TRAINING PROJECT IN PEDOLOGIE

KISII KENYA

The effects of soil type, fertilisation and the date of planting on the root development of maize in South - Western Kenya

PRELIMINARY REPORT NO 7

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THE EFFECTS OF SOIL TYPE, FERTILIZATION AND THE DATE OF PLANTING ON THE ROOT DEVELOPMENT OF MAIZE IN SOUTH-WESTERN KENYA

A Field study

by

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TRAINING PROJECT IN PEDOLOGY, KISII KENYA.

Agricultural University, Wageningen - The Netherlands.

Contents

Preface

This report of the Training Project in Pedology at Kisii, Kenya of the section on Tropical Soil Science of the Agricultural University at Wageningen, The Netherlands, is the seventh one of a series to be presented to Kenyan officials.

The project started in November 1973 after assent had been granted by the Office of the President of Kenya. It is meant for training of post graduate students of the Agricultural University at Wageningen and for furnishing research opportunities to the staff. The activities of students and staff are directed to obtaining a better knowledge of the soils and the agricultural condition of the project area to provide a basis for the further agricultural development of the area.

The Project in Kisii is conducted by:
Ir. W.G. Wielemaker, teaching and research
Ing. H.W. Boxem, management
Visiting specialists from the Agricultural University at Wageningen help to resolve special problems.

This report is the result of a special study of rootdevelopment of maize as a trial to explain the noticed fluctuation of the grain yields of maize. As the soil affects the development of the roots system a study of its characteristics was made accordingly. Partly field-data were obtained from the detailed soil survey of Marongo (P.R. no.3) and study sites were selected in cooperation with the maize agronomist from the National Agricultural Research Station at Kisii. Many thanks are due to Mr. B.S.K. Masyanga.

This report has been written and compiled by Mr. H.E. Verwey. Mr. H.W. Boxem edited and recompiled it to this presentation. We hope to pay back with these report a small part of the great dept we owe to Kenya in general and to many Kenyans in particular for their valuable contribution to the good functioning of the project.

The supervisor of the project
J. Bennema, Professor of Tropical Soil Science.

1. Introduction

By studying the root development of maize, which is the most important food crop in Kenya, it may become possible to explain the measured fluctuation of the grain of the maize.
The soil affects the development of the maize plant through its effect on the development of the root system. The root system can tell us the effects of certain measures that have been taken. For instance, fertilization increases yields of the maize, but there may be circumstances under which fertilization may not be profitable. If the applied fertilizer has been placed in the topsoil, the roots will not penetrate the soil as deep as in case of no fertilization at all. This may influence the drought resistence of the maize.
Besides the effect of fertilization on the development of the maize root system, also attention is paid to differences between soils, which are derived on various parent material, the effect of the presence of an interfering layer in the soil profile and the date of planting. It ought to be mentioned that the time available for this investigation was restricted, so that one location could be sampled once. This is one of the reasons that it was very hard to interpretate the results very accurately especially the results of the date of planting trials.
Another factor is that it is very hard to quantify the extent of the root systems.

For the excution of this study I was assisted in the field by Mogire Nyabonda, Toel Kananga, Samuel Nyarega, James Nyambane and Peter Mokua. Without their help it would have been impossible for me to complete so much work.

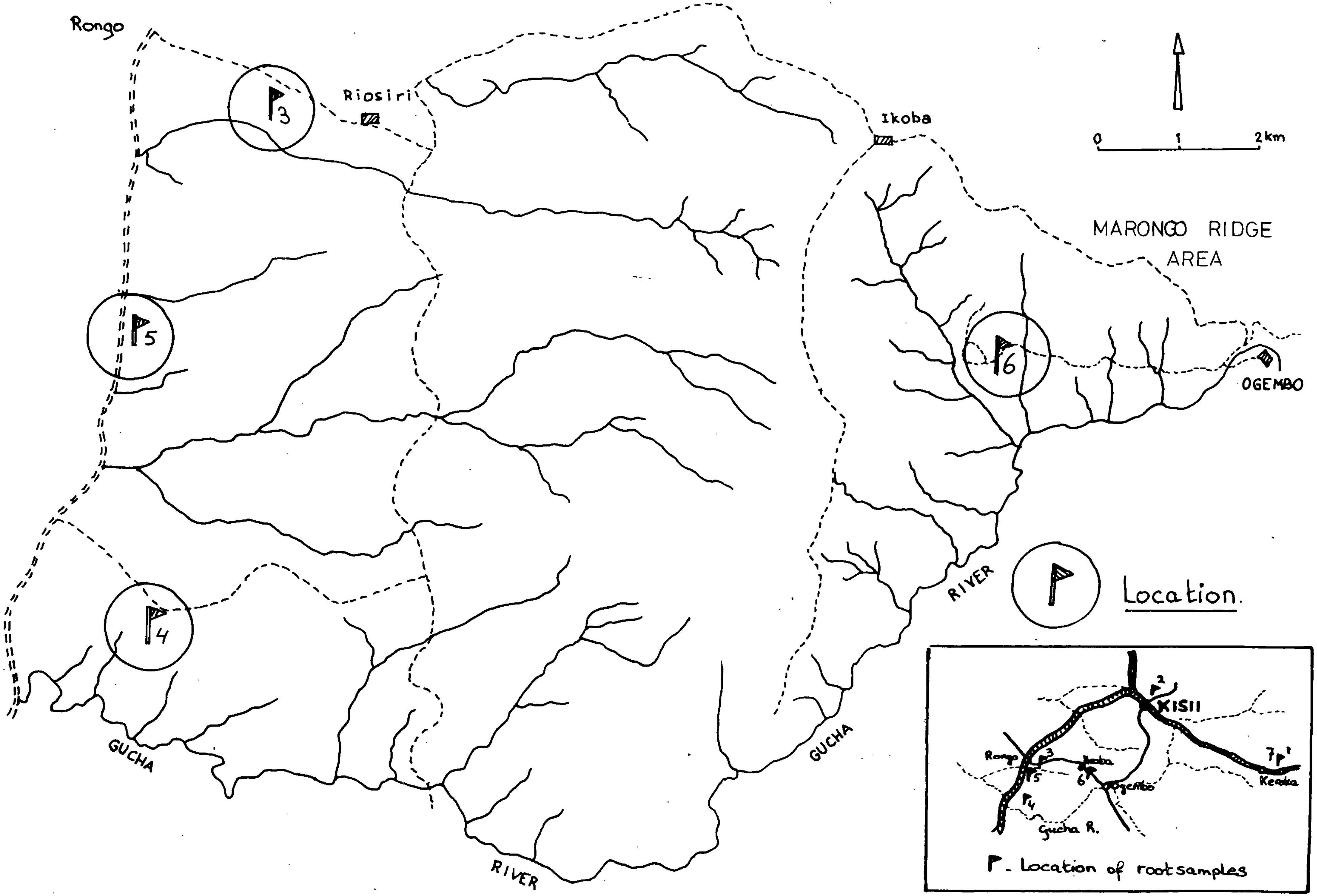


Fig. 1 Location of the sampled sites.

2. Materials

The selection of soils was mainly based on the established soil map of the 'Marongo Ridge sample area' and the various trial fields of the Agricultural Research Station. The selected locations are shown on the map. The table underneath shows the different objects more in detail.

Table 1: Locations of rootdevelopment studies (Fig. 1)

map no.	objective of study	profile number	parent material	location (see fig.1)
1	effect of N,P,K	220	Andesite	Keroka
2	fertilization	216	Basalt	Kisii
3	and soil type	224	Granite	Rongo
4	effect of soil	221	Rhyolite	Kitere
5	depth	225	Granite	Rongo
6	depth	223	Basalt	Ikoba
7	date of planting	219	Andesite	Keroka

To study the effect of fertilization on the rootdevelopment, it was necessary to find locations, which received the same treatment. It was a great opportunity to be able to use the trial fields of the Agricultural Research Station, with one of the fields located in the Marongo Ridge area. The soils are all deep weathered and are developed on different parent material. For the purpose of studying the effect of the soil depth on the rootdevelopment of maize, three locations were selected. The Kitere soil, derived on rhyolite rock, shows at a depth of 95 cm the upper boundary of the partly weathered rock, while the other two profiles posses a layer of cemented manganese and iron concretions.

The 'date of planting' trial field near Keroka was used to study the influence of the date of planting on the development of the maize rootsystem. This soil is very similar to the Keroka soil, which has been used to study the effect of fertilization.

3. Methods

The soils

In the field the soils have been described according to the FAO 'Guidelines for soil description' and the Munsell soil colours, Charts. In the appendices all soil descriptions of the studied soils are presented.
Besides a description, samples (undisturbed and disturbed) have been taken to be able to study the bioporosity and to be used for textural and soil fertility analyses.
The biopores, that have been counted with help of a binocular microscope, were divided into five classes.

Table 2: Biopore classes

class		size (mm)	counted per sq.
I	coarse	4-6	dm
II	medium	2-4	dm
III	fine	1-2	dm
IV	very fine	0.2-1	dm
V	micro	-0.2	cm

The 'equivalent pervious surface', that can be calculated from the amount of biopores and the biopore size distribution, gives us a measure that can be handled very easily.
Equation to calculate the 'equivalent pervious surface:

$$\text{e.p.s (in } mm^2/dm^2) = n\ (\bar{n}r_1^2 + \bar{n}_2 r_2^2 \cdot r_2^4/r_1^4 + \bar{n}_3 r_3^2 \cdot r_3^4/r_1^4)$$

For each soil profile a diagram showing the change of the amount of biopores and the change in e.p.s. value with increasing depth of the soil, was created.
The ring samples, which have been taken at some locations, were dried in the oven for 12 hours. The loss of weight represented the loss of water. Besides the moisture content, also the bulk density and the porosity (volume taken in by soil air after the removal of the moisture) could be measured.

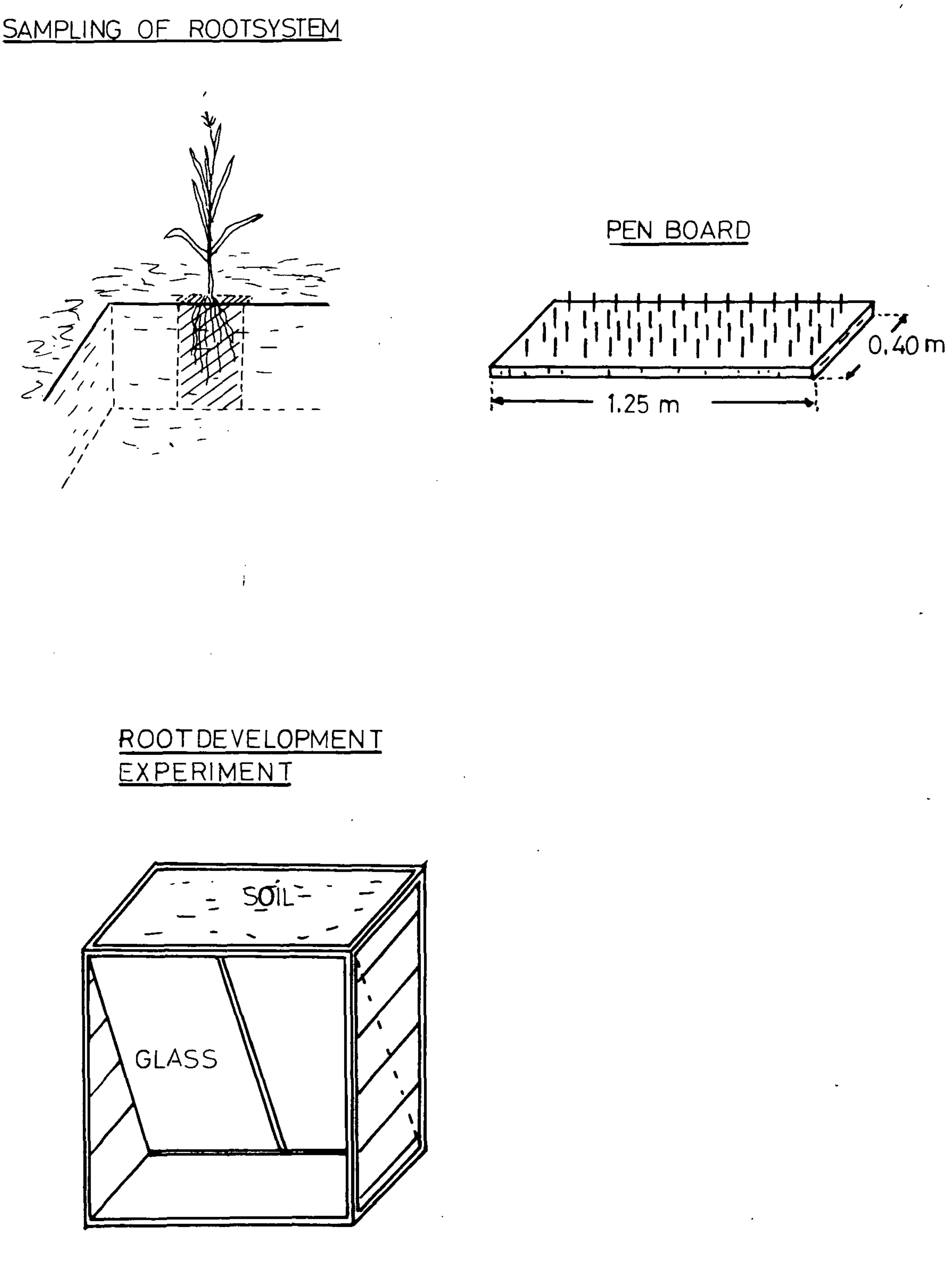


Fig. 2 Sampling of the rootsystem with a penboard and a sketch of a box used for a rootdevelopment study.

Root system

The selection of the plant to be studied, was done in the field, by measuring the aerial parts of five plants in the immediate surrounding, so that an 'average' plant could be sampled. These measurements have been used later to relate the dimensions of the maize plants with the extent of the root system.

A pit, sized 1.5 x 1 m 1.5 m deep, was dug near the plant. After description of the soil and taking soil samples, a penboard (sized: 1.25 x 0.40 m with pens of a length of 10 cm) was pushed into the wall of the pit, as is shown by the drawing. (Fig. 2).

By this method if is possible to remove an undisturbed column of soil and after washing the soil away between the roots, it is possible to photograph and measure the sampled system. Aproblem was, that a lot of small root hairs were damaged by this washing practice, especially when the sampled plants were emerging their seeds.

The measurements that have been carried out are the maximum depth of penetration of roots, the thickness of the roots at various depth below the soil surface, the amount of primary roots, a general description of the amount of horizontal roots and root hairs.

