini sands has been and is hampering crop growth on these soils.

4.2 LIMING TRIAL

A liming trial would be undertaken if acid soils (see 4.1) would be found. The objectives of this trial were to study the effect on maize yields of increasing pH-H_2O to 5.4, and to compare the effectiveness of two liming materials. The liming materials were calcareous dunesand and agricultural lime. Calcareous dunesand occurs along the coast north of

Kilifi (see Figure 1.2 or 4.1). The idea of applying it arose from a lab date obtained in the project before 1982, estimating its lime content at 70 %. Agricultural lime functioned as a reference.
The decision to increase pH to 5.4 was based on the results of studies summarized by e.g. SANCHEZ (1976). However, other studies have shown that crops perform better if grown on soils with pH 6.0 than on soils with pH 5.4 (van RAIJ, 1982). Janssen and Bennema agreed upon liming to pH 5.4.

4.3 FERTILIZER TRIAL

The fertilizer trial was part of a larger soil fertility research designed to study the nutrient supply by the various soils of the Kilifi area. In former studies (de BIE, 1982; BATJES, 1982; WINKELHORST, 1983) it was shown that on most soils nitrogen was the most limiting nutrient, and that phosphorus became limiting once nitrogen had been applied as fertilizer, while application of potassium did not increase yields. Therefore it was decided to study N and P only.
The experimental design was a 2^2 factorial, with N at 0 and 50 $kg.ha^{-1}$ and P at 0 and 30 $kg.ha^{-1}$. These fertilizer levels were chosen, because they usually were the most remunerative ones in former studies. - Of N fertilizer, 25 kg. ha^{-1} would be applied at the planting date, while the application of the other 25 $kg.ha^{-1}$ was planned 6 weeks after planting to increase total N effect.

The fertilizer and the liming trials were conducted in the same trial fields and were consisting of three replicates or blocks. In the liming trial one fertilizer treatment was used: 50 $kg.ha^{-1}$ N + 30 $kg.ha^{-1}$ P, because lime effects were expected to be most clear at these fertilizer levels. In the fertilizer trial the replicates received different lime treatments; in other words block and liming effect were confounded.
(This rather complicated design was the result of a misunderstanding: The fields had already been limed before the final decisions on the design of the fertilizer trial were taken.)

<u>Water availability</u>
During the growing season, it was decided to sample both trial fields to determine readily available water for maize. Perhaps lime leaching during the growing season could also be studied this way. Further, it was a question whether a simple rooting pattern inventory could be undertaken to observe differences in rooting depth between different treatments.

Table 4.1. Treatment schemes[1].

SOKOKE trial field
S 3°30'47" E 39°48'16"

NGERENYA
S 3°31'21" E 39°49'45"

LIME treatment schemes

North ↑

plot no. 4 7 9 25-30

9 z	10	11	12	29 d	30 z
5	6	7 d	8	27 a	28 d
1	2	3	4 a	25 z	26 a

slope direction 11 %

plot no. 15 16 19 31-36

21	22	23	24	35 a	36 z
17	18	19 a	20	33 d	34 a
13	14	15 d	16 z	31 z	32 d

slope direction 4-5 %

Lime treatments:

z = zero
d = calcareous dunesand
a = agricultural lime

The three replicates (all confounded with NP fertilizer treatment) consisted of treatment plots numbered as follows:

Rep. no.	plot no.	(alternative)	Rep. no.	plot no.	(alternative)
1	25 29 27	(30 29 27)	1	31 33 35	(36 33 35)
2	30 28 26	(25 28 26)	2	36 32 34	(31 32 34)
3	9 7 4		3	16 15 19	

FERTILIZER treatment schemes

North ↑

plot no. 1-12

fertilizer trial				liming trial	
9 NP	10 P	11 O	12 O	29	30
5 P	6 N	7 NP	8 N	27	28
1 P	2 O	3 N	4 NP	25	26

slope direction 11%

plot no. 13-24

fertilizer trial				liming trial	
21 P	22 O	23 P	24 N	35	36
17 O	18 N	19 NP	20 O	33	34
13 N	14 P	15 NP	16 NP	31	32

slope direction 4-5%

Fertilizer treatments:

O = zero
N = Nitrogen (50 kg.ha^{-1})
P = Phosphorus (30 kg.ha^{-1})
NP = N and P combined

Replicates (confounded with liming)
- zero lime treatment
- calcareous dunesand
- agricultural lime

1) The plots 1-12 and 13-24 were meant for fertilizer testing, whereas the plots 4,7,9 and 25-30, resp. 15,16,19 and 31-36 i.e. all plots with NP fertilizer treatment were used for the lime trial.

To increase the degrees of freedom for the analysis of variance, the results of both locations can be pooled.

Table 4.2. ANOVA tables.

FERTILIZER trial	single field	pooled fields	LIMING trial	single field	pooled fields
Niv	1	1	Niv	1	1
N*	1	1	Calc. dunesand* } lime*	1 } 2)	1 } 2)
P*	1	1	Agric. lime* } lime*	1 } 2)	1 } 2)
NP*	1	1	Location*		1
Location*		1	(Lime x location)*		2
(N x location)*		1	Replicates*	2	2
(P x location)*		1	Error*	4	10
(NP x location)*		1	TOTALS	9	18
Lime*	2	2			
Error*	6	14			
TOTALS	12	24			

* *effect perpendicular to Niveau.*

4.4 LEACHING TRIAL AT THE SOKOKE FIELD

Objectives

(This trial was undertaken after the harvest.) One of the reasons for the liming trial on somewhat acid soils was that acidity can hinder nutrient availability, and so reduce crop growth. Magarini subsurface soils are more acid than their surface soils. During the drier season water is only available in these subsoils, e.g. below 30 cm depth. It is however questioned whether root growth is sufficient in that layer to extract enough nutrients. Besides nutrient availability is hindered by the acidity of the subsurface soil.

Further it was questioned whether some lime would leach (Bennema's statement), or whether the applied lime would react quantitatively with H^+-ions, thus preventing any leaching as lime (Janssen's statement).

The leaching trial was set up to answer part of these questions by estimating whether or not leaching of $CaCO_3/MgCO_3$ and Ca^{2+}/Mg^{2+} occurs or not in a timespan of c. 10 years, imitated by percolation of large amounts of water.

For reasons explained in 5.4, the leaching trial took place at the Sokoke field only, on 3 plots representing the 3 liming treatments[1] zero, agricultural lime, calcareous dunesand (0, 1.14 resp. 2.32 ton. ha^{-1} of '$CaCO_3$'[2]).

1) Bennema's suggestion to leach with gypsum ($CaSO_4$-$2H_2O$) too, was neglected. Gypsum leaches relatively easy, but does not increase pH and was not applied in the preceding trial.

2) In this report '$CaCO_3$' means: the sum of all compounds that show a liming reaction like $CaCO_3$, $Ca(OH)_2$ and $MgCO_3$, expressed as the equivalent % or ton.ha^{-1} $CaCO_3$.

5 METHODS AND MATERIALS

5.1 ACIDITY SURVEY 'MAGARINI SANDS'

Methods Aiming at an acidity map, the following activities were undertaken. The soil map was drawn on topographic maps (1:50,000) for use during the field work, from the preliminary mapsheet 198 (1:100,000) and the final southern half of soil mapsheet 198 (1:50,000). Observation sheets were designed (see App. 7).

The Magarini sands area was regularly sampled every 100 ha (km^2) at depths of 0-25 and 25-45 cm. The samples consisted of 3, or sometimes 2, subsamples taken from soil not influenced by the construction of the road. Auger sites were marked on the topographic maps. Next, land use around the sampled spots was observed, and the colour of the dry soil was determined; however, these data are not presented in this report because no very strongly acid soils (see Table 3.1) were found (see 6.1)[1].

In the laboratory, all samples were measured for pH-H_2O. At the start of pH-KCl measurements, the pH recorder of the Kilifi project was put irreparably out of order, - this being very unfortunate, because these pH estimates are generally more reliable than pH-H_2O estimates. At the laboratory (Kilifi, office house) pH-H_2O of the samples was determined as follows.

Alternative instruction for the procedure of pH estimation in Kilifi

(According to BOXEM, results from this procedure were identical to results obtained with the official instruction for the M.Sc. course, Agricultural University, Wageningen (1982, pers. comm.).)

Weigh out 8.00 g of air-dry soil, transfer to a glass bottle and add 20 ml of water, or KCl or $CaCl_2$. Shake mechanically 3 times 5 minutes with intervals of half an hour. Allow the suspension to settle for 24 hours and measure the pH in the supernatant liquid.

Remarks: 1) By shaking possibly present gypsum will dissolve. (However, in these poor slightly acid sandsoils presence of gysum is improbable.)

2) Vast numbers of bottles can best be shaken in a wooden case.

In Wageningen, a pH test was undertaken in an attempt to solve some interpretation problems (see 6.1). The amount of soil weighed out to each pH determination had to be diminished to 2 g of sample per shaking

[1] In order to check upon connections between soil acidity, and soil unit and land use, these data could be processed.

tube, due to lack of sample material. Further the same method was applied as in Kilifi (1:2½ v/v).
In Wageningen the more acid samples from the area north of Kilifi Creek were measured again for pH-H_2O and pH-KCl. The rough maps (1:50,000) were planned to be refashioned into one final map (1:100,000). The fraction $\frac{2 \times \text{pH-H}_2\text{O topsoil} + 1 \times \text{pH-H}_2\text{O subsoil}}{3}$ or $\frac{2A + B}{3}$ was used to divide the results into acidity classes, thereby weighing the importance of both layers for crop growth. The acidity classification would facilitate the compilation of the acidity map. (However, after evaluating pH data, the acidity map was cancelled(see 6.1).)

5.2 LIMING TRIAL

For methods and materials used for both liming and fertilizer trial, the reader is referred to 5.3. Next to a liming trial on two trial fields, an incubation trial with both liming materials was undertaken at the Kilifi laboratory.

Liming trial

Firstly suitable trial fields were sought with the help of an assistant (see 5.3). For details on the contacts with farmers the reader is referred to Appendix 8. If the farmer permitted use of his field for a trial, two to six composite soil samples were taken (0-25 and 25-45 cm) of which in the lab pH values were estimated. The first field found on UE111 met the research requirements. On UE112 the first two fields were abandoned, but the third field was suitable (see App.12).

Calcareous white dunesand (see Photo 5.1) was collected from dunes along the Bofa road near Kilifi (see Figure 1.2) with a pick-up. Agricultural lime was obtained from the Kenya Farmers Association (KFA)-Mombasa branch[2].

On the field, all mulch (dead fallow vegetation) was removed. Rectangularity of the field was reached with the theorem of Pythagoras: $c^2 = a^2 + b^2$. Next the treatment plots were set out. - Weighed amounts of lime were worked through a soil layer of c. 15 cm depth with a rotovator on March 6th, (3½ weeks before the onset of the rains).
The fields were sampled in and below the limed layer from 0-10 and 20-30 cm on March 23rd.

[2] In bags of 50 kg with the direction HOMA LIME Co. Ltd., Koru, P.O. Box 1 and Calcium Carbonate (50 kilos) factory analysis 90 % $CaCO_3$ at a price of 320 Ksh. per ton exclusive transport costs.

In the lab pH was measured in the supernatant liquid after 24 hours according to the instruction given in 5.1, and after 80 hours.

Photo 5.1. Place of origin of calcareous dunesand (see Fig. 1.2). The white dunesand contained c. 94 % '$CaCO_3$' see footnote 1 in 6.2.1.2). This layer of fine white sand was in places 30 cm deep (WO 2).

Incubation trial

The following activities were undertaken to incubate unlimed samples (taken at the trial fields on March 23th) on field capacity with 5 lime treatments: apart from one zero treatment, the four other treatments aimed at an increase of pH of 0.5 and 1.0 unit respectively, using both liming materials.

Instructions on bringing air-dry soil to field capacity

The mentioned samples were divided into 5 (or if samples weighed less than 0.5 kg, 4) subsamples of 100 g of air-dry soil. First for both trial fields, water was added to 100 g of air-dry soil (, while kneading for homogeneity) until it was brought to its upper plastic limit or liquid limit (transition from smearing to soil flow). By then the weight of the soil was (100 + a) g (a = water weight). A rule of thumb says: a soil is on field capacity (pF 2) when containing 60 % of the water content of its liquid limit state. Thus 100 g of air-dry soil is incubated at field capacity by addition of 0.6 x a g demi-water (and kneading again).

Calculations of lime requirement in the incubation trial (based on rough estimates). The pH of Surinam sandy soils (with similar characteristics as the Magarini sands) increased by 1 unit, if base saturation at pH 4 was increased with 30 % (JANSSEN, 1978: 189 and pers. comm.). The CEC of Magarini sands was estimated at 2.0 mmol(+).100 g^{-1}, and thus adding 0.6 mmol(+).100 g^{-1} of lime would result in this increase by 1 pH unit. As 1 mmol(+) of $CaCO_3$ = 50 mg, 30 mg $CaCO_3$ was needed. $CaCO_3$ contents of calcareous dunesand and agricultural lime were 70 % (estimate from before 1982), resp. 90 % (factory analysis). The trial aimed at pH increases of 0.5 and 1.0 unit. The calculated treatments were zero, dunesand 21.4 and 42.9 mg, and agricultural lime 16,7 resp. 33.3 mg (see Table 15.2 in App. 15). The amount of water and 1M KCl respectively to be added to incubated subsamples of 8 g of air-dry soil for pH determination, is computed in Table 5.1.

Table 5.1. Procedure for pH estimation of samples incubated on field capacity (adapted from the procedure described in 5.1).

	Sokoke	Ngerenya
100 % moisture (liquid limit) in 100g air-dry soil weighs a (g)	22	28.5
60% moisture (field capacity) in 100g air-dry soil weighs a x 0.6 = b (g)	13	22
8.00 g of air-dry soil weighed out for pH estimation contains in incubated form b x $\frac{8.00}{100}$ = c (g) water	1.04	1.36
pH-H_2O: addition of aquadest 20.0 − c = **d** (ml)	18.96	18.64
pH-KCl: for this estimation, the water content of the incubated samples is neglected	20.0	20.0

5.3 FERTILIZER TRIAL

Selection of trial fields

The fields should represent the two largest soil units distinguished within soils developed on Magarini sands viz. UE111 and UE112. De BIE (1982) worked also on UE111, but his field was too sandy to represent this unit. Suitable trial fields were sought in the neighbourhood of formerly sampled spots that cohered with pH of 4.8 or lower. Further, suitability meant in this case: a field of about 500 m^2, homogeneous (e.g. without ant-hills) and with minimal slope.

Crop; spacing of plots and plants; border effect

Maize, Zea mays L. cv. Coast Composite was choosen as test crop, as maize is the main staple crop in the Kilifi area; "Coast Composite" is used to enable comparison with previous experiments and to facilitate duplication of the experiment, which would be difficult with the vaguely defined local varieties.

Plot size was planned at 4.5 x 4.5 m, and plants spaced at 90 x 30 cm which resulted in 75 plants per plot. Because border plants were excluded, only 33 plants were left for observation. Plant rows were planned north-south, but due to an error they were planted east-west in Ngerenya.

At the **office** several materials were prepared. - Rain gauges were prepared as follows. Plastic tubes of c. 13 cm diameter were exactly perpencicular sawn into pieces of about 1 m length. Each piece was closed at one end by glueing a plastic square as foot. - Few goats and chickens were observed in the vicinity of the trial fields, which formed a reason to fence them both. About 15 poles of 3 m length were prepared, as well as c. 500 wooden stakes (length c. 2 m). The stakes were placed every 3 to 4 dm and intertwined with the barbed wire, which was stretched in 4 heigths in the fence. Next, the stakes were pushed 1 to 2 dm into the ground. Bamboo was split up and made into pickets for marking plots and plot rows (2 x 28 + 2 x 120; c. 50 cm length). - A measuring chain was made to which red pieces of rope were knotted at planting distance (every 30 cm) coinciding with blue ones at row distance (every 90 cm). - Also a planting stick was made for pressing plant holes of 4 cm depth. The amounts of fertilizer required per row were weighed out at the office and put into small plastic bags. Each plot counted 5 rows. Both N and P were applied to 24 plots. Thus 120 pockets of P fertilizer were prepared, and as 50 $kg.ha^{-1}$ N was to be applied in two halves, 240 bags of N fertilizer. (For calculation of fertilizer weights, see App. 9.)

Field activities roughly consisted of crop husbandry and observations.

Husbandry

Land preparation and soil management in the (T.P.I.P.) trials

Appendix 4 gives a description of farmers practices.

Trial fields were cleared with a hoe, and the fallow (grass) vegetation was put aside on the farmers fields, as mulching should not be tested and the soil was to be worked with a rotovator. In this situation, the heavy rains on (except for the young maize plants) bare soils in the beginning of the growing season, caused 1½ to 2 cm sheet (and rill) erosion on the Sokoke field (slope 7-11 %) and about 1 cm on the Ngerenya field (4-5 %). (Soil level adjoining to the maize plants was higher than farther off (see Photo 5.2)).

Photo 5.2. **Slight** (on the Ngerenya trial field; slope 4 - 5 %) **to moderate** (on the Sokoke trial field; slope 7 - 11 %; this photo) **sheet and rill erosion - in clean weeded trial fields without mulch, after heavy rains.** Even one small gully occurred on the Sokoke field (WO 25).

Both farmers applied the fallow (grass) vegetation as mulch (see Photos 5.3 and 5.4), thus preventing part of the erosion due to heavy tropical rains.

After liming (see 5.2), the plots were delineated again with the measuring tape (30 m) and marked with short wooden sticks. Next plot rows were set out with bamboo pickets.

The period from planting to harvesting lasted 18 weeks, a little more than 4 months, from April 1st in Sokoke resp. April 2nd in Ngerenya to August 6th. On the **planting** dates was worked per plot. First the fertilizers were applied by making furrows of 8-10 cm deep with a hoe. The P and N fertilizer were distributed equally over the rows after which the furrows were closed with a rake. Then plant holes were pressed of 4 cm depth along the planting chain. Per stand 3 seeds were planted, and somewhat more than the prescribed ½ g (a tip of a tea

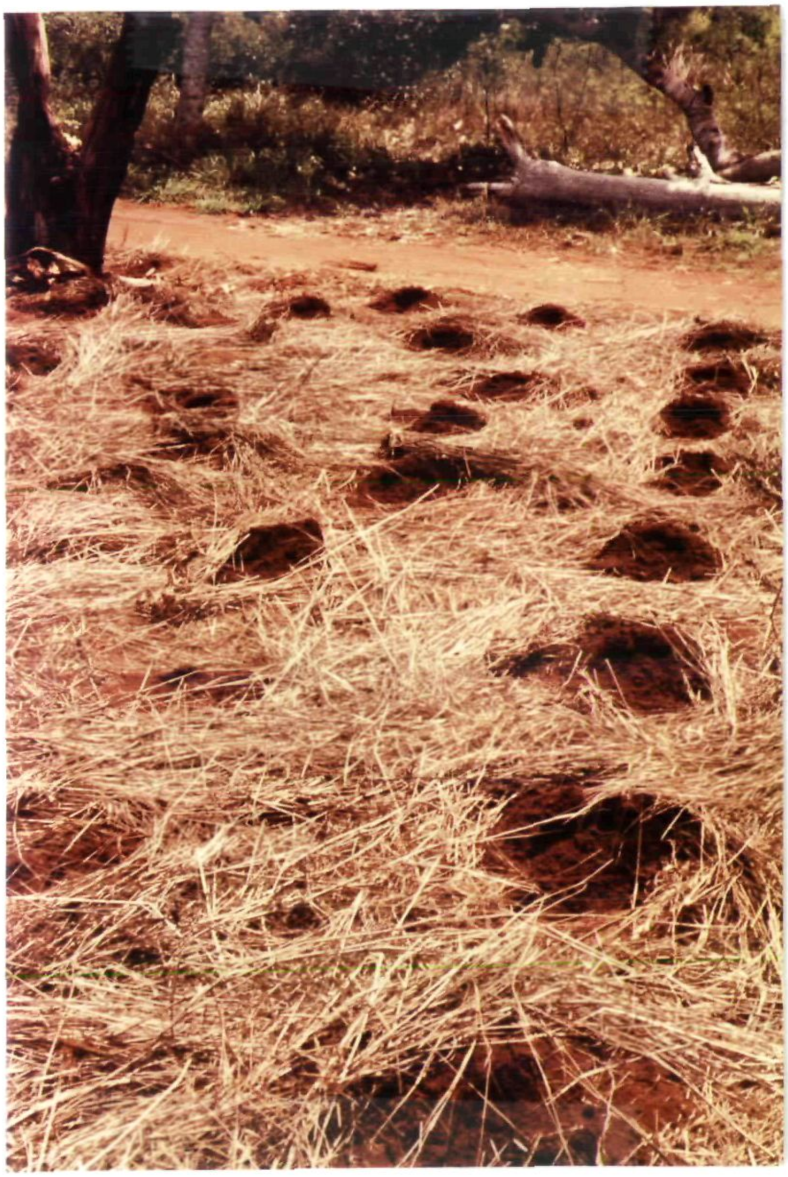


Photo 5.3. Farmers practice (farmer Malim, proprietor of the land whereupon the Sokoke trial field was established): burning in the past (see tree trunk at the top, left), utilizing the fallow vegetation as mulch (which reduces erosion hazard). Later in this season maize was grown on this spot in a not rectangular stand arrangement (c. 1 stand.m^{-2}, c. 6 plants per stand), which was partly intercropped with cassava (WO 8).

spoon) of the pesticide Furadan was added to prevent a.o. damage from stalk borers. Next the holes were closed and pressed to obtain good contact between seeds and soil.

Photo 5.4 shows the Sokoke field c. 1 week **after planting.** After 2 weeks the stands were thinned to 1 plant per stand. Empty stands as well as stands with only weak plants were replanted; the weak plants were not pulled out to give them a chance to recover; these stands also received two plants with shortened leaves, thinned out elsewhere. Replanted stands were thinned two weeks after replanting.

The fields were weeded 2, 4½, 6, 10 and 12 weeks after planting. The bulk of weed growth occurred in the first months. Furadan was applied in the funnel 4½ weeks after planting at a growing stage of 10-11 leaves. According to literature this should have taken place at a stage of 6-7 leaves, but the abundant first application probably compensated for this lateness.

Application of the second half of the N fertilizer planned 6 weeks after emergence, was delayed until 8 weeks after planting because of the excessive rains. It was worked in with a rake at the uphill side of the plant rows.

Photo 5.4. Sokoke trial field c. 1 week after planting (background: an old ant-hill and a strip of forest remnants) (WO 6).

Close to each trial field, a profile pit was dug and described according to FAO guidelines (1977).

Moisture sampling was undertaken on both fields from medio May every fortnight to July 9th (in which period the heavy rains were over) for moisture determination. Samples were taken every 10 cm to 3.0 m deep, mostly in border rows, thus not using the possibility to study leaching of lime during the growing season. This sampling depth was chosen because maize roots may extend to c. 3 m depth (2.5 m, PURSEGLOVE, 1972; c. 3.6 m in deep well drained fertile soils, ACLAND, 1971). Moisture contents (weight %) of all samples were determined in the Kilifi laboratory. In order to assess moisture availability for crops, soil moisture storage[3] was computed by subtracting moisture weight percentage at pF 3.7 from the corresponding percentage at pF 2.3 and multiplying this figure by the bulk density (basic data in App. 23).- Ring samples for pF determination were taken from the adjoining profile pits at distinguishing depths (three samples per depth) i.e. 0-10, 20-30, 50-60, 90-100, 140-150, 200-210, 270-280 cm, thus somewhat reflecting the decrease of root weight with depth.

Rooting pattern studies in the trial fields appeared to take too much time to be undertaken.

[3] This measure was also used by BOXEM et al., 1987 (see Appendix 23).

At the day of harvesting, August 6^{th}, first plants from border rows were cut down and put outside the field on heaps. Later the cobs were teared off, put in bags and brought to the farmer as first part of the harvest. Later he received the rest (see App. 8).

The procedure at the remaining net plots was as follows. First cobs were harvested, collected in a pouch and weighed by hanging the pouch onto a steelyard. After this, the ears were put into large numbered paper bags. Then stalks and leaves were chopped down, bundled and weighed too. Next they were sampled by cutting some transverse sections of c. 5 cm length out of the lower, middle and higher one third of the bundle (see Photo 0.1), mixing this on a piece of canvas and filling a numbered 4 l plastic bag with part of this sample. This bag was put in the corresponding paper bag.

After the harvest, the fences were dismantled and stored at the office. Soil sampling took place on about half of the treatment plots at 0-5, 7½-12½, 15-20, 22½-17½ cm (3 auger spots per plot; part of the sampling depths of the leaching trial to facilitate comparison with data (to be) found in the leaching trial (see 5.4)).

In the lab ears were separated in husks, grains and spills. Of components as well as of stover samples fresh weights were determined, after which (sub-)samples were dried in a stove for 24 hours at 70°C to estimate moisture content and dry matter production. Dried 10 grams samples of grains and stover were packed hermetically and sent to The Netherlands for chemical analysis.

Field observations

One week after planting (see Photo 5.4), emergence was counted roughly (emerged stands), whereas after two weeks emergence was counted exactly (emerged stands and emerged plants per stand). In between those observations, general field observation sheets were prepared with space for every stand (App. 10). Also a bookkeeping was held of replanted stands. - Further observations were on the level of the rain gauge (every week of fortnight), saltstress, symptoms of pests and diseases, growth differences and fertilizer effects, chlorosis, plant height[4], tasselling[5], empty stands, soil (profile pit description), and harvest weights.

[4] Plant height was measured halfway the growing season (May 28^{th}, after 8 weeks) and defined as: height in dm from the soil surface to the greatest height of the top leaf.

[5] Tasseling was counted during three weeks on June 4^{th}, 11^{th} and 18^{th}; each plot was counted twice to estimate the 50 % tasseling point by calculation afterwards. A plant was counted as tasseling if stamina were producing pollen.

Laboratory analyses and data processing

Part of the soil analyses were carried out according to HOUBA et al. (1985[a]): determination of organic matter according to Kurmies, CEC and base saturation with 0.01 M silver thiourea, pH, and total nitrogen as estimate for organic N, and phosphorus in a sodium-hydrogen-carbonate extract (Olsen's method). - Chemical analyses of crop samples took place according to NOVOZAMSKY et al. (1983) and HOUBA et al. (1985[b]) after digestion with H_2SO_4-Se-salicylic acid-H_2O_2.

After finishing and checking all calculations for both trials, all results were filled up in non-randomized schemes (see App. 11), and treatment means were computed.

5.4 LEACHING TRIAL

Choice of leaching water and leaching spot

The composition of rain water collected at Kilifi headquarters, was considered representative for normal rain water.

As labour and materials were limited, leaching could only take place on one trial field. The Sokoke field was chosen because of its lower CEC, and hence presumably stronger leaching effect.

The choice of the spots to be leached was a delicate matter. The field slopes 11 % along the diagonal 'SE-NW' (see Table 4.1) and was not mulched as is farmers practice; due to the method of cultivation the surface was very smooth. During the growing season the precipitation amounted to about 840 mm, exceeding the seasonal average with 80-90 %. The extremely heavy rains caused a loss of 1½ - 2 cm (10-13 % of the limed layer of 15 cm!) of the top soil as a result of sheet and also some rill erosion. Therefore the upslope plots at which no mixing of liming materials could have taken place, were chosen for the leaching trial. These plots numbered 30, 28, and 26 were all treated with N and P, and limed with resp. no lime, calcareous dunesand, and agricultural lime, and situated as follows:

North ----- 30 28 26 . For more details is referred to Figure 5.1. At the office most materials were available i.e. office rain water; a water level; plastic bottles (for water sampling); 3 rings made out of a drum, with c. 60 cm diameter (πr^2 = 0.28 m^2); flexible plastic tubes for water transport on the field); 2 drums of 200 l and a wooden lid covering both of them, and 6 water-tanks of 25 l (for transport of water to the field); 3 piles to hang on 3 water-casks.

Other materials had to be adapted before they became of use. The bottoms of the ring covers were perforated at regular distances

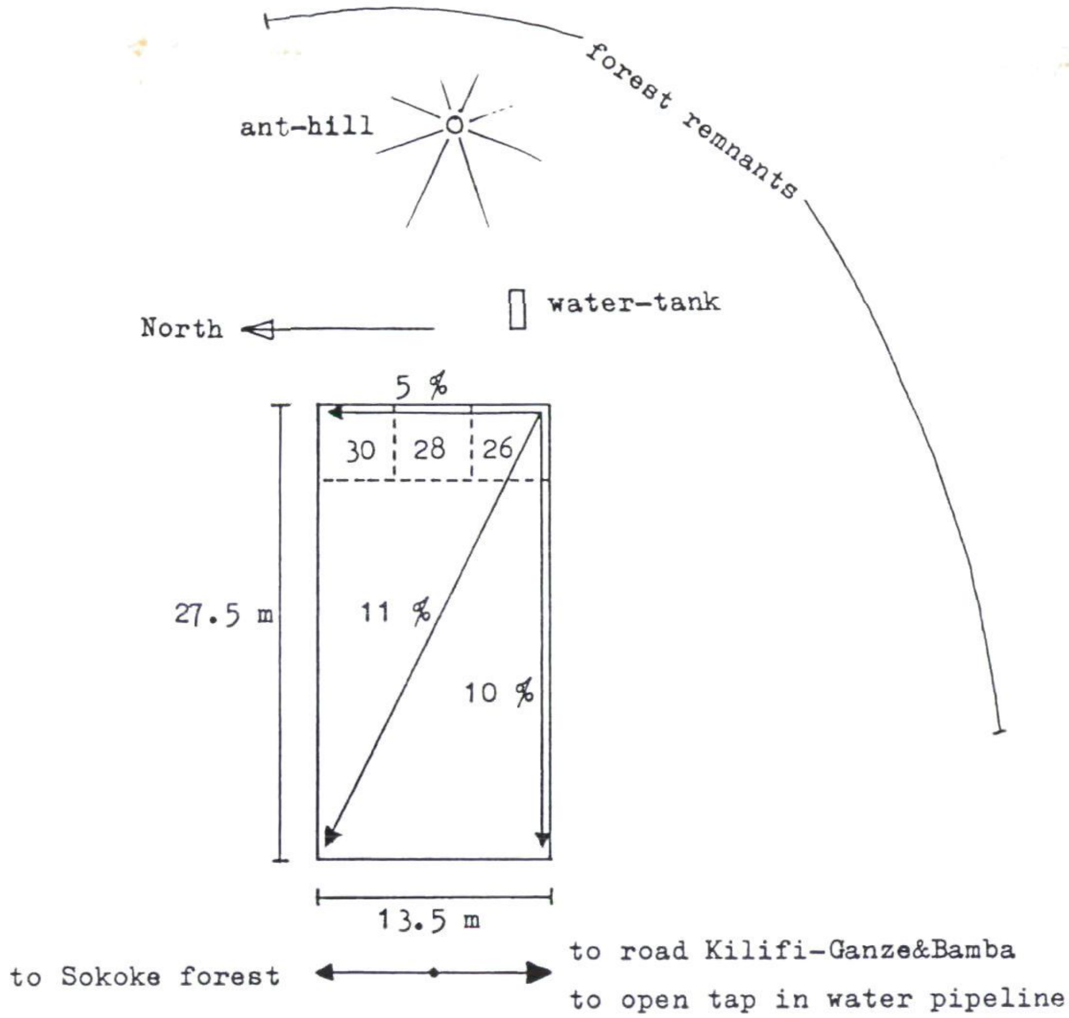


Figure 5.1. Lie of the Sokoke field, its slopes and leaching plots.

according to a three-equal-cornered relation. Striving for equally divided water distribution when level. The freight container of a trailer was dismantled, and converted into a water-tank, welding the bolt gaps in its bottom. The underframe of the trailer served for transport of the drums.

The leaching trial took place from Tuesday 7th (c. 9.00 p.m.) to Saturday 11th (1.45 p.m.) of September and lasted almost 90 hours. On Tuesday, the leaching trial was set up in the field, taking care that leaching spots lay within the net plots and had greatest possible mutual distance. Further these spots were lain between the 3rd and 4th plant row, numbering these rows from upslope. Photo 5.5 and Figure 5.2 show the set up in the field.

The water-casks functioned as intermediates between the main water-tank and the rings. With the taps of the water-casks, it was attempted to stabilize the outflow on a level that the soil was not inundated but percolation was taking place, thus imitating rainfall.

Photo 5.5. Lay-out of the leaching trial. The water-tank was placed upslope to create water pressure. For further explanation is referred to Figure 5.2 (WL81).

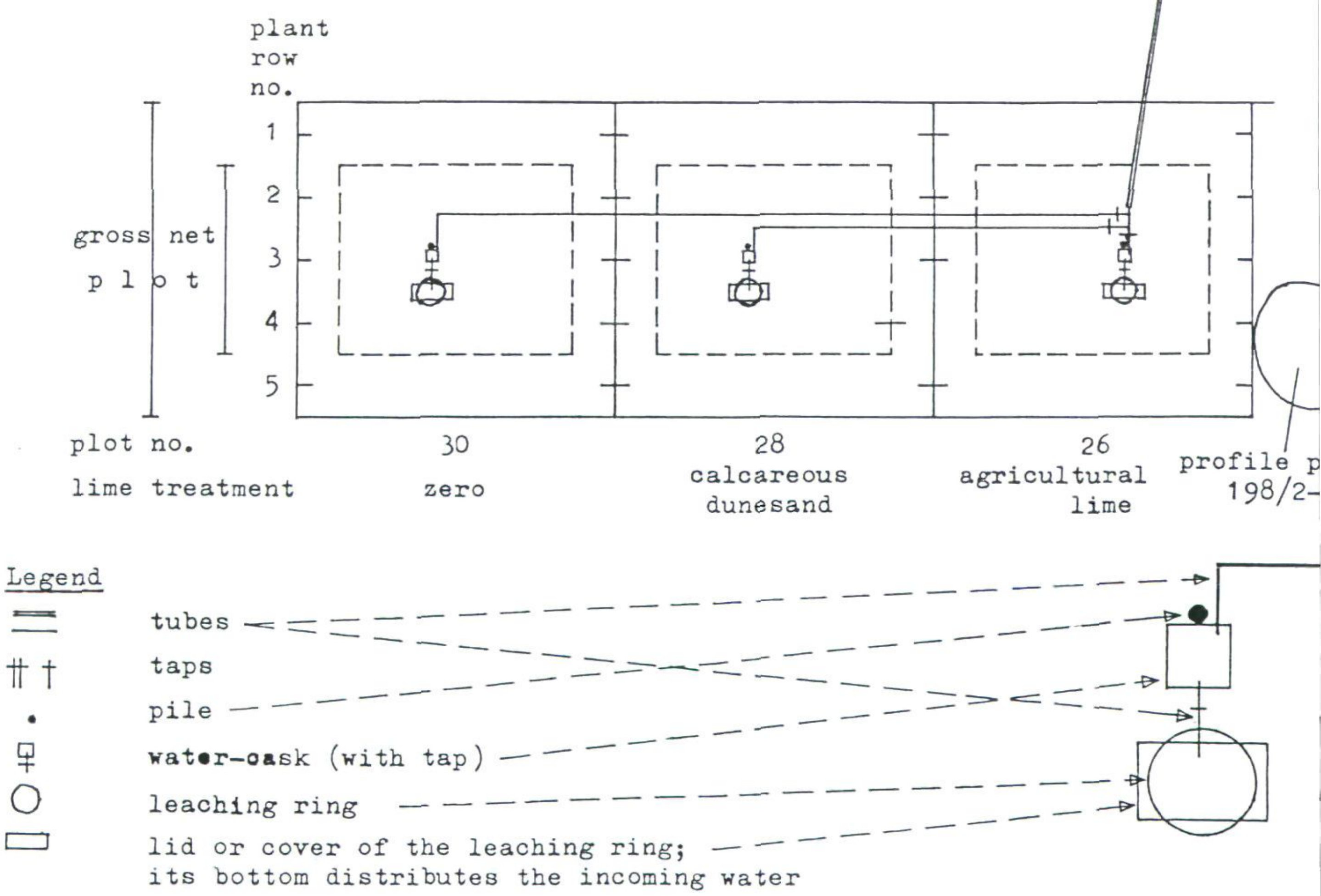


Figure 5.2. Field set up of the leaching trial (scale 1:100), and of a leaching spot (scale 1:25).

The outflows of water-casks into the leaching rings were measured and most times also adjusted, in intervals of 4 hours on average (more in daytime, less during nights (see App. 24). During these intervals, the trial was regularly controlled. The outflow was measured regularly by looking how many seconds it took to fill a measuring cylinder of 250 ml. - Outflows measured at two different moments were interpolated linearily to arrive at the water gift (mm) for any interval, although interpolations aling oblique curves varying from one to another interval could have resulted in better approximations of the real water supply per ring; this trial however was meant to be qualitative. Appendix 24 describes the applied method to calculate amounts of leaching water within the rings more comprehensively.
If inundation occurred, the outflow was decreased and measured again. If the outlook of the soil surface was not moist, the outflow was increased and measured again. Water was brought eight times (see Table 5.2 and Photo 5.6). The effective supply by the drums was estimated at

Photo 5.6. Water supplied in drums, was siphoned over into the water-tank (WL 79).

7/8 of their capacity, because they could not be filled to the rim or otherwise lost some water during transport. Thus one water transport, consisting of drums and water-tanks supplied 350 + 150 l = 0.50 m^3. A water sample for water analysis was taken every evening, thus dividing the leaching into 4 quarterly periods (see Table 5.2). In 1985 the 4 samples were analysed in Wageningen (see App. 25). In order to reduce transport costs, tap water was collected twice from an open tap along the road to Ganze-Bamba, 3 km from the trial field (see Figure 4.1). The distance to the office amounted c. 20 km.

Table 5.2. Origin of water supply during the leaching trial.

evening in September	kind of water supply		water sample no.[1)]	water composition in the tank
	office rain	tap		
Mo 6th	X	-		
Tu 7th	X	-	1	pure rain
We 8th	X	X	2	mixtures of rain and tap water
Th 9th	X	X	3	
Fr 10th	X	-	4	
Sa 11th	-	-		

1) as used in Appendix 25, and corresponding with the leaching quarter nos. I, II, III, IV in Appendix 24&26 and in Table 6.23.

The soil of the leaching plots (30, 28, 26) was sampled (at 3 spots per plot resp. within each ring) before as well as after the leaching trial at the depths: 0-5, 7½-12½, 15-20, 22½-27½, 30-35, 37½-42½, 50-60, 90-100, 140-150 and 200-210 cm for pH estimation and moisture content. For this last determination, after completion of the leaching trial samples were taken until 4 m depth. Before the leaching trial, care was taken to auger not too close by plot borders and leaching rings. After the leaching trial, samples (from within the ring!) until 50 cm depth were taken as follows: the whole 5 cm layer was dug out and put on a canvas cloth; on this canvas it was thoroughly mixed, and a subsample was put in a plastic bag. Below 50 cm, composite samples were taken from three auger points within the ring. Subsamples of c. 100 g were sent to Wageningen for analysis.

6 RESULTS AND DISCUSSION

This paragraph presents pH-values of soils developed on Magarini sands, found in Kilifi and Wageningen resp., and describes the interpretation problems (6.1.1). Thereafter the results are discussed briefly and some conclusions are given (6.1.2).

6.1 ACIDITY SURVEY 'MAGARINI SANDS'

6.1.1 RESULTS AND INTERPRETATION PROBLEMS

Table 6.1. pH-H_2O measurements acidity survey 'Magarini sands'[1].

Spot no.	Depth (cm) 0-25 (A)	Depth (cm) 25-45 (B)	$\frac{(2A+B)}{3}$ [2]	Spot no.	Depth (cm) 0-25 (A)	Depth (cm) 25-45 (B)	$\frac{(2A+B)}{3}$ [2]	Spot no.	Depth (cm) 0-25 (A)	Depth (cm) 25-45 (B)	$\frac{(2A+B)}{3}$ [2]
1	5.7	5.7	5.7	24	5.6	5.2	5.5	46	5.2	5.0	5.1
2	6.5	6.5	6.5	25	5.8	5.2	5.6	47	5.2	4.9	5.1
3	6.1	6.5	6.2	26	5.6	5.4	5.5	48	5.6	5.0	5.4
4	6.2	6.2	6.2	27	5.2	5.0	5.1	49	4.9	4.6	4.8
5	6.5	6.3	6.4	28	5.4	5.3	5.4	50	5.5	4.4	5.1
6	5.9	5.7	5.8	29	5.4	4.7	5.2	51	4.7	4.0	4.5
7	6.4	6.4	6.4	30	5.9	5.3	5.7	52	5.1	4.5	4.9
8	5.4	5.7	5.5	31	6.5	5.5	6.2	53	4.8	4.1	4.6
9	6.6	6.0	6.4	32	5.9	5.3	5.7	54	4.3	4.0	4.2
10	5.8	5.0	5.5	33	5.3	5.0	5.2	55	4.8	4.1	4.6
11	5.7	4.9	5.4	34	6.1	5.6	5.9	56	5.2	5.5	5.3
12	5.8	5.0	5.5	35	5.7	5.2	5.5	57	5.3	4.9	5.2
13	6.4	6.0	6.3	36	5.7	5.3	5.6	58	4.9	4.3	4.7
14	6.4	5.0	5.9	37	5.2	5.1	5.2	59	5.3	5.4	5.3
15	6.6	6.0	6.4	38	6.0	5.2	5.7	60	4.8	4.5	4.7
16	6.7	5.7	6.4	39	4.8	4.5	4.7	61	5.4	5.0	5.3
17	6.0	5.7	5.9	40	6.1	5.7	6.0	62	5.6	4.7	5.3
18	6.3	5.4	6.0	41	5.9	5.2	5.7	63	5.2	4.6	5.0
19	7.1	5.9	6.7	42	5.4	4.8	5.2	64	5.4	5.1	5.3
20	6.0	5.0	5.7	43	5.6	5.6	5.6	65	6.0	5.7	5.9
21	7.1	5.7	6.6	44	6.1	4.7	5.6	66	5.4	5.2	5.3
22	5.8	5.2	5.6	45	5.6	4.9	5.4	67	4.9	4.3	4.7
23	5.7	4.9	5.4								

Means + (St.dev.)	(A)	(B)
all 67 samples	5.7 (0.59)	5.2 (0.60)
S of Kfi Creek (1-45, 61-66)	5.9 (0.50)	5.4 (0.50)
N ,, ,, ,, (46-60, 67)	5.0 (0.33)	4.6 (0.48)

1) Measurements obtained in the T.P.I.P. laboratory, Kilifi, February 1982; first pH-H_2O was measured, and on Feb. 24th pH-KCl. pH-H_2O results appeared to be low (see text).

2) $\frac{2A+B}{3} = \frac{2 \times pH\ topsoil\ (0\text{-}25\ cm) + pH\ subsoil\ (25\text{-}45\ cm)}{3}$.

For more information on this ratio is referred to 5.1.

