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NUTRIENT AVAILABILITY CLASSIFICATION OF SOILS USED FOR MAIZE IN RIO JIMENEZ DISTRICT, ATLANTIC ZONE OF COSTA RICA

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PREFACE

The work presented in this report was carried out within the context of the Atlantic Zone Programme. The Programme started in 1986 with a diagnostic study of Costa Rica's planning region Huetar Atlántica. Following an exploratory survey, baseline studies were carried out in selected subareas.

Sustained land use in Huetar Atlántica is the central theme of this multidisciplinary research programme. A study of the region's soils and their potential for agricultural use forms an important aspect of the research. Information on this potential is essential for proper land use planning.

The soils' potential depends, amongst other things, on the availability of its nutrients to crops and information on this characteristic is used in land evaluation studies.

The present report on nutrient availability describes a study carried out in the subareas Rio Jimenez and Neguev, in the northern part of Huetar Atlántica. The soil units used in this study were selected from soil maps that had been prepared earlier.

The field work was carried out in the period May-July 1987 whilst the author did a study on workability problems in maize. The laboratory studies were done in the Netherlands in March and April 1988.

The report was presented in partial fulfillment of the Masters Degree in Crop Science of the Wageningen Agricultural University, the Netherlands.

The work was supervised by H. Waaijenberg MSc. of the Programme, and by F.C.T. Guiking MSc. of the Wageningen Agricultural University.

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Dr. Jan F. Wienk
Programme Coordinator

1 INTRODUCTION

In september 1986 the Tropical Agronomic Research and Education Centre (CATIE), the Costa Rican Ministery of Agriculture and Livestock (MAG), and the Agricultural University of Wageningen (AUW) signed a treaty. This treaty implied a multidisciplinary program of agricultural and related research in the Atlantic Zone of Costa Rica, at least till 1990 (CATIE-AUW-MAG, 1986).
The objective of the program is to contribute to the socio-economic and ecological development of the Atlantic Zone (CATIE-AUW-MAG, 1986).

The Atlantic Zone is a wet tropical lowland zone (<250 m above sea level) on the windward side of a volcanic mountain range. Average annual rainfall varies from 3,500 to 4,500 mm, with 2 drier periods, but still without a water deficit. Average maximum temperature is about 30 °C, average minimum temperature is about 20 °C. Air humidity shows little variation around the yearly average of 88 %. For more detailed climatological data on the sample zone see Erenstein (1987).

The program began with an exploratory survey in 1986 of the whole Atlantic Zone, which resulted in the selection of 3 subareas for a baseline study. The 3 subareas are quite different from each other but representative for different phases of agricultural development. The 3 subareas, Cocori, the Neguev settlement, and Rio Jimenez, are all found in the northern part of the Atlantic Zone of Costa Rica (see Figure 1.1), in the Cantons of Pococi, Guacimo, and Siquirres. The coordination centre of the program is based on the premises of the experimental station Los Diamantes, Guapiles.

The 'Lomas' (hills) of Cocori and surroundings are found about 50 km north of Guapiles. The subarea covers some 120 km^2 and is the 'youngest' one of the 3, being opened just some years ago and still consisting partly of primary rain forest.
The settlement of Neguev is found at about 30 km ENE of Guapiles, and covers some 54 km^2. Once it was a large 'hacienda' (estate) which exploited only part of the terrain as pasture. Around 1979 the hacienda was invaded by enchroachers ('precaristas'). The Institute for Rural Development (IDA) entered not much later to guide, organize and plan the development of the settlement.
The subarea of Rio Jimenez is found about 20 km ENE of Guapiles and covers some 55 km^2. It is the 'oldest' one of the 3, being opened 25 years ago (CATIE-AUW-MAG, 1986).

The baseline study began beginning of 1987 with an inventarization by means of 50 interviews in each of the 3 subareas. The second part of the baseline study (March - June 1987) consisted of indepth studies of the more common cropping systems (maize, roots and tubers, cocoa, banana and fruits), and other topics. The outcome of these studies form the basis for the research of the coming years. The nutrient availability classification presented here was done as part of this baseline study.