4. General description of the maize rootsystem and the factors, affecting its development.

4.1 The rootsystem of maize

Like all other rootsystem, the maize rootsystem accomplishes four main functions: (Newlin et. al., 1949)

- support and anchor the stalk
- absorb plant food (soluble salts and water)
- excrete organic substances (e.g. organic acids and CO_2)
- render plant food soluble by action of the excretions

The rootsystem of maize has a fibrous structure like the rootsystems of many other monocotyledons.

According to Newlin (1949) and Berger (1962) four types of maize roots can be distinguished, namely:

- Tap roots
- Seminal roots
- Permanent roots
- Brace roots

Tap roots:

The tap rootsystem is composed of the tap root, which is pushed downwards from the tip of the kernel, when it sprouts first.

Seminal roots:

These roots grow out sidewards from the kernel, immediately after the development of the tap root. During the first three or four weeks after the germination, the tap roots and the seminal roots furnish most of the food which the young plant obtains from soil. Later on these roots either decomposed or become unimportant.

Permanent roots:

The first two, three or even four nodes of the mature maize plant are seperated by very short internodes and are just below the soil surface. It is from these nodes, that the permanent roots start out laterally and then go downwards.

The large strong permanent roots are concentrated within 30 - 60 cm in the soil, only the small fibrous roots reach greater depth.

Brace roots:

The brace roots differ from the permanent roots in that they appear from the nodes above the soil surface. Sometimes the brace roots reach lengths of only a few cm from the node and will not penetrate the soil at all.
The brace roots from the first two nodes above the surface are of real help in maintaining an upright maize plant.

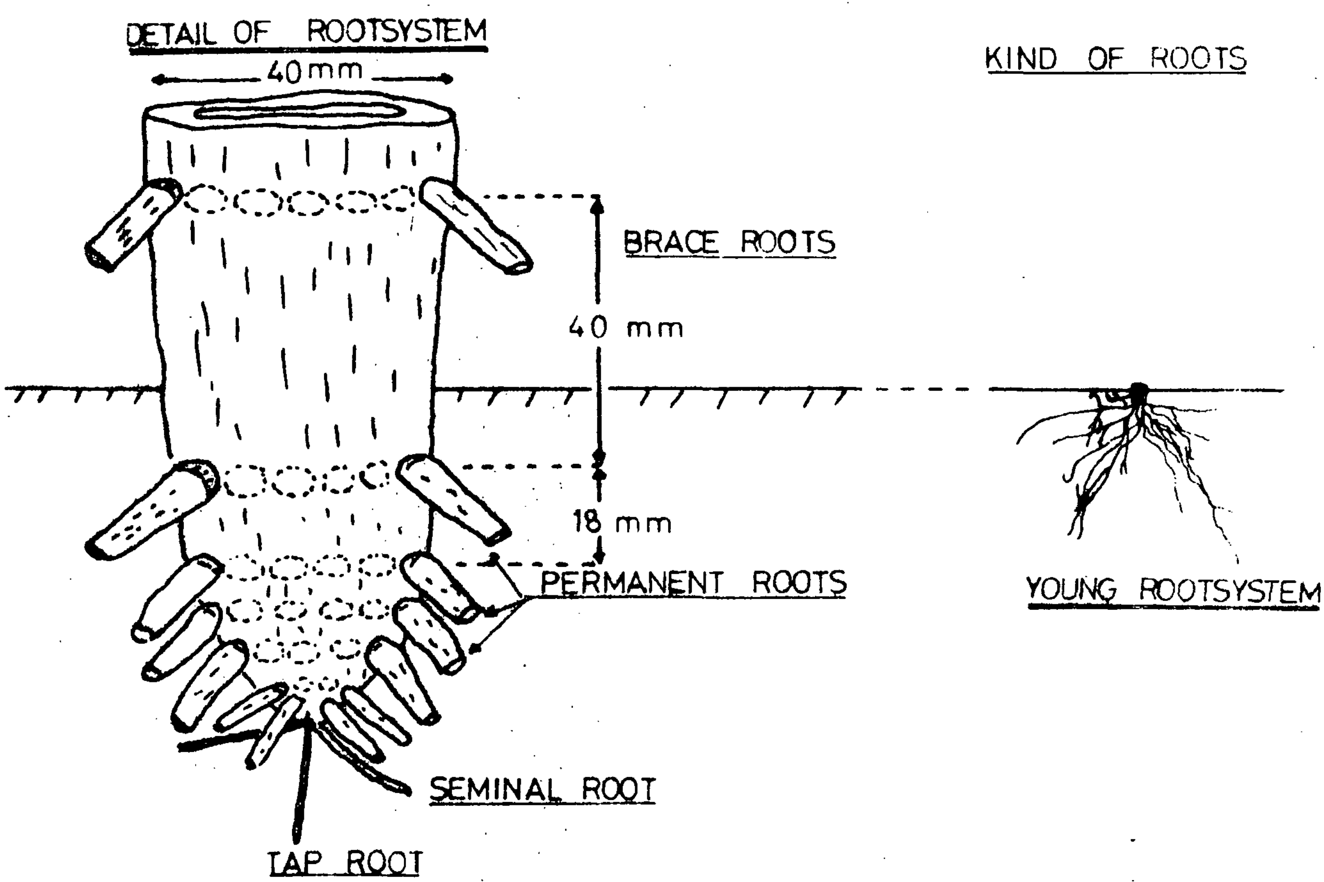


Fig. 3 The different types of maize roots and a young rootsystem

4.2 Factors, which affect the root development of maize.

The most important factors may be summarized as follows:

- porosity
- moisture content of soil
- aeration of the soil
- temperature
- availability of nutrients
- soil profile characteristics
- availability of carbohydrates

Porosity

It is most important, that a soil contains pores, which are large enough for roots to penetrate (Russell, 1961).
An interesting study was done by Wiersum (1957) about the relationship of the size of the pores and the structural rigidity of pores and their penetrating by roots. He concluded that a root is only able to penetrate a pore which has a diameter exceeding that of the young root. So the plasticity of the young root tip does not anable the root to pass through a narrow pore of a short constricted zone. However, observations in the field and in experiments clearly indicate that many roots can be encountered in soil layers, which on account of their particle size and poor aggregation, have pore sizes below the limit of the root diameter. This must be explained by assuming a mobility of the soil particles.
Veihmeyer and Hendrickson (1946) described field observations in which further penetration by roots is prevented by soil density, i.e. where the apparent specific gravity rises to 1.8 or more. This is also determined by the nature of the substrata, as shown in a second publication. The limit for sand may be 1.75 and for clay 1.46 - 1.63. The measured values of the specific gravity of the soils, in this study, vary between 1.31 and 1.0.
Kampe (1929) discussed the results of his experiment, in which rye roots were able to penetrate a layer of density compacted kaolinite, whereas maize roots hardly managed to get through.

This is partly related to the fact that rye has much thinner roots. If a diameter of about 0.2 mm is accepted as an average for roots having to grow into the subsoil for some distande, a rough calculations shows that a sand with a single grain structure will have pores below the limiting size, when the particles become smaller than about 0.3 mm. Preffer (1904) measured the force a single root can exert. Pressures in the range of 5 - 24 atm. have been noticed as being exerted by the root tips of the primary root of germinating seeds of maize. The forces acting in a radial direction can also be of the order of several atm.

Moisture content of the soil

It is often found that roots do not go into soil, which is dried out beyond wilting point moisture content (water under suction 7 - 10 at.) (Russell, 1961). On the other hand too much moisture also slows down the growth of the roots. Berger (1962) states that in general the roots grow longer in dry soils than in moist soils.

Aeration of the soil

The aeration of the soil is important in three respects:

a. oxygen content.

   Russell (1961) states that the oxygen content should be at least 5 percent, to make root growth possible. The demands of oxygen of the roots increase with increasing temperature.

   Some crops, like maize and peas, need a very good air supply.

b. Carbon dioxide content.

   This can, in case of poor aeration, become so high that it kills the roots. The content of carbon dioxide in the soil air should be under 1 percent to promote an optimal growth of the roots.

c. content of by-products of anaerobic decomposition.

   These products, which may accumulate in the soil, can easily cause a poisoning of the roots, when the soil is aerated poorly.

Temperature

For all crops it is possible to estimate an optimum temperature. For maize it was found (Grobbelaar) that the root growth is optimal at a temperature between 25 and 35°C, while the aerial parts of the maize plant need a optimum temperature between 20 and 30°C. Berger (1962) states that maize is a warm weathered plant and it was found that at the moment of germination the temperature plays an important role. He found that the temperature at the moment of germination should be 18.3°C. Lower temperatures, which may be due to high rainfall will result in a yield reduction of the maize crop. At the moment many investigators assume that at the time of germination the soil temperature is of even higher importance than a favourable soil air - water ratio.

Availability of nutrients

It is known, that especially phosphate promotes the rootdevelopment of maize. Other investigators (Russell, 1961) state, that the effect of phosphate can only be called an indirect effect on rootdevelopment. The position in the soil, where the fertilizer is put, may be important, since roots will ramify in the fertilized part, so that it is expected that deep fertilizer placement can affect the drought resistance of the maize.

Goedewaagen (1941) found that the effect of phosphate on the root development increased, when the size of the fertilizer grains decreased, especially in case of difficult soluble phosphate fertilizer.

Shortages of potassium may result in a poor development of the rootsystem.

The influence of nitrogen on the root growth is not very clear. Sometimes it is noticed that the development of root hairs increased by nitrogen application, but more often it is found that nitrogen only affects the aerial parts of the maize plants.

Soil profile characteristics

The rootability of soil profile is very much affected when the profile shows abrupt boundaries between layers with varying textural compositions, cementation, bulk density or soil acidity. Very rigid structures are encountered in hard-pans, especially those containing iron compounds. In extreme cases pans can be completely impermeable to both roots and water. Roots will not grow into these structures at all, unless cracks or channels are present.

The organic matter content of ths soil influences the root development because of its influence on the bioporosity, soil water and air supply to the roots.

Besides these factors, also soil structure and soil acidity have to be taken into account.

Availability of carbohydrates

The root growth of maize is stopped when the crop is ripening their seeds, for then the serial parts are drawing heavily on the available carbohydrates supplies.

5 The effect of N, P and K fertilization and the soil type on the rootdevelopment of maize

5.1 Introduction

All the maize on the fertilizer trials, which were selected, were planted at distances of 75 cm between the rows and 30 cm betweem the plants in the row. The harvested plot area was 18 square metres (6 x 3m).

Used fertilizer rates in kg/ha:

a. phosphate (kg p_2O_5/ha)	0	30	60	90
code number	-	-1	0	+1
b. nitrogen (kg N/ha)	0	40	80	120
code number	-	-1	0	+1
c. potassium (kg K_2O/ha)	0		50	
code number	-		0	

Treatment combinations, which have been used for studying rootdevelopment:

number of treatment	N	P	K
7	-1	+1	-
10	0	0	0
11	-	-	-

About two weeks before the fields were harvested, the rootsystems have been sampled by the pen board method. As already mentioned, the soils which have been used for this study are all deep weathered soils derived on various parent materials, namely granitic, basaltic and andesitic rock. For each soil profile a complete soil description can be found in Appendix 1. (page 54) In this chapter the three soils will be indicated by their soil profile number and the parent material:

Keroka - andesitic rock - no 220
Kisii - besaltic rock - no 216
Rongo - granitic rock - no 224

5.2 Results and discussion

The phenomena, which will be discussed here, are put in the following sequence:

- bioporosity of the soils and its relation with the root development
- the 'equivalent pervious surface' of the soils (e.p.s. calculated on base of the amount of biopores)
- profile characteristics, such as structure, organic matter content, colour etc.
- measured bulk density, porosity and moisture content
- differences between the different rootsystems
- measurements of the different maize plants and yields of the trial fields.

Bioporosity

In general we may say, that the amount of biopores decreases, when soil depth increases. However, it must be mentioned that very often there occurs a slight increase in the amount of biopores at a depth of about 40 cm below the soil surface. It may be that at this depth circumstances, especially the moisture content, are somewhat more favourable for the soil fauna The biopore size distribution, which is reflected very well by the e.p.s. value, changes remarkably between the soils. In the Rongo soil (224) no biopores, having a diameter of over 2 mm appeared and it is clear that this affects the rootability of this soil very much. The amount of biopores in the Kisii soil (216) is somewhat less than in the Keroka soil (220), but at a depth of more than 50 cm below the soil surface the Kisii soil posses more biopores. The latter soils are more easy rootable on account of the amount of biopores. (see the rootsystem drawings, Fig. 4).
Observing the rootsystems, which did not receive any fertilizer (N-P-K- treatment), we find a remarkable relationship between the development of the rootsystem and the bioporosity of the soil profile.

The most poorly developed rootsystem is found in the Rongo soils (224), which has a low bioporosity. In this soil most of the roots are concentrated in the loose topsoil (A_p - horizon), while the other two profiles with a much more favourable bioporosity are rooted also in the subsoil. The restricted rootdevelopment in the subsoil of the Rongo profile learns that pores with a diameter of less than 0.2 mm can not be used by the roots of the maize plant. It is not clear whether or not biopores in the 1 - 0.2 size class can be penetrated.

Equivalent pervious surface

The equivalent pervious surface (e.p.s.) is an accurate measure of both the total amount of biopores and the biopore size distribution. Because of the way the e.p.s. is calculated the larger sized biopores contribute to a great extent to the value of the e.p.s.
This explains the large difference between the Rongo soil and the others, as is shown in the table underneath.

Table 3. equivalent pervious surface (in $\bar{n}$ mm^2/dm^2)

depth (cm)	Rongo -224	Kisii -216	Keroka -220
0 - 15	1.5	58	185
15 - 30	1.1	42	188
30 - 45	0.8	45	125
45 - 60	0.8	44	11
60 - 75	0.8	43	10
75 - 90	0.4	17	8

The relationship between the e.p.s. value and the rootdevelopment is remarkable good. The low values in the Rongo soil result in a poor root growth in the subsoil. The other soils are rooted much deeper and the maximum depth of rooting seems to be related with a more or less strong decline of the e.p.s. value. In the Kisii soil it is noticed that at a depth of about 70 cm the growth of roots is stopped. At this depth the e.p.s. value decreases from about 40 to 17. The reason of the more shallow rooting in the Keroka soil can be explained by the decrease of the e.p.s. value at a depth of about 45 cm.