Topsoils had higher pH-values than subsoils (25-45 cm), means being 5.7 and 5.2 (see Table 6.1; Kilifi values). A group of samples was found meeting the pH-H_2O requirement (4.8 or lower if applied to the formula formula $\frac{2A+B}{3}$ (see Table 6.1). With exception of one spot (no. 39) which is neglected in the further discussion, these samples were found north of Kilifi Creek. The 16 northern samples represented about 1300 of the 2100 ha of soils developed on Magarini sands north of Kilifi Creek. 8 of them, representing 650 ha, met the pH requirement. It was decided therefore to undertake a liming trial (north of Kilifi Creek within the map-units of soils developed on Magarini sands (see 6.2)).

Table 6.2. pH-values acidity survey 'northern Magarini sands'.

		pH-H_2O				pH-KCl			
Depth (cm)		0 - 25		25 - 45		0 - 25		25 - 45	
Spot	Lab.	Kfi[1]	Wag[2]	Kfi	Wag	Kfi	Wag	Kfi	Wag
46		5.2	6.5	5.0	6.0	5.3	5.4	5.0	5.1
47		5.2	6.5	4.9	5.9	5.4	5.5	4.9	5.1
48		5.6	7.0	5.0	6.4	6.0	6.0	5.4	5.4
49		4.9	6.4	4.6	5.9	5.3	5.4	4.9	5.0
50		5.5	6.4	4.4	5.8	5.4	5.5	4.9	5.1
51		4.7	6.2	4.1	5.3	5.0	5.1	4.1	4.7
52		5.1	6.5	4.5	5.8	5.5	5.6	4.7	5.0
53		4.8	6.5	4.1	5.5	5.3	5.4	4.4	4.8
54		4.3	5.9	4.0	5.5	4.3	5.0	4.2	4.8
55		4.8	6.3	4.2	5.6	4.7	5.2	4.3	5.0
56		5.2	6.7	5.5	6.9	5.5	5.6	5.8	6.0
57		5.3	6.8	4.9	6.1	5.4	5.6	5.0	5.3
58		4.9	6.3	4.3	5.6	4.9	5.3	4.4	5.0
59		5.3	6.9	5.4	6.9	5.4	5.9	5.8	5.8
60		4.8	6.1	4.5	5.8	4.9	5.3	4.4	5.0
67		4.9	6.1	4.3	5.7	5.1	5.3	4.5	5.1
Mean		5.0	6.4	4.6	5.9	5.2	5.4	4.8	5.1
Δ means (Wag-Kfi)		1.4		1.3		0.2		0.3	
St.dev.		0.33	0.30	0.46	0.46	0.39	0.26	0.53	0.35
,, ,, Δ means		0.19		0.14		0.20		0.24	
r (corr.coëff.)		0.82		0.95		0.88		0.93	
intercept		2.66		1.54		2.36		2.21	
slope		0.75		0.95		0.59		0.61	

1) T.P.I.P. laboratory, Kilifi, February 1982.
2) Department of Soil Science and Plant Nutrition, Wageningen, 1985.

In 1985 the northern Magarini samples were analysed again, but this time in Wageningen (see Table 6.2). Table 6.2 also gives pH-KCl, both measured in Kilifi and in Wageningen. In Kilifi pH-KCl values were 0.2 unit higher than pH-H_2O values. This is quite unusual, and takes place only when the AEC of a soil is higher than its CEC (LEGGER, 1987: 22). However, the fields were limed already when more atenttion was payed to this matter (see 6.2). Re-estimations in Wageningen showed normal results: pH-H_2O c. 0.9 unit higher than pH-KCl. Comparing Kilifi and Wageningen data, it was found that pH-KCl values from Kilifi were about 0.25 unit lower than those of Wageningen, while for pH-H_2O this amounted to about 1.35 unit.

Searching for an answer how the differences between pH-estimates from Kilifi (February 1982 and Wageningen) were brought about, Janssen suggested to test some of the soil samples with extractants ranging from demi water to 1 M KCl (increasing salt concentration). Supposing standard buffers in Kilifi were correct (pH 4.0 resp. 7.0), the cause for the uncommon pH-H_2O estimates achieved in Kilifi was sought in the pollution of demi water by salts. The suggested extraction fluids were demi water, 0.01 M $CaCl_2$, and KCl 0.001, 0.01, 0.1 and 1 M. Battery water was added, because of its use in Kilifi in case no demi water was available. Also tap water functioned as a kind of blanc. - As soils to be tested, four samples were chosen from the acidity survey viz. 48 A and 56 B with 'high' pH, besides 54 A and 51 B with 'low' pH. Two standards were included as well (see Table 6.3). Their formerly obtained pH values are summarized in Table 6.4.

Table 6.3. pH test results obtained with 8 different extraction fluids (1:2½), in order of decreasing pH (corresponding with increasing salt concentration).

Extraction fluid: Standard soil/ survey spot no.	water tap	water demi	KCl 0.001M	water battery	KCl 0.01M	KCl 0.1M	$CaCl_2$ 0.01M	KCl 1M	mean
Stroomrug		7.6						7.4	
48 A	6.9	6.4	6.4	6.2	6.3	6.2	6.1	6.0	6.3
56 B	6.9	6.6	6.5	6.4	6.4	6.2	6.2	6.0	6.4
54 A	6.5	5.7	5.6	5.6	5.5	5.2	5.2	5.0	5.5
51 B	5.9	5.4	5.2	5.4	4.9	4.8	4.8	4.7	5.1
Belmonte		4.2						3.5	
mean (survey samples)	6.5	6.0	5.9	5.9	5.8	5.6	5.6	5.4	

Table 6.4. Reference pH-values for comparison with those of Table 6.3.

Standard soil/ survey spot no.	$pH-H_2O$ Kfi	$pH-H_2O$ Wag	pH-KCl Kfi	pH-KCl Wag
Stroomrug		7.9		7.4
48 A	5.6	7.0	6.0	6.0
56 B	5.5	6.9	5.8	6.0
54 A	4.3	5.9	4.3	5.0
51 B	4.0	5.3	4.1	4.7
Belmonte		4.2		3.5
mean (survey samples)	4.9	6.3	5.1	5.4

The data presented in Table 6.3 were achieved with the same method (1:2½ v/v), but only 2 g of sample per shaking tube. Three standard values were correctly estimated in the test; $pH-H_2O$ Stroomrug was 0.3 too low. Also test $pH-H_2O$ values were 0.3 lower than those of Table 6.4 that were accomplished with the normal methods. Maybe the relative drop of the $pH-H_2O$ values in the test was caused by pollution of the small plastic tubes. All pH-KCl values were estimated correctly in the test (a possible pollution was of no influence relative to the 1 M KCl concentration).

pH-KCl values were the lowest pH values obtained in the test, and $pH-H_2O$ values were 0.6 higher. Thus the test did not make clear why Kilifi $pH-H_2O$ estimates were 0.2 below corresponding pH-KCl data.

In Kilifi, the standard buffers were replaced by new ones, probably in March 1982. From then onwards normal pH results were obtained which will be discussed in 6.2. Still, this fact does not explain why pH-KCl values obtained in Kilifi were quite correct.

<u>Conclusion on pH measurements achieved in Kilifi for the acidity survey</u>: $pH-H_2O$ values are far too low, and at best have relative mutual worth; pH-KCl values seem correct because they approximate the values found in Wageningen by measuring again. Causes can have been: decline of standard buffers, pollution of demiwater with salts, glass bottles precedingly used with salts causing disturbance of $pH-H_2O$ measurements.

A pH-H_2O map could have been compiled of soils developed on Magarini sands by adding 1.4 to topsoil determinations of Kilifi, and 1.3 to subsoil data. The size of the proposed adjustments would be greater than the errors possibly made[1] and therefore this mapping would be worthwhile.

6.1.2 DISCUSSION AND CONCLUSIONS

The terminology for soil acidity (measured as pH-H_2O) is enumerated in Table 3.1. Table 6.5 gives summarized and corrected pH results.

Table 6.5. Summarized and corrected[2] pH values (means and standard deviations)[1].

	pH-H_2O		pH-KCl	
Depth (cm)	0-25	25-45	0-25	25-45
Location	mean s.d.	mean s.d.	mean s.d.	mean s.d.
S. of Kfi Creek[2]	7.3 (0.5)	6.7 (0.5)		
N. of Kfi Creek[3]	6.4 (0.3)	5.9 (0.5)	5.4 (0.3)	5.1 (0.4)
S & N[2]	7.1 (0.6)	6.5 (0.6)		

1) based on the Tables 6.1 (Kilifi lab) and 6.2 (Kilifi lab and Wageningen lab).
2) data from Table 6.1 corrected by adding 1.4 and 1.3 for topsoil and subsoil data respectively.
3) data from Table 6.2 (Wageningen lab).

On the whole, soils developed on Magarini sands have neutral topsoils and slightly acid subsoils (see Table 6.6). South of Kilifi Creek topsoils and subsoils are neutral. North of Kilifi Creek the acidity ranges from slightly acid in topsoil to medium acid in subsoils. (A more detailed picture of the acidity statusses of these soils might have been obtained after splitting pH results according to their soil units.)

[1]) Possible errors are:
a) differences between data from Wageningen and Kilifi vary from sample to sample, i.e. the standard deviations of these differences lay around 0.2 (see Table 5.2);
b) obtained pH values always have inaccuracies until 0.1 unit;
c) the period between both analyses (Kilifi and Wageningen) lasted three years, which probably did not alter pH (acidity characteristics) on these soils (after HESSE, 1971, in LANDON, 1984).

Summarized corrected pH results show, that acidity is a much smaller agricultural problem of soils developed on Magarini sands than it appeared at first, because in Wageningen, none of the acid northern samples fulfilled the acidity criteria justifying a liming trial (pH-H_2O 4.8 or lower, pH-KCl 4.0 or lower).
According to LEGGER (1987), this pattern in the investigated Oxisols of subsoils with lower pH and organic matter contents (than topsoils) contradicts the normal pattern, to wit: in the subsoil of Oxisols pH is frequently higher than in surface horizons with pH near 5, partly because of a lower organic matter content.

<u>**Conclusions**</u> of the acidity survey are:

1) pH-H_2O values obtained for the survey in Kilifi appeared to be more than 1 unit too low, and only have relative mutual worth.
2) (Moreover) soil acidity is no problem of these soils in the investigated upper 0.5 m, if judged related to the acidity criteria for topsoils justifying a liming trial.
3) Hence no acidity map of soils developed on Magarini sands will be presented.
4) A striking acidity difference of almost 1 pH unit exists between Magarini sands situated north and south of Kilifi Creek, with mean surface soil (0-25 cm) pH values of 6.4 and 7.3.
   The rainfall amounts and distribution patterns of both regions are nearly equal, and thus they do not explain the difference in acidity. As the correlation between sampling spots and soil map-units is not (yet) clear, conclusions on the relation between soil acidity and soil texture of these soils developed on Magarini sands can not be drawn.

Further consequences of the acidity status of these Oxisols for crop production will be discussed in 6.2.

6.2 LIMING TRIAL

After all it appeared acidity was no major problem on soils developed on Margarini sands. Nevertheless, by then a liming trial was set up, mainly based on too low pH estimates and also due to misunderstanding (giving some importance to subsoils with lower pH).

6.2.1 LIMING EFFECT ON SOIL CHARACTERISTICS

6.2.1.1 STARTING PH VALUES TRIAL FIELDS AND INTRODUCTION

For acidity mapping, a fixed relation between top(A)- and subsoil(B: 25-45) cm) was designed, viz. (2A + B)/3 (see 5.1). Due to some misunderstanding, this relation was also utilized when judging potential trial fields regarding the acidity criterium for starting up a liming trial (pH-H_2O below 4.8 or pH-KCl (below) 4.0). So not the topsoil pH values 4.8 and 4.9 were used, but the (formula) values 4.6 and 4.7 (see App. 12), that 'met' the criterium. Therefore, a liming trial was undertaken.

For reasons mentioned in 4.2, liming aimed at raising pH to 5.4. The fields were limed on March 6^{th} 1982.

Table 6.6. Summarized pH-H_2O data from both trial fields (before and after the growing season) (0-20cm).

Trial field & treatment	A	B	C	D	E	F
<u>Sokoke</u>						
zero	4.8[2)]	5.6	5.6	5.6	5.5	7.1
agricultural lime		6.1	6.3	5.6	5.4	6.8
calcareous dunesand		6.3	7.0	6.9	6.0	7.4
<u>Ngerenya</u>						
zero	4.9[2)]	5.8		5.8		
agricultural lime		6.2		6.3		
calcareous dunesand		6.4		6.8		
Data from:	App. 12	Table 6.8	Table 15.1	App. 16 Table 6.9	Table 6.27	

1) A: trial field selection.
   B: samples taken on March 23^{rd}, after liming, before the rains; (0-10 cm); not incubated
   C: samples taken on March 23^{rd}, after liming, before the rains; (0-10 cm); incubated.
   D: after the harvest.
   E: after the harvest on leaching plots before leaching.
   F: after the harvest on leaching plots after leaching.
2) unreliable values, see 6.1.

Table 6.6 summarizes all pH data obtained from both trial fields.
In March 1982 the old pH standard buffer fluids were replaced by new ones. By the end of March and later in Wageningen, pH data were obtained for Sokoke and Ngerenya amounting to 5.6 and 5.8 on average (see Table 6.6), thus contradicting former results and higher than 5.4 at which pH liming aimed. Thus, no liming trial should have been undertaken.
Evaluating all pH data of both trial fields, **conclusions** are:
- no liming trial should have been undertaken;
- liming resulted in an unwished raising of pH;
- liming may have resulted in an unwished deterioration of the soil structure;
- positive effects of liming on maize yields can not be expected.

After this evaluation of the initial acidity of the soils, - liming levels, and their effects on pH and soil structure are discussed in 6.2.1.2 and 6.2.1.3.

6.2.1.2 LIMING LEVELS

Before liming, lime requirements were computed based on the outcome of Wesemael's test ('$CaCO_3$'[1] content of the liming materials), pH-H_2O values of the trial fields (see App. 12), and results of research by van RAIJ (1982) (see Table 6.7). In Kilifi after liming, and later in Wageningen, lime requirements were measured again and based on final data (see App. 13 and Table 6.7), and ultimately (after processing pH data) it appeared no liming would have been required. - Yet liming materials were applied, and so changed soil characteristics and affected crop production. Therefore the history of the application is discussed below.

<u>At the outset</u> lime requirements (see Table 6.7) were computed based on:
- pH data amounting to 4.6 and 4.7 for resp. the Sokoke and the Ngerenya field (see 6.2.1.1 and App. 12);
- the factory analysis of agricultural lime: 90 % '$CaCO_3$', and the outcome of Wesemael's test (short version in BEGHEIJN & van SCHUYLENBORGH, 1971) for calcareous dunesand being 56 % '$CaCO_3$';
- liming results obtained by van RAIJ (1982) on similar soils: 'dark red latosol, sandy phase', with CEC ranging between 24 and 30 mmol.(+)kg^{-1} of soil. For the Sokoke and Ngerenya fields CEC amounts to 33 and 43 mmol (+).kg soil respectively (see Table 2.2). Application of 1.5 $ton.ha^{-1}$ of lime (38 % CaO and 27 % MgO) i.e. 2.02 $ton.ha^{-1}$ '$CaCO_3$' raised soil pH from 4.9 to 5.4.

[1] See footnote 2 on p. 27 (4.4).

Table 6.7. Tentative and final estimates of required amounts of both liming materials as derived from van RAIJ (1982).

Place & date of estimation	Kilifi, February/March 1982				Wageningen, 1982 & 1985	
	tentative estimates				final estimates[e]	
	'CaCO$_3$'	required	actually applied			required
pH(van RAIJ)=0.5	(Wesemael)	liming material	liming material	'CaCO$_3$'[d]		liming material
	%	ton.ha^{-1}	ton.ha^{-1}	ton·ha^{-1}	%	ton.ha^{-1}
van RAIJ's liming mat. (38 % CaO, 27 % MgO)	68[a]	1.5	0	0	135[b]	1.5
Agricultural lime	90	1.13[c]	1.23	1.14	92	2.20[f]
Calcareous dunesand	56	1.82	2.47	2.32	94	2.15

a) based only on the CaO content of van RAIJ's liming material.
b) based on both CaO and MgO content of van RAIJ's liming material.
c) computation e.g. $\frac{68}{90} \times 1.5 = 1.13$ ton·ha^{-1} (x $\frac{20.25\ m^2}{10,000\ m2}$ = 2.3 kg.plot^{-1}).
c)
d) according to final 'CaCO$_3$' estimate (see App. 14).
e) except for pH.
f) computation e.g. $\frac{135}{92} \times 1.5 = 2.20$ ton·ha^{-1} (x $\frac{20.25\ m^2}{10,000\ m^2}$ = 4.5 kg·plot^{-1}).
f)

Computed lime requirements of agricultural lime and calcareous dunesand were 1.13 and 1.82 ton.ha^{-1}, respectively (per plot 2.3 resp. 3.7 kg). On the field these application rates were rounded off at 1.23 resp. 2.47 ton .ha^{-1} which corresponds with 2.5 resp. 5.0 kg per plot (see Table 6.7).

Finally for the following parameters improved estimates were obtained

- pH data appeared to be 5.6 and 5.8, thus no liming trial should have been set up,
- 'CaCO$_3$' contents of agricultural lime and calcareous dunesand were 92 and 94 % (see App. 14), and
- it was perceived, at first computation the liming effect of MgO in van Raij's liming material was disregarded.

As agricultural lime and calcareous dunesands have approximately equal 'CaCO$_3$' contents and calcareous dunesand was applied at twice the rate of agricultural lime, liming levels related as 0:1:2.

Conclusion: as soil pH values on the Sokoke and the Ngerenya field are 5.6 and 5.8 respectively (see Table 6.6 D), and liming aimed at raising pH till 5.4, all liming was overliming.

6.2.1.3 LIMING EFFECTS ON SOIL PH (AND SOIL STRUCTURE)

Introduction

In order to find how liming affected the trial fields, they were sampled (see 5.2) and measured with regard to pH.

As the soils appeared to have originally pH 5.6 and 5.8, all liming appeared overliming. Therefore liming effect on pH (and soil structure) are discussed below.

pH is an important indicator of how liming affects the trial fields. Three sets of pH data are presented and discussed in detail.

Table 6.8. pH-H_2O results of both trial fields from samples (0-10 and 20-30 cm) taken after liming and before the onset of the rains (March 23rd), and measured twice: I) after about the normal settling time for the suspension, and II) more than 3 days (c. 80 hours) later.

		SOKOKE					NGERENYA				
	Before liming[1] (0-20 cm)	4.77					4.87				
	After liming (0-10 cm) Block[2]	1	2	3	Mean	s.d.	1	2	3	Mean	s.d.
I)	Zero	5.4	5.7	2.17*	5.55	0.21	5.85	.	5.75	5.80	0.07
	Agricultural lime	6.2	6.35	5.7	6.08	0.34	6.24	6.1	6.4	6.25	0.15
	Calcareous dunesand	6.15	6.25	6.5	6.30	0.18	6.25	6.3	6.75	6.43	0.28
	Mean	5.92	6.10	6.10	6.01		6.11	6.20	6.30	6.18	
II)	Zero	5.95	6.05	2.5*	6.00	0.07	6.35	.	6.27	6.31	0.06
	Agricultural lime	6.55	6.94	6.33	6.61	0.31	6.5	6.45	6.65	6.53	0.10
	Calcareous dunesand	6.59	6.7	6.45	6.58	0.13	6.65	6.56	6.98	6.73	0.22
	Mean	6.36	6.56	6.39	6.42		6.50	6.51	6.63	6.54	
	Before liming[1] (20-40 cm)	4.39					4.24				
	after liming (20 - 30 cm)										
I)	Zero	4.3	4.5	4.5	4.43		4.8	.	4.2	4.5	
	Agricultural lime	4.05	4.55	4.15	4.25		4.55	4.0	4.25	4.27	
	Calcareous dunesand	4.5	4.55	4.3	4.45		4.1	4.61	5.19	4.63	
	Mean	4.28	4.53	4.32	4.38		4.48	4.31	4.55	4.46	
II)	Zero	4.64	4.57	4.24	4.48		5.04	.	4.45	4.75	
	Agricultural lime	4.26	4.35	4.25	4.29		4.92	4.32	4.45	4.56	
	Calcareous dunesand	4.43	4.45	4.26	4.38		4.23	4.9	5.55	4.89	
	Mean	4.44	4.46	4.25	4.38		4.73	4.61	4.82	4.73	

* outlying values that are neglected.
1) based on results for selection of trial fields (see App. 12).
2) According to the tentative trial design, both fields were laid out in 3 blocks (see field schemes in Table 4.1). (Lime treatments were randomly allotted per block.)

Table 6.8 shows pH values of both fields in top- and subsoil after liming but before the onset of the rains. The incubation trial of end March 1982 (samples incubated with the liming materials) is discussed in App. 15. Table 6.9 summarizes post harvest pH values.

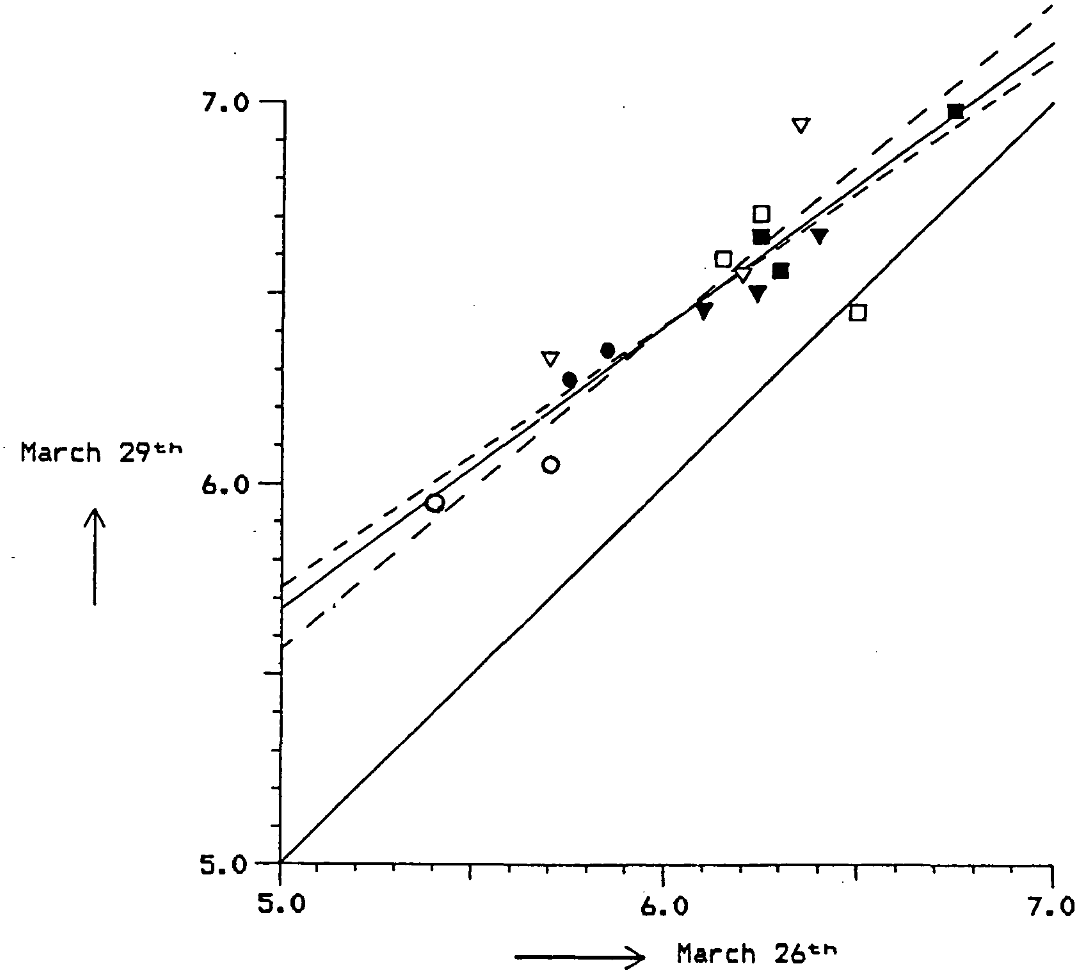


Figure 6.1. Relation between pH values measured on March 26th and measured again on March 29th (80 hours later; basic data in Table 6.8).

○ ● zero treatment
▽ ▼ agricultural lime on the Sokoke resp. Ngerenya field
□ ■ calcareous dunesand

<u>Starting pH values - after liming, before the rains</u>

Table 6.8 enumerates pH results from sampling on <u>March 23rd</u>. Subsoil (20-30 cm) values were not affected by liming as the working depth of the rotovator was 15 cm. Liming affected topsoil (0-10 cm) pH. Both liming materials increased pH-H_2O by around 0.6 (see Table 6.8, data set I).

Letting stand for 80 more hours probably without any shaking, and measuring again in the supernatant liquid (data set II and Fig. 6.1) gave higher pH values, also of unlimed samples and reduced lime effect relative to zero samples on the Ngerenya field, especially for agricultural lime. (E.g., at first determination (set I), the minimum average in Sokoke amounted to 5.55 (zero treatment) and the maximum to 6.30 (ds).

After standing (set II), both extremes were increased to 6.00 (zero) resp. 6.61 and 6.58 (al and ds).)

Figure 6.1 shows a pH increase of 0.3 to 0.5 after standing for 80 hours.

Post harvest pH values (Table 6.9) are consonant with incubation results (see App.15). Post harvest pH data are evaluated in two ways: first liming effects on pH are examined in the same horizontal layer, and secondly they are compared concerning that different depths.

Comparison of pH in the same horizontal layer

On the Sokoke field, both liming materials merely raised pH in the zone 0-5 cm, whereas on the Ngerenya field this appears till 27½ cm depth. At the Sokoke field agricultural lime even seems to slightly decrease pH from 7½ to 27½ cm depth. (see Tables 6.9 and 6.10).

Table 6.9. Mean post harvest pH values as measured in Wageningen (1985); for all values is referred to App.15.

	pH - H_2O			pH - KCl			△ pH-H_2O		△ pH-KCl	
	Lime treatment									
Depth (cm)	zero	agr. lime	calc. dunesand	zero	agr. lime	calc. dunesand	al	cds	al	cds
Sokoke trial field(UE111)										
0 - 5	5.74	6.22	7.41	4.70	5.31	7.05	0.5	1.7	0.6	2.4
7½ - 12½	5.64	5.52	6.42	4.60	4.58	5.60	-.1	0.8	0.0	1.0
15 - 20	5.44	5.18	6.74	4.51	4.37	6.11	-.3	1.3	-.1	1.6
22½ - 27½	5.28	5.05	5.63	4.43	4.27	4.69	-.2	0.4	-.2	0.3
Mean (0-27½)	5.53	5.49	6.55	4.56	4.63	5.86	0.0	1.0	0.1	1.3
Mean (0-20)	5.61	5.64	6.86	4.60	4.75	6.25	0.0	1.3	0.2	1.7
Mean (0-12½)	5.69	5.87	6.92	4.65	4.94	6.33	0.2	1.2	0.3	1.7
Ngerenya trial field										
0 - 5	5.97	6.66	7.18	5.17	6.18	6.92	0.7	1.2	1.0	1.8
7½ - 12½	5.90	6.28	6.87	5.13	5.61	6.43	0.4	1.0	0.5	1.3
15 - 20	5.60	5.87	6.40	4.80	5.01	5.85	0.3	0.8	0.2	1.1
22½ - 27½	5.20	5.60	5.95	4.41	4.86	5.13	0.4	0.8	0.5	0.7
Mean (0-30)	5.67	6.10	6.60	4.88	5.42	6.08	0.4	0.9	0.5	1.2
Mean (0-20)	5.82	6.27	6.82	5.03	5.60	6.40	0.5	1.0	0.6	1.4
Mean (0-12½)	5.94	6.47	7.03	5.15	5.90	6.68	0.5	1.1	0.8	1.5

Table 6.10 gives the ratio of liming effects on pH between calcareous dunesand and agricultural lime to facilitate assessment of the relative effects of bath liming materials, and to see whether they function as expected.

One would expect a △ pH ratio of about 2, corresponding with the amounts of applied '$CaCO_3$' (see Table 6.7). In view of the higher solubility of cds (Janssen, 1982, pers. comm., App.14) the ratio could be higher.

Table 6.10. Liming effect on △ pH-ratio $\frac{\text{calc.dunesand (2.32 ton.ha}^{-1})}{\text{agr.lime (1.14 ton.ha}^{-1})}$.

Trial field	Depth (cm)	△pH ratio of pH-H_2O values	△pH ratio of pH-KCl values	average ratio's
Sokoke	0 - 5	3.48[1]	3.85	3.7
	7½ - 27½	∞	∞	
Ngerenya	0 - 5	1.75	1.73	1.7
	7½ - 12½	2.55	2.71	2.6
	15 - 20	1.96	5.00[2]	2.0
	22½ - 27½	1.88	1.60	1.7

1) $\frac{\text{pH-H}_2\text{O(calc.dunesand plots - zero plots)}}{\text{pH-H}_2\text{O(agric.lime plots - zero plots)}}$
2) neglected.

Most pH-H_2O ratios are accordant with pH-KCl ratios of the same field and layer. Only the pH-KCl ratio of 15-20 cm (at the Ngerenya field) deviates strongly from surrounding values and is therefore neglected. In the following lines averages of pH-H_2O and -KCl ratios per layer will be discussed (see Table 6.10). In Sokoke the pH ratios for 0-5 cm amount to about 3.7, which can be explained by the liming rates of the liming materials and the much quicker dissolving of calcareous dunesand. In Ngerenya, the ratios in the four sampled layers down to 27½ cm amount successively 1.7, 2.6, 2.0 and 1.7. The effect 2.6 in the layer 7½-12½ cm can be explained just as for Sokoke from 0-5 cm.

Vertical effects of both liming materials on pH

Below, pH changes up to and including 0.3 will be neglected. In Sokoke (on UE111), agr. lime only raised pH from 0-5 cm (by 0.5); calcareous dunesand increased pH-H_2O and -KCl till 20 cm depth (by, downwards, 1.7/2.4, 0.8/1.0, 1.3/1.7). In Ngerenya (on UE112) from 0-12½ and 22½-27½ cm agricultural lime raised pH (by 0.7/1.0, 0.4/0.5, 0.4/0.5);

calcareous dunesand did so from 0-27½ cm (at least) (consecutively 1.2/1.8, 1.0/1.3, 0.5/1.1, 0.8/0.7).

Beneath the limed layer at 15 cm depth, pH increases beyond 0.3 indicate lime leaching in the short run (one year). Such indications exist for calcareous dunesand on both fields (till 20 resp. 27½ cm) and for agricultural lime possibly on the Ngerenya field (till 27½ cm).

Considering change of pH in the topsoil (0-20 cm, see Table 6.9), agricultural lime only shows a clear effect in Ngerenya (increase 0.5), whereas calcareous dunesand raised pH on both fields by 1.7 and 1.4 in Sokoke resp. Ngerenya. The lower CEC of the Sokoke field (see Table 2.1) explains the stronger pH effect of dunesand on this field.

Table 6.11. Mean topsoil pH values on lime treatment plots before and after the growing season.

Trial field	Lime treatment	March 23rd first determination	(after 80 hours)[a]	Incubation trial (field samples)		Post harvest	
	Depth (cm)	0 - 10		0 - 10		0 - 10	
		pH - H_2O		H_2O	KCl	H_2O	KCl
Sokoke	zero	5.55	(6.00)	5.62	4.55	5.69	4.65
	agr.lime	6.08	(6.61)	6.26	5.53	5.87	4.94
	c. dunesand	6.30	(6.58)	7.05	5.96	6.92	6.33
Ngerenya	zero	5.80	(6.31)			5.94	5.15
	agr. lime	6.4	(6.53)			6.47	5.90
	c. dunesand	6.75	(6.73)			7.03	6.68
Source		Table 6.8 Set I	Set II	Table 15.1		Table 6.9	

a) given in parenthesis because these data are of less importance.

Table 6.11 indicates change of pH in topsoils of both trial fields. The layer 0-10 cm resp. 0-12½ cm is chosen in stead of 0-20 cm to facilitate comparison of pre-planting and post-harvest data. Incubation results represent some part of the growing season.

Combining pH-H_2O and -KCl results, pH of unlimed topsoils increase by 0.2. Inexplicable is the post-harvest pH on Sokoke plots treated with agricultural lime, that is lower than the pre-planting value; in Ngerenya the raise of pH is 0.1. Dunesand treatment increased pH by 0.5 on Sokoke plots, and by 0.3 on Ngerenya plots.

pH-H_2O results from unlimed topsoil samples are summarized in Table 6.12.

During the long rains, run off from limed to unlimed plots may have raised pH of these unlimed plots. Unlimed plot 30 situated upslope on

Table 6.12. pH-H_2O data from unlimed samples[a] (0-20 cm) throughout 1982[b].

trial field	map unit	Feb.1982[c]	March 1982		1985	
Sokoke	UE111	4.8[c]	5.6	5.6	5.6	5.5
Ngerenya	UE112	4.9[c]	5.8		5.8	
Source:		trial field selection App.12	samples taken after the liming date before the rains not incubated Table 6.8:I	⟷ incubated Table 15.1	after harvest App.16	plot 30 before leaching Table 6.27

a) see 5.2.
b) derived from Table 6.6.
c) unreliable values, see 6.1.

the field had pH 5.5, which is 0.1 unit (i.e. of the size of inaccuracies of pH estimates) lower than the average (5.6 ± s 0.33) on some unlimed plots downslope. Thus lime supply by run off may have happened, but no proof exists.

<u>**Soil structure**</u>

The application of calcareous dunesand raised pH-H_2O in the limed layer (0-15cm) till 7 (see Table 6.9). At this pH, the charge of sesquioxides that strengthen the packing of kaolin minerals changes from postive to neutral (see 3.1). This diminishes the electric attraction forces between the negatively charged kaolin minerals (see 3.1) and sesquioxide-coatings, thus reducing structure stability. Hence at pH 7 the soils of both trial fields were liable to structure deterioration.

Conclusion

Calcareous dunesand increased pH stronger and deeper than agricultural lime, caused by its much higher solubility, and its double application rate.

pH results indicate leaching of liming materials in the short run (one year): 1) for calcareous dunesand on the Ngerenya field (27½ cm) and also on the Sokoke field (20 cm); 2) this tendency exists for agricultural lime on the Ngerenya field.

It remains unclear why agricultural lime did not significantly raise the pH of the topsoil (0 - 20 cm) in Sokoke; in view of CEC values of both fields, this change of pH was expected to be higher in Sokoke (but it appears to be lower), and accordant with the effects of calcareous dunesand.

On both trial fields the high application rate of calcareous dunesand raised soil pH to 7, at which the soils are liable to structure deterioration. Therefore any liming rate should not raise pH beyond 6 to preserve soil structure.

6.2.2 LIMING EFFECT ON CROP CHARACTERISTICS

6.2.2.1 GENERAL INTRODUCTION TO DISCUSSION ON TREATMENT EFFECTS (see 6.2.3.2 + 3 and 6.3)

Effect of rainfall on yields

(Per lime treatment) NP results of adjoining NP plots situated in the liming trial (part of the trial field; see Table 4.1) mostly were higher than those of NP plots lying between other fertilizer treatments. The growing season lasted 18 weeks. After fertilizing and planting on April 1st and 2nd, 2 months of excessive rains followed (700 mm, see Fig.2.1) which may have leached part of the first application of N fertilizer (25 $kg.ha^{-1}$) (after SOUBIES et al., 1952, as cited by JANSSEN, 1978:98). Probably this somewhat reduced yields on N and NP plots.

The second application of N fertilizer was delayed from 6 to 8 weeks after planting because of and just next to the continuous extreme rains. However, after this application rains delayed somewhat and only in the 12th ,13th and 14th week of the growing season reasonable rainfalls were registrated (see Figure 2.1; no exact rainfall estimates are known for the 15th to 18th week). Thus the second N application may have remained underutilized. Still, because this N fertilizer was worked in more surfacially than the first application, run off may have caused some loss of N to adjacent plots, thus raising their yields somewhat but diminishing N and NP plot yields. This effect was reduced by mutual compensation on the adjoining NP plots.

Therefore, eventually all 9 NP plot results were taken together when processing effects.

Data processing and size of effects

All averages mentioned in Tables 6.13-6.18 are derived from 3 plot results (except for NP, that are derived from 9 plot results). Statistical processing was not undertaken in order to save time. Hence effect were ascertained if no overlap existed between ranges of zero and one factor treatments (one factor effects: zero - agricultural lime, zero - calcareous dunesand, 0 - N and 0 - P), or one factor and two factor ranges (interaction effcts: N - NP, and P - NP). Possible replicate effects in fertilizer trials consist of a liming effect that may be confounded with the different natural soil fertilities of the replicates.

For treatment of outliers is referred to Appendix 17.

If one out of three treatment results somewhat overlaps with another treatment range, or is equal to one of its values, this is described as '<u>some</u> (e.g. dunesand) <u>effect</u>'.

Positive and negative one factor results, and interaction results greater or smaller than one factor results are underlined as follows in Tables 6.13 to 6.18: ——— effect; - - - some effect; ..... <u>possible effect</u>, blurred by one (or more) outliers, and generally not discussed.

<u>Order of discussion</u>

First, factor (= treatment) effects are discussed in the sequence effects occurring on both fields and on one field respectively. Second, effects of the trial fields c.q. soil units are discussed by comparing mean results of zero treatment plots, because they reveal the original statusses of the soils more properly than mean field results, that are discussed as well. - Effects of the fields are mentioned if the ratio Ngerenya/Sokoke for those features is (below) 0.9 or (exceeding) 1.1 or the absolute effects are worth mentioning.

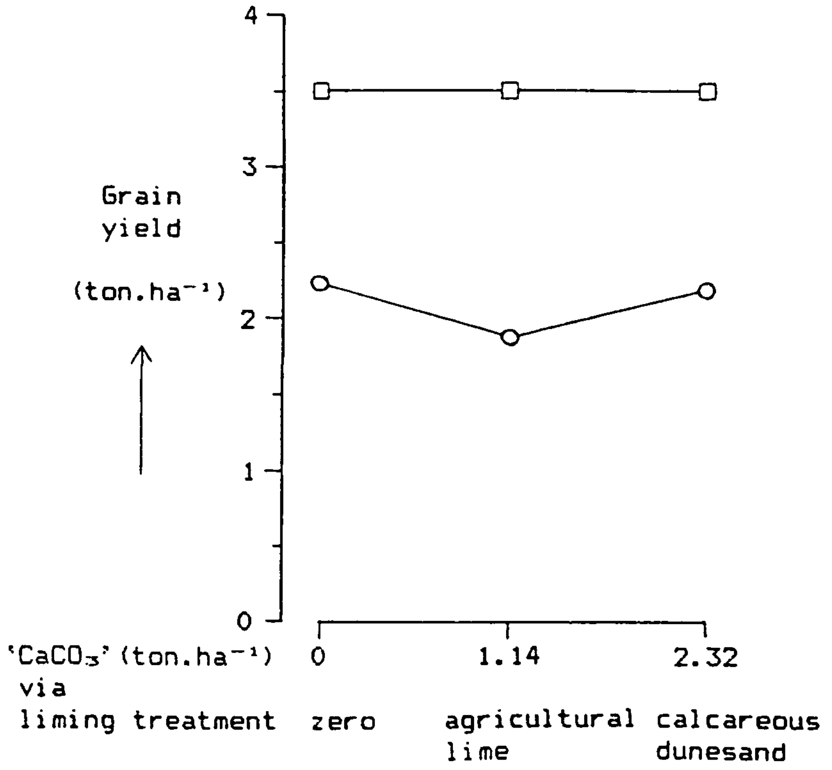


Figure 6.2. Grain yields liming trial.

□ Ngerenya
o Sokoke
trial field

6.2.2.2 GROWTH AND YIELDS LIMING TRIAL

Liming effects No general factor effects occurred in the liming trial. - On the Sokoke field calcareous dunesand possibly increased plant height, and it somewhat advanced the 50 % tasselling point. Both liming materials and especially agricultural lime reduced the harvest index on the Sokoke field (UE111). Possibly agricultural lime also reduced this index om the Ngerenya field (UE112). (In Sokoke this is reflected by a lower yield of grains under treatment with agricultural

Table 6.13. Growth and yield data liming trial[a].

Sokoke UE111	Weeks after planting	Lime treatment zero	a.l.	d.s.	M e a n Sokoke	Ngerenya
Emergence of stands (%)	2	95	99	100	98.0	95.7
Plant height (dm)	8	11.3	[10.2][b]12.2	13.2	11.6	16.0
50% tasselling[c]	9-10	68	69	67	68	63
grain moisture % at	18	19.6	20.2	19.8	19.9	20.0
stover moisture % harvest[d]	,,	40.0	37.1	36.2	37.8	42.9
From harvested net plants						
mean dry weights (g, 0% moisture) of:						
- grains per ear	,,	55	42	52	49	86
- stover per plant	,,	65	55	75	65	114
- grain yields (ton.ha^{-1};	,,	2.23	1.88	2.19	2.10	3.51
- stover yields 12% moisture)	,,	2.65	2.79	3.15	2.86	4.67
harvest index[e]	,,	0.453	0.399	0.407	0.420	0.431
Ngerenya UE112					Ratio **Ngerenya / Sokoke** means	zero's
Emergence of stands (%)	2	95	95	97	0.98	1.00
Plant height (dm)	8	16.1	15.7	16.2	1.38	1.42
50% tasselling[c]	±9	63	62	63	0.93	0.93
grain moisture % at	18	20.4	20.4	19.3	1.01	1.04
stover moisture % harvest[d]	,,	41.8	44.3	42.7	1.13	1.05
From harvested net plants						
mean dry weights (g, 0% moisture) of:						
- grains per ear	,,	89	86	83	1.76	1.62
- stover per plant	,,	118	108	116	1.75	1.82
- grain yields (ton.ha^{-1};	,,	3.51	3.52	3.51	1.67	1.57
- stover yields 12% moisture)	,,	4.82	4.40	4.79	1.63	1.82
harvest index[e]	,,	0.423	0.447	0.424	1.03	0.93

a) legend of underlinings: ——— effect
----- some effect
..... possible effect blurred by one (or more) outlier(s)

b) between brackets are given any means computed from one 1st class outlier and 2 'normal' values. (For outlier definition, see App.17).

c) days from planting.

d) moisture % related to fresh weight.

d) harvest index = $\frac{\text{grain yield}}{\text{(grain + stover) yield}}$, calculated per ha.

lime, and higher stover yields after liming with dunesand, and in Ngerenya by lower stover yields after agricultural liming.) Possibly agricultural lime decreased the weight of grains per ear in Sokoke.

Field effects exceed factor effects. The Sokoke field (UE111) had 4.4 dm shorter plants, that tasselled 5 days later. The Ngerenya field (UE112) yielded 5:3 more than the other field. - Field effects are explained by the relatively better Ngerenya soil (see 2.2.2).

6.2.2.3 PLANT NUTRIENT CONCENTRATIONS AND REMOVALS LIMING TRIAL

Table 6.14. Nutrient contents liming trial[a)b)].

	treat- ment	zero	a.l.	d.s.	Mean Sokoke UE111	Mean Ngerenya UE112
Sokoke						
Grains	N	976	1105	1126	1069	1207
	P	62	79	79[d)]	73	69
	K	66	86	80	77	72
	Mg	34	37	34	35	36
	Mn[a)c)]	6.7	7.8	7.8	7.4	7.9
Stalks & leaves	N	399	428	404	410	436
	P	17	18	16	17	18
	K	289	281	273	281	297
	Na	22	[31][d]23	[23]19	[25]21	24
	Ca	48	50	[74]60	[57]53	52
	Mg	76	77	92	82	101
	Mn	267	362	285	305	159
Ngerenya					Ratio Ngerenya/Sokoke means	Ratio Ngerenya/Sokoke zero's
Grains	N	1246	1170	1204	1.13	1.28
	P	66	70	70	0.95	1.06
	K	76	[138]69	72	0.94	1.15
	Mg	38	36	36	1.03	1.12
	Mn	8.9	8.1	6.7	1.07	1.33
Stalks & leaves	N	438	430	440	1.06	1.10
	P	15	19	20	1.06	0.88
	K	341[e)]	326	269[e]	1.06	1.03
	Na	26	22	24	1.14	1.18
	Ca	42	52	63	0.98	0.88
	Mg	104	94	104	1.23	1.37
	Mn	171	157	149	0.52	0.64

a) in $mmol.kg^{-1}$, except Mn: in $mg.kg^{-1}$.
b) Between brackets [ ] are given any means computed from one 1st class outlier and 2 'normal' values. (For outlier definition, see App.17).
c) It was difficult to discern between outlying and normal values in Mn contents from Sokoke. Therefore no corrected values are mentioned.
d) A 2nd class high outlier was not corrected.
e) ,, low ,, ,, .

The whole liming trial was given N and P fertilizer, in order to prevent these nutrients from limiting liming effect (Ca uptake). Fertilizer effects are discussed in 6.3.

Liming effects The liming trial showed no striking factor effects, the greatest effect being the increase of Ca removal after treatment with calcareous dunesand (see Table 6.15 and Figure 6.3)

The Tables 6.14 and 6.15 give overviews of nutrient contents resp. removals in the liming trial.

Site effects Especially on unlimed plots N and K concentrations in grains were higher on the Ngerenya, and Mg and also Na contents in stalks and leaves were higher, but Mn stover contents were much lower. Nutrient contents of grains lay around the lower part of concentration ranges given by WALSH and BEATON (see Table 3.3), and thus no (severe) deficiencies occurred (see also 6.3.2).

No Mn removal exceeded 1.0 kg, the normal Mn removal for maize (see Table 3.3). Therefore probably no Mn toxicity occurred on these soils. Site effects on removals are discussed in 6.3.2 and 6.3.3.

Conclusions and recommendations liming trial

Differences between fields were larger than those between treatments. Liming effects varied from somewhat negative (agricultural lime) to somewhat positive (agr. lime and especially calc. dunesand). In view of original soil pH, yields and removals, liming is not worthwhile nor economically feasible on these soils. Calcareous dunesand appeared to be a quick working liming material and could be used on soils with pH below 5. However, it is not sure to which extent removal of these dunes is justified ecologically. Agricultural lime has lower solubility and may be more profitable on the long run. The cost of agricultural lime (see 5.2), transport costs and costs of facilities for both liming materials may hinder any lime application. More research could be undertaken to examine its yield reducing effect, and to find and evaluate its applications elsewhere in the area around Mombasa.

Table 6.15. Nutrient removals liming trial (kg.ha^{-1})[a].

	Treat-ment	zero	a.l.	d.s.	Mean Sokoke	Mean Ngerenya
Sokoke						
Grains	N	26.5	25.7	30.3	27.5	52.3
	P	3.8	4.0	4.4	4.1	6.6
	K	5.0	5.6	5.7	5.4	8.7
	Mg	1.38	1.67	1.80	1.62	2.81
	Mn	0.012	0.014	0.015	0.014	0.024
Stalks & leaves	N	13.1	14.6	16.4	14.7	25.2
	P	1.28	1.35	1.45	1.36	2.28
	K	26.3	27.0	29.6	27.6	50.1
	Na	1.19	1.29	1.42	1.22	2.30
	Ca	4.55	4.81	6.69	5.35	8.64
	Mg	4.25	4.53	6.22	5.00	10.15
	Mn	0.613	0.866	0.830	0.776	0.653
					Ratio Ngerenya / Sokoke	
Ngerenya					**means**	**zero's**
Grains	N	53.9	50.6	52.3	1.90	2.04
	P	6.4	6.7	6.7	1.65	1.68
	K	9.2	8.3	8.7	1.61	1.84
	Mg	2.95	2.70	2.77	1.73	2.14
	Mn	0.027	0.025	0.021	1.71	2.25
Stalks & leaves	N	26.0	23.5	26.1	1.71	1.98
	P	2.00	2.28	2.55	1.68	1.56
	K	49.7	49.6	47.4	1.82	1.89
	Na	2.62	1.97	2.31	1.89	2.20
	Ca	7.33	7.95	10.64	1.61	1.61
	Mg	10.83	8.98	10.65	2.03	2.55
	Mn	0.737	0.600	0.622	0.84	1.20

a) legend of underlinings, see Table 6.13.

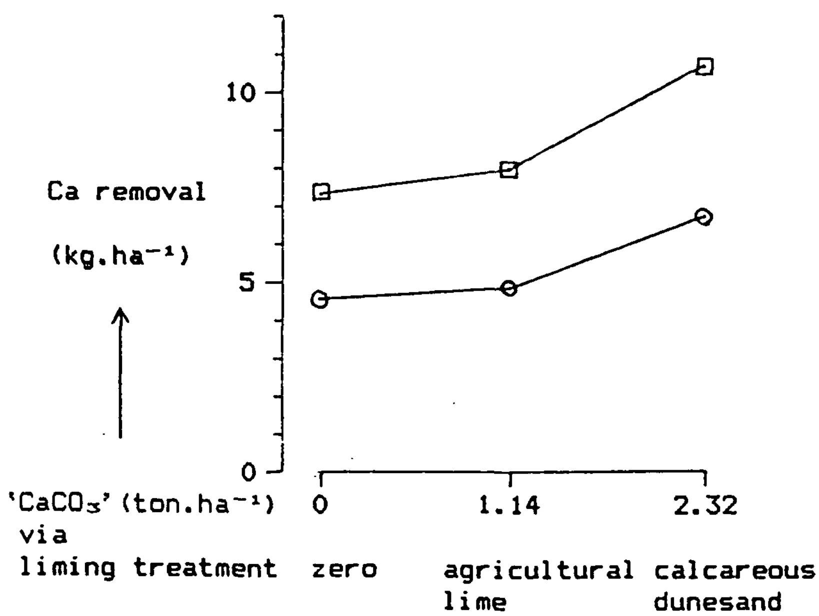


Figure 6.3. Ca removal liming trial.

□ Ngerenya
○ Sokoke
trial field

6.3 FERTILIZER TRIAL

For a general introduction to the discussion of treatment effects is referred to 6.2.2.1.
The order of discussion in this paragraph is 'growth and yields' (6.3.1), 'plant nutrient concentrations and removals' (6.3.2), and assessment of plant nutrient removal and yield estimates from and with QUEFTS (6.3.3).

6.3.1 GROWTH AND YIELDS

Fertilizer effects Table 6.16 summarizes the results.
NP treatment is connected with a tendency to higher emergence % on the Sokoke field (UE111). The lowest emergence % was 64 % on plot 6 under N treatment, and was probably caused by a burning effect of N-fertilizer, which occurred in young plants, mainly on the Sokoke field. Nevertheless, generally few plants died (see emergence data Table 6.25) and the burning effects vanished gradually.
About 2 weeks after planting blueish plants occurred especially on UE111, which was connected with burning effect of fertilizer in this soil with lowest CEC (3.3 me.(100 g)$^{-1}$).
Both single fertilizers increased plant height on UE111. Their combination increased plant height on both fields.
In Sokoke (UE111) no clear effects on 50% tasselling were proved, although this point occurred quicker in the order 0, N and P, NP; further especially N and P treatment showed more difference with 0 treatment than in Ngerenya (UE112). In Ngerenya some NP effect occurred.
Moisture contents Moisture content coheres with ripeness and stage in the life cycle of a crop. Combining assessment of moisture contents of grains and stalks and leaves, in Sokoke crops were riper (drier) in the sequence 0, P, N and NP, - and in Ngerenya (within a smaller range) in the sequence N, 0, P and NP.
Mean dry weight of grains per ear Next to strong N effect a tendency to P effect on N-level exists; both N and NP effect are relatively stronger on UE111 (Sokoke), but absolutely of the same size. With P fertilizing only, N limits yield increases.
Mean stover dry weight N effect occurs on both soil units, again stronger on UE111. Single P effect is found on UE111, whereas P effect on N level occurs on UE112.

Table 6.16. Growth and yield data fertilizer trial[a].

	Weeks after planting	0	N	P	NP	Means Sokoke	Means Ngerenya
Sokoke							
Emergence of stands (%)	2	90	88	93	98	92.3	95.4
Plant height (dm)	8	5.7	7.2	7.9	11.6	8.1	13.1
50 % tasselling[b]	9-10	74	72	71	68	71	65
From harvested net plants[c]:							
- grain moisture %[d]	18	22.7	20.6	19.5	19.9	20.7	20.0
- stover moisure %[d]	,,	53.2	39.9	46.8	37.8	44.4	44.4
- mean dry weights (g, 0 % moisture) of:							
- grains per ear	,,	19	40	23	49	33	68
- stover per plant	,,	19	40	42	65	43	85
grain yields ($ton.ha^{-1}$; 12 % moisture)	,,	0.75	1.61	0.90	2.10	1.34	2.58
stover yields ,,	,,	1.04	1.67	1.70	2.86	1.82	3.47
harvest index[e]	,,	0.416	0.494	0.332	0.420	0.415	0.425
						Ratio means	**Ngerenya / Sokoke zero's**
Ngerenya							
Emergence of stands (%)	2	95	95	96	96	1.03	1.06
Plant height (dm)	8	11.7	12.9	11.7	16.0	1.62	2.05
50% tasselling[b]	±9	66	66	65	63	0.92	0.89
From harvested net plants[c]:							
- grain moisture %[d]	18	19.1	21.0	20.0	20.0	0.97	0.84
- stover moisture %[d]	,,	45.9	46.9	42.0	42.9	1.00	0.86
- mean dry weights (g, 0% moisture) of:							
- grains per ear	,,	56	80	50	86	2.06	2.95
- stover per plant	,,	63	91	72	114	1.98	3.32
grain yields ($ton.ha^{-1}$; 12% moisture)	,,	1.92	3.05	1.82	3.51	1.93	2.56
stover yields ,,	,,	2.59	3.68	2.94	4.67	1.91	2.49
harvest index[e]	,,	0.423	0.460	0.387	0.431	1.02	1.02

a) see Table 6.13.
b) days from planting.
c) The number of harvested net plants was often below 33 (100%), because plants from replanted stands were not harvested (see App.19).
d) at harvest; moisture % related to fresh weight ($\frac{F-D}{F}$) x 100, in which F = net fresh weight, and D = net dry weight).
e) harvest index = $\frac{\text{grain yield}}{\text{(grain + stover) yield}}$, calculated per ha.

Grain and stover yields Again N effects are relatively most striking on UE111 (Sokoke), but absolutely stronger on UE112. On UE111 a tendency to P effect is found for stover yields. P effects on N level occur regarding stover yields, and somewhat concerning grain yields on UE111.

Harvest index On UE111, N treatment positively, but P treatment negatively affects the harvest index, thus neutralizing the effects of N and P fertilizing (relative to zero treatment). Same tendencies are seen on UE112.

Maximum yields of grains are achieved under NP treatment (see Table 6.16 and Figure 6.4). Single N effect (yield increase 0.9-1.1 $ton.ha^{-1}$) exceeds P effect on N level (0.5 $ton.ha^{-1}$). If fertilizers could be remunerative according to a feasibility study for low budget farming on these soils, single N application would be most rewarding to attempt first (under the supposition of equal prices and transport costs of the N and P fertilizers).

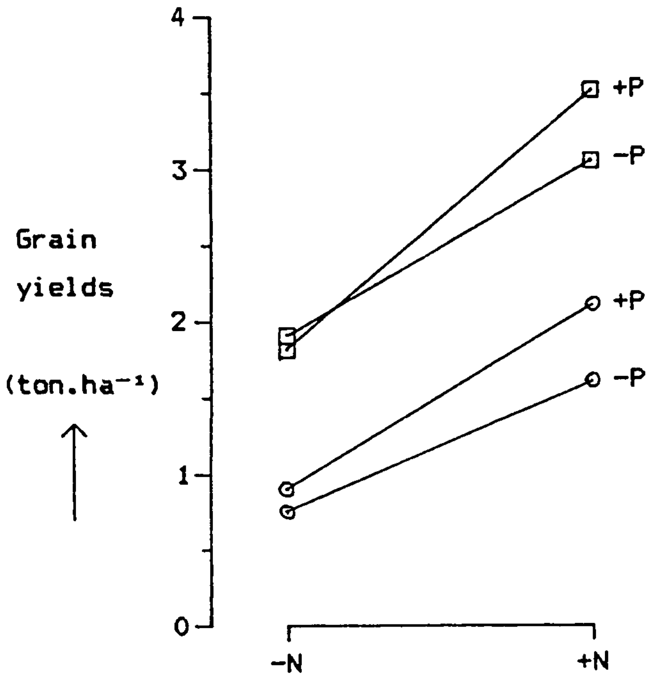


Figure 6.4. Grain yields fertilizer trial.

□ Ngerenya trial field
○ Sokoke

<u>Field effects</u>

<u>N effect</u> prevails on both soils, with relatively more effect on UE111, but absolutely more effect on UE112 (see also Fig. 6.4). This coheres with the longer consecutive use (see App.4) of the Sokoke trial field (UE111) and its hence more depleted soil; besides its CEC is lower. The higher nutrient availability of the Ngerenya field results in a stronger absolute effect of N fertilization.

<u>Some P effect</u> occurs on UE111 for stover yields, and P effect at N level for grain and stover yields. On UE112 no P effects are proved, but at N level P effect is established for stover yields. Harvest index results show positive N and negative P effect on UE111; results from UE112 show the same tendencies. Single P effects only on UE111 oppose the lab result (see Table 2.2) of higher P-Olsen on this soil, which is further discussed in view of Figure 6.6 below).

Conclusions on fertilizer effects

Growth

Especially on UE111 the combination of N and P fertilizing furthered higher plants. NP fertilized plants matured earlier which is reflected by earlier tasselling and riper plants at harvest time (lower stover moisture percentages). Single fertilizer applications mostly showed the same tendencies.

Yields

N effect on yields were relatively strongest on UE111 but absolutely stronger on UE112 (e.g. increase of grain yields 0.86 resp. 1.13 ton. ha^{-1}).

Single P fertilizing did not affect yields of grains.

Some positive NP interaction was found in grain yields on UE111 (same tendency on UE112).

Effects on stover yields are also reflected in the harvest index, with on UE111 positive N and negative P effect and (resulting in) relative to unfertilized soil neutral NP effect.

Conclusions on field effects

Differences between the two trial fields are more striking than (N) fertilizer effects. Checking mean field values, and, if deviating, in parenthesis values from unfertilized soil (see the ratios between Ngerenya and Sokoke values in Table 6.16), the following is observed. On the Ngerenya field (UE112) plants are 0.5 (0.6) m higher, tassel 6 (8) days earlier, (are riper,) per plant grains per ear and stover weigh twice (three times) as much, and the crop yields about two and a half times as much grains.

All ratios Ngerenya:Sokoke from mean field values (0+N+P+NP results)/4 are closer to 1 than field ratios from unfertilized plots. Thus fertilizing reduces relative differences between the two trial fields; for growth characteristics (plant height and tasselling) fertilizing even absolutely reduces field differences.

6.3.2 PLANT NUTRIENT CONCENTRATIONS AND REMOVALS

Fertilizer effects on plant nutrient contents (see Table 6.17)

N treatment somewhat reduced stover P content on UE111, and showed the same tendency for grains. Thus on UE111, natural P availability may have limited yield increases under N treatment. N treatment reduced Mn content on UE111 and somewhat did this on UE112; next it is connected with higher Mg content in stalks and leaves on UE111.

Table 6.17 Plant nutrient contents fertilizer trial[a].

		0	N	P	NP	Means Sokoke	Means Ngerenya
Sokoke							
Grains	N	1070	1023	916	1069	1020	1043
	P	70	63	74	73	70	72
	K	83	83[d]	89	77[e]	83	90
	Mg[b]	(18)	(17)	(31)	(35)	.	37
	Mn[a]	13.9	6.1	2.5	7.4	7.5	7.2
Stalks & leaves	N	396	373	403	410	396	400
	P	21	13	26	17	19	19
	K	282	297	217	281	269	286
	Na	15	19	19	21	19	21
	Ca	40	[117][c]45	46	[57]53	46	50
	Mg	88	[88]99	96	82	91	94
	Mn	319	247	316	305	297	160
						Ratio means	Ratio Ngerenya/Sokoke zero's
Ngerenya							
Grains	N	1069	1171	1124	1207	1.12	1.00
	P	66	66	77	69	0.97	0.94
	K	[135]93	81	112	[95]72	1.08	1.12
	Mg	34	37	40	36	.	.
	Mn	7.2	5.8	7.8	7.9	0.96	0.52
Stalks & leaves	N	445	351	[309]369	436	1.01	1.12
	P	22	[14]21	16	18	1.00	1.05
	K	284	310	238	312	1.06	1.01
	Na	20	23	18	24	1.11	1.33
	Ca	55	53	40	52	1.09	1.38
	Mg	101	93	80	101	1.03	1.15
	Mn	177	136	166	159	0.54	0.55

a) in $mmol.kg^{-1}$, except Mn in $mg.kg^{-1}$; see also footnote c) in Table 6.14.
b) Mg contents as measured in the A series were not interpretable and are put between round brackets - obtained values lay between 0 and those of the lowest standards, which had a resp too low and too high value. (Both high standards were far too low.)
c) Between brackets [ ] are given any means computed from one 1st class outlier and 2 'normal' values (For outlier definition see App.17.)
d) A 2nd class low outlier was not corrected.
e) A 2nd class high outlier was not corrected.

Under P treatment, N content in grains on UE111 decreased, and this tencency was also observed in stalks and leaves on UE112; thus the availability of N limited yield increases under P treatment. P treatment somewhat raised P contents except for lower stover P content on UE112. P treatment is connected with lower stover content of K, and lower stover Ca and Mg content on UE112. It somewhat raised stover Mg content on UE111.

The only relevant interaction effect is stover N concentration on UE112, which is however about equal to corresponding stover N content under zero treatment.

Levels of nutrient contents in grains are assessed below by comparison with data from WALSH & BEATON (1973) for mature grains (see 3.3). Both

fields showed some chlorosis, light green leaves specially under zero and P fertilizer treatment, mainly caused by N-deficiency.
Still, found N-contents do not lie in the lowest part of the range (714-1786 mmol.kg^{-1}). On both fields P-contents lie in the lowest part of the range (65-194). In Sokoke the value under N-treatment lies below the range, confirming P-shortage in these soils. P-fertilizing might raise P-contents, but not significantly.
Except K-content under P-treatment, which lies just beyond the range (51-103 mmol.kg^{-1}), all K-contents lie around and above the middle of the range. Mg-content in Sokoke under NP-treatment (and probably the other Sokoke contents too) and all Mg-contents in Ngerenya lie around 38 mmol.kg^{-1}, the lowest point of the range (38-82 mmol.kg^{-1}).
Mn-contents lie within the range 5-15 (mg.kg^{-1}), except the one obtained under P-fertilizing in Sokoke. Mn deficiency will not occur however on these soils with frequent small Mn concretions.
Deficiency symptoms of P, Mg and Mn were not observed.
Levels of nutrient contents in stalks and leaves are not discussed here.

Table 6.18. Plant nutrient removals fertilizer trial (kg.ha^{-1}).

		0	N	P	NP	Means Sokoke	Means Ngerenya
Sokoke							
Grains	N	10.0	20.2	10.4	27.5	17.0	36.7
	P	1.5	2.7	2.0	4.0	2.6	4.8
	K	2.1	4.6	2.8	5.4	3.7	7.7
	Mg	(0.31)[a]	(0.61)	(0.62)	1.61	(0.79)	2.10
	Mn	0.008	0.008	0.002	0.013	0.008	0.016
Stalks & leaves	N	5.2	7.6	8.4	14.7	9.0	17.4
	P	0.58	0.58	1.20	1.36	0.93	1.86
	K	10.2	17.1	12.9	27.6	17.0	34.8
	Na	0.32	0.60	0.69	1.30	0.73	1.52
	Ca	1.51	2.62	2.87	5.35	3.09	6.25
	Mg	1.98	3.52	3.66	5.00	3.54	7.09
	Mn	0.287	0.359	0.445	0.776	0.467	0.478
						Ratio Ngerenya/Sokoke **means**	**zero's**
Ngerenya							
Grains	N	24.8	44.3	25.3	52.3	2.16	2.48
	P	3.4	5.5	3.8	6.6	1.85	2.27
	K	6.2	8.5	7.2	8.7	2.07	2.95
	Mg	1.26	2.70	1.67	2.78		
	Mn	0.012	0.015	0.013	0.024	2.00	1.50
Stalks & Leaves	N	14.0	16.7	13.5	25.2	1.93	2.69
	P	1.58	2.23	1.35	2.28	2.00	2.72
	K	25.3	39.5	24.3	50.1	2.05	2.48
	Na	1.05	1.64	1.10	2.30	2.08	3.28
	Ca	5.12	6.96	4.30	8.64	2.02	3.39
	Mg	5.54	7.56	5.10	10.15	2.00	2.80
	Mn	0.393	0.421	0.446	0.653	1.02	1.37

a) see footnote b) under Table 6.17.

<u>Fertilizer effects on plant nutrient removals</u> (see Table 6.18 and Figures 6.5 and 6.6). Total removals are commented upon in 6.3.3. Considering removals, significant N effects prevail, especially on UE111. Relevant P effects occur merely on UE111, and most interaction effects are found on UE111 as well; this contradicts chemical soil data (see the end of 6.3.1 and Table 2.2) and is explained below in the light of Figure 6.5.

<u>Field effects on plant nutrient removals</u>

Fertilizer recoveries are presented in Table 6.19.

Table 6.19. N and P recoveries of lime (NP) and fertilizer (O, N, P, NP) trials.

trial field	map unit	N	P	NP
N recovery				
Sokoke	UE111	0.253		0.468
Ngerenya	UE112	0.445		0.774
P recovery				
Sokoke	UE111		0.039	0.071
Ngerenya	UE112		0.007	0.038

On both fields, N recovery on P level is about 1.8 times higher than under single N treatment. N recovers best on UE112. On both fields, P recovery on N level is c. 0.030 higher than under single P treatment, P recovering best on UE111.

N recoveries suggest a higher fertility of the Ngerenya field in agreement with chemical soil data that show a higher availability of other nutrients than N, (Table 2.2) and with growth and yield and removal data (Tables 6.16 and 6.18). On the contrary P recoveries suggest a higher fertility of the Sokoke field, but negative values on several Ngerenya plots make these recoveries extremely low and less reliable.

Recoveries under NP treatment belonged to the input of the QUEFTS computer-programme (see 3.3).

Next to Table 6.19, also Figures 6.5 and 6.6 show factor as well as field effects.

N removal is positively correlated with organic N %, and fertilizer-N (Figure 6.5).

Figure 6.6 shows lower P removals from the soil with (according to Table 2.2) higher P availability, which is illogical. Growth and yield data (Table 6.16) as well as nutrient removals (Table 6.18) show all single P effects and most P effects on N level on the Sokoke field. Moreover, P recoveries on this field exceed the Ngerenya ones. However Table 2.2 gives a lower P-Olsen for the Ngerenya field. This makes the reliability of both P-Olsen values questionable (see further 6.3.3 (p.73) on this matter).

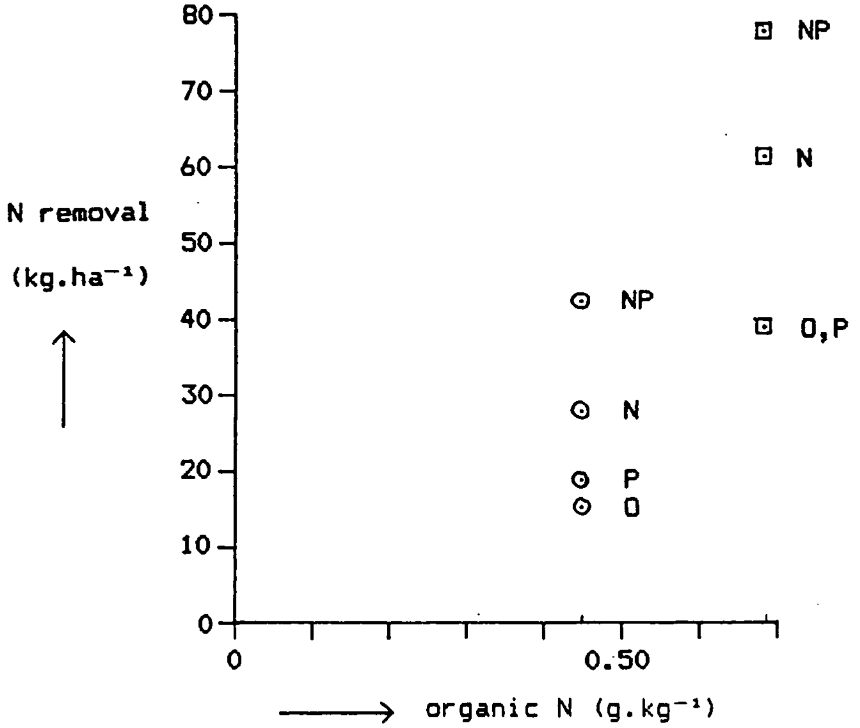


Figure 6.5. N removal in relation to organic N.

□ Ngerenya trial field
○ Sokoke

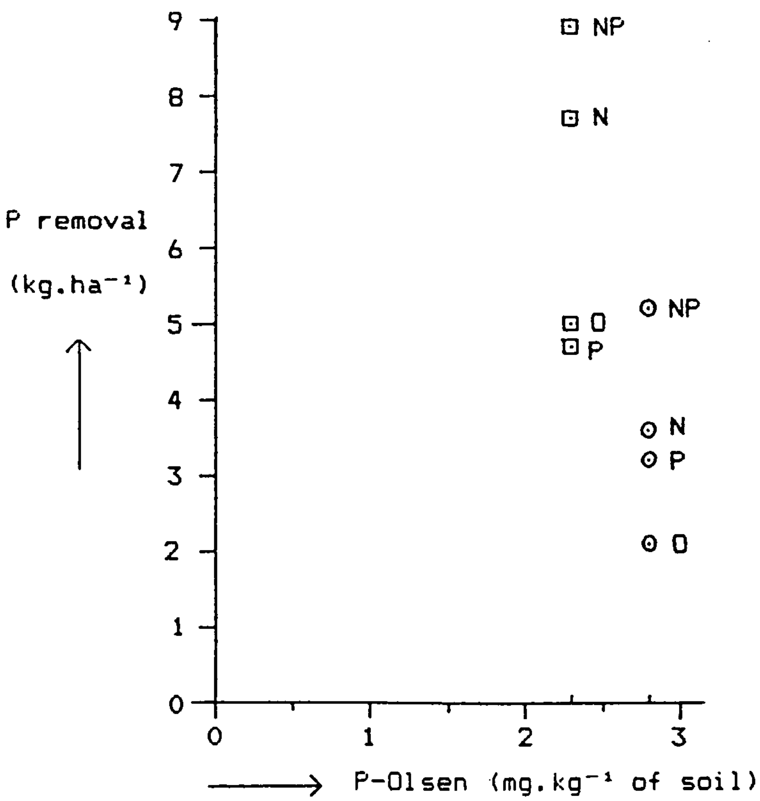


Figure 6.6. P removal in relation to P-Olsen.

□ Ngerenya trial field
○ Sokoke

Conclusions

Nutrient contents

a) Fertilizer effects

Corresponding with the natural availability of P on UE111 and N on both soils, N resp. P treatment reduced concentrations of these nutrients. As P (and also Mg) contents contrary to N contents lie in the lowest part of the range given by WALSH and BEATON (1973), P shortage seems more limiting than N shortage. Nevertheless, N fertilizing resulted in twice as high yield increases as P fertilizing.

N fertilizing reduced Mn contents, especially on UE111 where highest Mn contents occurred, thus diminishing a possible Mn toxicity. (Both soils contain frequent(?) small Mn concretions.) At the applied N and P levels, the analytical data do not suggest, any other nutrient limits increases of yields. Some risk of Mg shortage exists however. (Adding a discussion of nutrient contents in stalks and leaves might generate clearer conclusions.)

b) Field effects

On the Ngerenya field (UE112) occur higher Na contents on unfertilized plots and explained from its higher fertility status lower Mn contents than on the Sokoke field (UE111).

Removals

a) Fertilizer effects

N fertilizing relevantly raised many removals on both soils a.o. P removal by grains. P fertilizing merely raised some removals on UE111 a.o. not N removal. This shows N was the most limiting nutrient on both soils.

NP interaction somewhat raised or tended to raise many removals, greater increases occurring more on UE111. Recoveries of NP fertilizing were much greater than single N and P recoveries.

b) Field effects

CEC's, organic N contents and (after correction) P Olsen values are reflected in twice as high removals on UE112.

Differences between removals on unfertilized plots are discussed in 6.3.3.

6.3.3 ASSESSMENT OF PLANT NUTRIENT REMOVAL AND YIELD ESTIMATES FROM QUEFTS AND FROM JANSSEN AND SANCHEZ

As the QUEFTS computer model gives uptake and yield estimates based on equations, it transcends being constrained to work with uptake-and-yield-classifications. Therefore 'Quantitative Evaluation of the Fertility of these Tropical Soils' is more extended than the evaluation according to data from JANSSEN and SANCHEZ.

Comparison with data from the QUEFTS computer model

The QUEFTS computer model was developed from data sets of 15 trials, 4 of which being undertaken in the Kilifi area, of which in turn 1 trial was carried out on Magarini sands (in 1981 by de BIE). Thus it is more likely that the QUEFTS model raises questions about this field trial (1982) than vice versa. However, next to assessment of experimental uptakes and yields, also both predicting data sets from the QUEFTS model will be compared and discussed.

Table 6.20 sums up N, P and K uptakes and grain yields for both trial fields. Columns 1 and 2 sum up most important QUEFTS estimates, 1 being based on chemical soil data and 2 on experimental data. Column 3 presents results of this fertilizer trial. Completer data sets are found in Appendix 22.1 and 22.2 (QUEFTS) and the Tables 6.16 and 6.18 and Appendix 18 (this trial).

Table 6.20. Uptakes and yields derived from 1) chemical soil data, 2) experimental uptakes, both predicted by the QUEFTS computer model, and 3) obtained in the experiments.

Trial field	Fertilizer treatment			Uptake ($kg.ha^{-1}$)									Yield ($ton.ha^{-1}$)			Yield increase[a]		
				N			P			K								
soilmap unit	N	P	K	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Sokoke	0	0	0	19.6	18.6	15.1	2.8	3.0	2.1	36.7	26.5	12.3	0.95	0.86	0.75			
UE111	0	30	0	19.9	18.8	18.8	4.3	4.3	3.2	36.7	26.5	15.7	1.02	0.93	0.90	0.1	0.1	0.2
	50	0	0	38.1	38.0	27.8	3.0	3.3	3.3	49.3	29.9	21.7	1.46	1.38	1.61	0.5	0.5	0.9
	50	30	0	41.1	40.7	42.2	5.0	5.2	5.4	59.6	31.6	33.1	2.06	1.77	2.10	0.6	0.4	0.5
Ngerenya	0	0	0	31.9	38.5	38.8	4.3	6.9	5.0	36.0	50.4	31.5	1.49	2.04	1.92			
UE112	0	30	0	32.4	38.6	38.8	5.2	7.7	5.2	36.0	50.4	31.5	1.58	2.10	1.82	0.1	0.1	-0.1
	50	0	0	60.8	72.2	61.1	4.4	7.5	7.7	36.9	55.0	48.0	2.00	3.03	3.05	0.5	1.0	1.1
	50	30	0	64.1	73.5	77.5	5.5	8.6	8.9	38.0	55.8	58.7	2.31	3.24	3.51	0.3	0.2	0.5

a) For single P and N treatment relative to the yield after zero treatment;
for NP ,, ,, N ,, .

Predicting data sets

Appendix 22.1 adds potential supplies to column 1 (and column 2). It also includes Table 2.4.

The 52 % actual uptake for K on the Sokoke field is raised to 70 resp. 85 % of potential supply after applying N resp. N and P.

Column 2 may give more realistic predictions than column 1 because next to maximal N and P recoveries also nutrient uptakes obtained in the experiment belonged to the input of the QUEFTS-computer model. Therefore, actual uptakes can deviate less from potential supplies, and more realistic predictions can be expected.

Comparison of both predicting data sets

Both predictory data sets (Table 6.20.1 and .2) are discussed in view of Appendix 22.1 and 22.2 - The relative supply of N, P and K according to chemical soil data is quite unbalanced in Sokoke, but rather balanced in Ngerenya. The situation in Sokoke is due to the high potential K supply, resulting in a low uptake relative to the uptakes of N and P (App. 22.1 and to a less extent, 22.2) - In Ngerenya relative to estimates from chemical soil data (column 1), higher uptakes from experimental data (column 2) without fertilizing, result in higher increases of uptakes with fertilizing.

Discussion on all three data sets

As calculations based on chemical soil data via the QUEFTS model (Table 6.20: 1) produce higher P-uptakes on the Ngerenya field, which is in accordance with reality (Table 6.20: 3), no reason exists to reject the P-Olsen data (see 6.3.2 and Table 2.2).

The three data sets can be compared e.g. absolutely by comparing yield heights (which is done below), and relatively by comparing predicted and real yield increases.

All three columns show increasing yields in the sequence 0-P-N-NP, except for the experimental data on the Ngerenya field, where P-treatment causes a small increase of P uptake and also 0.1 $ton.ha^{-1}$ grain yield reduction. However P effects if significant are so small that they will be neglected.

The three data sets (columns 1, 2 and 3) showed the following yield increases after treatment with N: 0.5, 0.5, 0.9 on the Sokoke field and 0.5, 1.0, 1.1 on the Ngerenya field, and additional yield increases after treatment with N and P 0.6, 0.4, 0.5 on the Sokoke field and 0.3, 0.2, 0.5 on the Ngerenya field. Thus 5 out of 8 predicted yield increases are too low.

Evaluating QUEFTS data, 2 out of the 4 predicting data sets gave quite good estimates of real yields, and a third one moderately and the 4^{th} one badly. Predictions of yields from chemical soil data of the Sokoke field are quite well corresponding with experimental yields, whereas from uptake data Ngerenya yields are estimated more closely. The uptake based set of Sokoke gave moderate yield estimates (too low for N and NP treatment). Estimates for the Ngerenya field based on chemical soil data are much lower than experimental results.

Comparison with data from Janssen and Sanchez (Table 3.2)

Table 6.21 presents mean values of total nutrient uptake and grain, stover and total yield as obtained in the experiment.

Table 6.21. Experimental data on uptake for N, P and K ($kg.ha^{-1}$) and yield (12% moisture; $ton.ha^{-1}$).

Trial field on soil map unit	Fertilizer treatment N P K	Uptake or Removal N	P	K	Na	Ca	Mg	Mn	Yield of part: Grain	Stover	Total
Sokoke UE111	0 0 0	15.1	2.1	12.3	0.32	1.51	>1.98	0.30	0.75	1.04	1.79
	0 30 0	18.8	3.2	15.7	0.69	2.87	>3.66	0.45	0.90	1.70	2.60
	50 0 0	27.8	3.3	21.7	0.60	2.62	>3.52	0.37	1.61	1.67	3.28
	50 30 0	42.2	5.4	33.1	1.22	5.35	6.61	0.79	2.10	2.86	4.96
mean		26.0	3.5	20.7	0.71	3.09	>3.94	0.48	1.34	1.82	3.16
Ngerenya UE112	0 0 0	38.8	5.0	31.5	1.05	5.12	6.80	0.41	1.92	2.59	4.51
	0 30 0	38.8	5.2	31.5	1.10	4.30	6.77	0.46	1.82	2.94	4.76
	50 0 0	61.1	7.7	48.0	1.64	6.96	10.26	0.44	3.05	3.68	6.73
	50 30 0	77.5	8.9	58.7	2.30	8.64	12.93	0.68	3.51	4.67	8.18
mean		54.1	6.7	42.4	1.52	6.26	9.19	0.50	2.58	3.47	6.05
Ngerenya:Sokoke	(means)	2.08	1.91	2.05	2.14	2.03	<2.33	1.04	1.92	1.91	1.92
,, : ,,	(zero's)	2.57	2.38	2.56	3.28	3.39	<3.43	1.37	2.56	2.49	2.52

Comparing highest uptakes, those under NP-treatment in Ngerenya, with uptakes given by JANSSEN (1978; Table 3.2), only N removal approximates the lowest value of the range (80-120 $kg.ha^{-1}$). P, K, Ca and Mg removal are roughly half of the lowest range value. This suggests the 'Coast Composite' maize was producing far below its yield potential.

SANCHEZ (1976; data quoted in Table 3.2) gives maize removals for grain, stover and total plant (probably only shoots like in this report, no roots) at yield rates comparable with lowest and highest mean yields in this experiment, viz. without fertilizing on the Sokoke field resp. with N and P fertilizing on the Ngerenya field. Nevertheless relative to Sanchez' uptake data, uptakes under these treatments are 20 to >40 % for the lowest yields and 50 to 90 % for the highest yields. So especially in the lowest yields, nutrients are much more diluted than expected from Sanchez. According to Sanchez' data, most limiting nutrients on both fields seem P and Ca.

<u>Field effects</u>

Removals and yields under NP treatment on the Sokoke field are generally only slightly higher than under zero treatment on the other field (except for Mg removal: slightly smaller, and Mn removal: higher).

Comparing natural soil fertility of both fields (zero treatment), uptakes on the Ngerenya field are 2.4 to 3.4, and yields 2.5 times as high as on the Sokoke field. This confirms the higher fertility of the Ngerenya field.

Conclusions

The QUEFTS computer model gives quite good predictions if 'fed' with correct data. Its predictions based on experimental uptake data are more accurate, but such data are less (soon) available than chemical soil data.

Fertilizer effects on (grain) yields

The only single P effect is on stover yields in Sokoke. Single N application yields the highest increase of grain production on both fields: 0.86 resp. 1.13 $ton.ha^{-1}$. NP interaction causes additional increases of grain yields: 0.49 resp. 0.46 $ton.ha^{-1}$.

Field effects

Field effects have at least equal size as N fertilizer effects. Especially in the lowest yields, obtained under zero treatment in Sokoke, nutrients are much more diluted than expected (from SANCHEZ' data); further on both fields most limiting nutrients are P and Ca.
The also after fertilizing low nutrient uptakes (relative to JANSSEN's data) indicate this level of maize production is far below its yield potential. These low fertile soils however, may have yielded to their in these long rains economically feasible (because paying) potential.
In Sokoke fertilizing causes relatively higher yield increases, because fertilizing with N and P corrects the rather unbalanced nutrient supply. In Ngerenya fertilizing causes absolutely higher yield increases by its higher soil fertility (higher availability of other nutrients).

6.3.4 SOME REMARKS ON THE ECONOMICS OF FERTILIZER USE (adapted after SCHREURS, 1984: 26,27)

The preceding paragraphs 6.3.1, (.2, and .3) show application of (N)-fertilizer(s) raised maize yields. Before recommending fertilizer use to farmers, the application should not only be technically possible, but also economically paying. Only then, and if social and cultural factors do not raise constraints, one can safely recommend a certain level of fertilization.
In the present trials a package of cultural measures (not used by farmers) was applied including improved tillage, crop protection and frequent weeding. This hampers proposal of fertilizer levels appropriate for the management practices of small farmers. Yet it is worthwhile to calculate the profitability of fertilizer use, assumming

that tillage and weeding are carried out properly, and pests and diseases can be controlled cheaply or are of no significance.

A measure to establish the profitability of inputs is the marginal 'rate of return' or marginal 'value/cost ratio' $\left(= \frac{\text{marginal net benefit}}{\text{marginal.cost}}\right)$, described by PERRIN et al. (1976). A marginal rate of return of 100 % means marginal net benefit equals marginal cost (value/cost ratio = 1). Often a marginal rate of return of 200 % (value/cost ratio = 2) is considered as a level at which a subsistence farmer is willing to adopt an improvement. Table 6.22 mentions marginal rates of return for the present fertilizer trials. The method of partial budget analysis (PERRIN et al., 1976) was used in deriving this table from yields and prices. Appendix 9.2 gives some background data. Several <u>assumptions</u>[1] were:

- from yields, 10 % was deducted for harvest and storage losses,
- the cost of fertilizers was calculated 10 % higher, because of transportation costs,
- per application, 2 man days were needed. The cost of one man day was valued at 15 Ksh. (Kenya shillings).

Table 6.22. Marginal rates of return at two maize prices for the yield data of de BIE (1982), SCHREURS (1984) and van LEEUWEN (1988); (%).

maize price:		1 Ksh/kg					1.5 Ksh.kg⁻¹				
$kg.ha^{-1}$	N	0	0	50	50	50	0	0	50	50	50
	P	15	30	0	15	30	15	30	0	15	30
de	CS[1)]	+ 9	+ 13	+ 4	+67	+17	+ 63	+ 69	+ 56	+151	+ 76
BIE[2)]	SH	+52	+ 13	+ 30	- 8	-38	+128	+ 69	+ 95	+ 38	- 8
	MG	+30	+ 69	- 35	-25	-32	+ 96	+154	- 3	+ 13	+ 2
	LS	+74	+ 2	-113	+17	-20	+161	+ 52	-119	+ 76	+ 20
SCHREURS[2)]											
	CS		- 83	- 74		-69		- 75	- 60		- 53
	SH		- 36	- 43		-41		- 4	- 14		- 11
van LEEUWEN											
	MG Sok		- 71	+ 27		+ 5		- 57	+ 91		+ 58
	Nge		-120	+ 68		- 2		-130	+152		+ 47

1) CS = Coastal sands, SH = Shales, MG = Magarini sands, LS = Lime Stones.
2) data from SCHREURS, 1984.

[1] SCHREURS' assumptions were slightly different from those of van LEEUWEN. Van LEEUWEN applied the N fertilizer in two halves (which increased labour costs by Ksh 30.=) and the cost for 1 kg N including 10 % transport costs amounted to Ksh. (SCHREURS: Ksh 12.65). SCHREURS did not present the price of 1 kg P.

The marginal rate of return appears to be strongly related with maize prices. Probably the actual price of maize lies closer to 1 $Ksh.kg^{-1}$ than to 1.5 $Ksh.kg^{-1}$. - At 1 $Ksh.kg^{-1}$ neither data from de BIE (trials in 1982) nor from SCHREURS or van LEEUWEN (trials in 1982) show marginal rates of return equal to or higher than 100 %. - At 1.5 $Ksh.kg^{-1}$ several figures reach 100 %: de BIE's data on Coastal sands NP 50 resp. 15 $kg.ha^{-1}$, on shales and limestones P 15 $kg.ha^{-1}$ and on Magarini sands P 30 $kg.ha^{-1}$; all SCHREURS' data show negative figures, which means money is lost; van LEEUWEN's data show N 50 $kg.ha^{-1}$ was paying fertilizer cost in Ngerenya and almost balancing marginal variable costs in Sokoke.