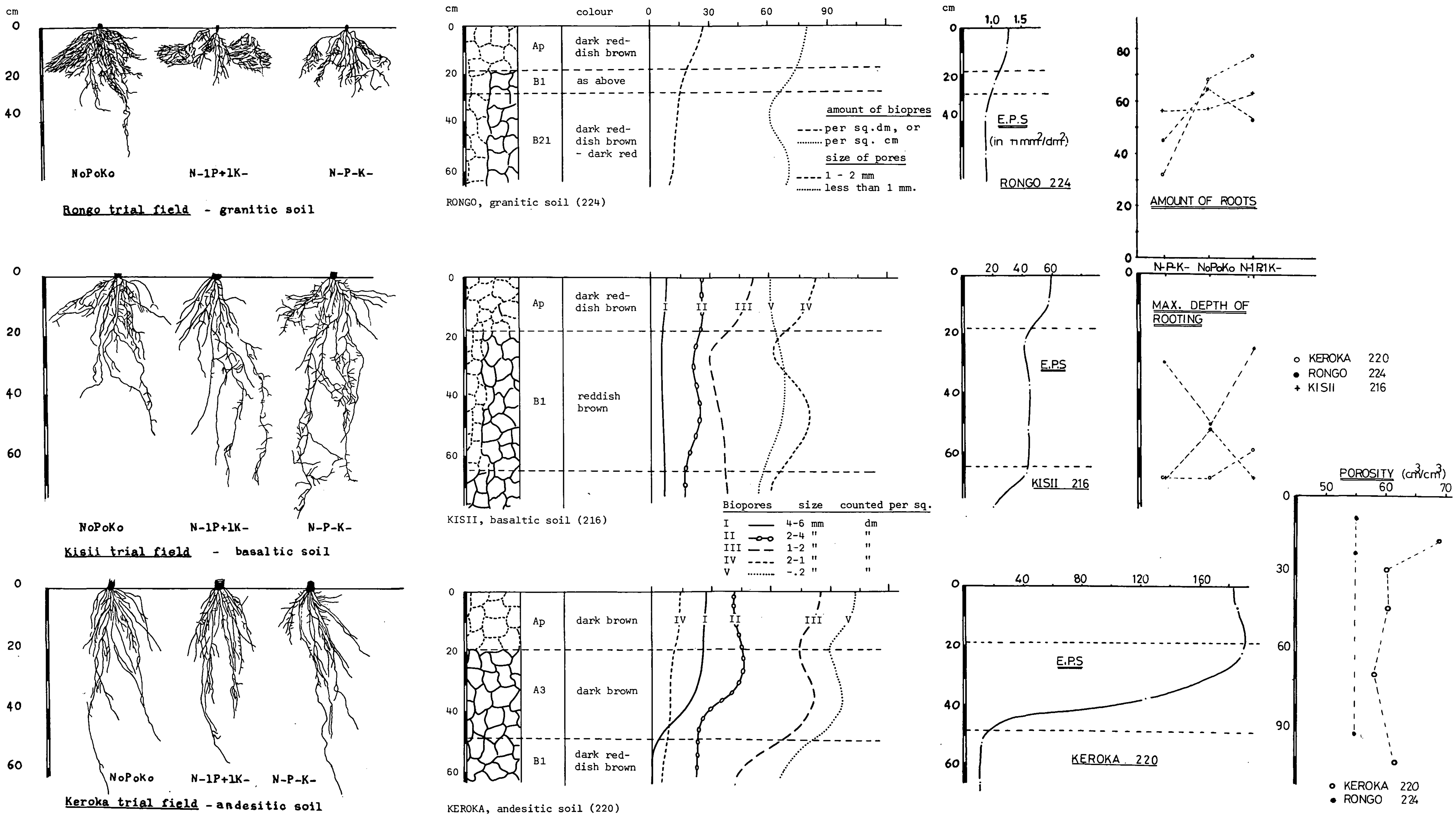


Fig. 4 Root development of maize at three sample sites with related diagrams

Soil profile characteristics

The three soil profiles do not have abrupt boundaries between the recognized soil horizons. Besides the soils seem to be uniform in texture.
An important feature, that is noticed in all of the studied soils, is the loosened topsoil, which is rooted preferentially because of its low mechanical resistance.
The thickness of the A_p - horizon is about 20 cm in all cases. Differences in colour, that may be used as an indication of the organic matter content of the soil, and the soil structure were observed. The soil profile description give more information of these phenomena. (see Appendix 1)

Measured bulk density, porosity and soil moisture content

Not at all locations ring samples have been taken in order to measure bulk density, porosity and moisture content of the soil. Table 4 presents data of the Keroka (219) and the Rongo soil (224).

Table 4: bulk density, porosity and moisture content

location	depth (cm)	bulk density g/cm^3	moisture content %	porosity cm^3/cm^3
Keroka	10 - 15	0.81	28.5	69
220	25 - 30	1.07	36.5	60
	40 - 45	1.07	38.0	60
	65 - 70	1.12	36.6	58
	90 - 95	1.02	34.2	62
Rongo	5 - 10	1.19	32.5	55
224	20 - 25	1.22	37.8	54
	80 - 85	1.18	32.9	55

The table shows a higher value of the bulk density in the Rongo soil than in the Keroka soil, but it does not explains the difference in rootability of the two soils. So it seems that measurements of both bulk density and the porosity are of restricted value in this study.

Interesting to conclude is the low bulk density value in the topsoil of the Keroka (220) soil. (Volcanic ash influence).

Differences between the studied rootsystems

Besides a general picture of the rootsystems, it is necessary to measure various properties of the rootsystems in order to obtain a quantitative measure of the effects of the various treatments and soils.

Besides measurements of properties, such as the amount of roots growing out from the nodes, total amount of roots, thickness of the roots at different depth, maximum depth of rooting, also a rough calculation is made of the rooted volume of soil. These measurements are presented in table 5, 6 and 7.

Table 5: Amount of roots grown out the different nodes

location	number of roots					
treatment	1	2	3	4	rest	total
Keroka - 220						
N- P- K-	7	8	8	-	9	32
No Po Ko	13	8	9	11	18	69
N-1P+1K-	21	15	13	9	20	78
Kisii - 216						
N- P- K-	17	13	12	8	16	56
No Po Ko	12	15	11	8	12	58
N-1P+1K-	15	12	9	-	27	63
Rongo - 224						
N- P- K-	12	8	8	-	17	45
No Po Ko	19	14	12	-	20	65
N-1P+1K-	10	10	10	5	17	52

Table 5 shows that fertilization increases the amount of roots. In the Keroka and Kisii soil the maximum amount of roots was reached when the highest phosphate gift was applied. The medium phosphate and potassium gift resulted in the largest amount of roots in the Rongo soil. The table also shows that the variation in the amount of roots between the different soils is higher in case of on fertilization than after applications of phosphate, potassium and nitrogen.

Table 6: The thickness of roots at different depth.

location treatment	thickness of the roots in mm measured at depth of: 10	20	30	50	70 (cm)
Keroka - 220					
N- P- K-	1.5	1.5	1.0	1.0	0.5
No Po Ko	1.5	1.0	1.0	1.0	1.0
N-1P+1K-	3.5	2.0	1.2	1.0	1.0
Kisi - 216					
N- P- K-	1.2	0.6	0.6	0.5	0.5
No Po Ko	2.5	1.0	0.5	0.4	-
N-1P+1K-	1.5	1.8	1.0	0.8	0.5
Rongo - 224					
N- P- K-	1.0	0.5	0.5	-	-
No Po Ko	2.5	1.5	1.0	1.0	-
N-1P+1K-	1.5	1.0	-	-	-

The roots in the topsoil increase in thickness after phosphate fertilization. In the Rongo soil also potassium may affect the thickness of the roots. For this purpose only primary roots have been measured, because the root hairs did not vary in size as much as the primary roots did.

Table 7 presents information about the rooted volume of soil and the maximum depth of rooting, which is an important measure of the amount of soil moisture that can be used by the plant. The rooted volume is calculated roughly by assuming that the extent of the rootsystem is similar in all directions, as shown in the drawings of the rootsystems.

Table 7: Rooted volume and maximum depth of rooting

location	treatment	max. depth of rooting (cm)	rooted volume (m^3)
Keroka	N- P- K-	70	0.20
220	No Po Ko	70	0.20
	N-1P+1K-	60	0.20
Kisii	N- P- K-	80	0.32
216	No Po Ko	53	0.20
	N-1P+1K-	70	0.27
Rongo	N- P- K-	30	0.19
224	No Po Ko	52	0.22
	N-1P+1K-	25	0.20

Table 7 shows that the maximum depth of rooting is slightly influenced by fertilization. In general we may state that the depth of rooting decreases, when phosphate fertilizer is applied. The rooted volume does bot reflect any influence of fertilization. In cases where the depth of rooting decreased, it was found that horizontal extent of the rootsystem increased, which resulted in the same rooted volume. The branching of the primary roots changes from case to case. In the Rongo soil (224) it was found, that the amount of root hairs increased, when more phosphate was applied. In the (N-1P+1K-) treatment a very dense network of root hairs, concentrated mainly in the A_p - horizon could be found. The other two treatments had less root hairs. A rough estimation may show that the amount of root hairs in the NoPoKo treatment was about 75% and in the N-P-K- treatment about 30 % of the amount of root hairs in the N-1P+1K- treatment.

The other soils did not show the effect of phosphate application as good as the Rongo soil did. In case of the Kisii soil (216) the rootsystem of the (N-P-K) treatment even showed to be developed better than the system of the treatment with the highest possible P - gift.

Rootsystems, like the system of the NoPoKo treatment in the Rongo soil (224), are very susceptible to be damaged by the weeding with the jembe, because the soil is tilled too deep. A more superficial tillage with a hoe may reduce the risk of damaging the rootsystem and may even improve the weeding.

Measurements of the aerial parts of the examined maize plants and the yields of the different trial fields

Table 8 presents averages of measurements of five maize plant at each treatment. The measurements include length of the plant, number of leaves, length of internodes and the thickness of the stem just above the soil surface. The grain yields have been recalculated at a moisture content of 20%.

Table 8: Measurements of aerial parts and grain yields

location treatment	the length of plant (cm)	amount of leaves	thickness of stem (cm)	length intermodes	yield kg/ha
Rongo - 224					
N- P- K-	198	13	1.5	12.7	not
N-1P+1K-	243	14	1.6	15.1	known
No Po Ko	276	15	2.7	15.8	
Kisii - 216					
N- P- K-	275	15	2.0	18.4	3440
N-1P+1K-	300	16	2.7	19.3	4330
No Po Ko	270	15	2.3	18.0	3660
Keroka - 220					
N- P- K-	245	14	2.3	15.1	1965
N-1P+1K-	320	18	3.0	16.0	2540
No Po Ko	350	17	3.0	20.8	2185

The differences in both size of the maize plants and yields between the Kisii and the Keroka trial fields are very interesting. The plants of the Keroka trial are developed a bit better than the plants of the Kisii trial, but the yields of the Kisii trial are much higher. On the other hand it was found that the extent of the rootsystem of the Kisii trial is larger than the Keroka trial. So it may be that the extent of the rootsystem is related more with the yield than the size of the plant does.

5.3 Conclusions

The effect of applications of fertilizers was mainly restricted to phosphate.

The effects of fertilization may be summarized as follows:

- the amount of both primary roots and root hairs increase, when phosphate is applied.
- the thickness of the primary roots in the upper layers of the soil is enlarged by phosphate fertilization
- indications were found that the maximum depth of rooting is reduced by phosphate gifts.
- the increase in both thickness and amount of roots were most pronounced in the topsoil, where the fertilizer was placed.
- despite differences in the maximum depth of rooting, the volume occupied by the rootsystem remained fairly constant
- the average rooted volume was found to be about 0.2 m^3.
- result of the shallower rooting of fertilized maize may be reduced drought resistance and an enlarged susceptibility to damage of weeding practises

- effects of fertilization on the aerial parts of the maize:

a. increase of grain yields (especially by phosphate)

b. increased length of the plant

c. enlarged thickness of the stem, measured just above the soil surface.

The differences between the three soils of their rootability could be described accurately by the bioporosity and the calculated e.p.s. - value.

The factors, which influence rootability most, can be listed as underneath:

The 'equivalent pervious surface' has to be above larger than a certain minimum value (about 10) to make root growth possible.

- abrupt changes of the e.p.s. - value result in a reduced development of the rootsystem.
- only biopores of size of more than 0.2 mm can be used by the young maize roots

- abrupt changes of the e.p.s. - value result in a reduced development of the rootsystem

- only biopores of a size of more than 0.2 mm can be used by the young maize roots

- measured bulk density and porosity are of restricted use in explaining differences in rootability of soils

- the loosened topsoil, having a low mechanical resistance, is preferentially rooted.

6. The effect of the depth of the soil on the root development of maize.

6.1 Introduction

Maize is often planted in soils with at some depth an interfering layer, which may vary in structure.
The selected locations are:

Kitere - rhyolitic soil - no.221
Ikoba - basaltic soil - no.223
Rongo - granitic soil - no.225

The kind of the different interfering layers differ among the selected locations. Also the thickness of the overlying soil varies. In the Kitere soil (221) it can be observed that at a depth of 95 cm the top of the partly weathered rock (rotten rock) is situated. The rotten rock is soft so that a knife can be pushed in,
In the Rongo soil (225) the interfering layer starts at a depth of 64 cm below the soil surface and is formed by a cementation of manganese and iron concretions. On top of this 'indurated plinthite' layer a zone with a thickness of about 24 cm, which contains a large amount of concretions, can be recognized.
Also the Ikoba soil (223) possesses a interfering cemented layer at a depth of over 65 cm.
In the appendix soil descriptions of the studied soils can be found.

6.2 Results and discussion

The interpretation of the results is somewhat more complicated than it was in the case of the fertilization experiments. In this study the maize did not receive an uniform treatment, such as planting date and kind of seeds.
To avoid this, it was tried to sample the different locations just before the harvest.
The presentation of this chapter will be set up similar to chapter 5.2.