The remunerativeness of P 30 $kg.ha^{-1}$ in de BIE's trial on Magarini sands in 1981 contrasts the remunerativeness of N 50 $kg.ha^{-1}$ on the Ngerenya trial field in 1982. Further, the 1982 trial fields on Magarini sands were more representative than the one of de BIE in 1981 (BOXEM, 1982, pers. comm.).

In the years 1981 and 1982, never a value/cost ratio of 2 (+ 200 %) was attained with any fertilizer treatment. Hence in view of present prices of fertilizers and maize, recommending N fertilizing would only be worthwhile for small farmers, if its effects on yields could be increased e.g. by less leaching than in 1982 (see 7.3.3 and 7.4).

For the subsistence farmer, the rates of return are probably less than the figures given in Table 6.22. By using traditional cultivation methods, these farmers operate at a lower yield level. Thus the absolute yield gain (obtained by applying fertilizer) is less, while the costs remain the same.

Possibly the use of fertilizers is more profitable on other crops. Rice and grain legumes have much higher prices than maize.

Other management practices, e.g. use of pesticides, herbicides or tillage might be equally or more profitable than application of fertilizers. For example with adequate crop protection, maize yields could have been doubled on the Coastal sands.

6.4 LEACHING TRIAL

Introduction

The leaching has been performed on the Sokoke field that had received both lime treatments and had been cropped with maize. The amounts and the composition of the leaching water were measured. Leaching results were measured with pH and moisture content determinations.
These data will be discussed in this paragraph in the following order. First in 6.4.1, attention will be paid to the amounts of leaching water, and estimation of the percentage that reached a certain depth. Then in 6.4.2, this will be connnected with chemical inputs, because of the composition of the leaching water. In this light, pH data from before and after the trial will be compared in order to draw some conclusions (6.4.3).

6.4.1 QUANTITATIVE WATER SUPPLY

Calculations of the amounts of leaching water (mm) that leached quantitatively through the upper 5 cm are presented in Appendix 24. The eventual amounts received by the soil within the rings below 5 cm depth, are rough estimates of the amounts received in reality.
Estimated amounts of water (mm) received within the leaching rings are summed up in Table 6.23.2. The leaching lasted 88 3/4 hours, which period was approximately divided in quarters of about 22 h (see Table 6.23.1). This helped discerning major changes and differences of infiltration rate (Table 6.23.4) and calculating chemical inputs via leaching water (discussed later on). Tables 6.23.2 and .4 are corrected for (the differences between) the ring areas (Table 6.23.3).
In order to guarantee optimal and comparable results, it was tried to supply the rings with as high and comparable outflows as possible (or in other words: high and equal infiltration rate or percolation, minding to prevent inundation). All plots received c. 840 mm rainfall during the preceding long rainy season. During leaching (after the harvest) however, considerable differences between separate infiltration totals were achieved varying from about 5,000 to 9,000 mm (Table 6.23.2), corresponding with 4.4 to 8.2 times the annual amounts of rain (see 2.1.1).

Table 6.23. Quantitative water supply.

1) Duration of the leaching quarters (h) — derived from App.24
2) Infiltration within leaching rings (mm) — derived from App.24
3) Ring areas (m^2)
4) Infiltration rates ($\mu m.s^{-1}$) = 2) / (1) x 3600 $s.h^{-1}$)
5) Water supply to leaching rings (m^3) = 2) x 3) / 1000

1) Duration of leaching quarters (h)

Plot no.	30	26	28
Lime trtmt	zero	agr. lime	calc. dune-sand
Quarter no.			
I	23.25	23.25	23.25
II	22.5	22.5	22.5
III	22.25	22.25	21.5
IV	20.75	20.75	21.5
	88.75	88.75	88.75

(exact quarter 22.1875)

4) Average infiltration rates ($\mu m.s^{-1}$)

	30	26	28
	zero	agr. lime	calc. dune-sand
Quarter no.			
I	32	20	28
II	23	18	31
III	10	12	19
IV	19	10	34
Mean	21	15	28

2) Infiltration in leaching rings (mm)

I	2709	1660	2316
II	1828	1434	2540
III	819	962	1496
IV	1444	770	2648
Cumulative infiltration F	6800	4826	9000

5) Water supply to leaching rings (m^3)

I	0.349	0.196	0.236
II	0.235	0.169	0.259
III	0.105	0.113	0.152
IV	0.186	0.091	0.270
Total	0.875 +	0.569 +	0.917= 2.361

3) Ring areas (m^2)

0.1288	0.1179	0.1018

Some difficulties during leaching held for the trial as a whole.

- It appeared to be difficult to maintain constant tap outflows (see Table 6.23.4 and App.24), at the water distribution point as well as at the water-casks (see Fig.5.2 in 5.4).
- Varying water heights in main tank and water-casks, and hand regulated taps caused varying outflows. Some times an overflowing watercask resulted in leaching around the single ring as well; a positive effect of this was prevention of some sidewards transport of ring leaching water. Still, a double ring system would have benefitted infiltration of the water supplied to the inner ring by continuous reduction of lateral seepage.
- Once, two taps ran dry overnight after a last check at 2.30 a.m. (see App.24). Nevertheless, total water supplies to the rings 28 and 30 were

of comparable greatness (c. 0.9 m^3, see Table 6.23.5). But comparing total infiltrations and average infiltration rates (Tables 6.23.2 and .4) of these rings shows considerable differences, caused by inequal ring areas (Table 6.23.3).

A difficulty particular to one ring was the following. Bound up with ring 26 was its inundation at relatively low infiltraton rates. This phenomenon grew more severe during the trial. Its cause was the relatively more treading around the profile pit (before the leaching trial), which disturbed the upper soil layers at that spot.

Table 6.24. Moisture contents (%) before and after leaching.

depth (cm)	before leaching plot 30	26	28	mean	s	after leaching plot 30	26	28	mean	s	> = <	moisture % at pF 2.0[1]
0 - 5	1.0	2.1	1.4	1.5	0.56	18.2	19.0	20.0	19.1	0.90	>	11.1
7½ - 12½	3.7	4.0	3.2	3.6	0.40	16.7	12.8[2]	15.8	15.1	2.04	>	(11.8)
15 - 20	4.1	4.1	4.3	4.2	0.12	12.8	11.5	13.2	12.5	0.89	=	(12.6)
22½ - 27½	4.2	3.9	4.3	4.1	0.21	12.1	11.6	12.7	12.1	0.55	<	13.3
30 - 35	4.9	4.2	4.7	4.6	0.36	12.4	12.1	14.0	12.8	1.02	<	(13.8)
37½ - 42½	5.2	5.0	5.1	5.1	0.10	8.3[3]	12.4	13.7	11.5[3]	2.82[3]	<	(14.2)
50 - 60	5.4	5.5	5.7	5.5	0.15	13.3	12.8	14.0	13.4	0.60	<	15.1
90 - 100	8.3	6.9	8.0	7.7	0.74	15.2	13.6	15.0	14.6	0.87	<	17.2
140 - 150	8.0	8.4	8.9	8.4	0.45	15.1	14.0	14.6	14.6	0.55	<	18.6
200 - 210	8.3	8.2	8.3	8.3	0.06	13.4	12.7	14.1	13.4	0.70	<	17.0
240 - 250						10.8	11.3	11.6	11.2	0.40		
270 - 280											<	19.1
290 - 300						18.0[3]	12.1	12.2	14.1[3]	3.38[3]		
340 - 350						12.0	11.1	12.0	11.7	0.52		
390 - 400						12.0	10.5	11.8	11.4	0.81		

1 derived from Appendix 23. Data in paranthesis are obtained by interpolation.
2 A quick decrease in moisture % relatively to other plots occurred within ring 26, probably because percolation is only disturbed in the surface soil layer from 0-5/7½ cm, whereas from7½ cm onwards percolation is not hindered and the soil below 7½ cm has an even higher water suction force, caused by lower infiltration.
3 value deviating from logical pattern.

After leaching, highest moisture percentages were found in the surface soil (see Table 6.24). Downwards they diminished until 1.0 to 1.5 m where a somewhat lower moisture maximum occurred. Below 1.5 m, moisture percentages decreased further.

Moisture contents during leaching may have been somewhat higher than reflected by moisture contents obtained from samples taken after finishing the leaching process. The soil is somewhat excessively drained; hence after saturation, the water content decreased quickly. Still, moisture contents from the upper layers reflect no saturation during leaching, but in view of data given in Appendix 23 until 20 cm depth the soil will have been above field capacity (pF 2.0) at c. pF

depth the soil will have been above field capacity (pF 2.0) at c. pF 1.5 during the trial. Thus the hydraulic conductivity (or permeabeability) has been maximally 1/10 of the saturated hydraulic conductivity and leaching capacity was small (see 3.4, and LANDON, 1984). Still, although the trial was undertaken with single rings on small areas (c. 0.12 m^2), the trial may have imitated circumstances under heavy rainfall.
After all the possibility of lime leaching is doubtful.

6.4.2 LIME SUPPLIES

The leaching trial was a follow-up of the liming trial in order to estimate long term liming effect. The previous history of the leaching trial is fully described in this report under the headline 'liming trial' (in 4.2, 5.2 and 6.2.1).
Preceding the leaching trial, a liming trial was carried out with the same lime treatments viz.

zero treatment (z)	0	$ton.ha^{-1}$	'$CaCO_3$'[1]
agricultural lime (al)	1.14	,,	,,
calcareous dunesand (ds)	2.32	,,	,,

The treatments were mixed with c. 15 cm surface soil. (This initial state of the later designed leaching trial, was sampled roughly: per two equally treated plots at 0-10 and 20-30 cm; for results with only relative mutual importance, see Table 6.8. The long rains of 1982 were extraordinary heavy and caused 1½-2 cm run off. Probably the run off was less severe at the upslope side of the convex slope where the leaching plots were situated, and was estimated to amount there 1½ cm i.e. 10 % of the limed layer.
The long rains amounted to about 840 mm on the leaching field (Sokoke), and initiated leaching processes in this permeable soil. Maize was grown during these rains, fertilized by N 50 $kg.ha^{-1}$ as CAN (25 % $CaCO_3$), and P 30 $kg.ha^{-1}$ as TSP.
The rain water sample had considerably lower ion concentrations and conductivity than the samples mixed with tap water (see App. 25). Fortunately, three quarters of the leaching water consisted of rain water. In all water samples, the sums of Ca^{2+} and Mg^{2+} resp. CO_3^{2-} and HCO_3^- appeared to counterbalance one another. (Although some other cation-anion combinations are also imaginable, it is assumed that this holds here.) Thus '$CaCO_3$' was applied with leaching water.

[1] See footnote 2 on p. 27 (4.4).

In summarizing calculations, all element supplies were expressed in kmol or kmol(+) per ha (in stead of: per ring area) to facilitate their comparison. Multiplication of quarterly leaching water amounts with corresponding chemical contents resulted in rough estimates of element supply with leaching water (see Table 6.25, and for details App.26).

Table 6.25. Element supply with leaching water ($kmol(+).ha^{-1}$ ($kmol.ha^{-1}$)).

Treatment		zero lime		agricultural dunesand		calcareous	
Plot no.		30		26		28	
Element							
Cations	$kmol(+).ha^{-1}$($kmol.ha^{-1}$)						
	Ca^{2+}	59.4	(29.7)	42.9	(21.4)	80.1	(40.0)
	Mg^{2+}	32.0	(16.0)	24.9	(12.4)	46.9	(23.5)
	Na^{+}	74.4		59.0		111.7	
	K^{+}	14.5		11.0		20.4	
	NH_4^{+}	0.6		0.4		1.0	
	Al^{3+}	0.4	(0.15)	0.3	(0.11)	0.6	(0.21)
	Total	181.3		138.5		260.7	
Anions							
	CO_3^{2-}	6.3	(3.1)	4.6	(2.3)	8.6	(4.3)
	HCO_3^{-}	99.5		75.5		141.5	
	SO_4^{2-}	42.2	(21.1)	33.1	(16.6)	62.3	(31.2)
	Cl^{-}	40.4		31.2		58.6	
	NO_3^{-}	1.3		0.8		1.5	
	Total	189.7		145.2		272.5	
Molecules	$kmol.ha^{-1}$						
	H_2SiO_4	8.5		6.8		13.0	

Table 6.25 shows that unintentional element supplies via leaching water were considerable.

A summary of all lime supplies during 1982 is presented in Table 6.26. In case that footnote 3 holds, Table 6.26 shows: lime supplies with leaching water exceed the lime treatments by a factor 3, and lime the zero ring to a level comparable with total lime supplies to ring 26. - In case note 3 does not hold and lime supplies with leaching water are as mentioned under footnote 5, lime supplies to the rings 26 (al) and 28 (ds) amount 22 resp. 21 % of the original lime supplies; further the zero plot is limed until 30 % of the original '$CaCO_3$' supply to ring 26.

Thus the testing of lime leaching was disturbed by lime supplies via leaching water.

Table 6.26. Lime supplies in 1982 before and during the leaching trial ('$CaCO_3$'[1]/"$CaCO_3$"[3]) kmol.ha^{-1}).

Period	Lime source supplies	Liming trial (April-July): liming materials 100 % (ton.ha^{-1})	liming materials 90 %[1] (ton.ha^{-1})	liming materials 'CaCO$_3$' (kmol.ha^{-1})	fertilizer[2] 192.3 kg.ha^{-1} x 25 % CaCO$_3$ ('CaCO$_3$', kmol.ha^{-1})	Leaching trial[6] (September): rainfall[3][4] 840 mm[5] ("CaCO$_3$"[3], kmol.ha^{-1})	leaching water ("CaCO$_3$"[3], kmol.ha^{-1})	TOTAL lime (kmol.ha^{-1})	RELATIVE TOTAL lime supplies (%)
30	zero	0	0	0	0.5	4.25	45.7	50.4	57
26	agr.lime	1.14	1.03	10.3	0.5	4.25	33.8	48.8	55
28	calc. dunesand	2.32	2.09	20.9	0.5	4.25	63.5	89.1	100

1) after 10 % sheet (and some rill) erosion during heavy rains.
2) CAN (26 % N), 50 kg N: 50 x 100/26 = 192.3 kg.ha^{-1}.
3) For a definition of '$CaCO_3$', see footnote 1 in 6.4.2 on page 80. In this report, '$CaCO_3$ and equivalents of $CaCO_3$ like $MgCO_3$, $Ca(OH)_2$ and (?) $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$' are written as "$CaCO_3$". On the supposition that all these components show a liming reaction.
4) Assuming that the composition of the pure rain water sample was representative for normal rain water composition, the composition of sample 1 (see App. 25) was used to achieve these data.
5) estimate of rainfall from end March-September 7th (see Figure 2.1).
6) (If only CO_3^{2-} and not HCO_3^{1-} can function as anion to provide lime characteristics, lime supply with rain and leaching water would be considerably lower, viz. 0.34 resp. 3.1, 2.3, 4.3 kmol.ha^{-1} (see table 6.25).

6.4.3 pH RESULTS

Table 6.27 presents pH results of the leaching trial. Processing of the results was facilitated by transforming them into those presented in Table 6.28. pH estimates from the zero plot were taken as reference values for this transformation.

(In an attempt to explain the results, the following can be said.)
The lime applied with agricultural lime was half the quantity applied with calcareous dunesand. Further, in Wageningen was noticed that agricultural lime dissolved much slower in hydrochloric acid than calcareous dunesand. Thus, the effect of calcareous dunesand was expected to be more than double the effect of agricultural lime.
Considerable amounts of lime appeared to have been supplied unintentionally with leaching water, thus disturbing the lime treatments as present before leaching. (Tap water contained most lime (see App.25)). Lime supplies by rain water, although considerable over

many years, are neglected here, because all rings received equal precipitations during the long rainy season of 1982.)

Leaching induced an overal increase of pH, which eclipses mutually different pH effects of the lime treatments (see Table 6.27).

Table 6.27. pH-H_2O (I) and pH-KCl (II) values before and after leaching.

Treatment	zero		agricultural lime		calcareous dunesand	
Plot no.	30		26		28	
Depth (cm)						
I) pH - H_2O	before	after	before	after	before	after
0 - 5	6.0	7.3	6.2	7.3	7.3	7.9
7½ - 12½	5.4	7.1	5.1	6.7	5.5	7.2
15 - 20	5.2	6.9	5.0	6.5	5.3	7.1
22½ - 27½	5.1	6.7	5.0	5.5	5.1	6.6
30 - 35	5.2	5.7	5.1	5.1	5.0	6.0
37½ - 42½	5.4	6.0	5.2	5.2	5.4	5.8
50 - 60	5.4	5.7	5.3	5.5	5.4	5.8
90 - 100	5.4	5.6	.	5.5	5.1	5.5
140 - 150	5.5	5.5	5.3	5.3	5.3	5.4
200 - 210	5.2	5.2	5.1	5.3	5.2	5.1
II) pH - KCl						
0 - 5	4.9	6.4	5.0	6.3	6.6	7.1
7½ - 12½	4.4	5.9	4.3	5.5	4.5	6.3
15 - 20	4.4	5.7	4.3	5.3	4.4	6.0
22½ - 27½	4.4	5.5	4.3	4.5	4.3	5.5
30 - 35	4.5	5.0	4.4	4.2	4.3	5.1
37½ - 42½	4.7	4.7	4.4	4.3	4.3	5.0
50 - 60	4.8	4.9	4.6	4.7	4.7	4.9
90 - 100	4.7	4.8	4.5	4.7	4.7	4.8
140 - 150	4.8	4.8	4.7	4.7	4.7	4.7
200 - 210	4.5	4.5	4.4	4.7	4.5	4.4

In view of Table 6.28[I], it was decided to neglect deviations from the zero treatment until 0.3 pH unit. - During the growing season pH increased only at the dunesand plot in the upper 5 to 7½ cm (within the limed layer). Leaching induced considerable increases of pH-H_2O and pH-KCl enhancing in the order agricultural lime, zero treatment, calcareous dunesand until depths of 27½, 42½, resp. 60 cm (see Table 6.28[II]).

Subtracting 'zero values after leaching' (as presented in Table 6.28[II]) from pH increases of both lime treatments leads to the following conclusion (see Table 6.28[III]).

On plot 26, treated with agricultural lime, a relative pH drop occurred from 7½ to 42½ cm, varying from 0.4 to 1.0 unit. On plot 28, treated with calcareous dunesand, a relative increase of pH occurred from 0 to

12½ cm. Thus agricultural lime shows a negative liming effect in and below the limed layer, whereas calcareous dunesand caused a relative pH increase, but only from 0 to 12½/15 cm, which corresponds with the limed soil layer.

Table 6.28. Effects of leaching on pH values, expressed as differences with pH values from zero plot (30).

Treatment	zero		agricultural lime		calcareous dunesand	
Plot no.	30		26		28	
Depth	pH - H_2O	KCl	H_2O	KCl	H_2O	KCl
I) <u>Before leaching</u>						
0 - 5	0.0	0.0	0.2	0.1	1.3	1.7
7½ - 12½	0.0	0.0	-0.3	-0.1	0.1	0.1
15 - 20	0.0	0.0	-0.2	-0.1	0.1	0.0
22½ - 27½	0.0	0.0	-0.1	-0.1	0.0	-0.1
30 - 35	0.0	0.0	-0.1	-0.1	-0.2	-0.2
37½ - 42½	0.0	0.0	-0.2	-0.3	0.0	-0.4
50 - 60	0.0	0.0	-0.1	-0.2	0.0	-0.1
90 - 100	0.0	0.0	.	-0.2	-0.3	0.0
140 - 150	0.0	0.0	-0.2	-0.1	-0.2	-0.1
200 - 210	0.0	0.0	-0.1	-0.1	0.0	0.0
II) <u>After leaching</u> relatively to pH zero plot, before leaching						
0 - 5	1.3	1.5	1.3	1.4	1.9	2.2
7½ - 12½	1.7	1.5	1.3	1.1	1.8	1.9
15 - 20	1.7	1.3	1.3	0.9	1.9	1.6
22½ - 27½	1.6	1.1	0.4	0.1	1.5	1.1
30 - 35	0.5	0.5	-0.1	-0.3	0.8	0.6
37½ - 42½	0.6	0.0	-0.2	-0.4	0.4	0.3
50 - 60	0.3	0.1	0.1	-0.1	0.4	0.1
90 - 100	0.2	0.1	0.1	0.0	0.1	0.1
140 - 150	0.0	0.0	-0.2	-0.1	-0.1	-0.1
200 - 210	0.0	0.0	0.1	0.2	-0.1	-0.1
III) <u>After leaching</u> relatively to pH zero plot, after leaching						
0 - 5	0.0	0.0	0.0	-0.1	0.6	0.7
7½ - 12½	0.0	0.0	-0.4	-0.4	0.1	0.4
15 - 20	0.0	0.0	-0.4	-0.4	0.2	0.3
22½ - 27½	0.0	0.0	-1.2	-1.0	-0.1	0.0
30 - 35	0.0	0.0	-0.6	-0.8	0.3	0.1
37½ - 42½	0.0	0.0	-0.8	-0.4	-0.2	0.3
50 - 60	0.0	0.0	-0.2	-0.2	0.1	0.0
90 - 100	0.0	0.0	-0.1	-0.1	-0.1	0.0
140 - 150	0.0	0.0	-0.2	-0.1	-0.1	-0.1
200 - 210	0.0	0.0	0.1	0.2	-0.1	-0.1

There is no proof of lime leaching, because '$CaCO_3$' was not determined. pH results could provide an indication of lime leaching, but conclusions rising from Table 6.28[II] and [III] contradict one another.

Lime supplies by leaching water may have annulled leaching effects existing before the leaching trial.

Review of the liming trial

Working with single rings reduced soil moisture contents and strongly reduced the hydraulic conductivity of the soil and thus the possibility of leaching.

It is possible that some lime loss occurred previous to the leaching trial, due to leaching by rain. However, the leaching water appeared to have supplied lime, thus disturbing this trial on lime leaching,- possibly to the extent that leaching effects present previous to the lime leaching trial, were nullified. (Evaluation of lime leaching happened with pH-H_2O and -KCl data, not with $CaCO_3$ measurements.)

7 SYNTHESIS AND CONCLUSIONS

This chapter consists of a final discussion to synthesize preceding results and discussions, and of conclusions and recommendations.
First inducements to this research are repeated (7.1). Then liming and leaching (7.2) respectively fertilizing (7.3) are highlighted, whereafter in 7.4 field results are generalized to the map units the fields represented.

7.1 RESEARCH INDUCEMENTS

This research started off with two questions.

1) Bennema's qualitative question was: can locally found calcareous dunesand (c. 70 % $CaCO_3$; see 4.2) at short term increase crop yields on acid soils in this region - first yard-stick being maize yields? Accompanying questions were: what are effects on soil acidity and soil structure in short and long run?
   A later added question was: does leaching of lime (long term liming effect) occur?
2) Janssen's quantitative question concerned soil fertility: within the studies on the fertility of the Kilifi soils, more data were wanted on nutrient availability and crop response to fertilizers for the two major soil units developed on Magarini sands.

7.2 LIMING AND LEACHING; ASSESSMENT OF LIMING MATERIALS

Liming trial

All liming was 'overliming' and no liming was required as the starting pH of both trial fields (5.6 resp. 5.8) exceeded the pH liming aimed at (5.4).
The liming rate of calcareous dunesand most probably deteriorated soil structure as it raised pH in the upper 15 cm till 7, around which pH the charge of sesquioxides changes from positive to neutral. - Any liming rate should not raise pH beyond 6 in order to preserve soil structure (see 6.2.1.3).
Yield differences between fields were larger than liming effects on yields that varied from somewhat negative (agricultural lime) to somewhat positive (agr. lime and especially calcareous dunesand). Beans Phaseolus vulgaris L., preferring neutral to mildly alkaline soils (see 3.2.1), might have provided a better testing crop in these experiments. However, beans form only a minor pulse crop in the area, probably

because they do not grow well below c. 600 m because high temperatures cause a poor fruitset (ACLAND, 1971).

Leaching trial

pH results indicated leaching of liming materials in the short run (1 year), stronger on the Ngerenya field (although it has a higher CEC). Leaching of calcareous dunesand raised pH on the Ngerenya field (till 27½ cm) and also on the Sokoke field (till 20 cm); this tendency exists for agricultural lime on the Ngerenya field.

Lime leaching was investigated in the long run (c. 7 years) on the Sokoke field, where from a lower CEC stronger leaching was expected. However no indications exist of leaching of calcareous dunesand, and treatment with agricultural lime even resulted in a pH drop beneath the limed layer.

Positive indications of lime leaching on short term contradict negative ones on long term.

Assessment of both liming materials

Calcareous dunesand appeared to be a good liming material. It is finer, and thus higher soluble and raising soil pH quicker than agricultural lime. Its effects on maize are consistently neutral to somewhat positive. Ecological justification of dunesand (= dunes) removal remains questionable.

The quality of agricultural lime as a liming material is yet doubtful. It has a more lasting effect than calcareous dunesand. Its effects on soil pH are not consistently positive, and part of its effects on maize were somewhat negative. More research should be undertaken to examine agricultural lime and how it affects soil pH and crop yields.

7.3 FERTILIZER TRIAL

7.3.1 FERTILIZER EFFECTS

Growth

NP fertilizing and to a less extent single fertilizer application resulted in a higher and earlier maturing maize crop, especially on the Sokoke field (UE111).

(Grain) yields

N fertilizing obviously raised yields on both fields (for grains by 0.9 resp. 1.1 ton.ha^{-1}).

Additional P fertilizing somewhat increased grain yields on the Sokoke field, and tended hereto on the Ngerenya field (0.5 ton.ha^{-1} on both fields).

No single P effects on yields of grains occurred.

Nutrient concentrations and removals

N fertilizing reduced P contents on the Sokoke field (c. 24 %). and relevantly raised many removals on both soils, a.o. P removal by grains. - P fertilizing reduced N content (c. 6 %) on both fields and raised some removals on the Sokoke field a.o. not N removal. Thus N was the most limiting nutrient on both soils. - NP interaction especially on the Sokoke field somewhat increased many removals. - Recoveries of NP fertilizing were much greater than single N and P recoveries.
Further, nutrient concentrations show some risk of Mg deficiency, and N fertilizing diminishes the hazard of Mn toxicity if existing at all. Ranged after decreasing importance, nutrient deficiencies exist for N, and also P; next, risks of Mg and Ca deficiency exist.

7.3.2 FIELD EFFECTS

CEC's, organic N contents and, after correction, P Olsen values show a higher soil fertility on the Ngerenya field on UE112, than on the Sokoke field on UE111.
Differences between the natural soil fertilities of both fields are more striking than the effect of N fertilizing and result in 2.5 times as high yields, and excluding Mn, 2.4 to 3.4 as high removals on the Ngerenya field. Fertilizing reduced these field differences to a factor 1.9 for yields and 1.9 to 2.3 for removals.
On the Sokoke field fertilizing caused relatively higher increases of nutrient removals and yields, because fertilizing corrects the imbalance in NPK supply (see 2.2). On the Ngerenya field single N ferti- lizing caused absolutely higher removal and yield increases by the higher soil fertility of the field. The low nutrient uptakes also after fertilizing, indicate this level of maize production is far below its yield potential (at least 4 $ton.ha^{-1}$; see SCHREURS, 1984, App. II).

7.3.3 PRECIPITATION IN 1982 AND FERTILIZER APPLICATION

Excessive rains from the end of March until mid May have leached more N fertilizer than during a theoretical average year. Also the light rains after the 2^{nd} fertilizer application (8 weeks after planting) have reduced N fertilizer recovery.
Evaluating afterwards, (provided planting and applying fertilizer just after the onset of the rains like in this trial,) a more suitable time to apply a 2^{nd} rate of N fertilizer could not be found, as till 6 weeks after planting the rains were very heavy (leaching) and then a short dry spell started (see Fig. 2.1).

7.4 GENERALIZATION

In this paragraph all kinds of results will be 'extrapolated' from both trial fields to the corresponding, largest map units of soils developed on Magarini sands - in the order soil representativeness (7.4.1), agricultural assessment of both soils and recommendations (7.4.2), and results of liming and fertilizer trials (7.4.3).

7.4.1 REPRESENTATIVENESS OF THE TRIAL FIELDS FOR THE MAP UNITS UE1L1 AND UE1L2

Being medium acid (pH 5.6 resp. 5.8), selected trial fields in Sokoke and in the Ngerenya settlement scheme were relatively acid compared with the slightly acid soils north of Kilifi Creek (pH 6.4, s.d. 0.3) and the neutral soils south of Kilifi Creek (pH 7.3, s.d. 0.5). - For other soil characteristics than pH, both trial fields are quite representative. The representativeness of both trial fields is taken into account in the generalization of field trial results.

7.4.2 AGRICULTURAL ASSESSMENT OF BOTH SOILS AND RECOMMENDATIONS

Soil physics

Permeability, porosity and rootability of the soils are good, but the somewhat excessive drainage and limited amount of moisture storage (readily available water) cause a drought hazard.

Mulching should be applied on this sloping land to reduce risks of erosion and drought, as farmers usually practise on fallow land without bigger shrubs.

Soil chemistry

Chemically both soils are very poor, especially those on UE1l1, where also farmers obtained lower yields than on UE1l2. To restore soil fertility, fertilizers and/or fallow periods should be introduced. Shortage of land and population pressure make longer fallow periods almost impossible. Economic remunerativeness of fertilizers is variable under this erratic rainfall regime, (see 7.3.3). In 1982 even the strongest fertilizer effect (single N application) was not paying its cost at an estimated price of maize grain at Ksh. 1.= per kg (see 6.3.4).

Before deciding on these measures, further investigations are needed on availability of fertilizers (including transport), a possible increase of economic remunerativeness, presence of extension, and whether or not farmers would choose for the proposed measures.

7.4.3 LIMING AND FERTILIZING SOILS DEVELOPED ON MAGARINI SANDS (IN MAP UNITS UE1L1 AND UE1L2)

7.4.3.1 LIMING

Soils on Magarini sands (UE1l1 and UE1l2) do not need any liming as no relevant liming effects occur on the relatively acid trial fields and liming is only worthwhile if applied on soils with pH below 5, (then) reducing Al saturation. (Any liming rate should not raise pH beyond 6 (see 7.2).

7.4.3.2 FERTILIZING

As pH values almost all exceeded 5.5, soil acidity only indirectly affected soil fertility via nutrient availability, microbiological activity and soil structure.
Some remarks on soil structure are included in 7.2.
Microbiological activities like mineralisation of organic matter, nitrification and N fixation are less hampered north and especially south of Kilifi Creek, than on the relatively acid trial fields.
Nutrient availability alters with pH as shown by Table 7.1 (based on JANSSEN, 1978 (see 3.2.2) and JANSSEN et al., in press), but also depends on other (soil) factors.

Table 7.1. Nutrient availabilities in the Magarini sands area qualitatively related to nutrient availabilities on both trial fields.

Plant nutrient	Trial fields Sokoke UE1l1	Trial fields Ngerenya UE1l2	Magarini sands UE1l1 & UE1l2 North of Kilifi	Magarini sands UE1l1 & UE1l2 South Creek
pH	5.6	5.8	6.4(s.d. 0.3)	7.3(s.d. 0.5)
N	X		XX	XXX
P	XX		XX	X
K	XXX		XX	X
Ca	X		XX	XXX
Mg	X		XX	XXX
Fe	XXX		XX	X
Mn	XXX		XX	X
B,Zn,Cu	XX		XX	X
Mo	X		XX	XXX

1) Relative nutrient availabilities are proportional to the number of X's.

South of Kilifi Creek and to a less extent north of Kilifi Creek N, Ca, Mg and Mo are more available, while K, Fe and Mn are less available. P, B, Zn and Cu are equally available north and less available south of Kilifi Creek.
Relative to the trial fields less N and stronger P deficiency occur within the UE1 map units, thus increasing the importance and effect of P fertilizing. Unlike on the Sokoke field, no relative K surplus exists. Further lower risks of Mg deficiency and Mn toxicity occur.

Precipitation and fertilizer application

In these agro-ecological zones (see Table 2.1), in 6 out of 10 years (more than) enough rain required for a good maize crop can be expected, but in some years with low rainfall, fertilizing will not be worthwhile (and sometimes even reduce the harvest by a stronger vegetative growth in the first half of the growing season, thus too rapidly using up the available water). In years in which application of fertilizer(s) would be paying, very heavy rains reduce N fertilizer recovery (by leaching), whereas some leaching is required especially for a 2nd more superficial N application.
Ultimately a better criterium for remunerative fertilizing is the number of years with (for maize) sufficient rainfall, quite well spread over the decades. If fertilizing is not paying on average but only in some out of 10 years, a farmer deciding on the purchase or use of fertilizer(s) is dependent on weather-forecasts. If therefore seasonal and long term weather forecasting would become feasible, deciding on any fertilizing at all, and a possible 2nd application of N fertilizer would be made easier to farmers.

Some general recommendations for the Kilifi area

In 1982 the weeding period was the peak labour period, and lack of weeding labour limited farm yields. The planted area was larger than could be weeded. - Two recommendations concerning management, and holding for the Kilifi area as a whole, to increase the weeded area and the harvest, and to prevent waist of natural soil fertility (nutrient removal by weeds causing chlorotic maize yielding nil) are:

- rectangular plant arrangements could increase labour output or the area one (wo)man can weed;
- more male labour input of men already living in the rural areas could also increase the weeded area. (In the last decades their task to clear land had diminished (WAAIJENBERG, 1986).)

De BIE (in 1981) and SCHREURS and van LEEUWEN (in 1982) never obtained a marginal value/cost ratio of 2 for fertilizer investment in their experiments. Therefore generally use of fertilizers can not be recommended to small, risk avoiding farmers. Stil - if proper tillage, rectangular plant arrangements, crop protection and frequent weeding (and rain gauging) are included, more research on fertilizer effects may show some regions within the soils developed on Magarini sands (resp. in the Kilifi area), where (N) fertilizer can be applied succesfully in some out of 10 years. Especially lower fertilizer rates should be tested.

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APPENDICES

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APPENDIX 1 to 2.2

PART of the **LEGEND** to the

RECONNAISSANCE SOIL MAP OF THE KILIFI AREA (1:100,000; 1984)

(map sheet 198 of the Survey of Kenya)

describing map units representing **soils developed on Magarini sands** (geologically: Magarini (and Kilindini) Formation), a.o. UE111 and UE112.

U COASTAL UPLANDS (relief intensity less than 100m, slopes predominantly 0 - 16%)

UE1 Soils developed on unconsolidated medium grained sandy deposits (Magarini Formation)

UE1m1 — somewhat excessively drained, very deep, very dusky red to dark reddish brown, very friable, medium sand to loamy medium sand (ferralic ARENOSLS)

UE1m2 — well drained, very deep, dark brown to dark reddish brown, friable, medium sand to loamy medium sand overlying sandy clay (luvic ARENOSOLS)

trial fields:

UE111 (Sokoke 1982 de BIE 1981) — well drained, very deep reddish brown to dusky red, very friable, sandy loam to sandy clay; in places underlying 20 to 40cm loamy medium sand (chromic LUVISOLS and rhodic FERRALSOLS)

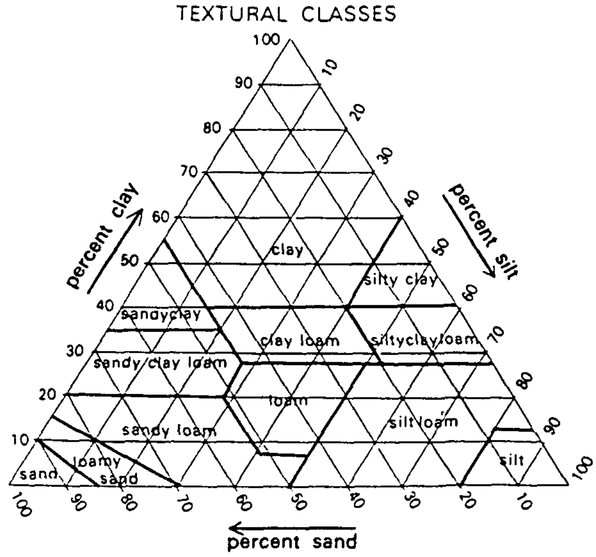
UE112 (Ngerenya 1982) — well drained, very deep, very dusky red to reddish brown, very friable, sandy loam to sandy clay loam, underlying 40 to 80cm loamy medium sand to sandy loam (rhodic FERRALSOLS)

UE2 Soils developed on unconsolidated medium grained sandy deposits (Magarini and Kilindini Formation)

UE2f — somewhat excessively drained, very deep, brownish yellow to yellow, very friable, fine to medium sand overlying mottled sandy loam (ferralic ARENOSOLS)

UE2l — well drained, very deep reddish yellow to yellowish red, friable sandy clay loam to sandy clay, underlying 40 to 80cm medium sand to sandy loam (chromic LUVISOLS)

TEXTURAL CLASSES



APPENDIX 2 to 2.2.

DATA ON PROFILES REPRESENTATIVE FOR THE MAP UNITS UE111 AND UE112, as given by the Kilifi report (BOXEM et al., 1987).

Unit UE111, Profile 20 The Sokoke trial field (1982) and de Bie's trial field (1981) lay in map unit UE111

Soil classification	chromic Luvisol; "rhodoxic" Paleustalf
Agro-climatic zone	III-1
Observation	198/4-41, Kilifi District, E 5.87.0 N 95.84.5, 105 m, 18-5-1982
Parent material	unconsolidated medium grained sandy deposits
Physiography	Coastal Uplands (Pingilikani upland)
Surrounding landform	rolling to hilly
Meso-relief	upper part of linear slope
Slope gradient	6%
Land use/land cover	multiple cropping: cashew/maize
Drainage class	somewhat excessively drained
Depth of groundwater table	below 150 cm
Presence of surface stones/rock outcrops	nil
Evidence of erosion	moderate to severe sheet, rill and gully erosion

Ah 0- 28 cm: Dark reddish brown (2.5YR 3/4) sandy loam; weak medium subangular blocky to granular; slightly hard, very friable, slightly sticky and slightly plastic; many very fine, few fine, medium and coarse pores; common very fine, few fine, medium and coarse roots; many charcoal particles; gradual and smooth transition to:

BA 28- 62 cm: Dark reddish brown (2.5YR 3/4) sandy clay loam; weak medium prismatic, breaking into weak medium angular to subangular blocky; slightly hard, friable, slightly sticky and slightly plastic; many very fine and fine, common medium, few coarse pores; common very fine, few fine, medium and coarse roots; many charcoal particles; gradual and smooth transition to:

Bt1 62-113 cm: Dusky red (10YR 3/4) sandy clay loam; weak medium prismatic, breaking into weak medium angular blocky; friable, slightly sticky and slightly plastic; patchy thin clay skins; many very fine, common fine and medium pores; few very fine, fine, medium and coarse roots; few charcoal particles; diffuse transition to:

BC 113-150+cm: Dusky red (10YR 3/4) sandy clay loam; weak medium prismatic, breaking into weak medium angular blocky; friable, slightly sticky and slightly plastic; patchy thin clay skins; many very fine, common fine, few medium and coarse pores; few roots.

Unit UE112, Profile 21 The Ngerenya trial field lay in map unit UE112

Soil classification	rhodic Ferralsol; typic Haplustox
Agro-climatic zone	IV-1
Observation	198/2-3, Kilifi District, E 5.89.9 N 96.05.7, 95 m, 9-1-1980
Parent material	unconsolidated medium grained sandy deposits
Physiography	Coastal Uplands (Pingilikani upland)
Surrounding landform	gently undulating
Meso-relief	flat-topped ridge; many termite mounds
Slope gradient	0%
Land use/land cover	multiple landuse: cashew, scattered coconut (former plantation) and bushland with extensive grazing underneath
Drainage class	well drained
Depth of groundwater table	below 150 cm
Presence of surface stones/rock outcrops	nil
Evidence of erosion	nil
Soil fauna	termites

Ah 0- 13 cm: Very dusky red (2.5YR 2/2) loamy sand; very weak fine subangular blocky to granular; loose, very friable, non-sticky and non-plastic; common very fine, fine and medium pores; many (15-40%) black spherical Mn-concretions; gradual and smooth transition to:

Bt 13- 98 cm: Dusky red (10YR 3/4) loamy sand to sandy loam; very weak fine subangular blocky to granular; soft, friable, non-sticky and non-plastic; many very fine and fine pores; common very fine and fine roots; many small Mn-concretions; clear and smooth transition to:

BC 98-150 cm: Dusky red (10YR 3/4) sandy loam; very weak medium subangular blocky; soft, friable, slightly sticky and non-plastic; common very fine and few fine pores; no roots; many small Mn-concretions.