Bioporosity

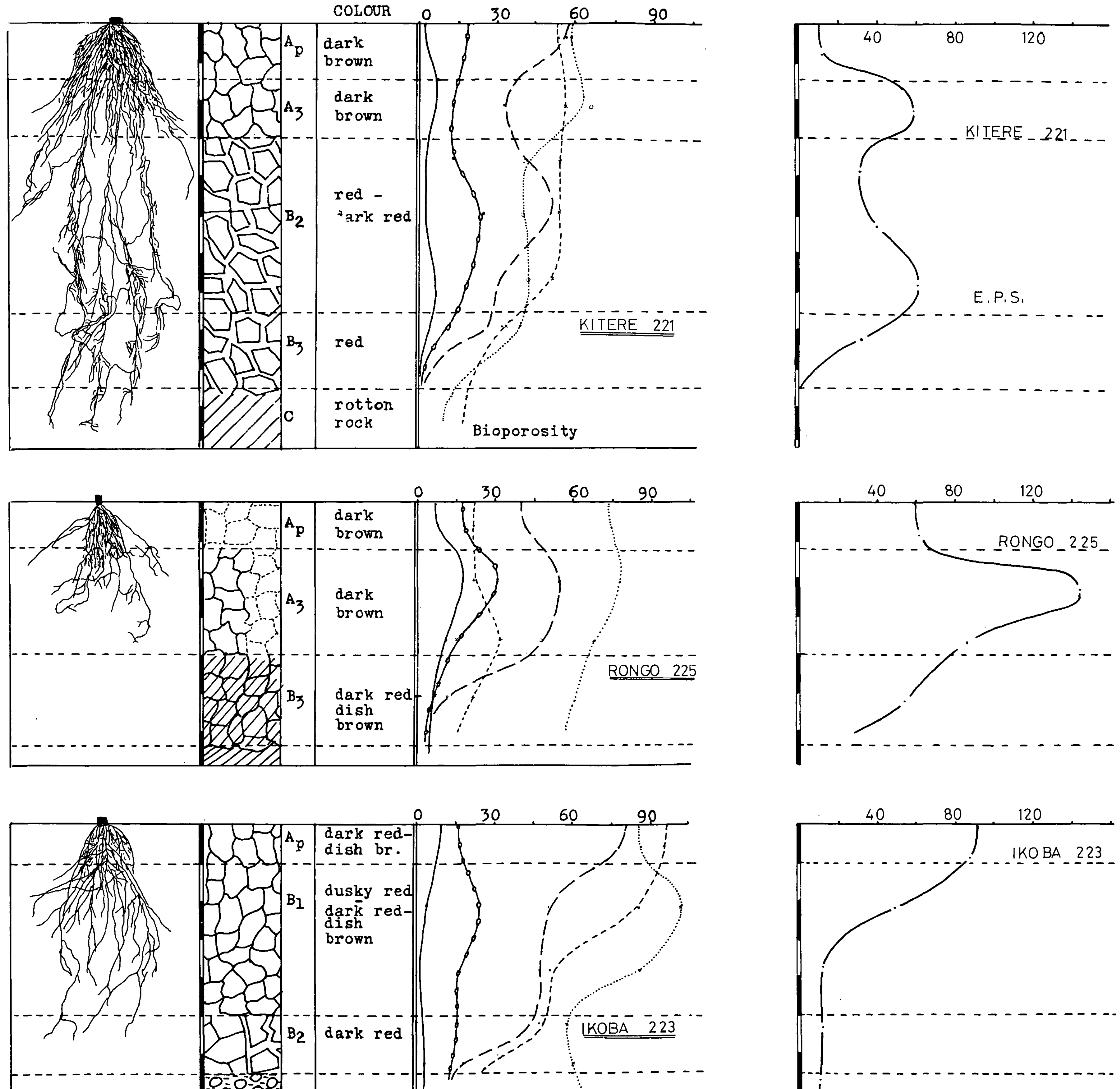
Differences of the bioporosity are not as pronounced as in the former chapter.
As can be seen in the three graphs, showing the bioporosity in relation to the soil depth, the amount of biopores in the interfering layers is reduced to zero. Only the very small biopores do occur to some extent, so it would not be surprising to discover that the interfering layers are unrooted.
This observation may give additional prove to the conclusion, that pores with a diameter of less than 0.2 mm can not be used by the young maize roots.

Equivalent pervious surface

Table 9 presents the calculated values of the equivalent pervious surface at various depth below the soil surface.
In the interfering layer the e.p.s. value is reduced to zero.

Table 9: Equivalent previous surface (in $\bar{n}$ mm^2/dm^2)

depth (cm)	Kitere - 221	Rongo - 225	Ikoba - 223
0 - 15	13	62.4	87.8
15 - 30	60	144.4	48.1
30 - 45	33	85.9	11.0
45 - 60	40	54.7	11.0
60 - 75	62	-	10.1
75 - 90	33	-	7.0
90 -105	0	-	0



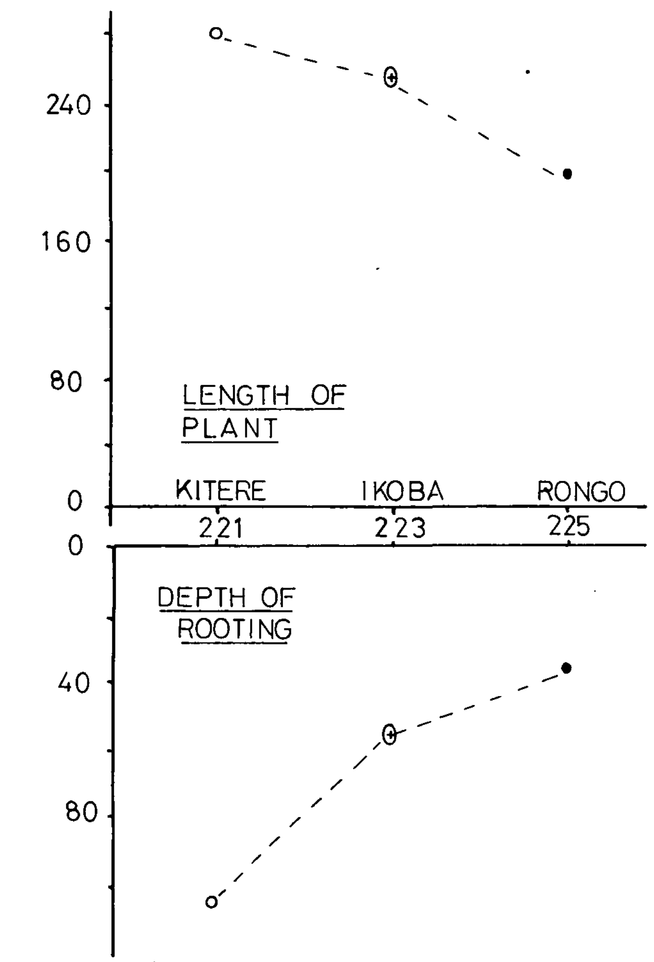


Fig. 5 Root development of maize at three sample sites with related diagrams.

The increase of the e.p.s. in Kitere soil at depth of 60-75 cm is very interesting.
This increase may explain the more extended development of the rootsystem at this depth. Up to the top of the rotten rock the value of the e.p.s. remains so high that until this depth the rootsystem is developed unrestricted.
Also in the Rongo soil (225) the e.p.s. remains high enough up to a depth of 60 cm, but the rootsystem remained small.
In the Ikoba soil (223) a decrease of the value of the e.p.s. is found at a depth of 30 cm and it is obvious that the extent of the rootsystem also is reduced at this depth.

Soil profile characteristics

The three investigated soils vary remarkably in soil depth, structure, kind of interfering layer and organic matter content.
The depth and kind of the interfering layers are allready explained.
The soil structure varies between a strong angular blocky structure (Kitere - 221) and a weak subangular blocky structure. (Rongo - 225) The effect of the soil structure on the root development of maize is not very clear. The presence of small cracks and open spaces between the soil peds (indivisible soil particles), a strong angular blocky structure might influence the root development possitively. On the other hand a strong angular blcoky structure may reduce the branching of the primary roots, as is found in the Kitere soil.
The amount of root hairs in the angular blocky structured horizon was found to be negligible. Of course this will cause a reduced volume of soil that can be exploited effectively by the rootsystem. Thickness of the dark topsoil, which can be used as rough measure of the organic matter content, varies too.
Especially the Rongo soil (225) posses a very thick (40 cm) dark brown topsoil, which may reflect the wet position of this profile, because of its impermeable plinthite layer.

The dark brown topsoil of Kitere soil (221) is thinner and is rooted more intensively than the rest of the profile.
The Ikoba soil (223) posses a thin topsoil. Part of it may be eroded, due to the physiographic position of this profile.

The measured bulk density, moisture content and porosity

The Rongo soil and the Ikoba soil have been sampled in order to measure bulk density, moisture content and porosity. Table 10. presents the relevant data of these measurement.

Table 10. Bulk density, moisture content and porosity

location	depth (cm)	bulk density g/cm^3	moisture content	porosity cm^3/cm^3
Rongo	5 - 10	1.22	23.3	54
225	30 - 35	1.31	26.6	51
Ikoba	5 - 10	0.92	32.8	65
223	10 - 35	0.93	38.6	65
	60 - 65	0.98	45.1	63

The obtained bulk density values show a remarkable difference between the Rongo and Ikoba soil and thus it is likely that the Ikoba soil is rooted preferentially above the Rongo soil. Similar remarks can be made about the porosity.

The main differences between the three investigated root systems

Table 11 presents the counted amounts of primary roots, which have been grown from the different nodes.

Table 11: The amounts of primary roots.

location	node no. 1	2	3	4	rest	total amount of primary roots
Kitere 221	17	20	11	9	21	78
Rongo 225	16	10	11	8	12	57
Ikoba 223	19	14	10	6	22	71

Whether there is a relationship between the total amount of roots and the depth of the soil, is doubtful, even if table 11 indicates this relationship.
Table 12 gives information about the thickness of the roots, which have been measured at various depth below the soil surface.

Table 12. The thickness of the primary roots (in mm)

location	at a depth of: 10	20	30	50	70 (cm)
Kitere 221	3.5	2.0	1.0	1.0	1.0
Rongo 225	2.0	1.0	0.5	0.5	
Ikoba 223	2.8	1.5	1.5	1.0	1.0

It can be noticed that the rootsystem, which is developed very good (in this case the Kitere system), possesses the thickest roots. The volume of soil, that is exploited by the various rootsystems and the maximum depth of rooting is presented in Table 13.

Table 13: Maximum depth of rooting and the rooted volume.

location	rooted volume m^3	maximum depth of rooting cm	depth of top interfering layer - cm
Kitere 221	0.50	106	95
Rongo 225	0.09	37	40
Ikoba 223	0.19	55	65

Table 13 shows a very good relationship between the depth of the top of the interfering layer, rooted volume of soil and the maximum depth of rooting.

As already mentioned, it is very obvious that the Kitere rootsystem did not branch between a depth of 20 to 50 cm. The total amount of primary roots, penetrating the subsoil were found to be over 30. The reason for this was found to be the strong angular blocky soil structure.

In the Ikoba soil the branching of the primary roots was most pronounced in the upper 20 cm of the soil profile. Besides a lot of root hairs in the topsoil, also a number of horizontal roots could be noticed.

A factor, that may have influenced the development of the Rongo rootsystem, may be because this maize was planted about two weeks after the other fields have been planted.

Measurements of the aerial parts of the maize plants

The measurements presented in table 14 are averages of measurements of five plants at each location.

Table 14. Measurements of the aerial parts (cm)

	Kitere 221	Rongo 225	Ikoba 223
length of the plant	280	193	258
number of leaves	15	16	14
thickness of stem	3.0	2.4	3.0
length of stem parts	18.2	10.4	16.6

As table 14 shows, there is some relationship between the development of the rootsystem and the length of the plant and also the length of the stem parts.

6.3 Conclusions

Because we are dealing with a lot of variable factors (such as soil depth, soil structure, bulk density, depth of top interfering layer and kind of interfering layer) and with differences in management practices of the fields, it is not easy to draw conclusions from the obtained results. But still an attempt is made, resulting in the following conclusions:

- counting of biopores and calculating the equivalent pervious surface in the studied soils showed a decrease in the rootability of the interfering layers in respect with the overlying soil.
- an interfering layer of rotten rock can be penetrated more easily than an indurated plinthite layer.
- the presence of micro biopores (diameter less than 0.2 mm) in the unrooted plinthite layer, may give additional prove to the thesis, that young maize roots are unable to penetrate the very small pores.
- a strong angular blocky soil structure is likely to improve the rootability of the soil profile by the primary roots, but reduces their branching.
- a good relationship was found between the depth of the soil on top of the interfering layer and both the rooted volume of soil and the maximum depth of rooting.
- some indications are found, that the amount of primary roots and the thickness of these roots are related to the depth of the soil.
- a good relationship exists between the aerial parts and the rootsystem.

7. The effect of the time of planting on the rootdevelopment of maize.

7.1 Introduction

It has been stated by many investigators, that the maize plant is very susceptible to unfavourable soil air/moisture relationships, especially during the first four or five weeks of its life.
According to Grover (1957) the optimum rainfall during the first five weeks after sowing is about 200 mm. More rain is likely to reduce seedling growth and grain yield. But recently more attention is paid to the effect of the soil temperature as being the main factor governing the growth of the young maize plant.
Of course a relationship exists between the amount of rainfall and the soil temperature. In periods with high precipitation, the soil temperature will be much lower than in times of considerable drought.
It will be clear that variation in grain yields of fields with a different date of planting will be caused by the climatical conditions during the growing season, and for maize probably during the first part of its growing season.
Quite a lot of investigators studied the effect of soil temperature on the development of the maize rootsystem Mosher et. al.(1972) studied the influence of the soil temperature on the geotropic response of maize roots. They found that the angle of radicle growth varied from 30° from the horizontal at 18°C to 61° from the horizontal at 36°C. So at low temperatures the roots will grow in a horizontal direction and when the temperatures increase in a more vertical direction.
The influence of soil temperature on the direction of growth, explains many observations on root growth from the literature. Hays (1889) suggested that the horizontal growth of the roots was caused by low subsoil temperature, but Hawkins (1963) stated that this was not the reason.

Hawkins found that when the temperature was low early in the growing season, the roots grew horizontal and later in growing season, when the soil warmed up in a more vertical direction.

Kiesselbach (1949) reported that when corn was planted after the soil warmed up, all the roots grew vertically and no horizontal growth occured.

Hawkins (1963) and also Miller (1930) investigated the horizontal root growth during the early seedling stage. Both authors reported that the direction of growth of the radicle, seminal and first nodal roots depended upon the texture of the soil.

But in fact, this is an indirect effect, because fine textured soils warm up more slowly in the spring than do coarse- textured soils, because of the higher soil moisture contents of the former. The direction of growth of not only the radicle, but also the seminal and the nodal roots seems to depend upon the soil temperature, that varies with soil texture and moisture content.

The discussed literature shows very clearly that climatic conditions influence the development of the maize seedlings. Studying these influences may resort such information that it is possible to determine those planting dates, which are likely to be most favourable to the young maize plant.

Also in Kenia quite a lot of study has done, but never about the effect of the soil temperature on the growth of maize.

Uchendu (1969), Allan (1967) also Dowler (1964) have reported results of various date of planting trials.

In this study attention will be paid to the soil properties, which may affect root growth, development of the aerial parts of the maize plants, differences between two different Hybrids and also the climatic conditions during the beginning of the growing season.

Table 15 presents the different planting dates and dates of harvesting of the fields of the Keroka "date of planting" trial. Besides different planting dates three different Hybrids were used there. In this study only Hybrid 613 C, bred for altitudes above 6000 ft., and Hybrid 512, that was bred for the lower altitude, will be discussed.

Table 15; Dates of planting and harvesting

code	date of planting	date of harvesting	hybrid	
T 1	5 - 10 - '73	16 - 5 - '74	512	X
T 2	12 - 10 - '73	16 - 5 - '74	512	
T 3	19 - 10 - '73	7 - 6 - '74	512	
T 4	23 - 10 - '73	12 - 7 - '74	512	
T 5	26 - 10 - '73	7 - 6 - '74	512	
T 6	2 - 11 - '73	7 - 6 - '74	512	X
T 7	9 - 11 - '73	7 - 6 - '74	512	
T 8	16 - 11 - '73	7 - 6 - '74	512	
T 9	30 - 11 - '73	7 - 6 - '74	512	X
T 10	7 - 12 - '73	12 - 7 - '74	512	
T 11	14 - 12 - '73	12 - 7 - '74	512	X
T 12	21 - 12 - '73	12 - 7 - '74	512	
T 13	28 - 12 - '73	12 - 7 - '74	512	
T 14	4 - 1 - '74	26 - 7 - '74	512	X
T 15	11 - 1 - '74	26 - 7 - '74	512	
T 16	18 - 1 - '74	11 - 9 - '74	512	X
T 17	25 - 1 - '74	26 - 7 - '74	512	
T 18	1 - 2 - '74	11 - 9 - '74	512	
T 1	2 - 10 - '73	7 - 6 - '74	613 c	
T 2	5 - 10 - '73	16 - 5 - '74	613 c	X
T 3	12 - 10 - '73	16 - 5 - '74	613 c	
T 4	19 - 10 - '73	7 - 6 - '74	613 c	X
T 5	26 - 10 - '73	7 - 6 - '74	613 c	
T 6	2 - 11 - '73	26 - 7 - '74	613 c	
T 7	9 - 11 - '73	12 - 7 - '74	613 c	X
T 8	16 - 11 - '73	12 - 7 - '74	613 c	
T 9	23 - 11 - '73	12 - 7 - '74	613 c	
T 10	30 - 11 - '73	12 - 7 - '74	613 c	
T 11	7 - 12 - '73	12 - 7 - '74	613 c	X
T 12	14 - 12 - '73	26 - 7 - '74	613 c	
T 13	28 - 12 - '73	26 - 7 - '74	613 c	
T 14	4 - 1 - '74	26 - 7 - '74	613 c	X
T 16	18 - 1 - '74	11 - 9 - '74	613 c	X
T 17	25 - 1 - '74	11 - 9 - '74	613 c	
T 18	1 - 2 - '74	11 - 9 - '74	613 c	

The selected fields have been indicated with X.
The field work was done in the second and third week of March 1974

Climatical conditions

In the neighbourhood of the trial field, the 'date of planting' trial, the Keroka Passion Fruit Station measures the rainfall and minimum and maximum temperatures daily. These data are presented in a diagram at the following pages. It gives some interesting information like is shown in the table underneath.

Table 16: Monthly rainfall and temperature

month	average temperature °C	month rainfall mm
September '73	20.6	370.0
October	21.4	67.5
November	19.1	138.0
December	23.8	51.0
January '74	23.4	80.0
February	25.9	47.5
March	25.1	?

It was found at the end of October and the beginning of November, the lowest weekly temperatures were measured (17 - 18°C). After the end of November the temperature rises to valued of about 23-24°C, and in February even to values of 26-27°C.
This implies a difference between November and February of almost 10°C. Such a large difference must influence maize growth. Maize that has been planted after November develops under more favourable temperature conditions.
Like has been stated before, the young maize plant is very susceptible to the temperature regime in the first stages of growth. Acland (1973) reports that the optimum temperature for maize growth is 30°C. Up till now we have spoken of the air temperature, but combining the rainfall and temperature measurements, it is possible to obtain an idea of the soil temperature fluctuations during the growing season.
Rainfall will decline soil temperature, like it does the air temperature. In periods with some occassional showers, the sun will warm up the soil to temperatures, that may exceed 30°C.

From the end of October to March two periods with reduced rainfall occurred, namely the first three weeks of December and the period between the 20th of January and the 20th of February. Especially the last period, when only 14 mm of rainfall was measured, lack of moisture to the plants, may have caused a stagnation of the growth of the maize, The effect of this drought probably depends on the stage of development of the maize in which this drought occurs.
It is known that the young maize plants are more drought resistant than the older plants are.
To discover whether there is many relationship between the rainfall and temperature conditions in the early stages of growth of the maize and the grain yield, table 17 presents data about climatical conditions around the time of planting and the obtained grain yields.

Table 17: Climatical conditions and grain yields

planting date	rainfall (mm) 1 week before planting	rainfall (mm) 5 weeks after planting	average temperature during the first 5 weeks after planting °C	yield kg/ha
Hybrid 613 c				
T 2	26.5	52.8	20.9	2420
T 4	18.0	127.6	18.6	1550
T 7	72.0	58.3	20.4	4320
T 9	6.0	68.1	23.2	4700
T 11	0.5	73.6	23.9	5300
T 13	26.3	89.1	23.9	5050
T 14	33.5	55.6	24.4	5100
T 16	50.8	13.8	25.3	3880
Hybrid 512				
T 1	26.5	52.8	20.9	2120
T 5	8.5	125.3	18.5	2620
T 9	27.5	40.6	23.8	2500
T 11	7.0	70.9	23.6	3030
T 12	6.8	115.4	23.6	5880
T 14	33.5	55.6	24.4	3510
T 16	50.8	13.8	25.3	1640

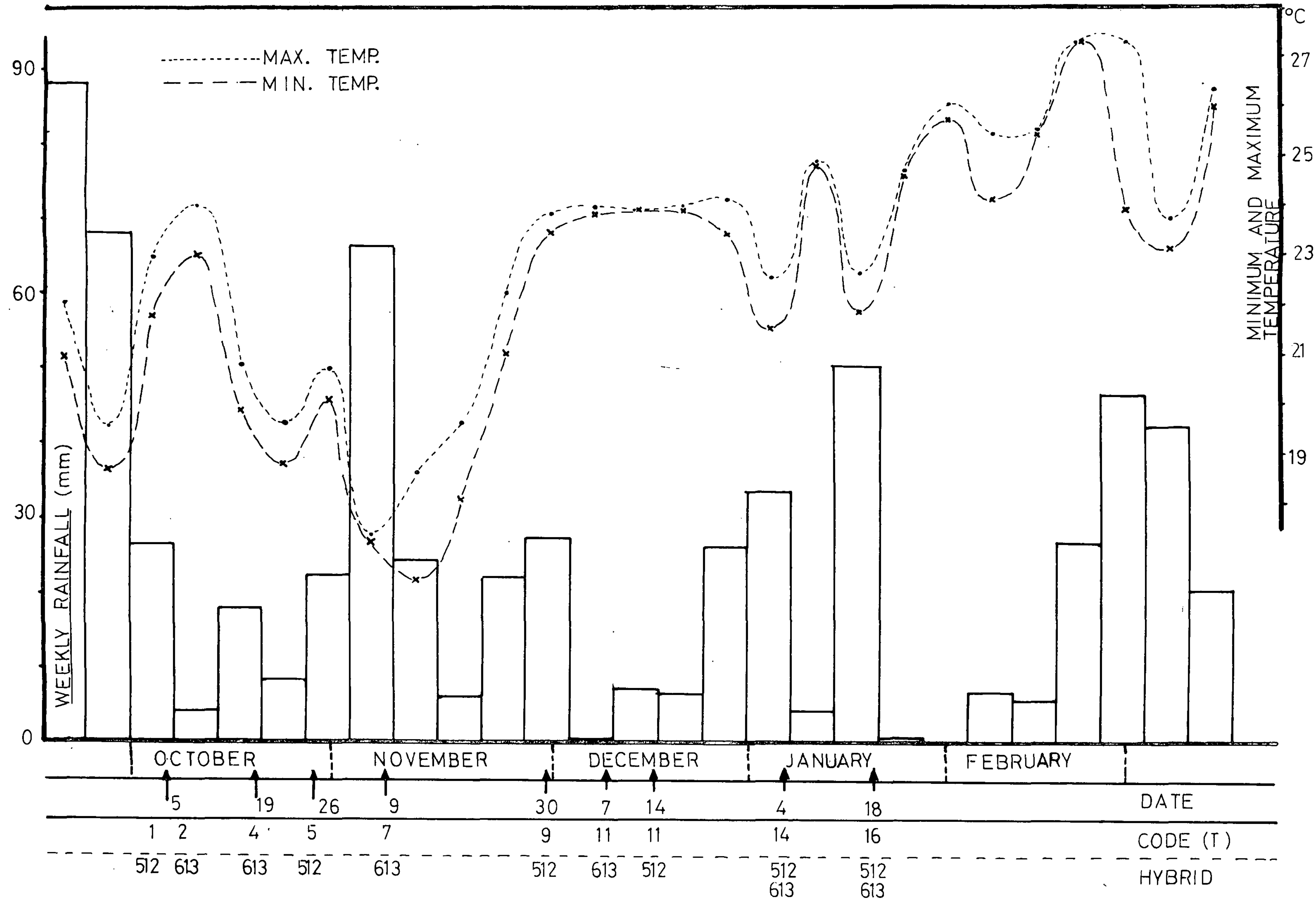


Fig. 6 Meteorological data during Oct.-Jan.(growing period of maize).

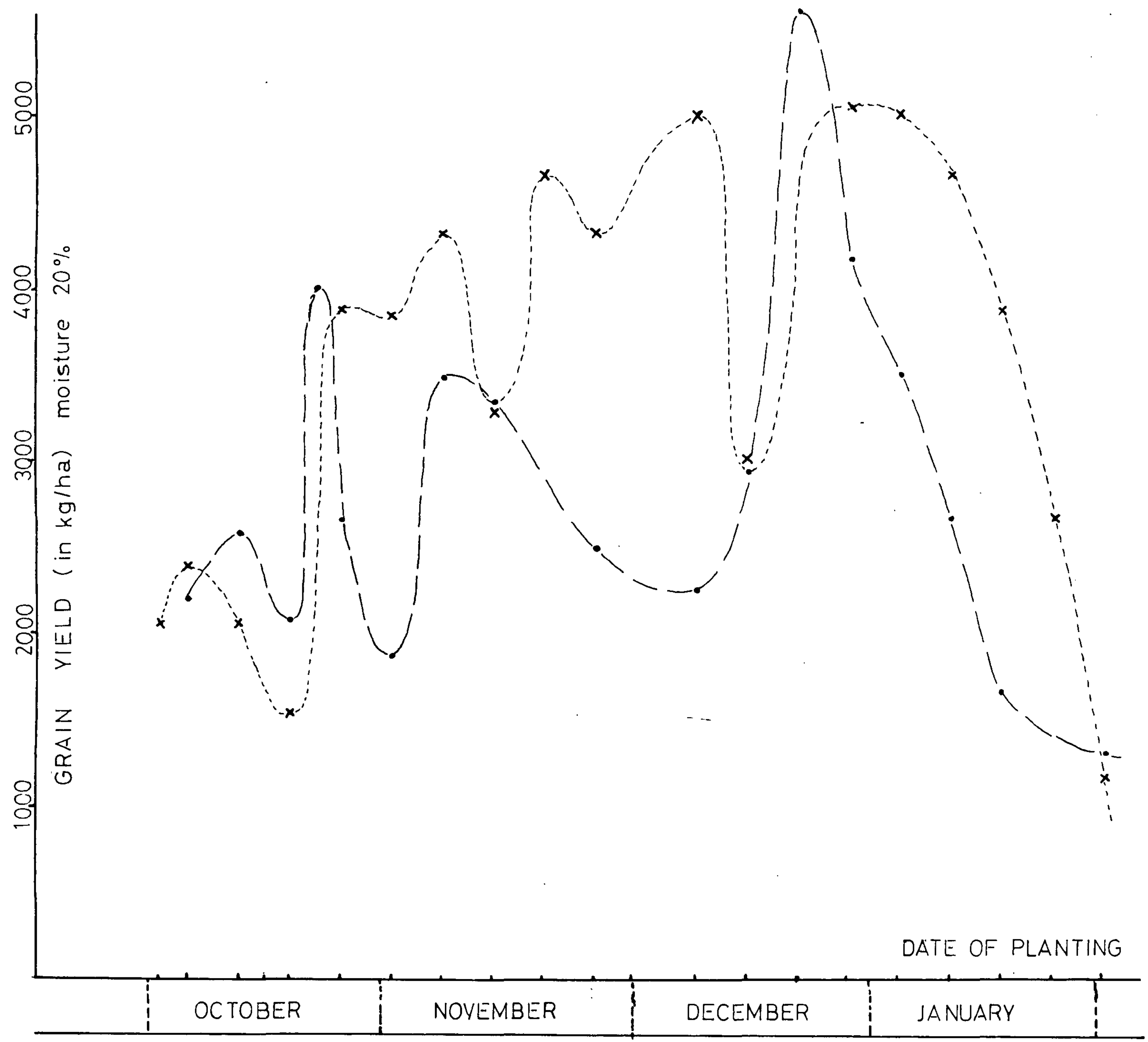
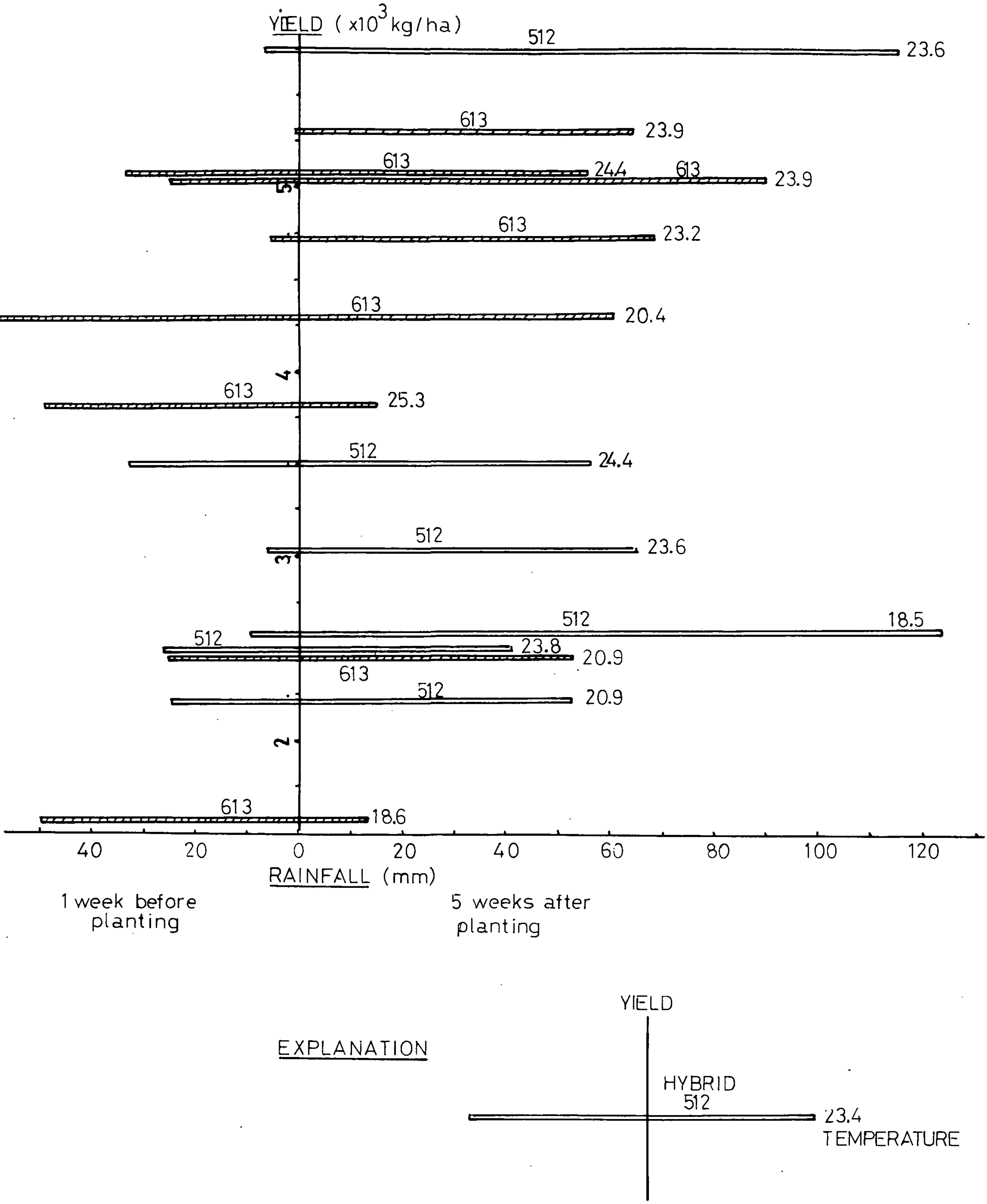