Profile 20

Laboratory no. 1982	7239	7240	7241	7242
Horizon	Ah	BA	Bt1	BC
Depth (cm)	5-15	40-50	80-90	120-130
pH-H_2O(1:2.5 v/v)	6.5	6.6	6.4	5.7
pH-KCl "	5.1	5.3	5.2	5.0
EC(mS/cm) "	0.03	0.03	0.04	0.04
$CaCO_3$ (%)	n.d.			
C (%)	0.4	0.2	0.1	0.1
N (%)	n.d.			
P-Mehlich (mg/kg)	16			
P-Olsen (ppm)	3	2	1	1
CEC (me/100g), pH 7.0	2.5	1.3	1.5	1.5
Exch.Ca (me/100g)	0.9	0.8	0.8	0.6
Exch.Mg "	0.3	0.2	0.2	0.2
Exch.K "	0.5	0.3	0.2	0.2
Exch.Na "	0.1	tr	0.1	0.1
Sum of bases	1.8	1.3	1.3	1.1
Base sat.%, pH 7.0	72	100	81	73
Exch. Al+H (me/100g)	n.d.			
ESP at pH 7.0	4	<3	7	8
Gravel %	<2	<2	<2	<2
Texture, limited pretreatment:				
Sand % 2.0-0.05 mm	84	76	72	74
Silt % 0.05-0.002 mm	2	2	0	2
Clay % 0.002-0 mm	14	22	28	24
Texture class	SL	SCL	SCL	SCL
Texture USDA:	not determined			
Sand % 2.0 - 1.0 mm				
Sand % 1.0 - 0.50 mm				
Sand % 0.50-0.25 mm				
Sand % 0.25-0.10 mm				
Sand % 0.10-0.05 mm				
Total sand %				
Silt %				
Clay %				
Texture class				
Bulk density	1.38	1.34	1.52	1.52
Moisture % w/v at:	5-10	40-45	85-90	125-130 cm
pF 0	46.9	44.1	39.3	38.7
pF 2.0	16.1	18.7	23.3	22.3
pF 2.3	13.1	15.2	18.4	17.6
pF 2.7	12.5	14.9	18.1	16.2
pF 3.0	10.1	11.4	14.2	12.5
pF 3.7	8.6	10.2	12.6	11.1
pF 4.2	7.8	9.6	12.3	10.5

Profile 21

Laboratory no.					
Horizon	Ah	Bt	Bt	BC	CB
Depth (cm)	0-13	13-50	50-98	98-150	150-175
pH-H_2O(1:2.5 v/v)	n.d.				
pH-KCl "	n.d.				
EC(mS/cm) "	n.d.				
C (%)	n.d.				
N (%)	n.d.				
P-Mehlich (mg/kg)	n.d.				
CEC (me/100g), pH 8.2	n.d.				
Exch.Ca (me/100g)	n.d.				
Exch.Mg "	n.d.				
Exch.K "	n.d.				
Exch.Na "	n.d.				
Sum of bases	n.d.				
Base sat.%, pH 8.2	n.d.				
Exch. Al+H (me/100g)	n.d.				
ESP at pH 8.2					
Gravel %	<2	<2	<2	<2	<2
Texture, limited pretreatment:					
Sand % 2.0-0.05 mm					
Silt % 0.05-0.002 mm			n.d.		
Clay % 0.002-0 mm					
Texture USDA:					
Sand % 2.0 - 1.0 mm	1	1	1	1	1
Sand % 1.0 - 0.50 mm	12	16	16	12	14
Sand % 0.50-0.25 mm	51	50	48	42	45
Sand % 0.25-0.10 mm	19	16	16	20	16
Sand % 0.10-0.05 mm	1	tr	1	1	1
Total sand %	84	83	82	76	77
Silt %	5	3	3	17	18
Clay %	11	14	15	7	5
Texture class	LS	LS	SL	SL	SL
Bulk density	1.62	1.53	1.58	1.56	1.64
Moisture % w/v at:	5-10	20-25	60-65	120-125	160-165 cm
pF 0	38.9	44.9	41.6	41.7	35.4
pF 2.0	18.6	16.2	21.0	22.1	23.3
pF 2.3	15.9	13.8	17.9	19.4	20.1
pF 2.7	12.2	11.0	13.5	14.1	14.7
pF 3.0	8.6	6.6	9.1	8.1	7.5
pF 3.7	5.5	5.3	6.2	7.3	8.3
pF 4.2	5.4	5.2	6.1	7.4	7.4

APPENDIX 3. SOIL DATA FROM TRIAL FIELDS ON 'MAGARINI SANDS'[1].
to 2.2

1) Sokoke trial field
2) Ngerenya trial field — S. van Leeuwen, 1982
3) trial field — C.A.J.M. de Bie, 1981

I Information on the site — 1) Sokoke trial field

a. Profile number: 198/2-47

b. Map unit: UE111

c. Higher category classification: FAO rhodic Ferralsol

USDA typic Haplustox

d. Date of examination: June 23rd 1982

e. Author: T. de Meester, S. van Leeuwen, W.J.H. Schreurs, I. van der Noll

f. Location: E 39°48'16", S 3°30'47"; near trial field/ 3 km North of the T-cross-road situated along the northern border of Sokoke Plantation, along a narrow motorable trac (The T-cross-road leads eastwards to the main road Kilifi-Malindi, and westwards to Ganze and Bamba.)

g. Elevation: 198 m (650 ft)

h. Landform: i) Physiographic position of the site: convex slope

ii) Topography of surrounding country: undulating to hilly

iii) Microtopography: flat

i. Slope on which the profile is sited: sloping (7-11 %)

j. Landuse/vegetation: upper slope: with major crops maize and cassava in mixed cropping; fallow vegetation (main species 'Kairè', a Pennisetum sp.) is applied as mulch; no rectangular plant arrangements, 5-7 plants per stand (no thinning); no application of fertilizers or chemical control; ca. 2 % trees i.e. remnants of Sokoke Forest, which was broken up here in 1974; lower and steeper slope: fruit trees: cashew, cocos; the soil surface under and between the trees grown over with grasses and some shrubs and other trees (gra and browsed by some goats).

k. Climate: see Chapter on climate in: 2.1 based on BOXEM et al., 1987, Ch.1.2.

II General information on the soil

a. Parent material: Magarini sands

b. Drainage: somewhat excessively drained i.e. class 5

c. Moisture condition of the profile: abundant moisture until 30 cm, farther throughout the profile

d. Depth of groundwater level: greater than 10 m

e. Presence of stones and rock outcrops: nil/nil i.e. class 0/class 0

f. Evidence of erosion: moderate sheet and rill erosion (in clean weeded trial field) after heavy rains

g. Presence of salt and alkali: nil i.e. class 0

h. Human influence: on the upper slope clearing and cultivation with a hoe; clearing of thick trees by burning; maybe sometimes more burning

on the trial field, lime was worked in with a rotovator before planting, and fertilizing took place

[1] Many missing data are deposited with the NAL, (National Agricultural Laboratories, Nairobi). For both trial fields fertility aspects were analysed, but the author did not receive its results. For soil profile 198/2-46, data from pH to CEC rest with the NAL.

III <u>Brief description of the soil</u> (profile pit 198/2-47)

Very deep, somewhat excessively drained, red profile, uniform in appearance throughout its depth. Structure is weak throughout, and the whole profile is very friable, porous and permeable. There is a slight increase in clay content with depth, but an argillic B is not evident. Root distribution is normal with the majority in the upper 50 cm. Striking are the many small rounded black manganese concretions. The chemical condition of the profile is very poor.

IV <u>Profile description</u>

Ap 0-6 cm very dusky red to dusky red (2.5 YR 2.5/2 and 3/2) moist, and dark reddish brown (2.5 YR 2.5/4 and 3/4) dry, sandy loam (to sandy clay loam); structure: weak, fine, subangular blocky; consistence: slightly sticky and nonplastic when wet, very friable when moist, soft when dry; many micro and very fine pores; very many (= frequent ?) small Mn concretions; clear and wavy boundary; pH 5.3.

From 0 to 50 cm the roots distribution is common very fine, few fine.

Au 6-60/80 cm dark reddish brown (2.5 YR 2.5/4) moist, and dark red (2.5 YR 3/6) dry, sandy loam to sandy clay loam; structure: weakly massive, granular, structureless; consistence: slightly sticky and nonplastic when wet, very friable when moist, slightly hard when dry; many micro, common very fine pores; very many (= frequent ?) small black Mn concretions; diffuse boundary.

Below 50 cm very few fine and very fine roots occur.

B 60/80- 170 cm dusky red (10 YR 3/4) moist, sandy clay loam; structure: massive, granular, structureless; consistence: slightly sticky and nonplastic when wet, very friable when moist, slightly hard when dry; common micro, very fine and fine pores; many (= few ?) very small black Mn pellets; pH 5.0.

I Information on the site   2) Ngerenya trial field

a. Profile number: 198/2-46

b. Map unit: UE112

c. Higher category classification: FAO rhodic Ferralsol
USDA typic Haplustox

d. Date of examination: August 4th 1982

e. Author: S. van Leeuwen

f. Location: E 39°49'45", S 3°31'21"; ~~ca. 70 m East of~~ near trial field the road Kilifi-Vitengeni ~~in the area~~ called Ngerenya (between Garania (W) and Ngererena (E)); 3 km North of the cross-road near Kakanjuni, which is situated along the northern border of Sokoke Plantation

g. Elevation: 91 m (300 ft)

h. Landform: i) Physiographic position of the site: convex slope
ii) Topography of surrounding country: (gently) undulating to rolling
iii) Microtopography: flat

i. Slope on which the profile is sited: gently sloping i.e. class 2 (4-5 %)

j. Landuse/vegetation: upper slope: arable land, major crop: maize (for the 3rd sequential year)*; the arable land covers 80-90 % of the area, whereas trees cover 10-20 % : fruit trees with an undergrowth of grasses and some shrubs, and fallow trees with grasses and many shrubs as undergrowth; this area is grazed and browsed by some goats

* the fallow vegetation is applied as mulch (main species being a Pennisetum sp a grass locally called 'Kairè')

k. Climate: see chapter on climate in:
2.1 based on BOXEM et al., 1987, Ch.1.2.

II General information on the soil

a. Parent material: Magarini sands

b. Drainage: somewhat excessively drained i.e. class 5

c. Moisture condition of the profile: top of profile dry, moderately moist below

d. Depth of groundwater level: greater than 10 m

e. Presence of stones and rock outcrops: nil/nil i.e. class 0/class 0

f. Evidence of erosion: slight sheet and rill erosion after heavy rains (in clean weeded trial field)

g. Presence of salt and alkali: nil i.e. class 0

h. Human influence: clearing and cultivation with a hoe; maybe the field is sometimes cleared by burning
(on the trial field, lime was worked in with a rotovator before planting, and fertilizing took place)

III **Brief description of the soil** (profile pit 198/2-46)

Very deep, somewhat excessively drained, red profile, uniform in appearance throughout its depth. Structure is weak throughout, and the whole profile is very friable, porous and permeable. There is a slight increase in clay content from the Ap to the Au horizon, and maybe a small decrease to the B horizon. Root distribution is normal. Striking are the many small rounded black manganese concretions. The chemical condition of the profile is very poor.

IV **Profile description**

Ap 0-25 cm dark reddish brown (5YR 3/3) moist, reddish brown (5YR 4/4) dry, sandy loam to sandy clay loam; structure: weak, fine, subangular blocky; consistence: slightly sticky and nonplastic when wet, very friable when moist, soft when dry; few medium and fine, many very fine pores; very many (= frequent ?) small Mn pellets (reaction on H_2O_2 +++); common very fine, few fine, very few medium and coarse roots; clear wavy boundary; pH 4.9.

Au 25-70/90 cm dark reddish brown (2.5YR 3/4) moist, dark red (2.5YR 3/6) dry, sandy clay loam; structure: weakly massive, granular, structureless; consistence: slightly sticky and slightly plastic when wet, very friable when moist, slightly hard when dry; very many (= frequent ?) small black Mn concretions (reaction on H_2O_2 ++); few very fine, very few fine roots; diffuse boundary; pH 5.0.

B 70/90- 200 cm dark reddish brown (2.5YR 3/4) moist, dark red (2.5YR 3/6) dry, sandy loam to sandy clay loam; structure: massive, granular, structureless; consistence: slightly sticky and slightly plastic when wet, very friable when moist; few fine pores; many (= few ?) very small black Mn concretions (reaction on H_2O_2 +); very few very fine roots; pH 5.3.

3) **de BIE's trial field - 1981** (from de BIE (1982).

Description Magarini Sands trial field; maize.

Information on the site

Pit nr. 198/2-18; Magarini-Sands; Kilifi district; E39°48'26", S 3°34'41"; 400ft; Cambini level, coastal uplands; 28-5-'81, long rainy season. The topography is rolling to hilly; the plot is situated on top of a ridge and the slope is almost flat (1-2%).

Landuse and vegetation

The landuse is mainly maize and cashew; the fallow vegetation consists mainly of shrubs and grasses. During the previous growing season the crop was maize.

Mapunit and soilname

USm1 (1:100,000); UcA3 (1:20,000)

Legend USm1 : exessively drained, very deep, red to dark red, very friable, sandy-loam to sandy-clay-loam, underlying 20-40 cm of loamy-sand.

USDA: typic Haplustox

FAO/KSS: rhodic Ferralsol

Drainage and erosion

Well drained soil. The depth of the groundwater is very deep. There is no potential erosion hazard.

Roots and soilfauna

From 0-20 cm there are a few very fine, fine and medium roots; from 20-50 cm there are common very fine and a few fine, medium and coarse roots. Deeper than 50 cm there are a few very fine and very few medium roots. Anomalholes have been found up to 1.00 m.

Horizon descriptions

Au 0-15cm: very dusky-red (10R2.5/2) moist, dark red (2.5YR3/6) dry; loamy-sand; few fine Mn-concretions; very fine granular; loose when dry, very friable when moist, non sticky and non plastic when wet; few fine pores; clear and smooth to:

Bu 15-(150)cm: very dusky-red (10R2.5/2) moist and dry; loamy-sand to sandy-loam; few fine Mn-concretions; very fine granular; loose when dry, very friable when moist, non sticky and non plastic when wet; few fine pores.

) de BIE's trial field - 1981 (from de BIE, 1982, and T.P.I.P. data).

LABORATORY DATA OF PROFILE DESCRIPTION No: 198/2-18 de BIE's trial field (1981)

ELD OBSERVATION No. MAPPING UNIT: UE111

SOIL CLASSIFICATION: FAO/KSS rhodic Ferralsol; USDA typic Haplustox

Laboratory no. 1981 /	5871	5872	5873			
Horizon						
Depth (cm)	0-10	20-50	50-100			
pH-H_2O (1:2½ v/v)	5.9	5.7	5.4			
pH-KCl ..	5.1	4.2	4.8			
EC (mmho/cm) ..	0.03	0.02	0.03			
$CaCO_3$ (%)						
$CaSO_4$ (%)						
C (%)	0.34	0.26	0.11			
N (%)						
C/N						
CEC (me/100g), pH 8.2	3.7	2.3	1.7			
CEC .. .. pH 7.0						
Exch.Ca (me/100g)	1.3	0.2	Tr.			
.. Mg ..	0.7	0.2	0.4			
.. K ..	0.11	0.05	0.09			
.. Na ..	Tr.	Tr.	Tr.			
Sum of cations	2.11	0.45	0.09			
Base sat. %, pH 8.2	57	19	5			
.. .. %, pH 7.0						
ESP at pH 8.2						
Saturation extract:						
Moisture %						
pH-paste						
ECe (mmho/cm)						
Na (me/l)						
K ..						
Ca ..						
Mg ..						
Sum of cations (me/l)						
CO_3 (me/l)						
HCO_3 ..						
Cl ..						
SO_4 ..						
Sum of anions (me/l)						
Adj. SAR						
Clay mineralogy:						
SiO_2/Al_2O_3 (mol/mol)						
SiO_2/R_2O_3 ..						
Fe_2O_3 (mmol%)						
X-ray report:						

Depth (cm)	0-10	20-50	50-100	100-150		
Gravel %						
Texture, limited pretreatment:						
Sand % 2.0 - 0.05 mm	95	91	86			
Silt % 0.05-0.002mm	1	1	2			
Clay % 0.002-0 mm	4	8	12			
Texture class	S	S	LS			
Dispersed clay %						
Flocculation index						
Texture USDA:	0-10	10-50	50-100	100-150		
Sand % 2.0 - 1.0mm	0.6	0.1	0.2	0.1		
.. .. 1.0 - 0.50mm	5.0	2.2	1.9	2.4		
.. .. 0.50 - 0.25 mm	61.1	50.8	49.2	51.5		
.. .. 0.25 - 0.10mm	17.1	26.7	27.2	20.5		
.. .. 0.10 - 0.05mm	0.8	1.0	0.7	3.8		
Total sand %	84.6	80.8	79.6	78.3		
Silt %	5.7	6.0	12.2	13.9		
Clay %	9.7	13.2	8.3	7.8		
Texture class	LS	LS	to	SL		
Bulk density						
Moisture % w/v at:	0-10	30-35	70-75			
pF 0	46.4	40.2	40.5			
pF 2.0	10.5	13.2	14.9			
pF 2.3	9.5	11.1	12.0			
pF 2.7	8.3	10.0	10.1			
pF 3.0						
pF 3.7	6.3		7.8			
pF 4.2						

Fertility aspects: (0- cm) Laboratory no. /	Available	Total
Ca (me/100g)		
Mg ..		
K ..		
P (ppm)		
Mn (me/100g)		
Exch. acidity (me/100g)		
pH-H_2O (1: v/v)		
C%		
N%		

Kenya Soil Survey
Drawing No 79050

1) SOKOKE trial field - 1982

LABORATORY DATA OF PROFILE DESCRIPTION No: 198/2-47 Sokoke trial field

FIELD OBSERVATION No. 1   1985 MAPPING UNIT: UE11   SOIL CLASSIFICATION: FAO rhodic Ferralsol; USDA typic Haplustox

Laboratory no1982/		7383	Wage-ningen	7384	7385	
Horizon		Ap	(Ap/Au)	Au	B	
Depth (cm)		0-6	0-20	6-60/80	60/80-170	
pH-H_2O(1:2½ v/v)		4.9		4.9	5.0	
pH-KCl ..		3.6		3.7	4.1	
EC(mmho/cm) ..		0.04		0.02	0.06	
$CaCO_3$(%)		-		-	-	
$CaSO_4$(%)						
C (%)		0.23	0.51	0.12	0.06	
N (%)			0.0053			
C/N			96			
CEC (me/100g), pH 8.2		4.1		4.3	4.3	
CEC .. .. AgTu			3.3			
Exch.Ca (me/100g)		0.85	1.60	1.45	1.85	
.. Mg ..		0.64	0.46	0.20	0.68	
.. K ..		0.25	0.16	0.18	0.25	
.. Na ..		Tr.	0.004	Tr.	Tr.	
Sum of cations		1.74	2.22	1.83	2.78	
Base sat. %, pH 8.2		42		43	65	
.. .. %, AgTu			67			
ESP at pH 8.2						
Saturation extract:						
Moisture %						
pH-paste						
ECe (mmho/cm)						
Na (me/l)						
K ..						
Ca ..						
Mg ..						
Sum of cations (me/l)						
CO_3 (me/l)						
HCO_3 ..						
Cl ..						
SO_4 ..						
Sum of anions (me/l)						
Adj. SAR						
Clay mineralogy:						
SiO_2/Al_2O_3(mol/mol)						
SiO_2/R_2O_3 ..						
Fe_2O_3(mmol%)						
X-ray report:						
P-Olsen (mg/100 g)			0.28			

Depth (cm)		0-6	6-60/80	60/80-170		
Gravel %						
Texture, limited pretreatment:						
Sand % 2.0 - 0.05 mm		80	78	70		
Silt % 0.05-0.002mm		0	2	2		
Clay % 0.002-0 mm		20	20	28		
Texture class		SCL/SL	SCL/SL	SCL		
Dispersed clay %						
Flocculation index						
Texture USDA:						
Sand % 2.0 - 1.0mm						
.. .. 1.0 - 0.50mm						
.. .. 0.50 - 0.25mm						
.. .. 0.25 - 0.10mm						
.. .. 0.10 - 0.05mm						
Total sand %						
Silt %						
Clay %						
Texture class						
Bulk density						
Moisture % w/v at:						
pF 0						
pF 2.0						
pF 2.3						
pF 2.7						
pF 3.0						
pF 3.7						
pF 4.2						

Fertility aspects: (0- cm)	Laboratory no. /	
	Available	Total
Ca (me/100g)		
Mg ..		
K ..		
P (ppm)		
Mn (me/100g)		
Exch. acidity (me/100g)		
pH-H_2O (1: v/v)		
C%		
N%		

Kenya Soil Survey
Drawing No 79030

LABORATORY DATA OF PROFILE DESCRIPTION No: 198/2-47 Sokoke trial field

.D OBSERVATION No.

MAPPING UNIT: UE111

SOIL CLASSIFICATION: FAO rhodic Ferralsol; USDA typic Haplustox

aboratory no 1982/(Kilifi)						
orizon						
epth (cm)						
H-H_2O(1: v/v)						
H-KCl ..						
C(mmho/cm) ..						
aCO_3(%)						
aSO_4(%)						
(%)						
(%)						
/N						
EC (me/100g), pH 8.2						
EC .. .. pH 7.0						
xch.Ca (me/100g)						
.. Mg ..						
.. K ..						
.. Na ..						
um of cations						
ase sat. %, pH 8.2						
.. .. %, pH 7.0						
SP at pH 8.2						
Saturation extract:						
loisture %						
H-paste						
Ce (mmho/cm)						
a (me/l)						
..						
a ..						
g ..						
um of cations(me/l)						
O_3 (me/l)						
CO_3 ..						
l ..						
O_4 ..						
um of anions(me/l)						
dj. SAR						
Clay mineralogy:						
O_2/Al_2O_3(mol/mol)						
O_2/R_2O_3 ..						
e_2O_3(mmol%)						
-ray report:						

Depth (cm)	0-10	20-30	50-60	90-100	140-150	200-210	270-280
Gravel %							
Texture, limited pretreatment:							
Sand % 2.0 - 0.05 mm							
Silt % 0.05-0.002mm							
Clay % 0.002-0 mm							
Texture class							
Dispersed clay %							
Flocculation index							
Texture USDA:							
Sand % 2.0 - 1.0mm	0.1	0.0	0.0	0.0	0.0	0.0	0.0
.. .. 1.0 - 0.50mm	8.7	3.0	3.9	6.1	6.1	4.6	5.3
.. .. 0.50 - 0.25mm	56.9	57.3	49.8	53.8	53.0	51.7	51.6
.. .. 0.25 - 0.10mm	14.8	21.0	16.4	11.8	12.2	13.8	12.3
.. .. 0.10 - 0.05mm	1.0	1.4	1.0	0.8	0.8	1.0	0.8
Total sand %	81.5	82.7	71.1	72.8	72.1	71.1	70.1
Silt %	2.0	2.3	6.7	3.1	4.6	4.2	3.9
Clay %	16.5	15.0	22.1	24.2	23.3	24.7	26.0
Texture class	SL	SL	SCL	SCL	SCL	SCL	SCL
Bulk density	1.43	1.47	1.49	1.51	1.56	1.56	1.52
Moisture % w/v at:							
pF 0	45.3	42.9	40.0	39.3	39.1	39.3	39.1
pF 2.0	11.1	13.3	15.1	17.2	18.6	17.0	19.1
pF 2.3	10.8	13.0	14.5	15.8	17.4	15.9	16.7
pF 2.7	10.4	12.4	13.9	15.0	16.7	15.0	16.4
pF 3.0	7.9	9.0	9.5	11.9	11.7	8.9	10.3
pF 3.7	6.1	7.4	8.0	9.0	9.5	8.9	9.7
pF 4.2	5.9	7.0	7.4	8.2	8.5	8.8	9.2

Fertility aspects: (0- cm)	Laboratory no. /	
Ca (me/100g)	Available	Total
Mg ..		
K ..		
P (ppm)		
Mn (me/100g)		
Exch. acidity (me/100g)		
pH-H_2O (1: v/v)		
C%		
N%		
"field capacity"		

Kenya Soil Survey
Drawing No. 78050

2) NGERENYA trial field - 1982

LABORATORY DATA OF PROFILE DESCRIPTION No: 198/2-46 Ngerenya field

FIELD OBSERVATION No. 2 MAPPING UNIT: UE112 SOIL CLASSIFICATION: FAO rhodic Ferralsol; USDA typic Haplustox

Laboratory no. 1982/			Wage-ningen	1985		
Horizon		Ap	(Ap)	Au	B	
Depth (cm)		0-25	0-20	25-80	80-200	
pH-H_2O(1: v/v)						
pH-KCl ..						
EC(mmho/cm) ..						
$CaCO_3$(%)						
$CaSO_4$(%)						
C (%)			0.97			
N (%)			0.0074			
C/N			131			
CEC (me/100g), pH 8.2 / AgTu			4.3			
CEC .. .. pH 7.0						
Exch.Ca (me/100g)			2.66			
.. Mg ..			0.72			
.. K ..			0.16			
.. Na ..			0.002			
Sum of cations			3.54			
Base sat. %, pH 8.2 / AgTu			82			
.. .. %, pH 7.0						
ESP at pH 8.2						
Saturation extract:						
Moisture %						
pH-paste						
ECe (mmho/cm)						
Na(me/l)						
K ..						
Ca ..						
Mg ..						
Sum of cations(me/l)						
CO_3(me/l)						
HCO_3 ..						
Cl ..						
SO_4 ..						
Sum of anions(me/l)						
Adj. SAR						
Clay mineralogy:						
SiO_2/Al_2O_3(mol/mol)						
SiO_2/R_2O_3 ..						
Fe_2O_3(mmol%)						
X-ray report:						
P-Olsen (mg/100 g)			0.23			

Depth (cm)		0-25	25-80	80-200		
Gravel %						
Texture, limited pretreatment:						
Sand % 2.0 - 0.05 mm						
Silt % 0.05-0.002mm						
Clay % 0.002-0 mm						
Texture class						
Dispersed clay %						
Flocculation index						
Texture USDA:						
Sand % 2.0 - 1.0mm		0.1	0.1	0.1		
.. .. 1.0 - 0.50mm		1.6	1.6	1.8		
.. .. 0.50 - 0.25 mm		50.1	38.7	38.6		
.. .. 0.25 - 0.10mm		24.7	20.6	23.1		
.. .. 0.10 - 0.05mm		1.0	2.3	3.8		
Total sand %		77.5	63.2	67.4		
Silt %		1.3	8.7	14.0		
Clay %		21.2	28.1	18.7		
Texture class		SCL	SCL	SL		
Bulk density						
Moisture % w/v at:						
pF 0						
pF 2.0						
pF 2.3						
pF 2.7						
pF 3.0						
pF 3.7						
pF 4.2						

Fertility aspects: (0- cm)	Laboratory no. /	
	Available	Total
Ca (me/100g)		
Mg ..		
K ..		
P (ppm)		
Mn (me/100g)		
Exch. acidity (me/100g)		
pH-H_2O (1: v/v)		
C%		
N%		

Kenya Soil Survey
Drawing No 78050

Texture data of the Ngerenya profile pit (198/2-46) contrast with one another. As seven characteristic (or distinguishing) depths were sampled (see next page) against three horizons of the profile pit, results from characteristic depths are considered to have more authority.

LABORATORY DATA OF PROFILE DESCRIPTION No: 198/2-46 Ngerenya trial field

D OBSERVATION No. MAPPING UNIT: UE112 SOIL CLASSIFICATION: FAO rhodic Ferralsol USDA typic Haplustox

boratory no. 1982 /(Kilifi)					
rizon					
pth (cm)					
-H_2O(1: v/v)					
-KCl ..					
(mmho/cm) ..					
CO_3(%)					
SO_4(%)					
(%)					
(%)					
N					
C (me/100g), pH 8.2					
C .. .. pH 7.0					
ch.Ca (me/100g)					
Mg ..					
K ..					
Na ..					
m of cations					
se sat. %, pH 8.2					
.. %, pH 7.0					
P at pH 8.2					
aturation extract:					
isture %					
-paste					
e (mmho/cm)					
(me/l)					
..					
..					
..					
m of cations(me/l)					
$_3$(me/l)					
O_3 ..					
..					
..					
n of anions(me/l)					
. SAR					
lay mineralogy:					
$_2/Al_2O_3$(mol/mol)					
$_2/R_2O_3$ ..					
$_2O_3$(mmol%)					
ray report:					

Depth (cm)	0-10	20-30	50-60	90-100	140-150	200-210	270-280
Gravel %							
Texture, limited pretreatment:							
Sand % 2.0 - 0.05 mm							
Silt % 0.05-0.002mm							
Clay % 0.002-0 mm							
Texture class							
Dispersed clay %							
Flocculation index							
Texture USDA:							
Sand % 2.0 - 1.0mm	0.1	0.1	0.0	0.1	0.1	0.1	0.1
.. .. 1.0 - 0.50mm	2.5	2.1	1.5	2.2	1.6	1.7	1.6
.. .. 0.50 - 0.25 mm	51.8	48.3	39.3	42.0	37.7	40.0	37.4
.. .. 0.25 - 0.10mm	22.7	23.0	24.6	21.2	22.7	22.7	22.7
.. .. 0.10 - 0.05mm	0.8	1.3	2.4	2.0	3.8	5.1	4.9
Total sand %	77.9	74.9	67.8	67.5	65.9	69.6	66.7
Silt %	11.2	4.0	4.9	7.6	13.4	7.0	4.5
Clay %	10.9	21.1	27.3	24.9	20.8	23.4	28.8
Texture class	SL	SCL	SCL	SCL	SCL	SCL	SCL
Bulk density	1.31	1.38	1.41	1.43	1.47	1.52	1.60
Moisture % w/v at:							
pF 0	47.8	47.7	44.2	43.0	43.0	41.8	40.3
pF 2.0	14.6	14.0	17.7	19.8	22.8	23.4	24.3
pF 2.3	14.3	13.4	16.8	17.9	20.3	21.0	21.5
pF 2.7	13.8	13.0	16.1	17.3	19.6	20.8	21.2
pF 3.0	11.6	10.9	11.3	11.9	12.4	13.6	14.2
pF 3.7	9.6	9.8	10.3	11.3	11.1	11.2	12.4
pF 4.2	7.9	8.8	9.2	10.2	10.8	11.4	12.2

Fertility aspects: (0- cm)	Laboratory no. /	/
Ca (me/100g)	Available	Total	Total
Mg ..		
K ..		
P (ppm)		
Mn (me/100g)		
Exch. acidity (me/100g)		
pH-H_2O (1: v/v)		
C%		
N%		

Kenya Soil Survey
Drawing No. 79050

APPENDIX 4. HISTORY OF BOTH TRIAL FIELDS (1982) & FARMERS PRACTICES. to 2.2

HISTORY TRIAL FIELDS

The **Ngerenya** trial field was cultivated with maize for the 3rd consecutive year, and had a more luxuriant (grass) fallow vegetation than the other field.
The **Sokoke** trial field/forest was reclaimed from the Sokoke forest in 1975, and in 1982 maize was grown for the 7th year. On May 10th, farmer Malim who managed/owned the land of the Sokoke trial field, also told something about past years of the field.
In 1978 the field received sufficient rainfall, comparable with 1982, and produced well (at the time of the conversation, the heavy rains still continued).
In 1979 the rains commenced well, but then paused, so that the plants drooped. Then the rains resumed so heavily that the first crop was partly washed away. The rains lasted this time which partly prevented new planting. Further, the remainders of the old crop and also the new crop rotted off. (Acland (1971) states: any waterlogging in the first four or five weeks of the life of maize seedlings - provides a check from which the plant never recovers, and reduces yields.)
In 1980 the rains were late and few; maize plants died at a height of 0.5 m, again without yield.
About 1981, no details are known.
In 1982, on May 10th, he expected yields of the same rate as in 1978.
Malim utilized mulch for the following reasons: to check run off and weeds, and as a fertilizer. (Mulch may be a pre-stage of organic matter in the soil, but it withdraws mineral N.)

FARMERS PRACTICES

Clearing by burning or hoeing

Clearing takes place in the dry season with or without burning. Burning especially happens when trees and shrubs are to be removed. Fields without trees and small shrubs are (mostly) cleared with a hoe; the dead fallow vegetation is left as mulch.
Advantages of mulch are reduction of erosion hazard (most fields have some slope) resulting in longer maintenance of the topsoil; further, reduction of soil temperature and of the deterioration rate of organic matter, and diminished evaporation. - Disadvantages are removal of soil

N by straw (fallow vegetations on both fields mainly consist of a Pennisetum sp., locally called 'Kairè'), and transfer of pests and diseases.

Effects of heavy rainfall in 1982 on farmers activities and crop growth

Rainfall effects on weeding and crop growth

The abundant and frequent rains diminished weeding effect, and possibly the farmers (wives) spent less hours on weeding. This labour problem on farmers fields, caused

low weeding frequences, which in their turn cause

denser and higher weed vegetations, so that

farmers (wives) could only pile up weeds (often together with mulch) between the stands, with the risk of rooting and spreading again.

As weeds thrived well, less nutrients were available for cultivated crops, and

most maize fields were more chlorotic than it would be expected from the natural soil fertility, and yielded little.

This labour problem did not play any role in T.P.I.P. field trials where before planting the fallow vegetation was removed and during crop growth under a frequent weeding regime weeds were put outside the trial fields, - and on the zero grazing farm of farmer Mwango in Kilifi, where besides fertilizers and cow dung were applied, resulting in a vigorous, dark green maize crop.

Rainfall and planting time

In the Kilifi area maize is always planted in the long rainy season as soon as enough moisture for emergence is available in the soil.

Reasons for this early planting are the unreliable rainfall regime;- and, partly connected with rainfall, the uncertainty about the increasing incidence of pests and diseases throughout the growing season.

Evaluating the long rains of 1982 however leads to the statement:

maize planting one month later i.e. in the beginning of May would probably have yielded more, because of the more favourable climate (sufficient rainfall, higher effectiveness of weeding, less leaching of fertilizers if applied, more sunshine hours) and the relatively low level of pests and diseases in 1982.

As neither length, intensity and (un)interuptedness of rainy seasons, nor (connected) incidence of pests and diseases are forecasted, farmers stick to their early planting practice.

APPENDIX 5 **RESEARCH PLAN**
to 4.2 & 4.3

RESEARCH PLAN FOR THE COMBINED 3 MONTHS SUBJECTS

Tropical Soil Science and Soil Fertility (by Sjoerd van Leeuwen)

February 27th A.D. 1982.

1. Introduction

In the Kilifi area (Mapsheet 198 of the Kenya Soil Survey) calcareous dune sands, with Ca. 70% $CaCO_3$, were found East of the Bofa-road in Kilifi. It was suggested to utilize them to raise the pH of acid soils occuring elsewhere in the area. Among the soils that are possibly acid are the poor red soils with low organic matter content, developed on the Magarini sands. My studies have been limited to these soils. Within the Kilifi mapsheet (200.000 ha) their area is approximately 7000 ha or 3½% distributed over an area of 4700 ha South of Kilifi creek and one North of the creek of ca. 2100ha. North of the mapsheet the Northern Magarini area still extends further.
The most important map units of the Magarini sands are UAc2 and UAc3 of which the UAc3 has a somewhat heavier B-horizon (higher clay percentage).

Bennema and Janssen suggested that improvement by adding calcareous dune sand or lime to these soils is justified only, if the surface soils have a pH-H_2O of 4.8 or lower, or a pH-KCl of 4.0 or lower. To start with I have sampled the whole Magarini sand area, taking about one sample per 100 ha. After checking the pH-H_2O a pH-map of the Magarini sands was compiled.

Results The northern Magarini sands within the mapsheet are obviously acid. The 16 samples taken there represent about 1300 of the 2100 ha and 8 of them representing ca 650 ha, meet the pH-H_2O requirement. These Magarini sands are occupied by the Sokoke plantation and part of a Settlement Scheme. Landuse are cashew and cattle resp. subsistence agriculture on small scale.
Conslusion: A liming trial is justified.

2 The Objectives of the liming trials

It has to be checked whether there is a relationship between maize production and soil acidity in the northern Magarini sands by comparing the yields of the zero plots with pH-H_2O of 4.8 or lower with those of limed ones where pH-H_2O is 5.4.

If the treated plots give higher yields, a technical solution for the acidity problems is at hand.
Economical feasability (a.o. with regard to high transport costs) and the ecological justification (in view of removing the dune sands) also are serious questions which are not taken into account yet. Still these matters are very important!

3 Methods and materials

The selection of trial fields

The average pH-H_2O over the 16 sampled places is 4.9. Of these 16, 8 fulfill the pH-H_2O - criterium of 4.8 or lower and their mean value is 4.6. Trial fields will be looked for in the neighbourhood of these 8 spots and before accepting them defenitly as a trial field, their pH-H_2O will be checked again.
One trial field will be on soilmap-unit UAc2 and one on UAc3

Crop: Maize, Zea mays cv Coast Composite. Maize is the main crop in the Kilifi area.
"Coast Composite" is used to enable comparison with previous experiments and to facilitate the duplication of the experiment which would be difficult with the vaguely defined local "varieties".

The spacing of plots, plants and border effect:
The plot size will be 4.5x4.5m and the plants will be spaced at 90 x 30cm planting distance which results in 75 plants per plot. While the border plants will be excluded, only 27 plants are left for observation.

Experimental design.

The trial field is a completely randomized block design in 3 replications with the factors: lime (as $CaCO_3$) in 3 classes at 2 levels: Zero, calcareous dune sand and agricultural lime, and fertilizer at 2 levels: Zero and NP (50-30). The codes for the treatments ($CaCO_3$, fertilizer) are: 00, 10, 20, 01, 11, 21.
The results will be examined with the help of analyses of variance.
The degrees of freedom are distributed as follows:

Niv	1	
$CaCO_3$*	2	The 6 treatments will randomly be
NP*	1	divided over every
$CaCO_3$ x NP*	2	replication.

Rep*	2
R	10
Total	18

Also mulch effect will be tested at 3levels: bare soil, burned soil and mulched soil. The largest part of the fallow vegetation is a Pennisetum sp. locally named <u>Kaire</u>. Mulch effect is confounded with block effect.
This extra effect is set in because the farmers often use the fallow vegetation as mulch (it raises moisture availability and the possibilities to get pests and diseases in the crop) or burn it for fertilizing. In connection with the liming of the soil with the help of the rotary cultivator the bare soil level is tested.

<u>Scheme of the trial fields:</u>

1st replication		2nd replication		3rd replication	
5	6	11	12	17	18
3	4	9	10	15	16
1(field number)	2	7	8	13	14

<u>Timescheme</u>

a. Preresearch on pH of the Magarini sands
Feb 1st - 23rd 3 introduction days
7 field days
5 lab days
5 days for thefinishing touch

b. The liming trial
Feb 24th - looking for a suitable trial field (low pH-H_2O)
- clearing of the fields when pH proved to be low enough.
- determination of the pH curve of the soil (lime-requirement).

- examination of the liming material according to Van Wesemael.
- fuxther preparation of the fields: fencimg, delineation, lime application; the lime will be worked in with the rotary cultivator (depth; 10cm) also the unlimed plots are worked with the rotary cultivator.
- the taking of composite soil samples for fertility analyses.
- the placing of a raingage.

Mar 15th
- planting of 3 seeds per stand .
- Fertilizer application after sufficient rain; phosphorus and half of the nitrogen on planting and the remaining nitrogen 6 weeks after emergence.

2 weeks after planting: emergence percentage , thinning to one plant per stand and replanting of the empty stands.

3 weeks after planting: first weeding

During the remaining part of the growing season from April to August: Working at the fields one day a week with assistants of the project:

- weeding when required.
- application of pesticide furadan when required.
- determination of the 50% tasseling point.
- bookkeeping of the precipitation.
- taking composite soil samples for pH and the determination of $CaCO_3$ eluviation in layers beneath the working depth of the rotary cultivator and fertility analysis.
- description and analysis of one profile pit next to each trial field.
- further sampling in the Northern Magarini sands for precising that part of the pH-H_2O map of the Magarini sands.

In the 2nd half of July or the 1st half of August harvest per plot:

- the number of cobs will be counted, and the weight of grain and the 1000-grain-weight are determined.
- plant samples will be taken for analyses in Wageningen for further analysis.
- except the plant monsters, the harvest will be given back to the farmers.

When back in Wageningen (February 1983) further soil and plant analysis will take 1½ weeks and reporting 1 month.

NB The trial time is not allowed to exceed 4 months work including analysis and reporting time.

		field*	lab*	reportin
Feb 1st - Mar 16th	preresearch and field preparations	3	1	1
Mar 15th	planting and fertilizing	1		
Apr - Aug	work during the growing season (1 d.p.w)	4	1	
Jul- Aug	Harvest	½	½	
Feb 1983	Wageningen		1½	4
		8.5	4	5 =17.
				=4 m

*the numbers estimate the number of weeks needed.

c.c. Prof. Dr Ir. J. Bennema
Dr. Ir. T. de Meester
Ing. H.W. Boxem
Ir H. Waayenberg
Ir W. Wielemaker
Prof. Dr. B.H. Janssen
B.Sc. I. van der Noll
B. Sc. W.J.H. Schreurs
Prof. Dr. Ir. A. van Diest

APPENDIX 6 SUPPLEMENT TO THE RESEARCH PLAN

to 4.2 & 4.3

Supplement to the research plan for the combined 3 months subjects:
Tropical Soil Science and Soil Fertility.

by Sjoerd van Leeuwen. May 1982

Introduction

For the preparation of the $pH\text{-}H_2O$ map of the Magarini Sands, the quantity

$$\frac{2 \times pH\ topsoil^{1)} + 1 \times pH\ subsoil^{1)}}{3}$$

was used. Due to some misunderstanding I used this quantity also as a criterium for the selection of the trial-fields for the liming trial and for the estimation of the amount of lime to be applied. As the effect of the liming is probably limited to the topsoil - at least during the first season - only the pH of the topsoil should have been considered. The consequences of this error are:

1. not very acid trial fields;
2. too high lime applications.

ad 1. $pH\text{-}H_2O$'s of the topsoil at the Sokoke-field and the Ngerenya-field resp. were 4.8 and 4.9, which is 0.2 higher than the values found from the formular.

ad 2. The $pH\text{-}H_2O$ of the topsoils after liming was meant to be 5.4. Measurement of the samples taken after lime-application (per treatment per replication) showed the limed plots to have a pH of ca 6.25. This was in agreement with calculations which estimated the applied amount of lime to be 2 to 5 times as high as required (for agricultural lime resp dune sand).

Conclusion: whether the lime treatments will result in higher yields or not is questionable; extension of the fertilizer part of the trial for obtaining interesting and relevant results is justified.

Experimental Design (adapted version) for the lime-fertilizer trial. The original experimental design contained for each field 3 lime treatments and 2 fertilizer treatments in 3 replications. The trial fields were already limed according with this design.

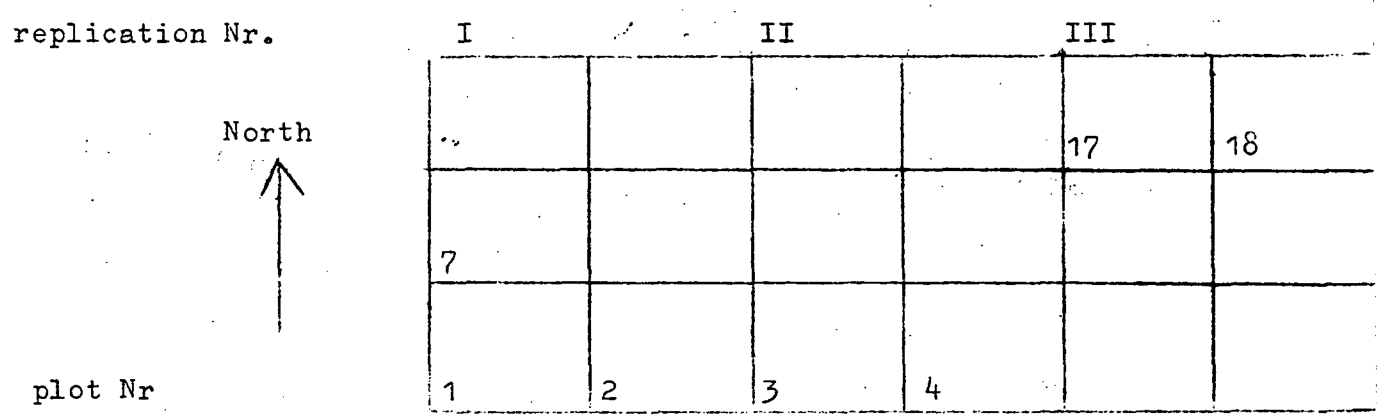
In the new experimental design the same fields are used, but the fertilizer treatments are extended. The trial is divided into 2 parts:

1) Topsoil 0-25cm
2) Subsoil 25-45cm

a) A 2^2 factorial NP-trial[2)] (0,1,2, 3, indicating zero, N,P and NP) in 3 replications. As replications or blocks function the already applied lime-treatments zero, calcareous dune sand and agricultural lime (0,1 and 2). Every replication will randomly be divided into 2 subblocks[3)] coresponding with the original block design. In turn N,P and NP will be confounded with the subblocks.
The applied fertilizers are CAN (50 kg N/ha) and TSP (30 kg P/ha).