Fig. 7 Grain yields of maize related date of planting.



ig. 8 Maize yield related to rainfall and temperature.

The interpretation of the results, as presented in table 17 and in the constructed diagram, is not very easy, because we have to deal with so many variable factors, such as the rainfall just before planting and during 5 weeks after planting the average temperature in the first stages of growth and the kind of Hybrid used. It can be noticed that the rainfall plays an important role. In general we may say, that grain yields increase, when the maize is planted after a period with reduced rainfall. followed by some weeks with quite a lot of rain (probably over 100 mm during the first five weeks after planting and less than 20 mm in the week before planting).

Besides this distribution of the rainfall, the temperature plays an important role too. The reason, that higher yields are obtained when the maize is planted after a period with reduced rainfall may be explained by the fact that the maize germinates when the soil temperature is closer to the optimum than in case of wet soil. After germination the temperature is also important, as can be noticed from table 17. The highest yields are obtained when the air temperature is about 24°C.

Besides the effects of the climatical conditions, table 17 also shows remarkable differences between Hybrid 512 and Hybrid 613 c. In general the yields of Hybrid 613c are higher than the yields of Hybrid 512, but the maximum yield of Hybrid 512 exceeds the maximum of 613 c. This very high yield of the Hybrid 512 field (5880 kg/ha) that was planted the 21st of December 1973, may be accidentally, but the conditions under which this maize grew may be the most optimal. Before planting only 6.8 mm of rain was measured, but in the first weeks after planting the total rainfall was 115 mm. The temperature in the first weeks was about 24°C.

Soil porosity and the 'equivalent surface'

Like the soil profile of the Keroka fertilizer trial field, the soil at site is a deep weathered andesitic soil, but its bioporosity is remarkably less. Especially the amount of coarse biopores (size - 4-6 mm) is less than in the other Keroka soil.

The amount of biopores decreases with increasing depth, but at a depth of about 50 cm an increase can be noticed. It is very remarkable that in almost every studied soil such an increase at a depth of about 50 occurs.
Table 18 presents the calculated values of the e.p.s.

Table 18. Equivalent pervious surface

depth (cm)	e.p.s (in $\tilde{n}$ mm^2/dm^2)
0 - 10	145
10 - 20	36
20 - 30	10
30 - 40	12
40 - 55	38
55 - 70	28
70 - 85	10
85 -100	10

Whether the low e.p.s values at a depth of 20 - 40 cm restrict root penetrating is not very clear, as can be noticed from the rootsystem drawnings at the following page.

bulk density, porosity and moisture content

Table 19.

depth (cm)	bulk density g/cm^3	porosity %	moisture content %
10 - 15	0.81	70	28.5
25 - 30	1.07	59	36.5
40 - 45	1.07	59	38.0
65 - 70	1.12	57	36.6
90 - 95	1.02	62	34.2
120-125	1.27	51	16.9

The high e.p.s. value in the topsoil is very well related to a low bulk density. The porosity, measured by ring sampling, is also very high in the topsoil.
It is a pity, that it was not possible to measure the moisture content more often during the growing season, in order to get an idea about the relationship between rainfall and moisture content of the soil.

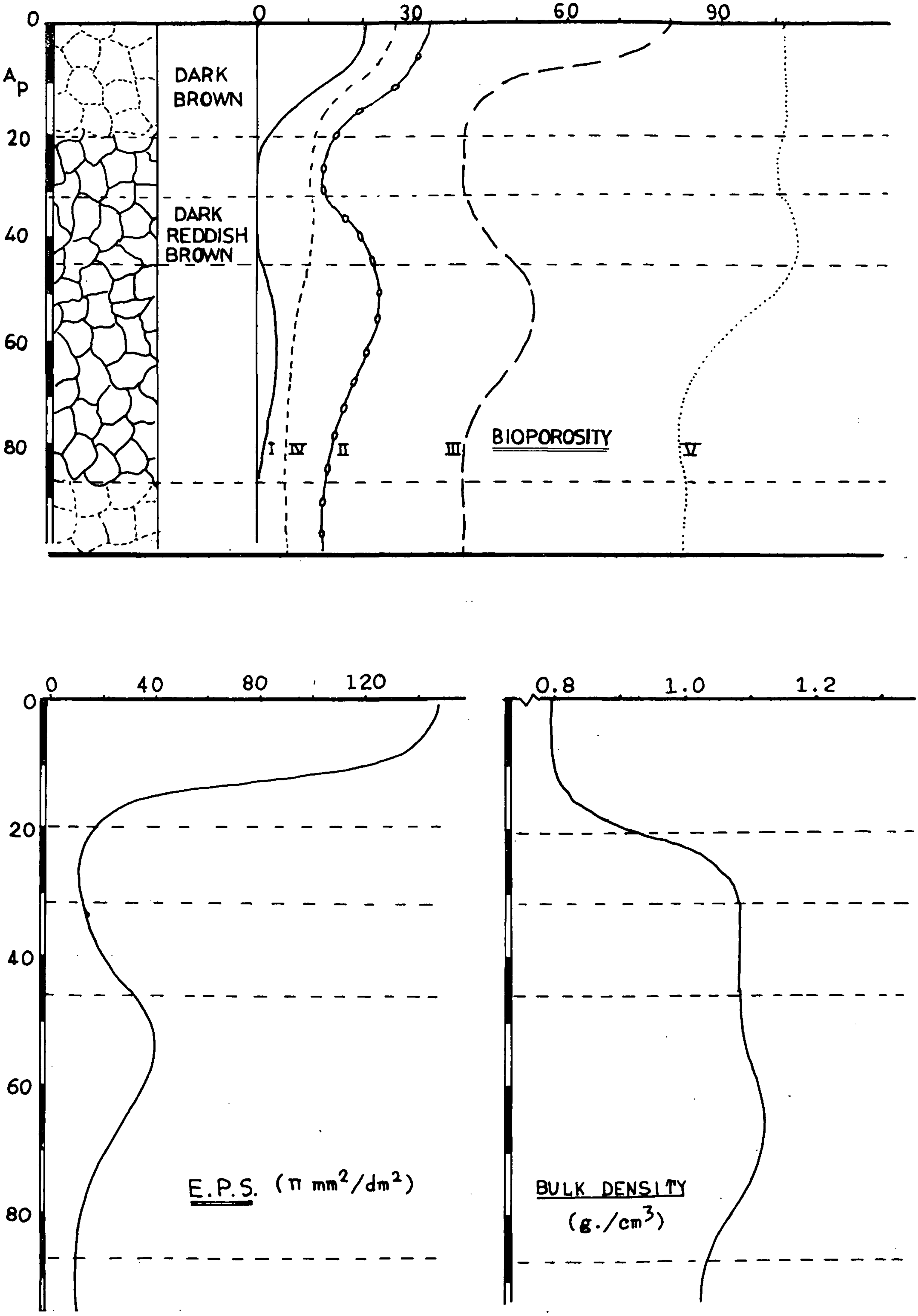


Fig. 9 Diagrams of the Keroka "date of planting" trial field soil for explanation see Fig. 4, EPS and bulkdensity.

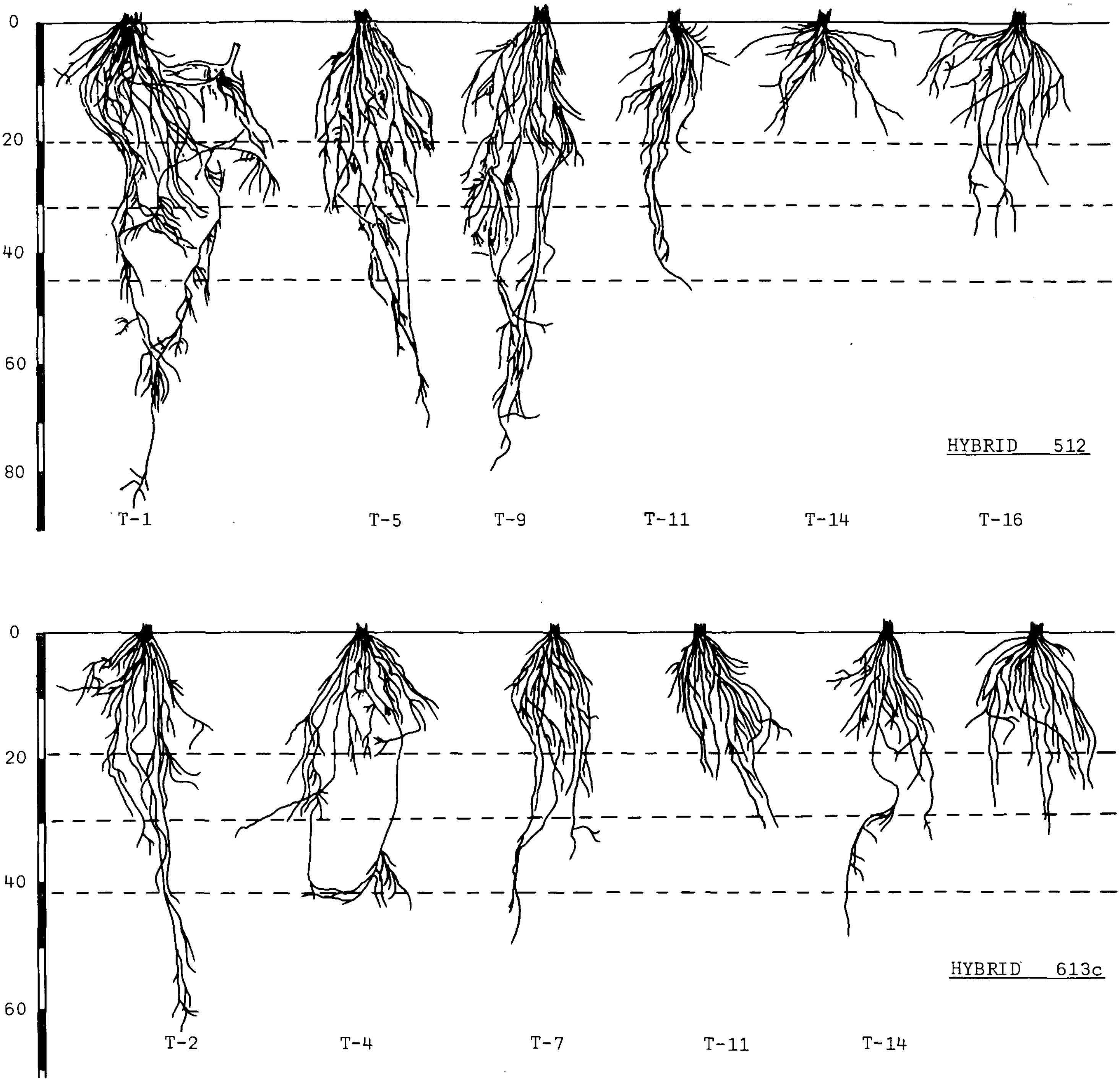


Fig.10 Root diagram at the different planting data for hybrid maize 512 and 613c.

Soil profile characteristics

The top 20 cm of this profile possesses a remarkable loose consistency and a weak structure. Up till 30 cm below the soil surface, the soil is dark brown, showing that this soil contains quite a lot of organic matter.

Besides the low value of the equivalent pervious surface, the soil profile does not show features, which are likely to restrict root penetration.

Differences between the studied rootsystems and Hybrids in relation to the planting date

Table 20 presents information about the various rootsystems. It should be remembered that the age of the presented systems varies, because of the different planting date. This makes it very hard to interpretate the results.

Table 20. The rootsystems of Hybrid 512 and 613 c, planted at different dates

planting date	amount of primary roots	max. depth of rooting (cm)	rooted volume (m^3)	length of plant (cm)
Hybrid 512				
T - 1	60	88	0.21	242
T - 5	64	72	0.15	205
T - 9	37	77	0.17	134
T - 11	35	45	0.06	190
T - 14	24	20	0.045	96
T - 16	35	35	0.08	65
Hybrid 613 c				
T - 2	64	63	0.11	235
T - 4	44	45	0.09	223
T - 7	47	50	0.08	220
T - 11	34	30	0.06	148
T - 14	42	45	0.05	98
T - 16	32	30	0.07	70

Table 20 shows very obviously the differences between the various treatments and between the two Hybrids. In how far a rootsystem is influenced by the climatical conditions in the early stages of growth is very hard to say. One would have expected that the rootsystems of the plants which have been planted in October (relative cold period with a lot of rain) are not as well developed as those which were planted later. In case of Hybrid 512 it is just the other way around.
The rootsystem of T-1 has the largest extent of all the studied systems, as can be seen at the following pages. On the other hand it also has to be said that T-5 is somewhat less developed than T-9. (hybrid 512) Table 17, that gives information about the climatical conditions in the early stages of growth, shows that T-5 was planted under much more favourable moisture conditions than T-9, but the average temperature during the first five weeks after planting varied almost 5°C. In case of T-5 this average was measured as being 18.5, while in case of T-9 it was 23.8. It should not be concluded that in this case a lower temperature during the first five weeks of growth decreases the extent of the rootsystem. Becasue of the high rainfall, it is obvious that the roots do not have to grow as deep as in the case of less rainfall. T-9 received only one third of the amount T-5 received during the first five weeks what may have been the cause of the deeper penetration of the roots.
The difference between the rootsystem of T-9 and the later planted fields is remarkable pronounced. It is not easy to explain this by the climatical conditions during the first stages of growth.
The rootsystems of Hybrid 613 c do reflect these climatical conditions during the beginning of the growing season. The older have only a somewhat more extended rootsystem than the younger have.
The T-16 treatment has in both cases a somewhat more extended rootsystem than the T-14 treatment, what may be explained by the amount of rainfall during the first five weeks. T-16 received only 14 mm of rain during this period, forcing the roots to penetrate the subsoil in order to be able to take up enough water.

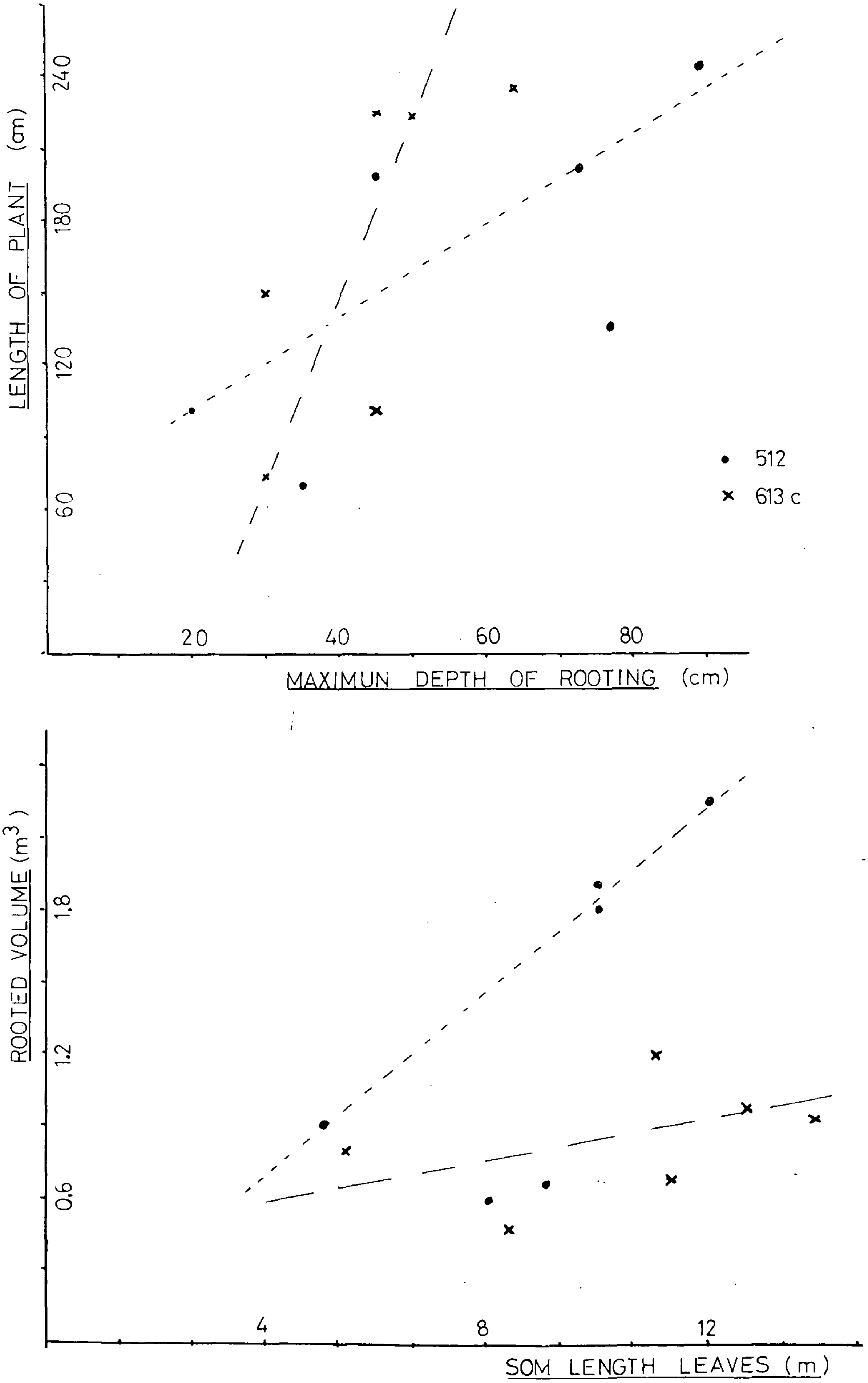


Fig. 11 Relations between plant length/root depth and rooted volume and leaflength.

Obtained grain yields and measurements of the aerial parts of the maize plants at the time of sampling

In order to find out whether the climatical conditions during the first stages of growth have also influence the aerial parts of the maize, five maize plants have been measured at each field. The relevant data of the investigated fields are presented in table 21.

Table 21: Aerial parts of the maize and grain yields

Hybrid 613	T-2	T-4	T-7	T-11	T-14	T-16
average length of internodes (cm)	19.2	16.0	27.5			
average length of leaves (cm)	69.0	74.2	81.0	73.8	55.5	45.1
average width of the leaves (cm)	8.4	6.0	7.6	5.9	5.3	3.9
length of plant (cm)	235	223	220	141	85	88
thickness stem (cm)	2.7	2.3	1.7	1.2	1.4	1.2

Hybrid 512	T-1	T-5	T-9	T-11	T-14	T-16
average length of internodes (cm)	14.7	16.7				
average length of leaves (cm)	74.8	61.5	66.7	53.4	54.0	46.5
average width of leaves (cm)	7.7	7.2	8.4	7.5	5.4	3.7
length of plant	242	205	134	193	101	73
thickness of stem	1.8	2.6	1.8	1.8	1.1	1.2

With help of this information, it must be possible to search for some relationship between the aerial parts and the root system, e.g. length of plant versus depth of rooting and some of length of leaves (indication for the dry matter production) versus rooted volume. Table 22 presents these data and also the obtained grain yields at the end of the growing season.

Table 22. Relationship between rootsystem and aerial parts

date		length plant (cm)	depth of rooting	rooted volume	some length of of leaves (m)
Hybrid	T-1	242	88	0.21	11.9
512	T-5	205	72	0.15	9.8
	T-9	134	77	0.17	10.7
	T-11	190	45	0.06	8.9
	T-14	96	20	0.045	8.1
	T-16	65	35	0.08	4.7
Hybrid					
613c	T-2	235	63	0.11	11.1
	T-4	223	45	0.09	12.6
	T-7	220	50	0.08	13.8
	T-11	148	30	0.06	11.8
	T-14	98	45	0.05	8.3
	T-16	70	30	0.07	5.4

As can be noticed, there are relations between the rootsystem and the aerial parts of the maize plants. The obtained relationships are not similar for Hybrid 512 and Hybrid 613. Hybrid 512 has a rootsystem, that penetrates the soil deeper and roots a larger volume of soil, than the rootsystem of Hybrid 613c. There is no difference between the aerial parts of these Hybrids.

Table 23: Obtained grain yields of the studied maize fields

Hybrid 512	date of planting	grain yields kg/ha	Hybrid 613 c	date of planting	grain yields kg/ha
	T - 1	2220		T - 2	2420
	T - 5	2660		T - 4	1550
	T - 9	2500		T - 7	4320
	T - 11	3030		T - 11	5300
	T - 14	3510		T - 14	5100
	T - 16	1640		T - 16	3880

7.3 Conclusions

Because so many variable factors influence the final extent of the root systems, it is hard to summarize a number of conclusions here. The problem is, that the relationships between the maize grain yields and the conditions during the first stages of growth are very complicated.
An investigation during a period of a large number of years and involving a detailed study of the climatical conditions during the early stages of growth (daily temperatures and rainfall), change of the soil moisture content and the soil /air water ratio, may solve quite a lot.
To be able to study the effects of all these factors on the development of the maize root system it is necessary to measure the extent of the root system at different times during the growing season. Besides the root system, it will also resort effect, when attention is paid to the aerial parts of the maize during its development.
The summarized conclusions of this investigation may be of some use to later investigations.

- The main effect of the climatical conditions during the early stages of growth on the root development of maize is that high amounts of rainfall (over 100mm) during the first five weeks after planting, reduces the maximum depth of rooting compared to drier conditions during this period, forcing the roots to penetrate the soil deeper.

- The effect of this climatical conditions was more pronounced in case of Hybrid 512, than in case of 613.

- Because it was found, that between the short rains of October - November and the dry period of February, the average daily temperature varied as much as 5°C, it is thought that the temperature may play an important role during the first stages of growth.

- It is known that maize, which has germinated under sold conditions produces more horizontal roots, than maize grown up in a warmed up soil. In this study such a relationship between direction of rooting and the soil temperature was not found, despite the fact that there was a variation of the temperature during the period that the maize was planted at the various trial fields.

- It is unlikely that temporarely waterlogging, due to high rainfall, influences the extent of the maize root systems or reduces its growth. What will happen when rainfall exceeds an intensity of 125 mm per week, is not clear. This conclusion is mainly based on the very slight variation of the extents of the root systems of hybrid 613 c and the very well developed Hybrid 512 root systems, which have been planted during the short rains.

- Not only the climatical conditions during the first stages of growth can explain accurately the finally obtained variation of yield, but also periods of drought later in the growing season are very important, perhaps even most important. Depending on the stage of development the maize plant is in, the effect of a period of reduced rainfall, will be of more or less importancy. In this study, it was found, that highest yields were obtained, if the maize was planted just after a small dry period during the first 2 weeks of December and about 4-5 weeks before the longer dry period in February and besides this if the rainfall during the first 5 weeks of growth exceeded 100 mm.

- At the time of planting reasonable relationships existed between the aerial parts of the maize plants and their root systems.
  Compared to Hybrid 512, the rootsystem of Hybrid 613 c is smaller, while the dimensions of the aerial parts are similar.

8. Literature

1. Acland, J.D. (1971) East African crops. Longman Group Limited, London

2. Allan, A.Y. (1973) The agroclimatology of maize. Technical conference on the agro-climatology of the highlands of Eastern Africa, Nairobi.

3. Allmaras, R.R. et al (1973) Corn root-configuration responses to soil temperature and Agron. Journal 65: 725-730.

4. Barber, S.A. (1971) Effect of tillage practice on Corn (Zea mays L.) root distribution and morphology. Agron. Journal 63: 724-726

5. Berger, J. (1962) Maize production and the manuring of maize. Centre d'Etude de l'Azote, Geneva.

6. Dowker, B.D. (1964) A note on the reduction in yield of Taboran maize by late planting. East Afr. Agr. For. Journal, July 1964.

7. Goedewaagen, M.A.J. (1942) Het wortelstelsel der landbouwgewassen. Dep. V. Landbouw en Visserij, Directie van de Landbouw, Den Haag.

8. Hawkins, G.W. (1963) Some factors affecting early root development of corn. Ph. D. thesis Lowa State University, Ames , lowa.

9. Hays, W.M. (1889) Corn, its habits of root growth, methods of planting and cultivation, notes on ears and stools and suckers. Minnesota Exp. Sta. Bull. 5: 5-33

10. Kampe, K. (1929) Studien Uber Bewurzelungsstarke und Wurzeleindringungsvermogen verschiedener Kultuurpflanzen. Wiss. Arch. f. Landwirtsch. Pflanzenbau no. 2: 1-29.

11. Kiesselbach, T.A. (1949) Structure and reproduction of corn. Nebraska Agr. Exp. Sta. Bull. 161.

12. Leeper, R.A et al (1974) Effect of plant-Available Stored Soil Moisture on Corn Yields.
I. Constant Climatical conditions
II. Variable Climatical Conditions
Agron. Journal vol. 66: 723-733

13. Millar, C.E. (1930) Root systems of young maize plants in relation to fertilizer applications. Agron. Journal vol. 22: 868-873.

14. Molz, F.J. (1971) Interaction of water uptake and root distribution. Agron..Journal vol. 63: 608-610.

15. Mosher, P.N. et al (1972) Influence of soil temperature on the geotropic responses of corn roots. Agron. Journal 64: 459-462.

16. Newlin, J.J. et al (1949) Corn and corn growing. Chapman and Hall, London.

17. Pfeffer, W. (1904) Pflanzenphysiologie, Ed. II. Kraftwechsel.

18. Russell, E.W. (1973) Soil conditions and plant growth. Tenth edition. Longman, London.

19. Schuurman, J.J. (1971) Methods for the examination of root systems and roots. second edition, Pudoc, Wageningen.

20. Uchendu, V.C. (1069) et al. Economic, cultural and technical determinats of agricultural change in tropical Africa. Food Research Institute, Stanford Un.

21. Veinhmeyer, F.J. (1948) et al. Soil density and root penetration. Soil Sc. 65: 487-495.

22. Wiersum, L.K. (1957) The relationship of the size and structural rigidity of pores to their penetration by roots. Plant and soil 9: 75-85.

Appendix I.

Profile no. 220 : (Keroka)

Classification : Soil Taxonomy 1970: Mollic Ultic Tropudalf
FAO 1970 : Luvic Phaeozem

Location : Keroka - N.P.K. fertilizer trial

Coordinates : 991480 N.; 71700 E.

Elevation : 6500 ft.

Described by : Verwey

Geomorphology : slightly convex slope of 5%

Parent material : andesitic rock

Relief and slope: normal and sloping

Stoniness : no stones

Erosion : none

Drainage : well drained

Moistness : surface and subsoil moist

Biology : depth of undisturbed soil over 1.50, many krotovinas

Land use : arable land

Soil Profile:

Ap 0 - 19 cm: Dark brown (7.5 YR 3/2) moist; very fine clay; weak fine subangular blocky; loose to very friable, slightly plastic; few coarse, few medium, common fine and common very fine, random, tubular biopores; many krotovinas; gradual and smooth boundary.

A3 19 - 47 cm: Dark brown (7.5 YR 3/2), moist; very fine clay; moderate very fine and fine subangular blocky; very friable, slightly sticky and slightly plastic; few coarse, few medium, common fine and common very fine, random, tubular, continous biopores; many krotovinas; broken clay and humus cutans; gradual and smooth boundary.