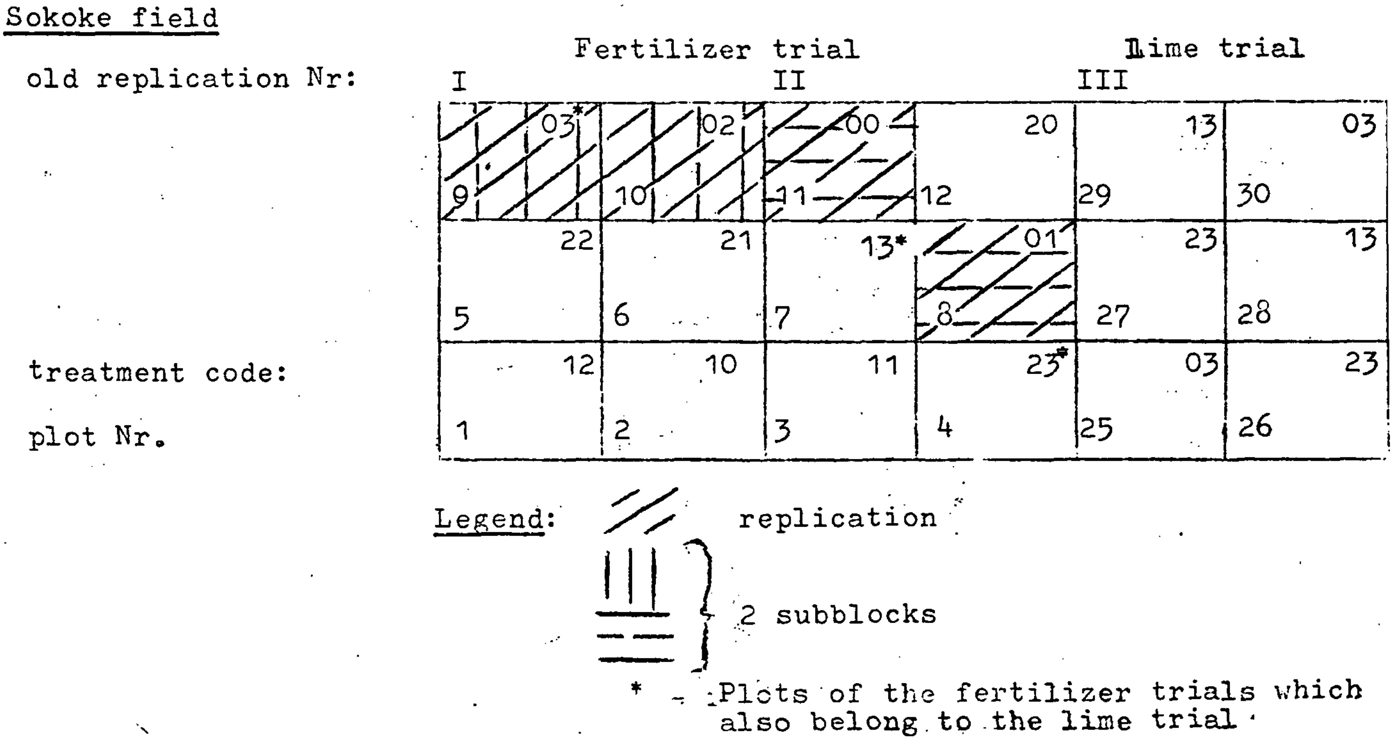
b) A liming trial[2)] in 3 replications with 3 lime-treatments. The liming effect is expected to be maximal at the NP-level. According to this the treatments are established as follows: 03, 13, 23. The NP-plots of the fertilizer trial form one of the three replications and are included in the lime trial.

The <u>former</u> structure of the <u>FIELD SCHEMES:</u>



The new <u>Field Schemes</u>:

<u>Sokoke field</u>



2) see the new field schemes
3) an example of this can be found in the new treatment scheme of the Sokoke field (indicated by shading)

Ngerenya- field

12 21	10 22	02 23	11 24	23 35	03 36
00 17	21 18	23* 19	20 20	13 33	23 34
01 13	22 14	13* 15	03* 16	03 31	13 32

To increase the degrees of freedom for the . analysis of variance, the results of both locations will be pooled.

ANOVA ables

NP-trial

Niv	1
Location*	1
Replications within the locations* 2 x 2 =	4
Subblocks within the replications* 6 x 1 =	6
N*	1
P*	1
NP*	1
(N x location)*	1
(P x location)*	1
(NP x location)*	1
Error	6
TOTAL	24

Liming trial

Niv	1	
Location	1	
Lime	2	
Location x lime	2	
(Replications 2x2		4)
Error	12	(8)
TOTAL	18	

Possibly errors can be pooled after the trial. Also to be considered are the possibilities to decrease or increase the error by lifting out resp. adding interactions.

In Wageningen consultation of the Department of Mathematics is required.

Lit: Cochran W.G and G.M. Cox, 1957. Experimental Design 2nd ed.:

Ch. 6.12vv p. 165vv. and Ch. 14.1,p.545 - 550

<u>Samples</u> to be taken are:

Soil samples, - 2 months after planting (when 50-100% of the maize plants are in the tasseling stage).
- Composite samples per plot of the topsoil (0-20cm) and the subsoil (20-40cm) to determine pH-H_2O and possibly pH-KCl.

Crop samples - When harvesting, the netplants will be divided into a) cobs or ears and b) stems and leaves. giving a total amount of 72 samples. After weighing, axis and husks will be thrown away.

Scheme of the HARVESTING PROCEDURE

working spot	measurement of:	
field	<u>fresh weight</u> whole harvest (100%) Samples (10-15%)	75 plants per plot 33 net plants / 42 border plants ears, stalks & leaves / ears, stalks, leaves ears, stalks & leaves
Office	dry weight Samples - 10-15% after 24 hours at 70°C	grains, husks, axis, cut in pieces possibly only 1 sample will be taken per 9 plots
Wageningen	Subsamples (10-20g) of the grains, stalks and leaves of the net plants will be taken for further analyses in Wageningen.	

Site		0-20cm							20-40cm					
No	slope%	Landuse	colour		texture		pH		colour		texture		pH	
			moist	dry	est	lab	H_2O	KCl	moist	dry	est	lab	H_2O	KCl

Appendix 7. Observation and lab data sheet acidity survey

to 5.1

Although the other data mentioned on this form are available with the author, only pH data are presented in 6.1 because soil acidity appeared to form no check upon crop growth (see 6.1).

APPENDIX 8. CONT(R)ACTS WITH FARMERS & FIELD YIELDS.
to 5.2

Cont(r)acts with farmers First, potential trial fields were selected on first view and checking whether the available area would suffice. After finding the farmer, he was asked to grant that piece of his land (about 15 x 30 m) for research eventually aiming to benefit farmers. He was promised a guaranteed harvest in return, which meant a reasonable amount of maize flour if crop and harvest would fail. Requested farmers were willing to lend their land. The contracts were concluded as verbal agreements. Project assistants were important intermediaries in finding, contacting and contracting the farmers.

The first trial field selected on UE111 fulfilled the criteria set in 4.2 (see App.12). On UE112, two fields were abandoned, of which the farmers were messaged before the onset of the rains, mentioning its reasons (pH higher than 4.8 i.e. too good soil quality, resp. occurrence of an old ant-hill within the boundaries of the field i.e. disturbed soil structure (see App.12).

Field yields Both trial fields consisted of 18 plots covering 364.5 m^2. Each gross plot (4.5 x 4.5 m = 20.25 m^2) was planned to contain 75 plants (5 rows x 15 plants) divided over 33 (= 3 x 11) net plants and 42 tare plants. At the harvest on August 6^{th}, the ears of the border plants amounting around 56 % (= 42/75 x 100) of the harvest, were brought to the farmer. The maize production of the net plots amounted to the remaining 44 (= 33/75 x 100) %. After processing the net harvest (see 5.3), and withdrawal of grains affected with pests and diseases and 10 g oven-dry samples per plot, the remaining 40 % of the harvest was returned to the farmers as grains. Malim in 'Sokoke' received about 21 kg, and Robert Charo in the Ngerenya settlement scheme circa 31 kg. These different yields illustrate the different soil fertilities of these areas. Also farmers in the Ngerenya Settlement Scheme obtained much higher yields than their collegues in Sokoke. These figures also reflect fertilizing levels field yields, and so they mask yield differences between these areas that farmers experience.

Some impression of farmers yields may be obtained by comparing yields of unfertilized plots on both trial fields in 1982 (from net plot yields calculated in App. 19). On the Sokoke resp. Ngerenya field, these yields amounted to 0.75 resp. 1.92 $ton.ha^{-1}$ (with standard deviations of 0.22 resp. 0.43). Under this management - plant arrangement and density, frequent weeding, and furadan against possible stalk borers - the Ngerenya field yielded a factor 2.6 more than the Sokoke field. It is clear, farmers in The Ngerenya Settlement Scheme need less soil (and thus labour!) to feed the family.

APPENDIX 9. FERTILIZER LEVELS & ECONOMICS.

to 5.3 & 6.3.4

Appendix 9.1. FERTILIZER LEVEL COMPUTATIONS.

to 5.3

No general application of fertilizers for other nutrients than N and P was given. N- and P-rates amounted to 50 resp. 30 $kg.ha^{-1}$.

Table 9.1. Fertilizer composition.

Nutrient	kg.ha-1	Fertilizer	Composition
N	50	Calcium Ammonium Nitrate (CAN)	$NH_4NO_3 + CaCO_3$; 26 % N, 25 % $CaCO_3$
P	30	Tripel [a] Superphosphate (TSP)	$Ca(H_2PO_4.H_2O$; 43-48 % P_2O_5 (water)

a) also called Double SuperPhosphate

If TSP contained 46 % P_2O_5, P-content was 20.1 %.

The following computation holds to transform the required nutrient ($kg.ha^{-1}$) in required fertilizer.

$$\underset{\text{nutrient}}{..(kg.ha^{-1})} \times \frac{100}{\%\ \text{nutrient in fertilizer}} = \underset{\text{fertilizer}}{..(kg.ha^{-1})} \quad (1)$$ **fertilizer per ha**

Both fertilizers were applied on 24 plots (see field schemes in 4.3) of 4.5 x 4.5 m = 20.25 m^2 (see 5.3). Each plot consisted of 5 equidistant rows. Pockets containing one of the fertilizers were weighed per row to further equal fertilizer distribution per plot.

The calculation factor from ha to plot row amounted to

$$\frac{20.25}{10{,}000} \times \frac{1}{5} = 4.05 \times 10^{-4} \quad (2)$$ **area to be fertilized**

Combining (1) and (2), following results were generated (Table 9.2).

Table 9.2. Fertilizer application rates.

fertilizer	$kg.ha^{-1}$	kg. 24 plots x 20.25 m^2	$g.plot^{-1}$ (20.25 m^2)	$g.row^{-1}$ (4.05 m^2)
CAN	192	9.346	389	78[1] = 39 + 39
TSP	149	7.254	302	60[2]

1) applied in two halves,
first half at planting, second half 8 weeks later.
2) applied at planting.

Appendix 9.2. to 6.3.4 FERTILIZER ECONOMICS - PARTIAL BUDGET ANALYSIS OF THE FERTILIZER TRIAL.

Table 9.3. Fertilizer prices (Ksh.).

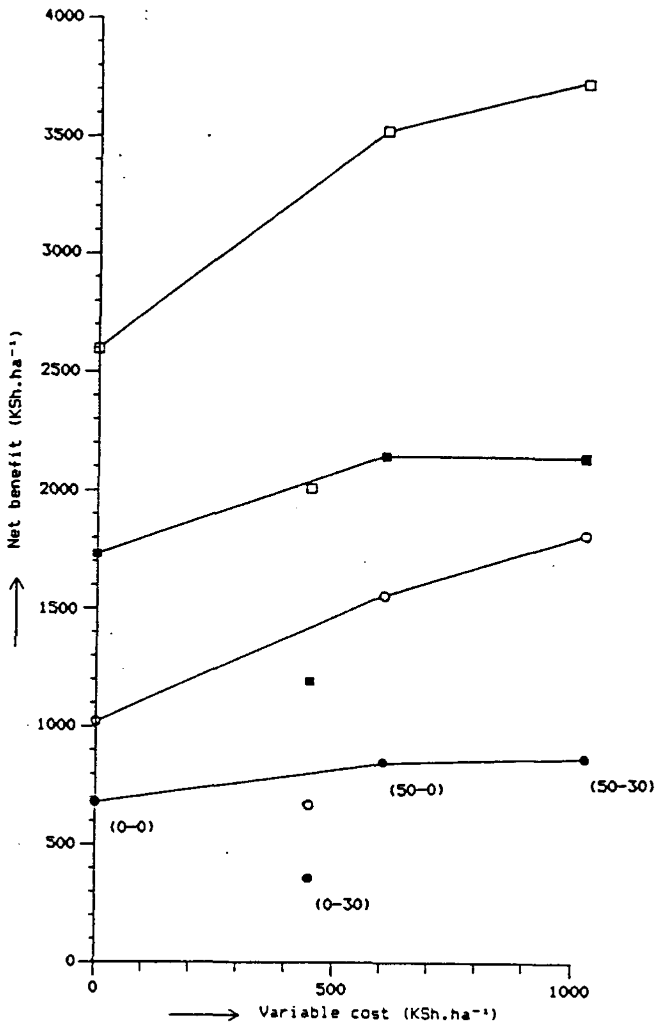
Fertilizer	Fertilizer price per amount (kg) Bag 50 kg	kg N or P	kg N or P including 10 % transport costs
CAN	129.30	9.93	10.92
TSP	213.10	12.70	13.97

Prices of labour and maize (grains) are included in Table 9.4.

Table 9.4. Partial budget of averaged data from fertilizer trial (per hectare basis).

Item	Fertilizer treatment N: / P:	0 / 0	0 / 30	50 / 0	50 / 30	0 / 0	0 / 30	50 / 0	50 / 30
(1) Average yield (ton.ha^{-1})[a]		0.75	0.90	1.61	2.10	1.92	1.82	3.05	3.51
(2) Net yield		0.68	0.81	1.45	1.89	1.73	1.64	2.75	3.16
(3) Gross field benefit (Ksh)[b]		680	810	1450	1890	1730	1640	2750	3160
(4) ,, ,, ,, ,, [c]		1020	1215	2175	2835	2595	2460	4125	4740
Variable money costs:									
(5) Nitrogen		0	0	546	546	0	0	546	546
(6) Phosphate		0	419	0	419	0	419	0	419
(7) Variable money costs (Ksh.ha^{-1})		0	419	546	965	0	419	546	965
Variable opportunity costs:									
(8) Number of applications		0	1	2	2	0	1	2	2
(9) Cost per application (Ksh.ha^{-1})[d]		0	30	60	60	0	30	60	60
(10) Opportunity cost (Ksh.ha^{-1})		0	30	60	60	0	30	60	60
(11) Total variable costs (Ksh.ha^{-1})		0	449	606	1025	0	449	606	1025
(12) Net benefit (Ksh.ha^{-1})[b]		680	361	844	865	1730	1191	2144	2135
(13) ,, ,, ,, [c]		1020	766	1569	1810	2595	2011	3519	3715

a) 12 % moisture
b) at a maize (grains) price of 1.= Ksh. per kg
c) at a maize (grains) price of 1.5 Ksh. per kg
d) 2 days at Ksh. 15.=. Combined application of two or more fertilizers is assumed to take no more time.



Besides each plotted vertical group of 4 points (with the same variable cost), nitrogen and phosphate level are shown in parenthesis.

A conclusion is: all single P treatments are dominated (less paying than other treatments with higher net benefits, and of no economical interest).

Figure 9.1. Net benefit curve for the fertilizer trials.

	Price ($Ksh.kg^{-1}$) 1.=	1.5
Trial field: Sokoke	●	○
Ngerenya	■	□

Figure 9.1 shows a net benefit curve for the trials on Magarini sands in 1982.

Computation examples of marginal analyses of fertilizer response data are: (0–P) (N–NP)

$$\frac{\text{marginal net benefit} = 361-680}{\text{marginal cost} = 449-\ \ 0} = -0.71 = -71\ \%;\ \frac{865-844}{1025-606} = +0.05 = +\ 5\ \%.$$

Results of these computations from the data of Table 9.4, lines 11 and 12, resp. 11 and 13 are given in 6.3.4, Table 6.22.

Sokoke

(Subsistence) farmer MALIM

Maize planting date: April 1st (Thursday) 1982

SLOPE direction: ▼ plot no. 12 30 / 1 25

North ↑ South = direction plantrows

REMARKS Date:

Raingage mm

Soil moisture depth from to m

APPENDIX 10 Field observation sheets lime fertilizer trial

to 5.2 & 5.3

9	10	11	12	29	30
O-NP	O-P	O-O	Al.-O	D.s.-NP	O-NP
5	6	7	8	27	28
Al.-P	Al.-N	D.s.-NP	O-N	Al.-NP	D.s.-NP
1	2	3	4	25	26
Ds.P	Ds-O	Ds.-N	Al.-NP	O-NP	Al.-NP

Ngerenya

APPENDIX 10 (continuation)

(Subsistence-)farmer ROBERT CHARO

Maize planting date: Friday April 2nd 1982

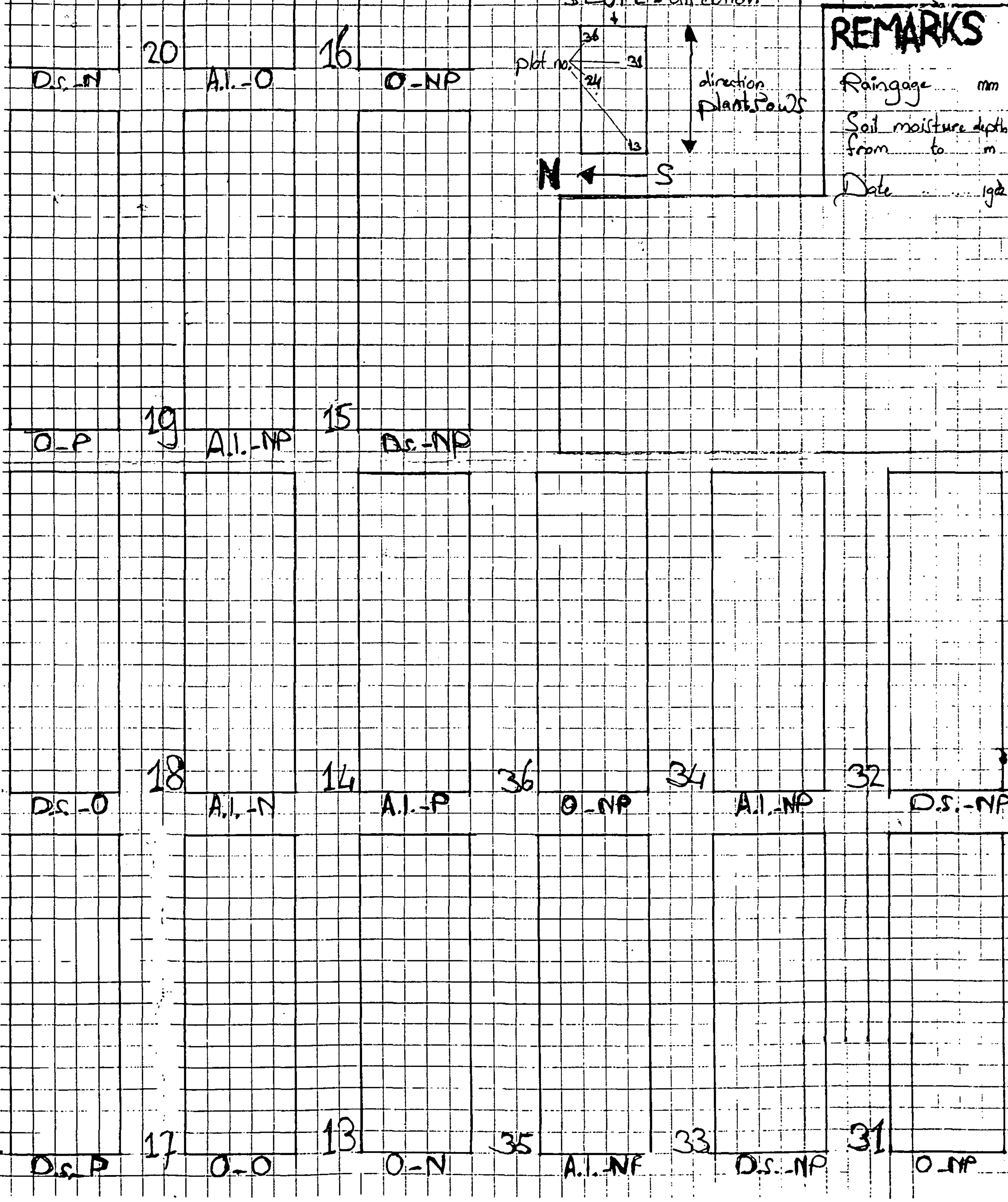
SLOPE-direction

REMARKS

Raingage .... mm

Soil moisture depth from .... to .... m

Date 1982

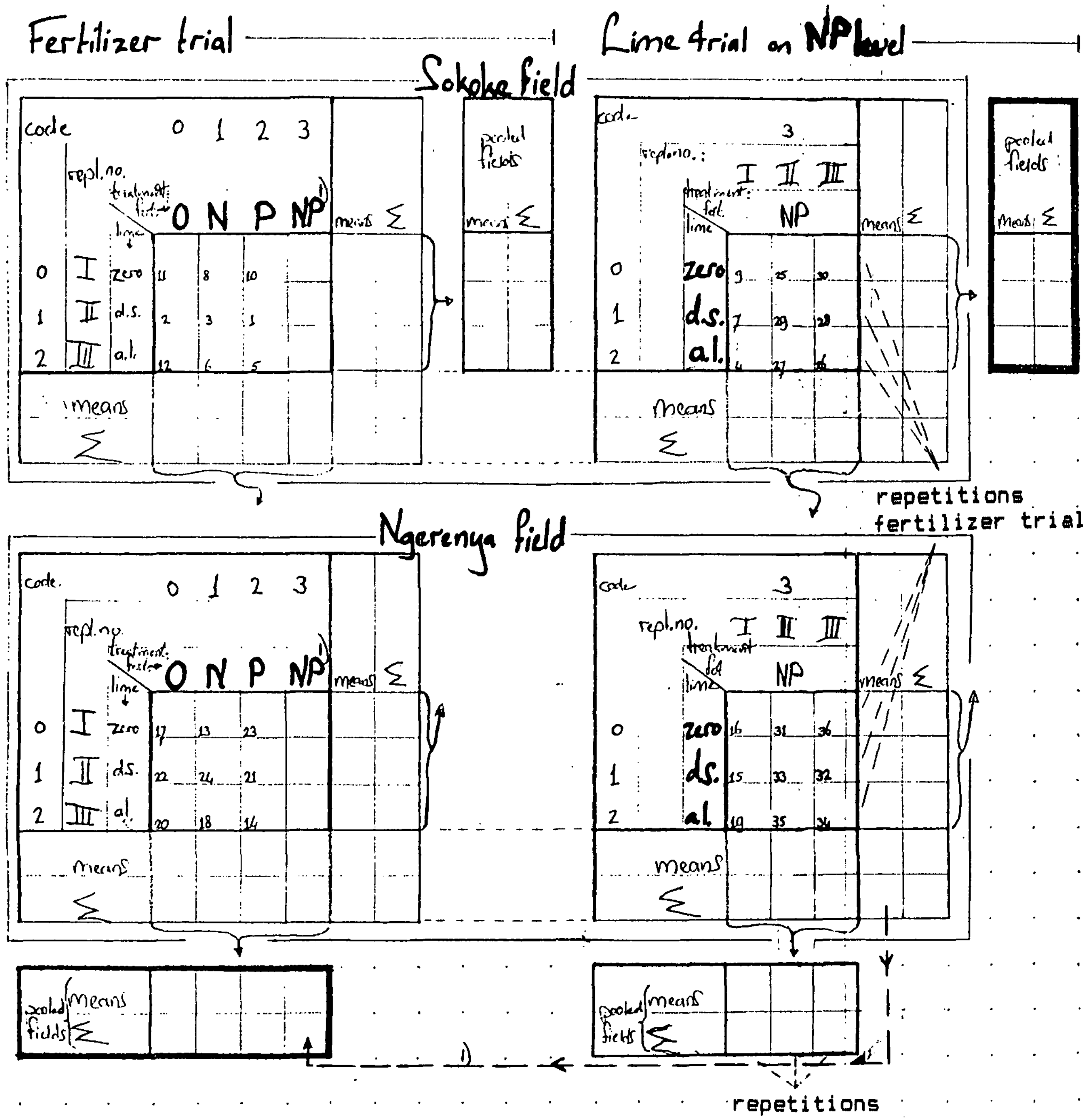


APPENDIX 11. DISENTANGLEMENT FORM (LIME AND FERTILIZER TRIAL). fertilizer treatments: [kg·ha⁻¹]
to 5.3 & 6.2.2.1

	0	N
0	0	50
P	30	50 30

lime treatments: $CaCO_3$ [tons·ha⁻¹]

zero	0
calcareous dunesand	2,32
agricultural lime	1,14



List of possible effects

Fertilizer trial

N fertilizer effect
P ,, ,,
NP interaction ,, — see below

Replicate effect (= lime effect)

Field effect

Estimation of fertilizer effects:

		N −	N +	
P	−	a	b	c
	+	d	e¹	f
		g	h	

N effect = $\frac{h-g}{2}$

P ,, = $\frac{f-c}{2}$

NP² ,, = (c−d)−(b−a)

¹ mean of all 9 NP plots
² In the fertilizer trial, assessment of NP effect was facilitated by filling up the NP column with mean NP values as computed for the liming trial (see arrow).

Liming trial

Agricultural lime effect
Calcareous dunesand ,, to 5.3 & 6.2.2.1

Replicate effect

Field effect

APPENDIX 12. pH-H_2O values of (potential) trial fields as measured in Kilifi (1982)*; (Appendix to 6.2.1).

Mapping unit	Location/ farmer	Depth 0 - 20 cm / A						mean	20 - 40 cm / B						mean	$\frac{2A+B}{3}$
UE111	Sokoke/ Malim	4.60	4.69	4.72	5.16	4.59	4.88	4.77	3.86	4.38	4.40	4.82	4.43	4.45	4.39	4.64
UE112	Settlement scheme/ Ndoro Wamele	5.37	5.64	5.07	5.03	4.80	5.52	5.24	4.49	4.80	4.51	4.63	4.61	4.89	4.66	5.05
	?/Manzala Kagohu	4.35	4.27	5.10	4.97			4.67	4.12	4.17	4.33	4.36			4.25	4.53
	Ngerenya Settlement scheme/ Robert Charo	5.00	4.76	4.97	4.74			4.87	4.06	3.94	4.49	4.45			4.24	4.66

The field of Ndoro Wamele was not sufficiently acid. The field of Manzala Kagohu was abandoned before the onset of the rains, because an old ant-hill was discovered during a second visit to the field, with correspondingly heavier texture than the rest of the field.

* Afterwards, early obtained pH data like in this appendix appeared to be too low (see 6.1), and therefore unreliable. As the decision to lime trial fields was based on these data, they nevertheless are mentioned here.

APPENDIX 13. LIMING LEVELS
to 6.2.1.2

First considerations before liming (based on results of van RAIJ (1982) and pH-data of February 1982) are given; next considerations after liming (mainly based on estimates of the liming factor and the same pH data), and lastly follows a comparison of all lime requirement computations.

Considerations before liming
Before lime application, one assumption was the equality of the lime requirements of a soil used by van RAIJ (1982) and these soils developed on Magarini sands (van RAIJ tested the influence of liming on a 'dark red latosol, sandy phase' which is comparable with 'Magarini sands'). Application of 1.5 $ton.ha^{-1}$ of lime (38 % CaO and 27 % MgO) i.e. 2.02 $ton.ha^{-1}$ $CaCO_3$ raised soil pH from 4.9 to 5.4, while the very low CEC of this soil[1)] ranged between 24 and 30 $mmol(+).kg^{-1}$ of soil.
In first calculations to estimate required lime amounts, only CaO (corresponding with 1.02 $ton.ha^{-1}$ $CaCO_3$) was supposed to have caused the raise of pH with 0.5 unit, thus even halving lime requirements for agricultural lime when estimated tentatively in Kilifi (see Table 13.1).
Lime contents of the liming materials were searched according to Wesemael's method, weighing in 2.0 to 2.4 g per sample, with results as follow. Dunesand contained 48-56 % '$CaCO_3$', and agricultural lime 21 % (a short, two-hours version of Wesemael's method, as described by BEGHEIJN and van SCHUYLENBORGH, 1971). As 21 % for agr. lime sharply contradicted factory analysis (90 % $CaCO_3$), the former value was rejected; further calculations (see Table 13.1) were based on 90 and 56 % for agr. lime and calcareous dunesand respectively. The resulting estimates of lime requirements (see Table 13.1) were 2.3 resp. 3.7 kg/plot for a.l. resp. d.s., which amounts by an irrational step were increased to 2.5 resp. 5.0 kg/plot.

Considerations after liming
After liming, the results of the test according to Wesemael were evaluated, revealing two crucial mistakes. First, the HCl applied amounted c. 32 mmol(+) (c. 8 ml x 4 M HCl), corresponding with c. 1600

[1] '$CaCO_3$' means the sum of compounds that show a liming reaction like $CaCO_3$, $MgCO_3$, $Ca(OH)_2$ expressed as the equivalent % $CaCO_3$.

mg $CaCO_3$. Thus agricultural lime (90 % $CaCO_3$) of which c. 2.2 g was weighed in, could not be measured correctly. Moreover, according to HOUBA et al. (1985), the method is tested for a maximum of 400 mg $CaCO_3$.). - Secondly, the test was carried out overnight March 5th-6th, because March 6th was the last possible liming date (before the excursion of the project to be certain of liming before the onset of the rains). Due to time pressure the short version of the method was chosen (BEGHEIJN and van SCHUYLENBORGH, 1971). This made the reaction time much shorter than the 22-30 hours prescribed in the long version (e.g. in HOUBA et al, 1985). Therefore after liming, the data obtained with <u>Wesemael's</u> method were rejected, and samples of the applied agricultural lime and dunesand were tested in <u>Wageningen</u> to result in 92 resp. 94 % '$CaCO_3$'. Agricultural lime dissolved much slower than calcareous dunesand, which explains the low lime content (21 %) found with the short version of Wesemael's method in Kilifi. From these '$CaCO_3$' contents, the lime requirements analogous to van RAIJ were computed again (see final estimates: Table 13.1).

Table 13.1. Tentative and final estimates of required amounts of both liming materials as derived from van RAIJ (1982).

Place & date of estimation	Kilifi, February/March 1982						Wageningen, 1982 & 1985		
	tentative estimates						final estimates[g]		
pH(van RAIJ)=0.5	'$CaCO_3$' (Wesemael) %	required liming material ton.ha^{-1}	kg.$plot^{-1}$ [a]	actually applied liming material kg.$plot^{-1}$ [a]	ton.ha^{-1}	ton.ha^{-1}	'$CaCO_3$'[f] %	required liming material ton.ha^{-1}	kg.$plot^{-1}$
van RAIJ's liming mat. (38 % CaO, 27 % MgO)	68[b]	1.5	.	.	0	0	135[c]	1.5	.
Agricultural lime	90	1.13[d]	2.3[e]	2.5	1.23	1.14	92	2.20[h]	4.5[i]
Calcareous dunesand	56	1.82	3.7	5.0	2.47	2.32	94	2.15	4.4

a) All plots covered 20.25 m^2.
b) Based only on the CaO content of van RAIJ's liming material.
c) Based on both CaO and MgO content of van RAIJ's liming material.
d),e) Computation e.g. $\frac{68}{90} \times 1.5 = \underset{d)}{1.13} \times \frac{20.25\ m^2}{10,000\ m^2} = \underset{e)}{2.3}$ kg.$plot^{-1}$.
f) According to final '$CaCO_3$' estimate (see App. 14).
g) Except for pH.
h),i) Computation e.g. $\frac{135}{92} \times 1.5 = \underset{h)}{2.20} \times \frac{20.25\ m^2}{10,000\ m^2} = \underset{i)}{4.5}$ kg.$plot^{-1}$.

The final estimate of the agricultural lime requirement based on van RAIJ (1982) almost doubled the original one. Also the requirement of calcareous dunesand was higher. Agricultural lime was applied at a rate of 56 % and calcareous dunesand at a rate of 115 % the finally computed rate. As agricultural lime and calcareous dunesand have approximately equal '$CaCO_3$' contents and calcareous dunesand was applied at twice the rate of agricultural lime, liming levels related as 0:1:2.

Liming happened by tentative lime requirements based on van RAIJ's results, and pH estimates obtained in Kilifi during February 1982.
As results of Wesemael's test were unreliable, lime requirements were computed again based on the liming factor (kg $CaO.ha^{-1}.dm^{-1}$ needed to increase pH by 0.1 unit). On sand soils this factor is estimated by c. 8 x CEC x bulk density (Bd).
Following results are based on tentative estimates from Kilifi and final results from Wageningen (see Table 13.2)
Combined with '$CaCO_3$' contents of both liming materials, in Kilifi tentative, and in Wageningen final lime requirements were estimated (see Table 13.3). (However afterwards was proved Kilifi pH-H_2O estimates had been too low.)

Table 13.2. Liming factor computation for both trial fields (kg $CaO \cdot ha^{-1} \cdot dm^{-1}$).

Laboratory / Trial field	Kilifi CEC	Kilifi Bd	liming factor	Wageningen CEC	Wageningen Bd	liming factor
				means over 0 - 20 cm		
Sokoke	2.0	1.5	24	3.3	1.44	38
Ngerenya				4.3	1.33	46

Table 13.3. Lime requirements as estimated from the liming factor; a) in Kilifi, based on tentative data, and b) in Wageningen, based on final data ($ton.ha^{-1} \cdot 2\ dm^{-1}$ ($kg \cdot plot^{-1} \cdot 2\ dm^{-1}$)).

	a) Kilifi estimates 'CaCO3'% liming materials	SOKOKE field		NGERENYA field		b) Wageningen estimates 'CaCO3'% liming materials	SOKOKE field		NGERENYA field	
Liming factor 1) (CaO→CaCO3)		2 4 → 4 3					38 → 68		46 → 82	
p H - H_2O 2)		4.6		4.7		4.8			4.9	
△pH (0.1 pH unit)		8		7		6			5	
Lime requirement										
Agricultural lime	90	0.76	(1.55)	0.69	(1.36)	92	0.89	(1.80)	0.89	(1.80)
Calcareous dunesand	56	1.23	(2.49)	1.08	(2.49)	94	0.87	(1.76)	0.87	(1.77)

1) see Table 13.2; 1f kg $CaO \cdot ha^{-1} \cdot dm^{-1}$ is equal to $\frac{100}{56}$ x 1f kg '$CaCO_3$'$\cdot ha^{-1} \cdot dm^{-1}$.
2) In Wageningen, lime requirements were derived from pH values as achieved in Kilifi for topsoil samples (A) during the selection of trial fields (see App. 12).

Comparison of final lime requirement computations

Results of all lime requirement computations are collected in Table 13.4. Final estimates obtained in Wageningen, are most reliable for they are based on more lab results and less rough estimates than the other data. Still, these last values are based on too low pH-H_2O values of topsoils as measured in Kilifi (Sokoke 4.8 and Ngerenya 4.9) (see App. 12).

Table 13.4. Lime requirements, applied quantities, and tentative and final estimates (ton.ha^{-1}).

	actually applied quantity of lime of '$CaCO_3$'	Lime requirements derived from: van RAIJ (1982)		the liming factor		
		Kilifi tentative	Wageningen final	Kilifi tentative		Wageningen final
trial field		S & N	S & N	S	N	S & N
agricultural lime	1.23	1.13	2.20	0.76	0.69	0.89
calcareous dunesand	2.47	1.82	2.15	1.23	1.08	0.87

Comparing estimates made in Wageningen, lime requirements based on estimates of the liming factor are about 40 % of values based on van RAIJ (1982). Thus a greater raise of pH will be expected if the liming factor formula holds for both trial fields.

APPENDIX 15. INCUBATION TRIAL.
to 6.2

Introduction

Table 15.1 shows results of the incubation trial (see 4.2), in which unlimed samples were incubated with liming rates smaller than on the trial field (see Table 15.3). Mean incubation results are presented in Figure 15.1, while Table 15.2 presents expected liming effects in this trial.

pH results

Table 15.1. pH results from incubated samples, and from air-dry samples of limed plots (Sokoke trial field)(0-10 cm).

Treat-ment	Planned △ pH	State of the sample	I H_2O	I KCl	II H_2O	II KCl	III H_2O	III KCl	Mean H_2O	Mean KCl	means
		Plot no.	9 & 10		8 & 11		25 & 30				
zero	0	incubated	5.71	4.45	5.60	4.65	5.55	4.55	5.62	4.55	1.07
al*1	0.5	"	5.75	4.98	5.86	4.83	5.75	4.81	5.79	4.87	0.92
al 2	1.0	"	5.95	5.35	5.35	5.00	5.95	5.07	5.92	5.14	0.78
		Plot no.	5 & 6		4 & 12		26 & 27				
al-field		air-dry	6.45	5.83	6.4	5.77	5.94	4.98	6.26	5.53	0.73
ds*1	0.5	incubated	5.86	4.83	5.77	5.13	5.78	4.95	5.80	4.97	0.83
ds 2	1.0	"	6.15	5.50	5.89	5.53	5.96	5.27	6.00	5.43	0.57
		Plot no.	1 & 2		3 & 7		28 & 29				
ds-field		air-dry	6.96	5.96	7.13	7.05**	7.05	6.87**	7.05	6.63**	0.42

* al = agricultural lime; ds = calcareous dunesand.
** see text.

From Table 15.1 follows, the difference between pH-H_2O and pH-KCl values of samples reduces with increasing pH.
Therefore, two asterisked pH-KCl estimates from the treatment with dunesand on the field are not rejected, although they differ only 0.1 to 0.2 unit from the pH-H_2O values.

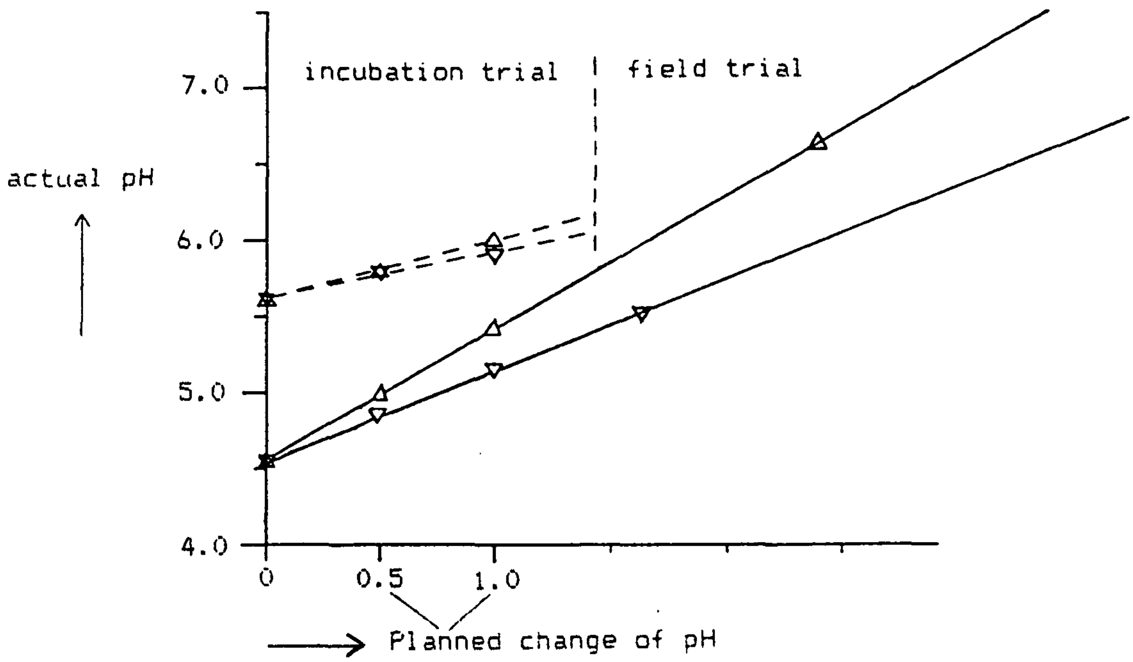


Figure 15.1. Mean pH results incubation trial.

▽ = agricultural lime —— pH-KCl
△ = calcareous dunesand) ---- pH-H_2O

Table 15.2. Change of pH expected before and after the incubation trial.

Liming material	agricultural lime		calcareous dunesand		
Planned △ pH beforehand	0.5	1.0	0.5	1.0	1
'CaCO$_3$' needed[1] (mg)	15.0	30.0	15.0	30.0	2
supposed 'CaCO$_3$' content (%) of the liming materials	90[2]		70[3]		
added liming material (mg)	16.7	33.3	21.4	42.9	
correct 'CaCO$_3$' content[4] (%)	92		94		
'CaCO$_3$' applied (mg)	15.4	30.6	20.1	40.3	3
Expected △ pH afterwards	0.51	1.02	0.67	1.34	$\frac{3}{2}$ x 1

1) in the supposition: CEC = 2.0 mmol(+)/100 g of soil. The CEC of the field was 3.3. Therefore the after all expected pH values are 0.31, 0.62, 0.41, and 0.81.
2) Factory analysis.
3) Lab date from before 1982.
4) From analysis in 1982 in Wageningen see App. 14.

pH-H_2O estimates show increases of pH for both liming materials. Al and ds raised pH-KCl by 0.6 resp 0.9 (see Figure 15.1 and Table 15.1) and relate as expected from Table 15.2, if the assumed CEC of 2.0 is replaced by the estimated 3.3 mmol(+).100 g^{-1} of soil, thus reducing the expected pH raises to 0.31 and 0.62 resp. 0.41 and 0.81. From the different liming rates and correct estimates of lime contents of both liming materials, the effect of calcareous dunesand would be expected to double the effect of agricultural lime.

Agricultural lime and calcareous dunesand raised pH-H_2O in the Sokoke field by 0.64 resp. 1.43, and pH-KCl by 0.98 resp 2.08, accordant with the expectation. The more than double increase of pH under treatment with dunesand also reflects the better solubility of this liming material.

Overliming

Liming rates in field trial and incubation trial can be compared if the liming rate of the incubation trial is expressed in $ton.ha^{-1}$ (see Table 15.3), 15 cm being the working depth of the rotovator (see 5.2). The liming trial aimed at an increase of pH of ground 0.5, just as the low liming rate in the incubation trial. In the field trial agricultural lime and calcareous dunesand were applied at rates more than 3 resp. more than 5 times the amounts applied in the incubation trial (see Table 15.3).

Two corrections can be made for wrong assumptions at the time of the incubation trial: for Sokoke resp. Ngerenya CEC data were 1.65 resp 2.15 times higher than the assumed 2.0 mmol(+)/100 g soil, and calcareous dunesand has about the same lime content as agricultural lime.

If overliming is defined as more lime than necessary to expect a change of pH with 0.5 unit, the overliming amounted to 1.9 (al) and 3.9 (ds) in Sokoke and 1.6 (al) and 3.3 (ds) in Ngerenya.