B1 47 - 87 cm: Dark reddish brown (5 YR 3/4), moist; very fine clay; moderate very fine and fine subangular blocky; friable, slightly sticky and slightly plastic; many krotovinas; no coarse, few medium, few fine and few very fine, tubular, random, continuous biopores; continuous moderately thick clay cutans; gradual and smooth boundary.

B2 87 - 125 cm: Reddish brown to yellowish red (5 YR 4/4-4/6), moist; very fine clay; moderate very fine and fine subangular blocky; friable, slightly sticky and slightly plastic; continous clay cutans; few krotovinas, colour of the clay cutans dark reddish brown (5 YR 3/4).

Profile no. 216 : (Kisii)

Classification : Soil Taxonomy 1970: Pachic Humoxic Palehumult
Location : Agricultural Research Station, Kisii.
Described by : Verwey
Geomorphology : convex slope of 5 %
Parent material : basaltic rock
Relief and slope : normal relief and nearly level
Stoniness : no stones
Drainage : well drained
Moistness : surface and subsoil moist
Biology : depth of undisturbed soil more than 1.50 m. many krotovinas (5-10/m^2)
Landuse : trial field.

Soil Profile:

Ap 0 - 19 cm: Dark reddish brown (5 YR 3/3) to dusky red (2.5 YR 3/2), moist; very fine clay; weak very friable, very fine and fine subangular blocky; slightly sticky and slightly plastic; few coarse, few medium, common fine and very fine, random, tubular, continuous biopores; many krotovinas; broken clay and humus cutans; gradual and smooth boundary.

B1 19 - 65 cm: Reddish brown (2.5 YR 4/4), moist; very fine clay; weak to moderate very fine and fine subangular blocky; few coarse, few medium, few fine and common very fine, random, tubular, continuous biopores; very friable, slightly sticky and slightly plastic; many krotovinas; broken clay cutans; gradual and smooth boundary.

B21 65 - 85 cm: Reddish brown (2.5 YR 4/4), moist; very fine clay; moderate very fine and fine subangular blocky; friable, slightly sticky and slightly plastic; few coarse, few medium few fine and common very fine, random, tubular, continuous biopores; many krotovinas; broken clay cutans; gradual and smooth boundary.

B22 85 - 125 cm: Red (2.5 YR 4/6), moist; very fine clay; moderate very fine and fine subangular blocky, partly angular blocky; firm, slightly sticky and slightly plastic; few coarse few medium few fine and common very fine, random, tubular, continuous biopores; many krotovinas; less roots than in the overlying horizons; broken clay cutans.

Profile no. 224	: (Rongo)
Classification	: Soil Taxonomy 1970: Humoxic Tropuhumult
	FAO 1970 : Humic Acrisol
Location	: near road from Rongo to Riosiri
Coordinates	: 991560 N., 67940 E.
Elevation	: 4900 ft.
Described by	: Verwey
Geomorphology	: uniform slope of 5%
Parent material	: granitic rock
Relief and slope	: normal, nearly level
Stoniness	: no stones
Drainage	: well drained
Biology	: depth of undisturbed soil at least 2.30 m. common krotovinas (2-5/ m^2)
Land use	: arable land trial field.

Soil profile:

Ap 0 - 12 cm: Dark reddish brown (5 YR 3/3), moist; fine clay; weak very fine and fine subangular blocky; soft to slightly hard, slightly sticky and slightly plastic; few coarse, few medium, few fine and many very fine, tubular, random, continuous biopores; many krotovinas; gradual to abrupt and smooth boundary.

B1 12 - 25 cm: Dark reddish brown (2.5 YR 3/4), when dry and wet; fine clay; moderate to weak very fine subangular blocky; hard, slightly sticky and slightly plastic; few coarse, few medium, few fine and many very fine, random, tubular continuous biopores; broken clay cutans; common krotovinas; gradual and smooth boundary.

B21 25 - 69 cm: Dark reddish brown (2.5 YR 3/4) to dark red (2.5 YR 3/6) moist, fine clay; moderate to weak fine subangular blocky friable, slightly sticky and slightly plastic; few coarse, few medium, few fine and many very fine, random, tubular, continuous biopores; some quarts gravels; common krotovinas; broken clay cutans; gradual and smooth boundary.

B22 69- 105 cm: Dark red (2.5 YR 3/6), moist; fine clay; moderate very fine subangular blocky; very friable, slightly sticky and slightly plastic; few coarse, few medium, few fine and many very fine, random, tubular, continuous biopores; some quarts gravels; broken clay cutans; many krotovinas, gradual and smooth boundary.

B23 105 - cm: Red (2.5 YR 4/6), moist; fine clay; moderate to weak very fine subangular blocky; very friable, slightly sticky and slightly plastic; few coarse, few medium, few fine, many very fine, random, tubular, continuous biopores; some quarts gravels; few krotovinas; broken clay cutans.

Profile no. 221 : (Kitere)
Classification : Soil Taxonomy 1970: Typic Rhodudult
FAO 1970: Orthic Acrisol
Location : few hundred meters west of the former Kitere gold min
Coordinates : 990910 N., 67840 E.
Elevation : 4850 ft.
Described by : Verwey
Geomorpholocy : uniform slope of 5%

Parent material : rhyolitic rock
Relief and slope : slope
Stoniness : some stones on the surface, which do not interfere tillage.
Drainage : well drained
Moistness : topsoil dry and subsoil moist
Biology : in the wall of the pit many large krotovinas depth of undisturbed soil - 0.75 m.
Land use : arable land.

Soil profile:

Ap 0 - 14 cm: dark brown (7.5 YR 3/2), when dry and wet; very fine clay; moderate very fine and fine subangular blocky; continous humus cutans; hard, slightly sticky and slightly plastic few coarse, few medium, many fine and many very fine, random, tubular, continuous biopores; few stones and gravels; gradual and smooth boundary.

A3 14 - 30 cm: Dark brown (7.5 YR 3/2), when dry and wet; very fine clay; moderate fine subangular blocky; very hard, slightly sticky and slightly plastic; few coarse, few medium, many fine and many very fine, random, tubular, continuous biopores; some quarts gravels and stone; gradual and smooth boundary.

B2 30 - 75 cm: Red to dark red (2.5 YR 4/6- 3/6), when dry, red (2.5 YR 4/6), when wet; very fine clay; strong fine angular blocky; very hard, slightly sticky and slightly plastic; continuous thick clay cutans, patchy humus cutans; few coarse, few medium, few fine, many very fine, tubular, random, continuous biopores; few black 2-3 mm sized Mn - concretions; some quarts gravels and stones at a depth of 65 cm very large krotovinas with a diameter of 10 cm ; gradual and smooth boundary.

B3 75 - 95 cm: Red, (2.5 YR 4/6), moist; very fine clay; strong fine angular blocky; friable to firm, slightly sticky and slightly plastic; thick continuous clay cutans; few coarse, few medium, few fine and many very fine, random, tubular, continuous biopores; many black 3-4 mm sized Mn-concretions; many quarts gravels and stones; krotovinas filled with dark brown (7.5 YR 3/2) coloured soil material; gradual and smooth boundary.

C 95 - cm: Rotten rock; colours: red (2.5 YR 4/6), reddish yellow (5 YR 6/8), black (5 YR 2/1), dark red (10 YR 3/6); few coarse, few medium, few fine, common very fine biopores.

Profile no. 225	: (Rongo)
Classification	: Soil Taxonomy 1970: Plintic Umbriorthox
	FAO 1970: Plintic Ferralsol
Location	: Along road Rongo - Rakwaro, Tanzania road
Coordinates	: 991560 N., 67940 E.
Elevation	: 4900 ft.
Described by	: Verwey
Geomorphology	: almost level
Parent material	: granitic rock (laterite)
Relief and slope	: normal, nearly level
Stoniness	: no stones
Drainage	: well drained
Moistness	: topsoil dry, subsoil moist
Biology	: depth of undisturbed soil - 64 cm
	in topsoil many krotovinas
Land use	: arable land

Soil profile:

Ap 0 - 12 cm: Dark reddish brown (5 YR 3/2 - 3/3), when dry, dark brown (7.5 YR 3/2), when wet; fine clay; weak very fine subangular blocky; few coarse; few medium, few fine and many very fine, random, tubular, continuous biopores; slightly hard, slightly sticky and slightly plastic; some black Mn- concretion; humus cutans; many krotovinas; gradual and smooth boundary.

A3 12 - 40 cm: Dark reddish brown (2.5 YR 3/2 - 3/3), when dry and dark brown (7.5 YR 3/2), when wet; fine clay; weak to moderate very fine subangular blocky; few coarse, few medium, few fine and many very fine, random, tubular, continuous biopores; slightly hard, slightly sticky and slightly plastic; some black Mn- concretions; humus cutans; many krotovinas; gradual and smooth boundary.

B3 40 - 64 cm: Dark reddish brown (5 YR 3/4), when dry and wet; fine clay; weak to moderate very fine subangular blocky; slightly hard, slightly sticky and slightly plastic; few coarse, few medium, few fine and many very fine, random, tubular, continuous biopores; some krotovinas; broken clay cutans; discontinuous and vesicular pan; very many Mn- concretions and iron compounds with colours: yellowish red (5 YR 5/6) dark red (2.5 YR 3/6), dark reddish brown (2.5 YR 3/4); gradual and smooth boundary.

L 64 - cm: Yellowish red (5 YR 5/6), dark red (2.5 YR 3/6), dark reddish brown (2.5 YR 3/4), when dry and wet; continuous and nodular pan; unrecognizable structure, texture and consistency; indurated plinthite layer.

Profile no. 223: (Ikoba)

Classification : Soil Taxonomy 1970: Padric Humoxic Palehumult
FAO 1970 : Humic Nitosol

Location : near road Ogembo - Ikoba, few hundred meters south of Itibo - village.

Coordinates : 991230 N.; 68860 E.

Elevation : 5250 ft.

Described by : H.E. Verwey

Geomorphology : concave slope of about 10 %

Parent material : basaltic rock, but in pit layer of quartzitic stones and boulders

Relief and slope: normal and sloping

Stoniness : no stones

Drainage : well drained

Moistness : topsoil dry and subsoil moist

Biology : depth of undisturbed soil - 65 cm many krotovinas

Land use : arable land

Soil Profile:

Ap 0 - 10 cm: Dark reddish brown (5 YR 3/3), when dry and wet; very fine clay; moderate very fine subangular blocky; few coarse, common medium, many fine and many very fine, random, tubular, continuous biopores; hard to very hard, slightly sticky and slightly plastic; some black Mn- concretions and quarts gravels; many krotovinas; humus cutans; clear and smooth boundary.

B1 10 - 50 cm: Dusky red to dark reddish brown (2.5 YR 3/3), when dry, dusky red (2.5 YR 3/2), when wet; very fine clay moderate very fine subangular blocky; few coarse, few medium, many fine and many very fine, random, tubular, continuous, biopores; hard, slightly sticky and slightly plastic; some black Mn-concretions and quarts gravels; many krotovinas; broken to continuous clay and humus cutans; clear and smooth boundary.

B2 50 - 65 cm: Dark red (2.5 YR 3/6), moist; very fine clay; moderate to strong very fine and fine subangular blocky, partly angular blocky; friable, slightly sticky and slightly plastic; few coarse, few medium, many fine and many very fine, random, tubular, continuous biopores; some black Mn-concretions and quarts gravels; krotovinas filled with material from the upper horizons; continuous clay and broken humus cutans; distinct and smooth boundary.

B3.1 65 - 104 cm: Dark red (2.5 YR 3/6), moist; very fine clay; structure unrecognizable because of concretions, no coarse, no medium, common fine and very fine, random, tubular, continuous biopores; very friable, slightly sticky and slightly plastic; very many black Mn-concretions; many boulders, stones and gravels of quartzitic rock; on surfaces of concretions continuous clay cutans; roots penetrate only 15 cm. into this horizon; clear and smooth boundary.

B3.2 104 cm: Dark red (2.5 YR 3/6), moist; very fine clay; structure, bioporosity and consistency as B3 horizon; many black Mn-concretions, no quartzitic boulders or stones; on surfaces of concretions continuous clay cutans.

Profile no. 219	: (Keroka)
Classification	: Soil Taxonomy 1970: Mollic Ultic Tropudalf FAO 1970 : Luvic Phaeozem
Location	: Keroka -'time of planting' trial field
Coordinates	: 991480 N.; 71710 E.
Elevation	: 6550 ft.
Described by	: Verwey
Geomorphology	: uniform slope of 15%
Parent material	: andesitic rock
Relief and slope	: normal and sloping
Stoniness	: no stones
Erosion	: few rills
Drainage	: well drained
Moistness	: topsoil dry and subsoil moist
Biology	: depth of undisturbed soil - over 2 m. many krotovinas
Land use	: arable land

Soil profile:

Ap 0 - 20 cm: Dark brown (7.5 YR 3/2), moist; very fine clay; weak very fine and fine subangular blocky; loose to very friable, slightly sticky and slightly plastic; few coarse few medium, common fine and many very fine, random, tubular continuous biopores; continuous humus cutans; many krotovinas; some quarts gravels; abrupt and smooth boundary.

A3 20 - 31 cm: Dark brown (7.5 YR 3/2), moist; very fine clay; moderate fine and very fine subangular blocky; very friable, slightly sticky and slightly plastic; no coarse, few medium, common very fine, few fine, random, tubular, continuous biopores; broken to continuous humus cutans, patchy clay cutans; less roots than in the Ap horizon; many krotovinas; some quarts gravels; gradual and smooth boundary.

B1 31 - 45 cm: Dark reddish brown (5 YR 3/3), moist; very fine clay; moderate very fine and fine subangular blocky; very friable, slightly sticky and slightly plastic; no coarse few medium, few fine and common very fine, random, tubula continuous biopores; broken thin clay cutans, patchy humus cutans; some quarts gravels; krotovinas with diameter of about 10 cm filled with dark brown (7.5 YR 3/2) soil material; gradual and smooth boundary.

B21 45 - 87 cm: Dark reddish brown (5 YR 3/4), moist; very fine clay; moderate very fine and fine subangular blocky; very friable, slightly sticky and slightly plastic; few coarse few medium, common fine and common very fine, random, tubular, continuous biopores; broken thin clay cutans; some quarts gravels; krotovinas filled with Ap material; gradual smooth boundary.

B22 87 - 120 cm: Dark reddish brown (5 YR 3/4), moist; very fine clay; weak very fine and fine subangular blocky; very friable, slightly sticky and slightly plastic; no coarse, few medium, few fine and few very fine, random, tubular, continuous biopores; in soil mass spheres of more compact material and more clayey with continuous clay cutans; colours of cutans at some places darker; krotovinas filled with dark reddish brown material.