Table 15.3. Liming rates in incubation and field trial $CaCO_3$ $ton.ha^{-1}.15\ cm^{-1}$ liming[1].

liming material / trial field	bd[2] mean	**agricultural lime** planned pH increase 0.5	1.0	applied on trial field as '$CaCO_3$'	**calcareous dunesand** planned pH increase 0.5	1.0	applied on trial field as '$CaCO_3$'
Sokoke	1.44	0.36	0.72	1.14	0.46	0.93	2.32
Ngerenya	1.32	0.33	0.66		0.42	0.85	

1) working depth of the rotovator.
2) derived from App. 23.

assumptions during planning:
CEC 2.0 mmol(+)/100 g soil
'$CaCO_3$' %, 90 resp. 70 % for al and ds.

Liming rates in field trial and incubation trial can be compared if the liming rate of the incubation trial is expressed in $ton.ha^{-1}.15\ cm^{-1}$ (see Table 15.3), 15 cm being the working depth of the rotovator (see 5.2). The liming trial aimed at an increase of pH of around 0.5, just as the low liming rate in the incubation trial. In the field trial agricultural lime and calcareous dune sand were applied at rates more than 3 resp. more than 5 times the amounts applied in the incubation trial (see Table 15.3).

Appendix 14 **Personal communication Janssen on the liming materials**
to 6.2.1.2 & App.13

Wageningen
Department of Soils and Fertilizers

Your reference
Your letter of
Our reference
Date 28 juni 1982
Enclosure(s)

Sjoerd van Leeuwen
Training Project in Pedology
Private Mail Bag
Kilifi
Kenya

Re.

Beste Sjoerd,

Als ik me goed herinner heb ik in een briefje aan Titus de Meester jou de resultaten van de analyse van duinzand en agricultural lime doen toekomen. Hier volgt wat uitvoeriger informatie.

Er werd afgewogen één gram zand, resp. lime. Daaraan werd toegevoegd 20 ml 1.02 M HCl ofwel 20,4 meq HCl. Nadat de gasontwikkeling was gestopt werd het niet door de kalk geneutraliseerde zuur terugge-titreerd met NaOH. De hoeveelheden gebruikte NaOH en de berekende % $CaCO_3$ zijn :

nr bepaling	duinzand		agric. lime	
	meq NaOH	$\%CaCO_3$	meq NaOH	$\%CaCO_3$
1	1,631	94	2.293	91
2	1.595	94	1.817	93
3	1.621	94	1.767	93
4	1.571	94	2.147	91

De berekening van het $\%CaCO_3$ gaat als volgt (voorbeeld duinzand 1)
Er was geneutraliseerd :

20,4 - 1,631 = 18,769 meq HCl. Dit komt overeen met : 18.769 x 50 = 938,45 mg $CaCO_3$ of 94% van 1 gram. Nu is het niet zeker dat de neutralisatie inderdaad uitsluitend door $CaCO_3$ heeft plaats gevonden; in het zand, resp. de lime kunnen ook stoffen als $MgCO_3$ en $Ca(OH)_2$ tot de neutralisatie van het zuur hebben bijgedragen.

Je kunt ook spreken over z.b.w. (zuurbindende waarde), die is in het bovenstaande voorbeeld gelijk aan 18.769 x 28 x 100/1000 = 52.6% (syllabus Bodemvruchtbaarheid II, 1981, blz. 199).

Tot slot dient opgemerkt te worden dat de agricultural lime veel langzamer oploste dan het duinzand. Dat moet in het veld ook wel te merken zijn.

Met vriendelijke groeten,

c.c. Prof.dr. J. Bennema
Dr. T. de Meester
Ing. H.W. Boxem

Bert

Dr.Ir. B.H. Janssen

Agricultural University/De Dreijen 3/6703 BC Wageningen/The Netherlands/Tel. (08370) 82339

APPENDIX 16. Post harvest pH values ($pH-H_2O_{pH-KCl}$) as measured in Wageningen (1985); (Appendix to 6.2.2).

Sokoke trial field

LIME	zero (z)								agricultural lime (al)						calcareous dunesand (ds)						grand means	
pH-	H_2O	KCl	H_2O	KCl	H_2O	KCl	mean		H_2O	KCl	H_2O	KCl	mean		H_2O	KCl	H_2O	KCl	mean			
Plot no.	11		9		10				6		5				2		1					
Fertilizer	(0)		(NP)		(NP)				(N)		(P)				(0)		(P)					
Depth (cm)																						
0 – 5	5.99	4.93	5.67	4.64	5.56	4.53	5.74	4.70	5.90	4.92	6.53	5.69	6.22	5.31	7.66	7.34	7.16	6.75	7.41	7.05	6.46	5.69
7½–12½	6.04	4.96	5.59	4.53	5.29	4.32	5.64	4.60	5.41	4.53	5.62	4.63	5.52	4.58	6.29	5.23	6.54	5.96	6.42	5.60	5.86	4.93
15 –20	5.84	4.76	5.42	4.40	5.06	4.36	5.44	4.51	5.10	4.30	5.26	4.44	5.18	4.37	6.47	5.59	7.00	6.63	6.74	6.11	5.79	5.00
22½–27½	5.52	4.61	5.22	4.37	5.11	4.30	5.28	4.43	5.03	4.23	5.06	4.30	5.05	4.27	5.48	4.52	5.77	4.86	5.63	4.69	5.32	4.46
Mean	5.85	4.82	5.48	4.49	5.26	4.38	5.53	4.56	5.36	4.50	5.62	4.77	5.49	4.63	6.48	5.67	6.62	6.05	6.55	5.86	5.86	5.02

Ngerenya trial field

LIME	zero (z)								agricultural lime (al)								calcareous dunesand (ds)								grand means	
pH-	H_2O	KCl	H_2O	KCl	H_2O	KCl	mean		H_2O	KCl	H_2O	KCl	H_2O	KCl	mean		H_2O	KCl	H_2O	KCl	H_2O	KCl	mean			
Plot no.	17		13		36				18		14		34				22		21		32					
Fertilizer	(0)		(N)		(NP)				(N)		(P)		(NP)				(0)		(P)		(NP)					
0 – 5	6.16	5.26	5.82	4.99	5.92	5.25	5.97	5.17	6.53	6.08	6.76	6.17	6.69	6.28	6.66	6.18	7.17	7.09	6.90	6.40	7.46	7.27	7.18	6.92	6.60	6.09
7½–12½	5.95	5.07	5.79	4.94	5.95	5.37	5.90	5.13	6.45	5.96	6.03	5.09	6.36	5.77	6.28	5.61	7.20	6.99	6.31	5.53	7.11	6.76	6.87	6.43	6.35	5.72
15 –20	6.06	5.25	5.37	4.66	5.37	4.48	5.60	4.80	6.13	5.31	5.51	4.59	5.97	5.12	5.87	5.01	6.93	6.58	5.56	4.68	6.70	6.30	6.40	5.85	5.96	5.22
22½–27½	5.24	4.40	5.13	4.39	5.24	4.45	5.20	4.41	5.88	5.28	5.26	4.49	5.66	4.82	5.60	4.86	5.90	5.01	5.44	4.61	6.52	5.77	5.95	5.13	5.58	4.80
Mean	5.85	5.00	5.53	4.75	5.62	4.89	5.67	4.88	6.25	5.66	5.89	5.09	6.17	5.50	6.10	5.42	6.80	6.42	6.05	5.31	6.95	6.53	6.60	6.08	6.12	5.46

	Sokoke (z)		Ngerenya (z)	
0 – 20	5.61	4.60	5.82	5.03

APPENDIX 17. STATISTICS: PROCESSING OF OUTLIERS.

to 6.2 & 6.3

Design of the trials

For the (history of the) statistical design of the trials is referred to Appendices 5 and 6.

Outliers

Suspiciously large variations (outliers) were considered as follows. First, causes were searched after. In cases no explanation was discovered, error partitioning took place, and the data were analysed further after generating corrected estimates by methods described below. In only one case, viz. grain and stover yield of plot 26, the low outliers were explained, but nevertheless corrected.

Error partitioning

Error partitioning must be undertaken via certain criteria to decide on rejection or acceptance of the deviating values. Most methods for testing a deviation that looks suspiciously large, are based on statistic processing or regression analysis; none of these methods were applied in processing these trials.

ROHRMOSER (1985) suggests the following outlier test:

if the deviating value is not found in the interval given by

(1) $\bar{x} \pm 4s_x$,

(in which $\bar{x}$ = average of other values resulting from this treatment,

s_x = standard deviation of these values)

it is assumed to be an outlier.

The number of values per treatment amounted 3, thus $\bar{x}$ and s_x are based on 2 values only, and if these values are e.g. 70 and 72, 65 and 77 are already considered to be outlying.

Results obtained in the tropics normally show large variations (e.g. caused by inhomogeneous trial fields) compared with more homogeneous results collected in the temperate zone. Therefore, smoothening of results from such tropical trials into homogeneity would result in many erroneous corrections.

Hence, ROHRMOSER's test is rejected for these trials. (Its discrimination could be improved by requiring more replicates.) The following rough method to find outliers was used.

Results outside the interval **c. $\frac{1}{2}\bar{x} < \bar{x} <$ c. $2\bar{x}$** (in which $\bar{x}$ = mean value of 2 correct treatment results) were considered as '1st class' outliers, rejected and corrected. Results within this interval, and outlying according to the criterium given by ROHRMOSER, were mentioned

'2nd class' outliers and finally not corrected.

This method to find real ('1st class') outliers does not take into account the variance of treatment values, which is a drawback compared with Rohrmosers method. However, it prevents erroneous corrections.

Corrective calculations applicable in two-way-classifications (e.g. treatments + replicates) see e.g. STEEL and TORRIE (1980), GOMEZ and GOMEZ (1984).

a) in case of one outlying or missing value.

(2) $Y = \dfrac{rB + tT - G}{(r - 1)(t - 1)}$, in which

r and t number of replicates (or blocks) and treatments,

B and T totals of observed observations in block and treatment containing the outlying or missing unit,

G grand total of the observed observations.

b) in case of more than one suspiciously deviating or missing value. Those corrections are accomplished via an iterative process. All missing values except one are estimated with the formula

(3) $Y_{ij} = \overline{Y_{i.}} + \overline{Y_{.j}}$. Next, the last missing value is estimated with formula (2), after which the earlier rough estimates are estimated again in arbitrary sequence (also with formula (2)). After this first cycle, a second cycle follows and possibly more, until new estimates are materially equal to those generated in the former cycle; from the second cycle on new estimates are determined in exactly the same sequence as chosen during the first cycle.

Some special cases occurred when a plot with outlying result belonged to both lime and fertilizer trial (plots 4,7,9 and 15,16,19, see Table 4.1 or App. 11). In these cases corrective values for this plot were calculated from both data sets separately; then, the average of both corrected values was assumed to be just and if any more corrections were required, used to estimate those results again.

All tables in 6.2 and 6.3 are based on corrected results. All results including originally missing and outlying values, are enumerated in Appendix 18.

APPENDIX 18. RESULTS OF FERTILIZER AND LIME TRIALS WITH MAIZE[a)].
to 6.2 & 6.3

GROWTH AND YIELDS

Plot no.	Treat-ment[c)]	Emer-gence[d)] (%)	Plant height (cm)	50 % Tassel-ling[f)]	Grain[g)] moisture %[i)]	Stover[h)] moisture %[i)]	Mean weight grains cob[j)] (g)	Mean weight stover[k)] (g)	Grain Yield[m)] (0 % moisture; ton.ha)	Stover Yield[m)] (0 % moisture; ton.ha)	T…
NP trial - Sokoke field											
1	ds-P	100	100	68	18.8	47.3	31	55	1.21	2.03	3.
2	ds-O	73[e)]	55	77	25.5	56.8	19	31	0.87	1.12	1.
3	ds-N	100	61	75	21.9	39.3	43	35	1.37	1.29	2.
4[b)]	al-NP	97	97	69	22.2	40.5	43	56	1.23	2.03	3.
5	al-P	88	71	72	22.0	48.7	22	42	0.77	1.47	2.
6	al-N	64[e)]	65	72	19.3	42.3	34	36	1.31	1.30	2.
7[b)]	ds-NP	100	104	68	20.6	39.1	39	60	1.32	2.22	3.
8	z-N	100	90	70	20.6	38.1	43	49	1.57	1.81	3.
9[b)]	z-NP	85	103	69	20.5	58.7	69	57	2.56	1.97	4.
10	z-P	91	65	72	17.7	44.3	16	30	0.38	0.98	1.
11	z-O	97	52	73	21.9	54.1	17	22	0.49	0.76	1.
12	al-O	100	61	71	20.8	48.6	20	23	0.63	0.87	1.
idem - Ngerenya field											
13	z-N	97	126	65	20.4	51.4	62	72	2.22	2.57	4.
14	al-P	97	104	65	20.7	47.1	43	52	1.34	1.91	3.
15[b)]	ds-NP	97	148	65	19.8	38.2	79	104	2.98	3.81	6.
16[b)]	z-NP	91	154	63	20.8	43.9	87	127	2.88	4.49	7.
17	z-O	85	112	66	18.3	42.2	60	60	1.99	2.06	4.
18	al-N	91	109	67	21.2	37.6	91	77	2.85	2.70	5.
19[b)]	al-NP	88	143	63	19.8	40.6	99	92	3.01	3.20	6.
20	al-O	100	111	67	20.2	49.3	51	56	1.26	2.08	3.
21	ds-P	100	123	66	20.5	41.3	56	72	1.77	2.57	4.
22	ds-O	100	128	65	18.8	46.2	58	72	1.81	2.69	4.
23	z-P	91	125	64	18.8	37.7	50	93	1.70	3.27	4.
24	ds-N	97	152	65	21.5	51.6	86	124	3.00	4.45	7.
Lime trial - Sokoke field											
25	z-NP	100	110	68	19.3	37.9	49	66	1.65	2.37	4.
26	al-NP	100	75	71	19.9	38.8	28	33	1.02[1)]1.75	1.24[1)]2.55	4.
27	al-NP	100	135	67	18.4	32.0	54	76	1.98	2.79	4.
28	ds-NP	100	143	67	19.0	34.2	60	72	2.40	2.62	5.
29	ds-NP	100	148	65	19.9	35.4	57	94	2.05	3.48	5.
30	z-NP	100	127	68	19.1	23.4	46	72	1.68	2.67	4.
idem - Ngerenya field											
31	z-NP	97	157	64	19.3	31.9	77	124	2.96	4.52	7.
32	ds-NP	94	168	62	19.0	46.8	89	136	3.37	4.84	8.
33	ds-NP	100	170	62	19.0	43.0	81	108	2.92	4.00	6.
34	al-NP	100	165	62	21.0	48.0	91	107	3.33	3.91	7.
35	al-NP	97	163	61	20.3	44.2	69	124	2.94	4.51	7.
36	z-NP	97	172	62	21.0	49.5	102	103	3.42	3.71	7.

1)2) Comment on the correction of outliers
1) First class outliers (see Appendix 17).
2) Second class outliers (see Appendix 17).
First class outliers in yields and nutrient contents are corrected. As removals result from multiplication of possibly corrected yield and nutrient content estimates, they are not corrected. Most of the outliers and corrections are indicated in this list.
'1') Second class outlier, which is nevertheless treated as a first class outlier and therefore corrected because it deviates obviously from the two other values with the same treatment.

a) Grain data regard not affected grains
b) NP plots also functioning in the lime trial.
c) Lime treatment — $CaCO_3$ (ton.ha^{-1})

Lime treatment		$CaCO_3$ (ton.ha^{-1})
z	= zero	0
al	= agricultural lime	1.14
ds	= calcareous dunesand	2.32

Fertilizer treatment		N	P (kg.ha
O	= zero	0	0
P	= Phosphorus	0	30
N	= Nitrogen	50	0
NP	= N + P	50	30

d) % of emerged stands.

ENDIX 18. RESULTS OF FERTILIZER AND LIME TRIALS WITH MAIZE[a] (continuation).
6.2 & 6.3

GROWTH AND YIELDS				
t treat- ment[c]	Grain Yield[m] (12 % moisture; ton.ha^{-1})	Stover	Total	Harvest index
trial - Sokoke field				
ds-P	1.38	2.30	3.68	0.373
ds-0	0.99	1.27	2.26	0.438
ds-N	1.56	1.47	3.03	0.515
) al-NP	1.40	2.36	3.76	0.377
al-P	0.88	1.67	2.55	0.344
al-N	1.49	1.48	2.97	0.502
) ds-NP	1.50	2.52	4.02	0.373
z-N	1.78	2.05	3.83	0.464
) z-NP	2.91	2.24	5.15	0.563
z-P	0.43	1.12	1.55	0.279
z-0	0.56	0.87	1.43	0.392
al-0	0.71	0.98	1.69	0.420
m - Ngerenya field				
z-N	2.52	2.92	5.44	0.463
al-P	1.52	2.17	3.69	0.412
) ds-NP	3.39	4.33	7.72	0.439
) z-NP	3.28	5.11	8.39	0.391
z-0	2.26	2.35	4.61	0.491
al-N	3.24	3.06	6.30	0.514
) al-NP	3.42	3.64	7.06	0.485
al-0	1.44	2.36	3.80	0.377
ds-P	2.01	2.92	4.93	0.408
ds-0	2.06	3.05	5.11	0.402
z-P	1.93	3.72	5.65	0.342
ds-N	3.40	5.06	8.46	0.403
e trial- Sokoke field				
z-NP	1.88	2.69	4.57	0.410
al-NP	1.15[l] 1.99	1.41[l] 2.80	4.79	0.406
al-NP	2.25	3.17	5.42	0.415
ds-NP	2.73	2.98	5.71	0.478
ds-NP	2.33	3.95	6.28	0.371
z-NP	1.91	3.03	4.94	0.386
m - Ngerenya field				
z-NP	3.36	5.14	8.50	0.395
ds-NP	3.83	5.50	9.33	0.410
ds-NP	3.32	4.54	7.86	0.422
al-NP	3.79	4.45	8.24	0.460
al-NP	3.35	5.12	8.47	0.395
z-NP	3.89	4.22	8.11	0.480

e) As a rule of thumb holds: up to 20 % empty stands are for yield counterbalanced by extra growth of the surrounding plants. For net plots with emergence rates lower than 80 %, a yield compensation is calculated until mean emergence rate of the other (≥ 80 %) plots. Excluding these low rates, field means are 95.8 % in Sokoke and 94.5 % in Ngerenya. Correction factors for the plots 2 and 6 (Sokoke field) are

plot 2: $\frac{(95.8-73)}{73} \times 0.50 = 15.6$ %

multiplication factor: 1.156

plot 6: $\frac{(95.8-64)}{64} \times 0.50 = 24.8$ %

multiplication factor: 1.248

However, the empty spots were planted again 2 weeks after planting. Although these plants remained backward and were estimated to yield only half as much as normal plants (derived from plant height observations, Appendix 21) the above calculated correction factors should be reduced to 50 %.

f) Days after planting.

g) Fresh weights determined 2 days after harvesting.

h) Fresh weights determined 5 days after harvesting; in the mean time the ears were processed into husks, grains (separated in sound and affected grains) and in axisses; see a).

i) Moisture % = $\frac{(F - D)}{F} \times 100$,

in which F = Fresh weight
and D = Dry weight.

j) Really harvested ears; weight estimates of grains from not harvested ears are based on these data (see also App. 19).

Idem for not harvested stalks and leaves (see lso App. 20).

The yields of plot 26 were halved as this plot id not receive the second half of the N fertilizer. These yields and as a consequence also removals were corrected (see m and App. 17) to approximate the production level after correct fertilizing.

See yield appendices 19 and 20 for computation.

APPENDIX 18. RESULTS OF FERTILIZER AND LIME TRIALS WITH MAIZE[*)] (continuation). to 6.2 & 6.3

NUTRIENT CONCENTRATIONS ($mmol.kg^{-1}$)

Plot no.	Treat-ment[c)]	N grains	N stalks & leaves	P grains	P stalks & leaves	K grains	K stalks & leaves	Na grains	Na stalks & leaves
NP trial - Sokoke field									
1	ds-P	996	411	91	29	95	234	5	24
2	ds-0	1055	428	75	19	80	292	0	12
3	ds-N	961	440	70	13	100	297	16	22
4[b)]	al-NP	1067	464	80	19	85	277	0	27
5	al-P	901	369	75	19	95	214	32	17
6	al-N	1147	345	75	19	90	282	16	22
7[b)]	ds-NP	1087	357	107[2)]	13	105	263	0	37[2)]
8	z-N	961	333	43[2)]	8	60	311	0	12
9[b)]	z-NP	889	351	59	12	65	301	0	24
10	z-P	. 850[n)]	428	. 62	30	. 77	204	. 15	17
11	z-0	1059	345	70	24	90	253	11	17
12	al-0	1095	416	65	19	80	302	11	17
idem - Ngerenya field									
13	z-N	1130	333	70	13	75	321	0	22
14	al-P	1087	178[1)] 358	69	13	75	209	5	17
15[b)]	ds-NP	1138	393	70	19	70	233[2)]	0	22
16[b)]	z-NP	1253	422	59	12	80	311	16	30
17	z-0	957	. 455	59	. 21	80	. 296	5	. 21
18	al-N	1099	274	53	3[1)] 20	80	287	5	27
19[b)]	al-NP	1095	399	70	17	270[1)] 61	316	0	24
20	al-0	1202	494	65	23	203[1)] 77	270	16	19
21	ds-P	1071	351	70	12	145	265	0	19
22	ds-0	1047	387	75	23	121	285	0	19
23	z-P	1214	399	91[2)]	23	116	240	0	19
24	ds-N	1285	446	75	29	87	321	0	19
Lime trial - Sokoke field									
25	z-NP	1029	470	53[o)]	23	61	285	3	24
26	al-NP	1118	482	86	23	92	301	0	41[1)] 19
27	al-NP	1130	339	70	12	82	265	0	24
28	ds-NP	994	303	59[o)]	12	66	280	3	14
29	ds-NP	1297	553	70	23	68	275	0	19
30	z-NP	1011	375	75	17	72	280	0	19
idem - Ngerenya field									
31	z-NP	1249	446	70	17	77	290	0	30
32	ds-NP	1285	446	75	17	77	285	0	30
33	ds-NP	1190	482	65	23	68	290	0	19
34	al-NP	1154	434	65	23	68	321	0	24
35	al-NP	1261	458	75	17	77	341	0	19
36	z-NP	1237	446	70	17	72	423[2)]	0	19

1)2) Comment on the correction of outliers

1) First class outliers (see Appendix 17).

2) Second class outliers (see Appendix 17). First class outliers in yields and nutrient contents are corrected. As removals result from multiplication of possibly corrected yield and nutrient content estimates, they are not corrected. Most of the outliers and corrections are indicated in this list.

'1') Second class outlier, which is nevertheless treated as a first class outlier and therefore corrected because it deviates obviously from the two other values with the same treatment.

b) NP plots also functioning in the lime trial.

c) Lime treatment — $CaCO_3$ ($ton.ha^{-1}$)

Lime treatment	$CaCO_3$ ($ton.ha^{-1}$)
z = zero	0
al = agricultural lime	1.14
ds = calcareous dunesand	2.32

Fertilizer treatment	N	P ($kg.ha^{-1}$)
0 = zero	0	0
P = Phosphorus	0	30
N = Nitrogen	50	0
NP = N + P	50	30

APPENDIX 18. RESULTS OF FERTILIZER AND LIME TRIALS WITH MAIZE[a] (continuation).
to 6.2 & 6.3

NUTRIENT CONCENTRATIONS (mmol.kg⁻¹)

Plot no	Treat-ment[c]	Ca grains	Ca stalks & leaves	Mg grains	Mg stalks & leaves	Mn grains	Mn stalks & leaves
NP trial - Sokoke field							
1	ds-P	0	50	(39)[p]	106	5.0	183
2	ds-O	12/15	50	(29)	94	5.0	283
3	ds-N	4/8	266[1] 51	(18)	104	1.7	245
4[b]	al-NP	0	58	(16)	91	3.3	360
5	al-P	0	54	(23)	99	0.0	438
6	al-N	4	46	(12)	62[1] 96	9.9	258
7[b]	ds-NP	0	58	(26)	103	8.3	268
8	z-N	0	39	(22)	97	6.6	237
9[b]	z-NP	0	50	(20)	91	3.3	310
10	z-P	.	35	. (31)	93	. 2.5	327
11	z-O	0	35	(13)	87	15.0	363
12	al-O	0	35	(11)	84	21.7	310
idem - Ngerenya field							
13	z-N	2	43	(29)	91	6.7	150
14	al-P	2	28	(24)	56[1] 74	5.0	100[2]
15[b]	ds-NP	0	72	(19)	98	5.0	145[2]
16[b]	z-NP	2	54	(13)	109	8.3	193
17	z-O	0	. 53	(10)	. 105	6.6	. 193
18	al-N	0	58	(15)	79	5.0	152
19[b]	al-NP	0	57	35	87	7.5	187
20	al-O	0	49	32	107	7.5	210
21	ds-P	0	42	37	84	9.2	215
22	ds-O	0	64	35	91	7.5	128
23	z-P	0	49	42	83	9.2	182
24	ds-N	0	57	37	109	5.8	105[2]
Lime trial - Sokoke field							
25	z-NP	0	38	33	69	7.5	268
26	al-NP	0	49	39	67	12.5	417[2]
27	al-NP	0	42	35	73	7.5	310
28	ds-NP	0	57	31	74	7.5	168
29	ds-NP	0	108[1] 64	36	99	7.5	418[2]
30	z-NP	0	57	35	68	9.2	222
idem - Ngerenya field							
31	z-NP	0	42	39	108	10.8	183
32	ds-NP	7	64	37	106	9.2	123
33	ds-NP	0	53	34	107	5.8	180
34	al-NP	0	49	34	90	7.5	138
35	al-NP	0	49	39	106	9.2	147
36	z-NP	0	31	37	96	7.5	138

n) To replace missing values, an estimate is derived from combining values obtained under the same treatment with ones from the same replicate (see App. 11 and 17).

o) measured in another series than other values mentioned in this part of the column, but corrected for differences if any between standard sample estimates.

p) Mg contents in grains in parenthesis are probably too low, as for 3 of the 4 standards too low values were obtained in the series containing samples of plots 1-18. Therefore, for the plots 1 - 18 no total Mg removals are given.

APPENDIX 18. RESULTS OF FERTILIZER AND LIME TRIALS WITH MAIZE[a] (continuation).
to 6.2 & 6.3

REMOVALS ($kg.ha^{-1}$)

Plot no.	Treatment[c]	N grains	N stalks & leaves	N total	N Recovery	P grains	P stalks & leaves	P total	P Recovery
NP trial - Sokoke field									
1	ds-P	16.9	11.7	28.6		3.4	1.8	5.2	0.083
2	ds-0	12.9	6.7	19.6		2.0	0.7	2.7	
3	ds-N	18.4	8.0	26.4	0.136	3.0	0.5	3.5	
4[b]	al-NP	18.4	13.2	31.6	0.286	3.0	1.2	4.2	0.013
5	al-P	9.7	7.6	17.3		1.8	0.9	2.7	0.030
6	al-N	21.1	6.3	27.4	0.252	3.0	0.8	3.8	
7[b]	ds-NP	20.1	11.1	31.2	0.052	4.4	0.9	5.3	0.060
8	z-N	21.1	8.4	29.5	0.370	2.1[2]	0.4	2.5	
9[b]	z-NP	31.9	9.7	41.6	0.624	4.7	0.7	5.4	0.097
10	z-P	4.5	5.9	10.4		0.7	0.9	1.6	0.003
11	z-0	7.3	3.7	11.0		1.1	0.6	1.7	
12	al-0	9.7	5.1	14.8		1.3	0.5	1.8	
idem - Ngerenya field									
13	z-N	35.1	12.0	47.1	0.146	4.8	1.0	5.8	
14	al-P	20.4	4.8[1] 9.6	30.0		2.9	0.8	3.7	-0.010
15[b]	ds-NP	47.5	21.0	68.5	0.586	6.5	2.2	8.7	-0.077
16[b]	z-NP	50.6	26.5	77.1	0.598	5.3	1.7	7.0	0.040
17	z-0	26.7	13.1	39.8		3.6	1.3	4.9	
18	al-N	43.9	10.4	54.3	0.374	4.7	0.3[1] 1.7	6.4	
19[b]	al-NP	46.2	17.9	64.1	0.682	6.5	1.7	8.2	0.060
20	al-0	21.2	14.4	35.6		2.5	1.5	4.0	
21	ds-P	26.6	12.6	39.2		3.8	1.0	4.8	-0.043
22	ds-0	26.5	14.6	41.1		4.2	1.9	6.1	
23	z-P	28.9	18.3	47.2		4.8[2]	2.3[1]	7.1	0.073
24	ds-N	54.0	27.8[1]	81.8	0.814	7.0	4.0[1]	11.0	
Lime trial - Sokoke field									
25	z-NP	23.8	15.6	39.4	0.580	2.7	1.7	4.4	0.063
26	al-NP	16.0[1] 27.3	8.4[1] 17.2	44.5	0.544	2.7[1] 4.6	0.9[1] 1.8	6.4	0.087
27	al-NP	31.3	13.3	44.6	0.546	4.3	1.0	5.3	0.050
28	ds-NP	33.4	11.1	44.5	0.318	4.4	1.0	5.4	0.063
29	ds-NP	37.3	27.0	64.3	0.714	4.4	2.5[2]	6.9	0.113
30	z-NP	23.8	14.0	37.8	0.540	3.9	1.4	5.3	0.093
idem - Ngerenya field									
31	z-NP	51.8	28.2	80.0	0.656	6.4	2.4	8.8	0.100
32	ds-NP	60.7	30.2	90.9	1.034	7.8	2.5	10.3	-0.023
33	ds-NP	48.7	27.0	75.7	0.730	5.9	2.8	8.7	-0.077
34	al-NP	53.8	23.8	77.6	0.952	6.7	2.8	9.5	0.103
35	al-NP	51.9	28.9	80.8	1.016	6.8	2.4	9.2	0.093
36	z-NP	59.3	23.2	82.5	0.716	7.4	2.0	9.4	0.123

1)2) Comment on the correction of outliers

1) First class outliers (see Appendix 17).

2) Second class outliers (see Appendix 17).

First class outliers in yields and nutrient contents are corrected. As removals result from multiplication of possibly corrected yield and nutrient content estimates, they are not corrected. Most of the outliers and corrections are indicated in this list.

'1') Second class outlier, which is nevertheless treated as a first class outlier and therefore corrected because it deviates obviously from the two other values with the same treatment.

b) NP plots also functioning in the lime trial.

c) Lime treatment — $CaCO_3$ ($ton.ha^{-1}$)

Lime treatment	$CaCO_3$ ($ton.ha^{-1}$)
z = zero	0
al = agricultural lime	1.14
ds = calcareous dunesand	2.32

Fertilizer treatment	N	P (kg.ha
0 = zero	0	0
P = Phosphorus	0	30
N = Nitrogen	50	0
NP = N + P	50	30

APPENDIX 18. RESULTS OF FERTILIZER AND LIME TRIALS WITH MAIZE[a] (continuation).
to 6.2 & 6.3

		REMOVALS (kg.ha^{-1})					
		K			Na		
Plot no.	Treatment[c]	grains	stalks & leaves	total	grains	stalks & leaves	total
NP trial - Sokoke field							
1	ds-P	4.5	18.6	23.1	0.14	1.12	1.26
2	ds-O	2.7	12.8	15.5	0	0.31	0.31
3	ds-N	5.4	15.0	20.4	0.50	0.65	1.15
4[b]	al-NP	4.1	22.0	26.1	0	1.26	1.26
5	al-P	2.9	12.3	15.2	0.57	0.57	1.14
6	al-N	4.6	14.3	18.9	0.48	0.66	1.14
7[b]	ds-NP	5.4	22.8	28.2	0	1.89[2]	1.89
8	z-N	3.7	22.0	25.7	0	0.50	0.50
9[b]	z-NP	6.5	23.2	29.7	0	1.09	1.09
10	z-P	1.1	7.8	8.9	0.13	0.38	0.51
11	z-O	1.7	7.5	9.2	0.12	0.30	0.42
12	al-O	2.0	10.3	12.3	0.16	0.34	0.50
idem - Ngerenya field							
13	z-N	6.5	32.3	38.8	0	1.30	1.30
14	al-P	3.9	15.6	19.5	0.15	0.75	0.90
15[b]	ds-NP	8.2	34.7	42.9	0	1.93	1.93
16[b]	z-NP	9.0	54.6	63.6	1.06	3.10	4.16
17	z-O	6.2	23.8	30.0	0.23	0.99	1.22
18	al-N	8.9	30.3	39.2	0.33	1.68	2.01
19[b]	al-NP	7.2	39.5	46.7	0	1.77	1.77
20	al-O	3.8	22.0	25.8	0.46	0.91	1.37
21	ds-P	10.0	26.6	36.6	0	1.12	1.12
22	ds-O	8.6	30.0	38.6	0	1.18	1.18
23	z-P	7.7	30.7	38.4	0	1.43	1.43
24	ds-N	10.2	55.9	66.1	0	1.94	1.94
Lime trial - Sokoke field							
25	z-NP	3.9	26.4	30.3	0.11	1.31	1.42
26	al-NP	3.7[1] 6.3	14.6[1] 30.0	36.3	0	1.17[1] 1.11	1.11
27	al-NP	6.3	28.9	35.2	0	1.54	1.54
28	ds-NP	6.2	28.7	34.9	0.17	0.84	1.01
29	ds-NP	5.5	37.4	42.9	0	1.52	1.52
30	z-NP	4.7	29.2	33.9	0	1.17	1.17
idem - Ngerenya field							
31	z-NP	8.9	51.3	60.2	0	3.12	3.12
32	ds-NP	10.1	53.9	64.0	0	3.34	3.34
33	ds-NP	7.8	45.4	53.2	0	1.75	1.75
34	al-NP	8.9	49.1	58.0	0	2.16	2.16
35	al-NP	8.9	60.1	69.0	0	1.97	1.97
36	z-NP	9.6	61.4	71.0	0	1.62	1.62

1) The yields of plot 26 were halved as this plot did not receive the second half of the N fertilizer. These yields and as a consequence also removals were corrected (see m) and App. 17) to approximate the production level after correct fertilizing.

APPENDIX 18. RESULTS OF FERTILIZER AND LIME TRIALS WITH MAIZE[a] (continuation).
to 6.2 & 6.3

REMOVALS (kg.ha⁻¹)

Plot no.	Treatment[c]	Ca grains	Ca stalks & leaves	Ca total	Mg grains	Mg stalks & leaves	Mg total[p]
NP trial - Sokoke field							
1	ds-P	0	4.07	4.07	(1.15)[p]	5.23	
2	ds-O	0.03	2.24	2.27	(0.61)	2.56	
3	ds-N	0.03	13.75[1] 2.64	2.67	(0.60)	3.26	
4[b]	al-NP	0	4.72	4.72	(0.48)	4.49	
5	al-P	0	3.18	3.18	(0.43)	3.54	
6	al-N	0.21	2.40	2.61	(0.38)	1.96 '1' 3.03	
7[b]	ds-NP	0	5.16	5.16	(0.83)	5.56	
8	z-N	0	2.83	2.83	(0.84)	4.27	
9[b]	z-NP	0	3.95	3.95	(1.24)	4.36	
10	z-P	0	1.37	1.37	(0.29)	2.22	
11	z-O	0	1.07	1.07	(0.15)	1.61	
12	al-O	0	1.22	1.22	(0.17)	1.78	
idem - Ngerenya field							
13	z-N	0.18	4.43	4.61	(1.57)	5.69	
14	al-P	0.11	2.14	2.25	(0.78)	2.60 '1' 3.44	
15[b]	ds-NP	0	10.99	10.99	(1.38)	9.08	
16[b]	z-NP	0.23	9.72	9.95	(0.91)	11.90	
17	z-O	0	4.38	4.38	(0.48)	5.26	
18	al-N	0	6.28	6.28	(1.04)	5.19	
19[b]	al-NP	0	7.31	7.31	2.56	6.77	9.33
20	al-O	0	4.08	4.08	0.98	5.41	6.39
21	ds-P	0	4.33	4.33	1.59	5.25	6.84
22	ds-O	0	6.90	6.90	1.54	5.95	7.49
23	z-P	0	6.42	6.42	1.74	6.60	8.34
24	ds-N	0	10.17	10.17	2.70	11.79	14.49
Lime trial - Sokoke field							
25	z-NP	0	3.61	3.61	1.32	3.98	5.30
26	al-NP	0	2.44[1] 5.01	5.01	0.97[1] 1.65	2.02[1] 4.15	5.80
27	al-NP	0	4.70	4.70	1.68	4.95	6.63
28	ds-NP	0	5.99	5.99	1.81	4.71	6.52
29	ds-NP	0	15.06 '1' 8.93	8.93	1.79	8.38	10.17
30	z-NP	0	6.10	6.10	1.43	4.41	5.84
idem - Ngerenya field							
31	z-NP	0	7.61	7.61	2.81	11.87	14.68
32	ds-NP	0.95	12.42	13.37	3.03	12.47	15.50
33	ds-NP	0	8.50	8.50	2.41	10.40	12.81
34	al-NP	0	7.68	7.68	2.75	8.55	11.30
35	al-NP	0	8.86	8.86	2.79	11.62	14.41
36	z-NP	0	4.61	4.61	3.08	8.66	11.74

1)2) Comment on the correction of outliers
1) First class outliers (see Appendix 17).
2) Second class outliers (see Appendix 17). First class outliers in yields and nutrient contents are corrected. As removals result from multiplication of possibly corrected yield and nutrient content estimates, they are not corrected. Most of the outliers and corrections are indicated in this list.
'1') Second class outlier, which is nevertheless treated as a first class outlier and therefore corrected because it deviates obviously from the two other values with the same treatment.

b) NP plots also functioning in the lime trial

c) Lime treatment — $CaCO_3$ (ton.ha⁻¹)

Lime treatment	$CaCO_3$ (ton.ha⁻¹)
z = zero	0
al = agricultural lime	1.14
ds = calcareous dunesand	2.32

Fertilizer treatment	N	P (kg.ha⁻¹)
z = zero	0	0
P = Phosphorus	0	30
N = Nitrogen	50	0
NP = N + P	50	30

APPENDIX 18. RESULTS OF FERTILIZER AND LIME TRIALS WITH MAIZE[a] (continuation).
to 6.2 & 6.3

REMOVALS ($kg.ha^{-1}$)

Plot no.	Treatment[c]	Mn grains	Mn stalks & leaves	Mn total
NP trial - Sokoke field				
1	ds-P	0.006	0.371	0.377
2	ds-O	0.004	0.317	0.321
3	ds-N	0.002	0.316	0.318
4[b]	al-NP	0.004	0.731	0.735
5	al-P	0.000	0.644	0.644
6	al-N	0.013	0.335	0.348
7[b]	ds-NP	0.011	0.595	0.606
8	z-N	0.010	0.429	0.439
9[b]	z-NP	0.008	0.611	0.619
10	z-P	0.001	0.320	0.321
11	z-O	0.007	0.276	0.283
12	al-O	0.014	0.270	0.284
idem - Ngerenya field				
13	z-N	0.015	0.386	0.401
14	al-P	0.007	0.191	0.198
15[b]	ds-NP	0.015	0.552	0.567
16[b]	z-NP	0.024	0.867	0.891
17	z-O	0.013	0.398	0.411
18	al-N	0.014	0.410	0.424
19[b]	al-NP	0.023	0.598	0.621
20	al-O	0.009	0.437	0.446
21	ds-P	0.016	0.553	0.569
22	ds-O	0.014	0.344	0.358
23	z-P	0.016	0.595	0.611
24	ds-N	0.017	0.467	0.484
Lime trial - Sokoke field				
25	z-NP	0.012	0.635	0.647
26	al-NP	0.013[1] 0.022	0.517[1] 1.063	1.085
27	al-NP	0.015	0.865	0.880
28	ds-NP	0.018	0.440	0.458
29	ds-NP	0.015	1.455	1.470
30	z-NP	0.015	0.593	0.608
idem - Ngerenya field				
31	z-NP	0.032	0.827	0.859
32	ds-NP	0.031	0.595	0.626
33	ds-NP	0.017	0.720	0.737
34	al-NP	0.025	0.540	0.565
35	al-NP	0.027	0.663	0.690
36	z-NP	0.026	0.512	0.538

1) The yields of plot 26 were halved as this plot did not receive the second half of the N fertilizer. These yields and as a consequence also removals were corrected (see m) and App. 17)to approximate the production level after correct fertilizing.

p) Mg contents in grains in parenthesis are probably too low, as for 3 of the 4 standards too low values were obtained in the series containing samples of plots 1-18. Therefore, for the plots 1 - 18 no total Mg removals are given.

APPENDIX 19. GRAIN YIELD CALCULATIONS (Appendix to 6.2 & 6.3)

Field no.	Weight fresh kg/8.91 m²	sample fresh g	sample dry g	Moisture[1)] %	Dry weight: Harvested net grains wgt[a)]	from cobs[b)]	Mean[c)] weight grains/cob g	Cobs lost before harvest[e)]: number[d)]	yield estimate[2)] g	Not harvested, later sown net plants[f)]: number	Multiplication factor[g)]	yield est.[g) 2)] g	x 10/8.91: Net plot yield[h)] corrected for harvest losses kg	YIELD[i)] tons·ha⁻¹, Moisture %: 0	12
NP trial - Sokoke field															
1	0.95	72.13	58.56	18.8	0.77	25	31	8	309				1.08	1.21	1.38
2	0.70	62.98	46.90	25.5	0.52	28	19	3	70	8	0.52	77	0.67	0.75 —j)→ 0.87	0.99
3	1.43	63.55	49.64	21.9	1.12	26	43	2	107				1.22	1.37	1.56
4	1.39	62.04	48.28	22.2	1.08	25	43			1	0.41	18	1.10	1.23	1.40
5	0.62	62.93	49.06	22.0	0.48	22	22	5	137	4	0.77	68	0.69	0.77	0.88
6	0.71	65.65	52.96	19.3	0.57	17	34	4	168	12	0.48	194	0.94	1.05 —j)→ 1.31	1.49
7	1.42	62.42	49.59	20.6	1.13	29	39	1	49				1.18	1.32	1.50
8	1.69	67.88	53.89	20.6	1.34	31	43	1	54				1.40	1.57	1.78
9	1.90	61.34	48.78	20.5	1.51	22	69	7	601	5	0.50	172	2.28	2.56	2.91
10	0.28	60.48	49.75	17.7	0.23	14	16	4	82	3	0.45	22	0.33	0.38	0.43
11	0.44	61.19	47.78	21.9	0.34	20	17	3	64	3	0.54	28	0.44	0.49	0.56
12	0.64	61.23	48.48	20.8	0.51	25	20	2	51				0.56	0.63	0.71
id. - Ngerenya field															
13	2.43	69.98	55.69	20.4	1.93	31	62			2	0.34	42	1.98	2.22	2.52
14	1.47	67.92	53.88	20.7	1.17	27	43			1	0.67	29	1.20	1.34	1.52
15	3.26	72.53	58.18	19.8	2.62	33	79			1	0.53	42	2.66	2.98	3.39
16	3.08	73.87	58.50	20.8	2.44	28	87			3	0.50	131	2.57	2.88	3.28
17	1.97	74.18	60.57	18.3	1.61	27	60			5	0.55	164	1.77	1.99	2.26
18	2.99	71.89	56.67	21.2	2.36	26	91			4	0.50	181	2.54	2.85	3.24
19	3.10	75.10	60.21	19.8	2.49	25	99			4	0.49	195	2.68	3.01	3.42
20	1.41	69.45	55.42	20.2	1.13	22	51						1.13	1.26	1.44
21	1.98	71.98	57.26	20.5	1.58	28	56						1.58	1.77	2.01
22	1.99	76.55	62.17	18.8	1.62	28	58						1.62	1.81	2.06
23	1.79	62.41	50.67	18.8	1.45	29	50			3	0.40	60	1.51	1.70	1.93
24	3.40	65.65	51.53	21.5	2.67	31	86						2.67	3.00	3.40
Lime trial - Sokoke field															
25	1.52	71.00	57.28	19.3	1.23	25	49	4	245				1.47	1.65	1.88
26	1.13	63.89	51.15	19.9	0.90	32	28						0.90	1.02	1.15
27	2.13	58.46	47.73	18.4	1.74	32	54			1	0.51	28	1.77	1.98	2.25
28	2.61	61.85	50.10	19.0	2.11	35	60			1	0.41	25	2.14	2.40	2.73
29	2.28	66.03	52.87	19.9	1.83	32	57						1.83	2.05	2.33
30	1.71	62.28	50.40	19.1	1.38	30	46	2	115				1.50	1.68	1.91
id. - Ngerenya field															
31	3.23	67.04	54.13	19.3	2.61	34	77			1	0.38	29	2.64	2.96	3.36
32	3.62	65.90	53.37	19.0	2.93	33	89			2	0.40	71	3.00	3.37	3.83
33	3.21	62.02	50.24	19.0	2.60	32	81						2.60	2.92	3.32
34	3.55	64.94	51.33	21.0	2.81	31	91	1	113	1	0.54	49	2.97	3.33	3.79
35	3.04	67.15	53.49	20.3	2.42	35	69	2	173	1	0.42	29	2.62	2.94	3.35
36	3.86	68.56	54.16	21.0	3.05	30	102						3.05	3.42	3.89

1)2) For footnotes 1 and 2, see App. 20.

a) fresh weight (kg·8.91 m⁻²) x $\frac{\text{(sub)sample dry weight}}{\text{(sub)sample fresh weight}}$ — dry matter production — see footnote 1

b) number as counted in the field during harvesting.

c) $\frac{\text{maize weight (=dry grains)}}{\text{number of harvested cobs}}$ → mean weight: $\frac{\text{grains}}{\text{cob}}$

d) The Ngerenya field was guarded better than the Sokoke field, resulting in less lost cobs.

e) The amount of cobs produced but lost before harvesting, was multiplied by $\frac{5}{4}$ x (mean weight $\frac{\text{grains}}{\text{cob}}$) to compensate for their loss. Multiplication by a factor greater than 1, was chosen because the lost cobs mostly were the biggest ones. For calculation, see the example under footnote g) in App. 19 and note e) in App. 20 with the result mentioned in the table above). The difference is negligible fortunately.

f) On some stands, no plants had emerged 2 weeks after planting, at which date these stands were planted again. Their plants remained backward, and were unfortunately removed before harvesting net plots. To compensate this yield loss, (see footnote g))

g) additional yields were estimated, supposing the relative heights of plants sown April 16th to plants sown April 1st/2nd to represent the ratio of their ultimate harvests. All plant heights were measured 8 weeks after planting (May 28th). For further explanation, see App. 21. calculation example also for footnote e, e.g plot 2:

example of footnote e): $19 \times 3 \times \frac{5}{4} = 71\ (\neq 70)$ — mean weight grains/cob; cobs lost; mult. factor; yield est.

example of footnote g): $\times 8 \times 0.52 = 79\ (\neq 77)$ — not harvested later sown net plants; mult. factor; yield est. — see footnote 1

h) Addition of net plot yields as mentioned under a), e) and g).

i) Yield per net plot $\left(\frac{kg}{8.91\ m^{-2}}\right)$ multiplied by $\frac{10}{8.91}$

$\left(\frac{10{,}000\ m^2 \cdot ha^{-1}}{8.91\ m^2/\text{net plot}}\right) \times \frac{1}{1{,}000}\ (kg \cdot ton^{-1}) = \frac{10}{8.91}$

→ 0 % moisture - dry matter yield

→ $\times \frac{100}{88}$ → 12 % moisture - estimate of farmers harvest

j) see footnote g in Appendix 20.

APPENDIX 20. STOVER YIELD CALCULATIONS (Appendix to 6.2 & 6.3)

	Yield per net plot (8.91 m²)				Dry weight: Harvested net plants +			Not harvested, later sown net plants			× $\frac{10}{8.91}$ [f]	YIELD tons·ha^{-1}	
Field no.	Weight fresh[a] $\frac{kg}{8.91\ m^2}$	subsample fresh g	subsample dry g	Moisture[1] %	wgt[b] kg	number[c]	Mean stover weight g	number	Multiplication factor[d]	yield[e] estimate[2] g	Net plot yield corrected for harvest losses kg	Moisture % 0	12
NP trial – Sokoke field													
1	3.425	39.17	20.64	47.3	1.80	33	55				1.80	2.03	2.30
2	1.7	47.91	20.72	56.8	0.74	24	31	8	0.52	127	0.86	0.97 →[g] 1.12	1.27
3	1.9	52.13	31.64	39.3	1.15	33	35				1.15	1.29	1.47
4	3.0	55.40	32.94	40.5	1.78	32	56	1	0.41	23	1.81	2.03	2.36
5	2.3	57.10	29.30	48.7	1.18	28	42	4	0.77	130	1.31	1.47	1.67
6	1.25	57.58	33.23	42.3	0.72	20	36	12	0.48	208	0.93	1.04 →[g] 1.30	1.48
7	3.25	52.21	31.78	39.1	1.98	33	60				1.98	2.22	2.52
8	2.6	52.37	32.42	38.1	1.61	33	49				1.61	1.81	2.05
9	3.9	62.41	25.76	58.7	1.61	28	57	5	0.50	144	1.75	1.97	2.24
10	1.5	67.41	37.55	44.3	0.84	28	30	3	0.45	40	0.88	0.98	1.12
11	1.4	68.00	31.22	54.1	0.64	29	22	3	0.54	36	0.68	0.76	0.87
12	1.5	60.09	30.89	48.6	0.77	33	23				0.77	0.87	0.98
id – Ngerenya field													
13	4.6	55.30	26.90	51.4	2.24	31	72	2	0.34	49	2.29	2.57	2.92
14	3.15	55.87	29.57	47.1	1.67	32	52	1	0.67	35	1.70	1.91	2.17
15	5.4	65.75	40.64	38.2	3.34	32	104	1	0.53	55	3.39	3.81	4.33
16	6.8	68.71	38.53	43.9	3.81	30	127	3	0.50	191	4.00	4.49	5.11
17	2.9	64.11	37.03	42.2	1.68	28	60	5	0.55	165	1.84	2.06	2.35
18	3.6	66.52	41.52	37.6	2.25	29	77	4	0.50	155	2.40	2.70	3.06
19	4.5	66.05	39.24	40.6	2.67	29	92	4	0.49	181	2.85	3.20	3.64
20	3.65	62.70	31.81	49.3	1.85	33	56				1.85	2.08	2.36
21	3.9	63.45	37.27	41.3	2.29	32	72				2.29	2.57	2.92
22	4.45	67.80	36.45	46.2	2.39	33	72				2.39	2.69	3.05
23	4.5	59.79	37.22	37.7	2.80	30	93	3	0.40	112	2.91	3.27	3.72
24	8.2	60.39	29.23	51.6	3.97	32	124				3.97	4.45	5.06
Lime trial – Sokoke field													
25	3.4	62.10	38.58	37.9	2.11	32	66				2.11	2.37	2.69
26	1.8	60.99	37.33	38.8	1.10	33	33				1.10	1.24	1.41
27	3.6	62.64	42.59	32.0	2.45	32	76	1	0.51	39	2.49	2.79	3.17
28	3.5	66.37	43.68	34.2	2.30	32	72	1	0.41	30	2.33	2.62	2.98
29	4.8	66.12	42.70	35.4	3.10	33	94				3.10	3.48	3.95
30	3.1	62.68	48.04	23.4	2.38	33	72				2.38	2.67	3.03
id. – Ngerenya field													
31	5.85	61.31	41.75	31.9	3.98	32	124	1	0.38	47	4.03	4.52	5.14
32	7.9	67.16	35.75	46.8	4.21	31	136	2	0.40	109	4.31	4.84	5.50
33	6.25	61.44	35.03	43.0	3.56	33	108				3.56	4.00	4.54
34	6.6	58.91	30.61	48.0	3.43	32	107	1	0.54	58	3.49	3.91	4.45
35	7.1	56.19	31.36	44.2	3.96	32	124	1	0.42	52	4.01	4.51	5.12
36	6.55	56.82	28.68	49.5	3.31	32	103				3.31	3.71	4.22

Remarks on both 'yield calculation' appendices:

1) Crop moisture % = $\frac{F - D}{F}$, in which D = net dry weight, F = net fresh weight

2) Because the calculator worked with more decimals than mentioned here, (additional) yield estimates show small deviations from yields obtained by processing the above mentioned data again (e.g. compare the outcome of the example in note e) (App.20) with the result mentioned in the table above; Of course the difference is negligible).

a) calculated from: Tare weight – 0.5 kg
id. – 0.3 kg
The bag in which all stover parts were collected weighed c. 0.5 kg; most net plot yields were weighed by hanging the bag on to a steelyard with a maximum capacity of 5 kg; the greater capacity steelyard (up to 25 kg) used for some plots gave 0.2 kg lower weight estimates.

b) see footnote a) in App.19.

c) Most net plots contained 33 net plants (or stands with 1 plant) divided over 'harvested net plants' and 'not harvested net plants'. Net plots 2,5,6,11, 21,24 and 25 had 1 empty stand, net plot 10 had 2 empty stands, resulting in 32 resp. 31 net plants.

d) Multiplication factor = weighed yield correction factor, derived from plant heights (dm) 8 weeks after planting. For further explanation is referred to footnote g) in App. 19, and App. 21.

e) see App. 19 footnotes f) and g), and App. 21; calculation example, e.g. plot 2:
31 (mean stover wgt) x 8 (plants) x 0.52 (mult.factor) = 129 g ≈ 127 (see note 1)

f) After addition of yields as calculated under b) and e), multiplication by $\frac{10}{8.91}$ (see footnote i) in App.19.

g) Yield correction factors for the plots 2 and 6 were derived from emergence data (see App.19) and amounted 1.156 and 1.248

APPENDIX 22. to 6.3.3 PREDICTED DATA ON N, P AND K UPTAKE AND GRAIN YIELD (12 % moisture) DERIVED WITH THE QUEFTS COMPUTER MODEL ($kg.ha^{-1}$).

Appendix 22.1. ... based on chemical soil data[1)2)].

Trial field (soil map unit)		Sokoke (UE111)				Ngerenya (UE112)			
treatment[3)]		O	P	N	NP	O	P	N	NP
Potential supply of	N[4)]	19.9	19.9	43.3	43.3	32.8	32.8	71.5	71.5
	P	3.0	5.2	3.0	5.2	4.5	5.6	4.5	5.6
	K	70.4	70.4	70.4	70.4	40.3	40.3	40.3	40.3
Actual uptake of	N[5)]	19.6	19.9	38.1	41.4	31.9	32.4	60.8	64.1
	P	2.8	4.3	3.0	5.0	4.3	5.2	4.4	5.5
	K	36.7	36.7	49.3	59.6	36.0	36.0	36.9	38.0
Final yield estimate[6)]		950	1017	1458	2058	1485	1581	2003	2309

1) Viz. the four diagnostic properties pH-H_2O, org. C, P-Olsen and exch. K, and the additional property org. N (as listed in Table 2.3) and the highest mean recoveries of N and P (see Table 6.19).
2) Files SJOERD 1. OUT and SJOERD 3. OUT deposited with G.J. Noij.
3) P: 30 $kg \cdot ha^{-1}$; N: 50 $kg \cdot ha^{-1}$ (see 4.3 and App. 9).
4) Step 5: potential supply after fertilization SN, SP & SK.
5) Step 2: final estimates of actual uptake for each nutrient UN, UP & UK.
6) Step 4: final yield estimate.

Appendix 22.2. ... from experimental uptake data[7)8)].

Trial field (soil map unit)		Sokoke (UE111)				Ngerenya (UE112)			
treatment		0	P	N	NP	0	P	N	NP
Potential supply of	N[4)]	18.8	18.8	42.2	42.2	38.8	38.8	77.5	77.5
	P	3.3	5.4	3.3	5.4	7.7	8.8	7.7	8.8
	K	33.1	33.1	33.1	33.1	58.7	58.7	58.7	58.7
Actual uptake of	N[5)]	18.6	18.8	38.0	40.7	38.5	38.6	72.2	73.5
	P	3.0	4.3	3.3	5.2	6.9	7.7	7.5	8.6
	K	26.5	26.5	29.9	31.6	50.4	50.4	55.0	55.8
Final yield estimate[6)]		860	925	1376	1772	2039	2095	3033	3237

7) Viz. uptake data from the experiment (underlined in this table) and the highest mean recoveries of N and P (see Table 6.19).

8) Files SJOERD 2. OUT and SJOERD 4. OUT, deposited with G.J. Noij.

APPENDIX 21. **<u>WEIGHED YIELD CORRECTION FACTORS</u> DERIVED FROM PLANT HEIGHTS[1] 8 WEEKS AFTER PLANTING.**

to App. 19 & 20

	I	II	33 plants planted April 1/2	16	III	IV
Fertilizer trial						
Sokoke						
1	10.0	10.0				
2	5.5	6.4	24	8	3.3	0.52
3	6.1	6.1				
4	9.7	9.8	32	1	4.0	0.41
5	7.1	7.5	28	4	5.8	0.77
6	6.5	8.3	20	12	4.0	0.48
7	10.4	10.4				
8	9.0	9.0				
9	10.3	11.1	28	5	5.6	0.50
10	6.5	7.3	28	3	3.3	0.45
11	5.2	5.6	29	3	3.0	0.54
12	6.1	6.1				
Ngerenya						
13	12.6	13.1	31	2	4.5	0.34
14	10.4	10.5	32	1	7.0	0.67
15	14.8	15.1	32	1	8.0	0.53
16	15.4	16.1	30	3	8.0	0.50
17	11.2	12.1	28	5	6.6	0.55
18	10.9	11.6	29	4	5.8	0.50
19	14.3	15.3	29	4	7.5	0.49
20	11.1	11.1				
21	12.3	12.7	32			0.00
22	12.8	12.8				
23	12.5	13.2	30	3	5.3	0.40
24	15.2	15.7	32			0.00
Lime trial						
Sokoke						
25	11.0	11.3	32			0.00
26	7.5	7.5				
27	13.5	13.7	32	1	7.0	0.51
28	14.3	14.5	32	1	6.0	0.41
29	14.8	14.8				
30	12.7	12.7				
Ngerenya						
31	15.7	16.0	32	1	6.0	0.38
32	16.8	17.4	31	2	7.0	0.40
33	17.0	17.0				
34	16.5	16.7	32	1	9.0	0.54
35	16.3	16.6	32	1	7.0	0.42
36	17.2	17.7	32			0.00

1) Plant heights were defined as height (dm) from soil surface to highest point of the highest (= mostly youngest) leaf.

I (sum of plant lenghts (net plots))/33 = mean plant height in the net plots (If 1 (or 2) empty stands occurred, its zero length was compensated by the lenghts of surrounding net plants. Thus the denominator of the fraction is 33 for each net plot.)

II Mean height of net plot plants planted April 1^{st} and 2^{nd}.

III Mean height of net plot plants planted April 16^{th} and not harvested August 6^{th} with the 'original' plants

IV $\frac{III}{II}$ = <u>Multiplication factor</u> as mentioned and used in the 'yield calculation appendices' 19 & 20.

<u>Background</u>

Eight weeks after planting, the second half of the 50 kg N was applied.

Although the tasselling stage was still to come, the plants had almost reached their final lengths. Length of plants is a length measure for their pro ductivity.

Stands empty during emergence counting (2 weeks after planting) were replanted immediately; its plants remained backward, and these plants were removed from the net plots before harvesting, because their individual yields did not represent the effects of the treatments. However, their yield belonged to the collective yield of 33 plants per net plot. Therefore yield compensation based on mean height of these later sown (not harvested) plants relative to mean height of the older and 'original' (harvested) seems justified.

App. 23. **Final ring results i.e. bulk density and pF values (averages from 3 samples per depth)**; (Appendix to 6.4.1).

198/2-46 (Ngerenya trial field, on UE112)										Profile pit 198/2-47	(Sokoke trial field, on UE111)									
Bulk dens.	Sat	1	1.5	2	2.3	2.7	3	3.7	4.2	pF value	Sat	1	1.5	2	2.3	2.7	3	3.7	4.2	Bulk dens.
	moisture content (%)									Depth (cm)	moisture content (%)									
1.31	47.8	35.6	21.0	14.6	14.3	13.8	11.4	10.0	7.3	0- 10	45.3	35.1	16.9	11.1	10.8	10.4	7.9	6.1	5.9	1.43
1.38	47.7	38.7	22.2	14.0	13.4	13.0	10.9	9.8	8.8	20- 30	42.9	35.2	21.0	13.3	13.0	12.4	9.0	7.4	7.0	1.47
1.41	44.2	39.3	29.1	17.7	16.8	16.1	11.3	10.3	9.2	50- 60	40.0	35.6	27.5	15.1	14.5	13.9	9.5	8.0	7.4	1.49
1.43	43.0	38.3	31.4	19.8	17.9	17.3	11.9	11.3	10.2	90-100	39.3	35.3	27.4	17.2	15.8	15.0	11.9	9.0	8.2	1.51
1.47	43.0	38.7	34.1	22.8	20.3	19.6	12.4	11.1	10.8	140-150	39.1	34.6	28.4	18.6	17.4	16.7	11.7	9.5	8.5	1.56
1.52	41.8	37.1	33.7	23.4	21.0	20.8	13.6	11.2	11.4	200-210	39.3	33.9	27.1	17.0	15.9	15.0	8.9	8.9	8.8	1.56
1.60	40.3	36.0	33.5	24.3	21.5	21.2	14.2	12.4	12.2	270-280	39.1	34.6	28.5	19.1	16.7	16.4	10.3	9.7	9.2	1.52
				FC										FC						

Field Capacity with the bend in the pF curve.

Available Water Capacity (AWC) is defined as moisture % (pF **2.0-4.2**) x b.d.

A definition of **Total Readily Available Water Capacity** (TRAWC) is ,, (,, **2.0-3.7**) x ,,

which definition is used in WIELEMAKER and BOXEM (1982). Other definitions are 0.66 resp. 0.75 x AWC (Landon, 1984).

Moisture storage is used in BOXEM et al. (1987) and defined as ,, (,, **2.3-3.7**) x ,,

These water capacities are expressed in mm per thickness (cm or m) of a layer.

APPENDIX 23 (continuation). MOISTURE CONTENTS (VOL. %) and bulkdensity[a].

Sokoke trial field

Date / Depth (m)	14/5	28/5	11/6	25/6	9/7	6/8[b]	6/9[c]	B.d.	pF 2.3	pF 3.7	pms[d]
0.0-0.1	20.7	16.2	5.6	29.3	24.5	13.8*	3.1	1.43	15.4	8.7	6.7
0.1-0.2	18.3	16.4	5.8	26.5	20.7	12.6*	4.6*	1.45*	17.3	9.8	7.5
0.2-0.3	16.9	18.4	4.6	23.1	27.2	16.6*	6.0	1.47	19.1	10.9	8.2
0.3-0.4	15.8	17.7	7.8	13.0	18.0	12.4*	6.7*	1.477*	19.9	11.2	8.7
0.4-0.5	15.6	16.2	8.5	14.4	19.6	13.6*	7.5*	1.483*	20.8	11.6	9.2
0.5-0.6	19.1	15.5	9.5	16.7	36.5	22.4*	8.2	1.49	21.6	11.9	9.7
0.6-0.7	17.2	15.7	10.5	13.6	17.8	13.5*	9.1*	1.495*	22.2	12.3	9.8
0.7-0.8	17.6	16.2*	11.3	13.4	17.6	13.8*	9.9*	1.50*	22.8	12.8	10.0
0.8-0.9	18.4	16.7	11.6	12.8	17.2	14.0*	10.8*	1.505*	23.3	13.2	10.1
0.9-1.0	19.0	16.8	12.5	13.4	20.8	16.2*	11.6	1.51	23.9	13.6	10.3
1.0-1.1	19.2	17.8	12.9	13.7	17.0			1.52*	24.5	13.8	10.7
1.1-1.2	19.6	18.7	13.9	15.0	17.4			1.53*	25.2	14.1	11.1
1.2-1.3	20.0	18.9	14.8	18.8	17.2			1.54*	25.8	14.3	11.5
1.3-1.4	19.7	19.8	15.0	15.8	16.7			1.55*	26.5	14.6	11.9
1.4-1.5	19.7	20.3	14.7	15.6	16.4	14.7*	13.1	1.56	27.1	14.8	12.3
1.5-1.6	20.3	20.0	14.8	15.1	16.1			,, *			
1.6-1.7	20.1	19.7	14.7	15.3	15.1			,, *			
1.7-1.8	20.1	19.3	14.2	15.0	15.9			,, *			
1.8-1.9	20.1	19.5	14.0	15.4	15.8			,, *			
1.9-2.0	19.7	18.9	14.4	17.5	15.6			,, *			
2.0-2.1	19.5	19.0	14.2	17.6	24.8	18.9*	12.9	1.56	24.8	13.9	10.9
2.1-2.2	19.6	19.3	13.5	14.6	41.5			1.554*			
2.2-2.3	19.2	18.6	12.1	15.8	14.9			1.549*			
2.3-2.4	19.3	18.7	13.3	15.4	14.5			1.543*			
2.4-2.5	19.7	18.1	13.1	15.5	14.4			1.537*			
2.5-2.6	19.9	18.5	13.9	15.8	15.6			1.531*			
2.6-2.7	20.1		14.3	16.0	15.4			1.526*			
2.7-2.8	20.7	19.2	14.7	16.7	17.2			1.52	25.4	14.7	10.7
2.8-2.9	20.5	19.5	15.2	17.9	17.8			,, *			
2.9-3.0	20.4	20.1	15.5	23.3	19.2			,, *			

* derived by interpolation from the other values, which are also mentioned on the foregoing page.
a) computed from original data expressed in weight percentages.
b) harvest date on both fields.
c) data from sampling just before leaching (see 5.4).
d) pms = potential moisture storage; moisture storage is related to the pF interval 2.3-3.7 (see preceding page).

Ngerenya trial field Date / Depth	6/5[e)]	14/5	28/5	11/6	25/6	9/7	3/8[e)]	10/8[e)]	1/9[e)]	B.d.	pF 2.3	pF 3.7	pms[d)] (m)
0.0-0.1	17.0	21.4	17.7	5.9	25.7	27.4	17.6	14.0	7.2	1.31	18.7	13.1	5.6
0.1-0.2	13.5	18.8	14.4	5.2	21.7	20.4	13.9	12.8	7.4	1.345*	18.6	13.3	5.3
0.2-0.3	13.2	17.0	16.6	6.2	20.7	21.3	13.7	11.9	8.0	1.38	18.5	13.5	5.0
0.3-0.4	15.2	17.7	15.7	7.2	17.8	20.4	14.6	12.5	8.5	1.39*	20.2	13.8	6.3
0.4-0.5	15.7	17.6	16.4	9.2	16.5	19.9	16.0	13.0	8.5	1.40*	22.0	14.2	7.7
0.5-0.6	15.8	18.6	16.2	9.4	16.8	19.5	16.4	13.1	8.6	1.41	23.7	14.5	9.2
0.6-0.7	15.7	19.0	16.6	10.0	15.1	18.8	16.4	13.7	8.9	1.415*	24.2	14.9	9.2
0.7-0.8	16.0	19.9	16.8	11.1	21.2	23.7	17.3	16.9	9.4	1.42*	24.7	15.4	9.3
0.8-0.9	16.0	20.2	16.8	11.4	14.7	19.1	17.1	15.0	10.1	1.425*	25.1	15.8	9.3
0.9-1.0	16.9	21.2	16.9	12.3	15.4	18.9	17.9	15.3	9.9	1.43	25.6	16.2	9.4
1.0-1.1	17.1	21.3	18.6	12.7	16.4	19.1	18.1	15.5	11.4	1.438*	26.4	16.2	10.2
1.1-1.2	18.7	21.4	18.5	13.3	16.1	18.8	18.2	15.9	11.9	1.446*	27.3	16.2	11.1
1.2-1.3	19.2	21.2	18.8	14.2	16.9	18.2				1.454*	28.1	16.3	11.8
1.3-1.4	19.0	21.5	19.3	14.8	18.4	17.4				1.462*	29.0	16.3	12.7
1.4-1.5	19.4	21.6	19.1	15.1	16.3	17.5				1.47	29.8	16.3	13.5
1.5-1.6	19.2	21.3	19.2	14.9	19.1	17.6				1.478*			
1.6-1.7	19.0	21.6	19.0	15.3	20.5	16.7				1.487*			
1.7-1.8	18.8	21.5	19.0	15.2	26.6	16.4				1.495*			
1.8-1.9		21.0	19.5	14.9	20.4	16.5				1.503*			
1.9-2.0		21.2	19.3	15.4	19.2	16.9				1.512*			
2.0-2.1		21.3	19.8	15.0	18.1	17.5				1.52	31.9	17.0	14.9
2.1-2.2		21.3	20.2	13.9	18.8	17.9				1.531*			
2.2-2.3		22.1	20.7	15.6	19.9	18.4				1.543*			
2.3-2.4			21.8	16.2	22.2	18.5				1.554*			
2.4-2.5		22.2	21.9	16.6	24.9	18.6				1.566*			
2.5-2.6		22.4	22.1	16.6	22.7	18.6				1.577*			
2.6-2.7		22.1	22.2	19.1	20.0	18.4				1.589*			
2.7-2.8		21.8	22.4	16.0	20.2	19.7				1.60	34.4	19.8	14.6
2.8-2.9		21.8	21.9	15.7	20.5	18.6				,, *			
2.9-3.0		21.9	21.8	15.7	19.2	18.4				,, *			

e) data from BOXEM's moisture research (unpublished).

APPENDIX 24.1 COMPUTATION OF ARTIFICIAL PRECIPITATION BY LEACHING (appendix to 6.4.1)

Working table LEACHING TRIAL carieed out in the TPIP (by S.v.L. under guidance of H.W.B.)

Plotno.: 26

Date in Sept. 1982	Time approx. (h)		Duration 250 ml outflow (s)	Precipitation mm/min	mm/h	during (h)	Precipitation (mm)	Cum. prec. (mm)	Remarks
Tu 7th	21.00	12	100	1.27	76.3	6	457.8	458	
We 8th	9.00	1	194	0.66	39.3	6½(6+½)	255.5	714	
–	10.00		108	1.18	70.7	½	35.3	749	
–		3	90	1.41	84.8	1½	127.2	961	
–	13.00		132	0.96	57.8	1½	86.7	1048	
–		2	49	2.60	155.8	1	155.8	1204	
–	15.00		125	1.02	61.1	1	61.1	1265	
–		3	71	1.79	107.5	1½	161.3	1426	
–	18.00		278	0.46	27.5	1½	41.2	1467	
–		4½	89	1.43	85.8	2¼	193.0	1660	1660 mm / 23.25 h = quarter I
–	22.30	9	107	1.19	71.3	6¾(2¼+4½)	481.6	2142	
Tu 9th	7.30		96	1.33	79.5	4½	357.8	2500	
–		2	79	1.61	96.6	1	96.6	2596	
–	9.30		92	1.38	83.0	1	83.0	2679	
–		3	304	0.42	25.1	1½	37.7	2717	
–	12.30		206	0.62	37.1	1½	55.6	2772	
–		2	162	0.79	47.1	1	47.1	2820	
–	14.30		883	0.14	8.7	1	8.7	2828	
–		4¼	167	0.76	45.7	2 1/8	97.1	2925	
–	18.30-19.00		96	1.33	79.5	2 1/8	169.0	3094	1434 mm / 22.5 h = quarter II
–	19.30	¾	134	0.95	57.0	1½(¾+¾)	85.5	3180	
–	21.00	1½	197	0.65	38.8	1¼(¾+½)	48.4	3228	
–	22.00	1	229	0.56	33.3	½	16.7	3245	
–	22.30	½	156	0.82	48.9	6((½+5½)	293.6	3538 2)	
Fr 10th	9.30	11	99 1)	1.29	77.1	5½	424.1	3963	
–		1½	146	0.87	52.3	¾	39.2	4002	
–	11.00		142	0.90	53.8	¾	40.3	4042	
–		2½	195	0.65	39.2	1¼	48.9	4091	
–	13.30		278	0.46	27.5	1¼	34.3	4125	
–		2	205	0.62	37.2	1	37.2	4163	
–	15.30	3	189	0.67	40.4	2½(1+1½)	101.0	4264	962 mm / 22.25 h = quarter III (corrected infiltration
–	18.30	3	221	0.58	34.5	3 (1½+1½)	103.6	4367	
–	21.30		355	0.36	21.5	1½	32.3	4399	
–		7	238	0.53	32.1	3½	112.3	4512	
Sa 11th	4.30		367	0.35	20.8	3½	72.8	4585	
–		7	154	0.83	49.6	3½	173.5	4758	
–	11.30	2¼	157	0.81	48.6	4 5/8(3½+1 1/8)	224.9	4983	
–	13.45		168	0.76	45.4	1 1/8	51.1	5034	770 mm / 20.75 h = quarter IV
–		88¾ h				88¾ h	Corrected total:	4826	

Calculation method: $\frac{1}{4} \times \frac{1}{X}$ ring area x60 = x60 = x hours = + former total =

1·s⁻¹ : m² x60 x60 x h

$mm \cdot s^{-1}$ $mm \cdot min^{-1}$ $mm \cdot h^{-1}$ $mm \cdot interval^{-1}$ mm(total from start)

1) Fr 10th 9.30 h the soil within this ring was found inundated.

2) For the interval during the night of 9th–10th (22.30–9.30 h) was calculated 5½ x 48.9 + 5½ x 77.1 = 268.95 + 424.05 = 693.0 mm. At 2.30 h, the tap was found working, but at 7.15 h its outflow was nil, whereas at that moment it was opened again. A recalculation of the water supply during the interval is: (4 + 2⅜) x 48.9 + 2¼ x 77.1 = 311.7 + 173.5 = 485.2 mm, which is 207.8 mm less than 693.0. Total infiltration is therefore rounded off at 4826 mm.

APPENDIX. 24.2 **COMPUTATION OF ARTIFICIAL PRECIPITATION BY LEACHING** (continuation)

Working table LEACHING TRIAL (TPIP by Sjoerd van Leeuwen under guidance of H.W. Boxem)

Plotno.: **28**

Date in Sept. 1982	Time approx. (h)		(seconds) duration 250 ml outflow	Precip. mm/min	mm/h	during (hours)	Precipitation (mm)	Cum. prec. (mm)	Remarks
Tu 7th	21.00	12	50	2.95	176.8	6	1060.9	1061	
We 8th	9.00	1	1125	0.13	7.9	6½(6+½)	51.1	1112	
–	10.00	3	62	2.38	142.6	2 (½+1½)	285.2	1397	
–	13.00	2	72	2.05	122.8	2½(1½+1)	307.0	1704	
–	15.00	3	77	1.91	114.8	2½(1+1½)	287.0	1991	
–	18.00		254	0.58	34.8	1½	52.2	2043	
–		4½	73	2.02	121.1	2¼	272.5	2316	2316 mm / 23.25 h = quarter I
–	22.30		32	4.60	276.0	2¼	621.6	2938	
–		9	103	1.43	85.8	4½	386.3	3324	
Th 9th	7.30	2	62	2.38	142.6	5½(4½+1)	784.3	4108	
–	9.30	3	78	1.89	113.3	2½(1+1½)	283.4	4391	
–	12.30	2	500	0.29	17.7	1½	26.5	4418	
–	14.30	4¼	63	2.34	140.3	3⅛(1+2⅛)	438.5	4856	
–	18.30-19.00			0	0	3⅛(1+2⅛)	0	4856	2540 mm / 22.5 h = quarter II
–		3¼	75	1.96	117.9	1⅝	191.6	5048	
–	22.00	11½	103	1.43	85.8	7⅜(1⅝+5¾)	633.0	5681	
Fr 10th	9.30		229	0.64	38.6	5¾	222.0	5903	
–		1½	119	1.24	74.3	¾	55.7	5959	
–	11.00		62	2.38	142.6	¾	107.0	6066	
–		2½	133	1.11	66.5	1¼	83.1	6149	
–	13.30	2	170	0.87	52.0	2¼(1¼+1)	117.0	6266	
–	15.30	1½	180	0.82	49.1	1¾(1+¾)	86.0	6352	1496 mm / 21.5 h = quarter III
–	17.00		788	0.19	11.2	¾	8.4	6360	
–		1½	92	1.60	96.1	¾	72.1	6432	
–	18.30		144	1.02	61.4	¾	46.1	6478	
–		3	80	1.84	110.5	1½	165.8	6644	
–	21.30	7	49	3.01	180.4	5 (3½+1½)	902.1	7546	
Sa 11th	4.30		64	2.30	138.1	3½	483.5	8030	
– 3)		7	57	2.59	155.1	3½	542.9	8573	3)
–	11.00	2¼	75	1.96	117.9	4⅝(3½+1⅛)	545.2	9118	
–	13.45		85	1.73	104.0	1⅛	117.0	9235	2648 mm / 21.5 h = quarter IV (corrected infiltration)
		88¾				Corrected total:		9000	

3) For the interval 4.30-11.30 was calculated 3½ x 155.1 + 3½ x 117.9 = 955.5
At Sa 11th 7.00 h, the water level in the supplying water-cask was found at tap level, thus supplying considerably less than at 4.30 h. An estimate of the real supply during this interval was calculated:
½ x (4.30-7.00) + 7.00-11.30 = 1¼ x 155.1 + 4½ x 117.9 = 193.9 + 530.6 = 724.4, which is 231.1 less than 955.5.
Total infiltration is therefore rounded off at 9000 mm.

APPENDIX 24.3 **COMPUTATION OF ARTIFICIAL PRECIPITATION BY LEACHING** (continuation)

Working table LEACHING TRIAL carried out in the TPIP (by S.v.L. under guidance of H.W.B.)

Plotno.: 30

Date in Sept. 1982	Time approx. (h)	Interval (h)	Duration 250 ml outflow (s)	Precipitation mm/min	Precipitation mm/h	during (h)	Precipitation (mm)	Cum. prec. (mm)	Remarks
Tu 7th	21.00		50	2.33	139.8	6	838.5	839	
We 8th	9.00	12	75	1.55	93.2	6½(6+½)	605.6	1444	
–	10.00	1	50	2.33	139.8	2 (½+1½)	279.5	1724	
–	13.00	3	40	2.91	174.7	1½	262.0	1986	
–		2	47	2.48	148.7	1	148.7	2134	
	15.00			trace	10	1	10.0	2144	
–		3	69	1.69	101.3	1½	151.9	2296	
–	18.00		95	1.23	73.6	1½	110.3	2407	
–		4½	52	2.24	134.4	2¼	302.4	2709	2709 mm / 23.25 h = quarter I
–	22.30		45	2.59	155.3	2¼	349.4	3058	
–		9	69	1.69	101.3	4½	455.7	3514	
Th 9th	7.30		116	1.00	60.2	5½(4½+1)	331.3	3845	
–	9.30	2	80	1.46	87.3	2½(1+1½)	218.4	4064	
–	12.30	3	460	0.25	15.2	1½	22.8	4086	
–		2	78	1.49	89.6	3⅛(1+2⅛)	280.0	4366	
–	14.30[4]		.	.	.		.	4366[4]	
–	18.30-19.00	4½	490	0.24	14.3	3⅛	44.6	4411	
–		3½	90	1.29	77.6	1⅝	126.2	4537	1828 mm / 22.5 h = quarter II
–	22.00		102	1.14	68.5	7⅜(1⅝+5¾)	505.2	5042	
Fr 10th	9.30	11½	85	1.37	82.2	6½(5¾+¾)	534.3	5577[5]	
–	11.00	1½	91	1.28	76.8	2 (¾+1¼)	153.6	5730	
–	13.30	2½	101	1.15	69.2	2¼(1¼+1)	155.7	5886	
–	15.30	2	101	1.15	69.2	2½(1+1½)	173.0	6059	819 mm / 22.25 h = quarter III (corrected[5] infiltratio[…]
–	18.30	3	171	0.68	40.9	1½	61.3	6120	
–		3	131	0.89	53.3	1½	80.0	6200	
–	21.30		136	0.86	51.4	5 (1½+3½)	256.9	6457	
Sa 11th	4.30	7	222	0.52	31.5	3½	110.2	6567	
–	.	7	140	0.83	49.9	3½	174.7	6742	
–	11.30		166	0.70	42.1	4⅝(3½+1⅛)	194.7	6937	
–	13.45	2¼	112	1.04	62.4	1⅛	70.2	7007	1444 mm / 20.75 h = quarter IV (corrected[5] infiltration)
–		88¾				Corrected total:		6800	

4) Outflows measured at 12.30 and ca. 18.45 h were used to estimate the infiltration during the intervals 12.30-14.30 and 14.30-ca.18.45, because it was unclear how the outflow was adjusted at 14.30 but water supply was obviously continued.

5) For the interval during the night of 9th-10th was calculated 5¾ x 68.5 + 5¾ x 82.2 = 866.5 mm (22.00-9.30 h). At 2.30 h, the tap was working, but it was found dry 7.15 h at which moment it was opened again. A recalculation of the interval is: ((22.00-2.30) + ½ x (2.30-7.15)) x infiltration rate 22.00 h + (7.15-9.30) x infiltration rate 9.30 h = (4½ + 2⅜) x 68.5 + 2¼ x 82.2 = 471.0 + 185.0 = 656 mm, which is 210.5 mm less than 866.5. Total infiltration is therefore rounded off at 6800 mm.

Appendix 25 RELEVANT CHEMICAL AND PHYSICAL CHARACTERISITICS OF LEACHING WATER SAMPLES
to 6.4.2 (mmol.m^{-3})

WATER ANALYSIS

Profile Sender Wielemaker Project Kilifi nr. VCW 2050-010 Bod. W 85-52

CHEMICAL: water soluble salts mmol kg^{-1}, ~~soil solutions~~, natural waters m mol m^{-3} = mmol(+).m^{-3}, resp. mmol(-).m^{-3}, resp. mmol.m^{-3}

nr.	1	2	3	4
½ Ca^{2+}	785	968	968	863
½ Mg^{2+}	226	705	776	458
Na^{+}	398	1739	1991	1078
K^{+}	134	313	307	179
NH_4^{+}	1	6	6	28
⅓ Al^{3+}	3	13	4	6
Σ	1549	3750	4052	2612
½ CO_3^{2-}	80	100	120	90
HCO_3^{-}	930	1990	2160	1400
Cl^{-}	319	863	944	574
½ SO_4^{2-}	279	938	1090	593
NO_3^{-}	29	10	0	22
Σ	1637	3901	4314	2679
H_4SiO_4	31	211	244	123
Al				
org.C				
inorg.C				

PHYSICAL

		1	2	3	4
pH	pH	7.71	7.91	7.98	7.97
conductivity	$\mu S\ cm^{-1}$	165	360	390	260
temperature	19 °C				

← Sample no. and leaching quarter nos. I, II, III and IV in App.26.

Sample 1 consisting of rain water from the T.P.I.P. office house;
samples 2,3,4 ,, ,, mixtures of rain and tap water
(on average in a ratio 60:40; see Table 5.2).

80-2-4

APPENDIX 26. **ELEMENT SUPPLY BY LEACHING WATER (kmol.ha⁻¹)[1]** (Appendix to 6.4.2)

Plot no.	Treatment code	Ca^{2+} Quarter no. I	II	III	IV	Total	Mg^{2+} I	II	III	IV	Total	Na^{+} I	II	III	IV	Total
30	(z)	10.63	8.85	3.96	6.23	29.7	3.09	6.44	3.18	3.31	16.0	10.78	31.79	16.31	15.57	74.4
26	(al)	6.52	6.94	4.66	3.32	21.4	1.89	5.05	3.73	1.76	12.4	6.61	24.94	19.15	8.30	59.0
28	(ds)	9.09	12.29	7.24	11.43	40.1	2.64	8.95	5.80	6.06	23.5	9.22	44.17	29.79	28.55	111.7
		Al^{3+}					NH_4^{+}					K^{+}				
30	(z)	0.03	0.08	0.01	0.03	0.15	0.03	0.11	0.05	0.40	0.6	3.63	5.72	2.51	2.58	14.4
26	(al)	0.02	0.06	0.01	0.02	0.11	0.02	0.09	0.06	0.22	0.4	2.22	4.49	2.95	1.38	11.0
28	(ds)	0.02	0.11	0.02	0.05	0.21	0.02	0.15	0.09	0.74	1.0	3.10	7.95	4.59	4.74	20.4
		CO_3^{2-}					HCO_3^{-}					Cl^{-}				
30	(z)	1.08	0.91	0.49	0.65	3.1	25.2	36.4	17.7	20.2	99.5	8.6	15.8	7.7	8.3	40.4
26	(al)	0.66	0.72	0.58	0.35	2.3	15.4	28.5	20.8	10.8	75.5	5.3	12.4	9.1	4.4	31.2
28	(ds)	0.93	1.27	0.90	1.19	4.3	21.5	50.6	32.3	37.1	141.5	7.4	21.9	14.1	15.2	58.6
		SO_4^{2-}					H_2SiO_4					NO_3^{-}				
30	(z)	3.78	8.57	4.46	4.28	21.1	0.84	3.86	2.00	1.78	8.5	0.79	0.18	0.00	0.32	1.3
26	(al)	2.32	6.73	5.24	2.28	16.6	0.51	3.03	2.35	0.95	6.8	0.48	0.14	0.00	0.17	0.8
28	(ds)	3.23	11.91	8.15	7.85	31.1	0.72	5.36	3.65	3.26	13.0	0.67	0.25	0.00	0.58	1.5

Calculation method and dimension analysis

basic data units: (App. 25) $mmol(+).m^{-3}$ resp. $mmol(-).m^{-3}$ x (Table 6.23.2) mm

$$\frac{1}{\text{valention}} \times \frac{1}{1{,}000{,}000}(\text{kmol} \times m^{-3}) \times (m^3 \times ha^{-1}) \frac{1}{1{,}000} \times 10{,}000$$

mmol -----> kmol m -----> $m^3 \times ha^{-1}$

calculated data unit: $(\text{kmol} \times ha^{-1})$

$$\frac{1}{\text{valention} \times 1{,}000{,}000} \times 10$$

net multiplication factor: $\frac{10^{-5}}{\text{valention}}$

1) Latest S.I. agreements prohibit expressing data in equivalents. In this table values from ions with valence 1+, 2+, 3+ should be multiplied by 1, 2 resp. 3 to arrive at the correct kmol(+).ha⁻¹.