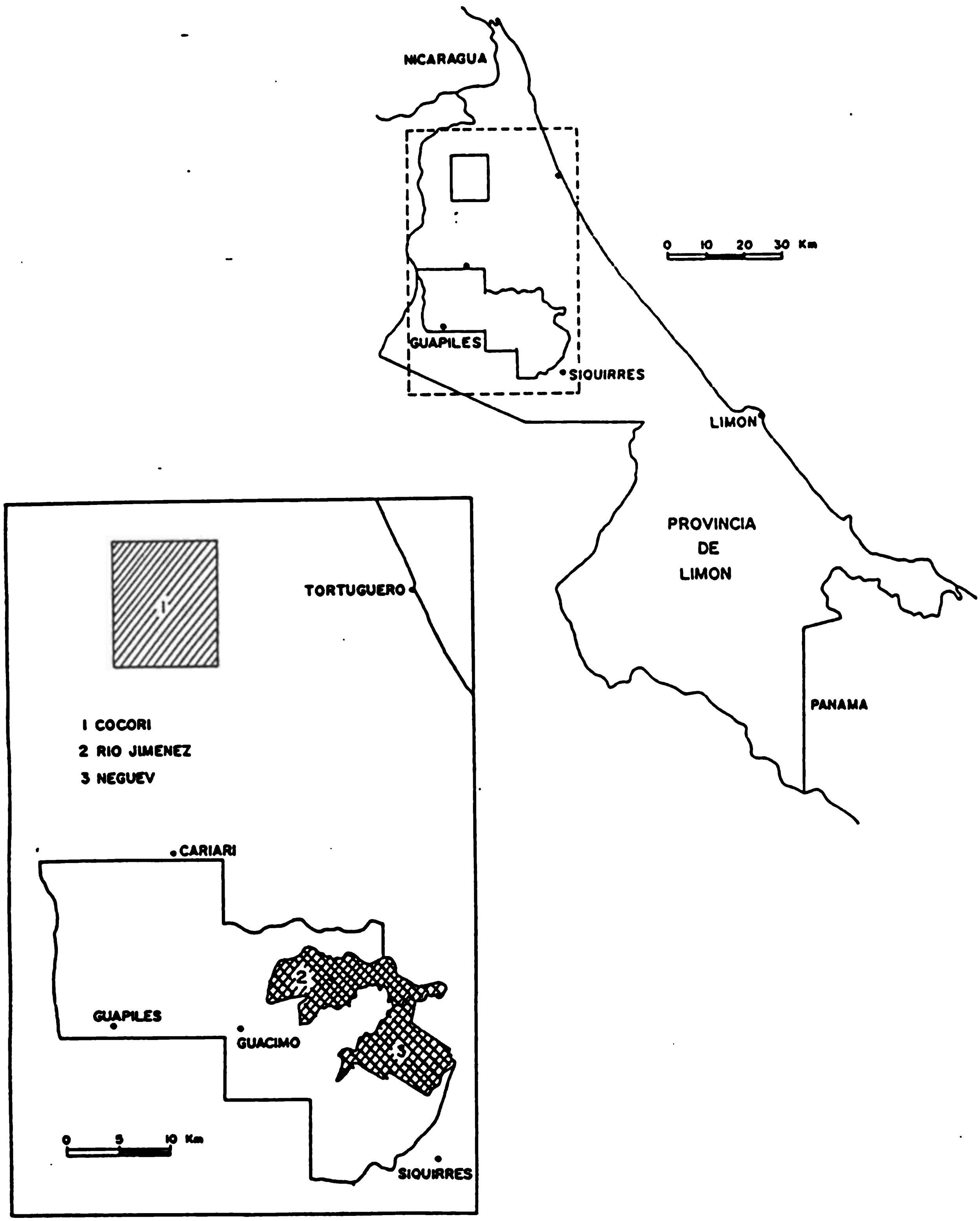

Figure 1.1 Location of subareas and sample area;
/// : subarea;
\\\ : sample area.

By means of soil and plant analysis, and a double pot experiment a classification is made of the N, P, and K availability of some soils used for maize (Zea mays) production in the Rio Jimenez and Neguev subareas. The Cocori subarea was left out for a number of reasons, such as :

* the difference between maize cropping system practised in Cocori and the 2 other subareas (relatively 'extensive', with nearly no inputs, versus 'intensive', with inputs);
* the relatively small numbers of maize fields found in Cocori;
* the distance between Cocori and the drying facilities.

The crop chosen for the analysis was maize as it was by far the most important crop in acreage in the Rio Jimenez and Neguev subareas.

The initial idea to collect leaf samples had to be abandoned due to the lack of drying facilities at the time the samples had to be taken (prior to tasseling). Therefore an alternative was sought in harvesting entire plants at harvest time (during the period May-June 1987, at what time drying facilities were available) to estimate the total dry matter production and total nutrient uptake. Next to the plant samples, soil samples were collected from the same field. The soil and plant samples were analysed in Wageningen end 1987.

The analysed soil units are Aluvial, Bosque, Cristina, Milano, Parismina and Union. From these soil series respectively 3, 5, 7, 6, 10 and 3 fields were sampled. From other soil units an even smaller number (< 3) of fields was available, and they were left out of this study.

In the following use is made of 90 % confidence intervals to compare the different averages of the soil series. These 90 % confidence intervals are all calculated by means of the following formula:

$$\bar{x} \pm t_{(n-1)}(0.05) * \frac{s}{\sqrt{n}}$$

where $\bar{x}$: mean;
n : number of data on which average is based;
s : standard deviation;
$t_{(n-1)}(0.05)$: tabulated value in Student's t-table for (n-1) degrees of freedom and the 5% level of significance.

Aluvial, Cristina and Union samples come from the Rio Jimenez subarea. Milano and Parismina samples mainly come from the Neguev subarea. Bosque samples come from the Neguev subarea.
The Neguev samples were taken mainly from the area north of Rio Parismina.

From each soil series one soil was selected for a 'missing element' pot experiment to determine the nutrient supplying capacity of the soil. This experiment took place in the greenhouses of the Department of Soil Science and Plant Nutrition of the AUW from the 9th of March to the 5th of April 1988.

This paper consists of 7 chapters, the 1st being the introduction.
The 2nd chapter gives a brief analysis of the sample field selection, plant and soil sampling methods used for this study.
The 3rd chapter presents the field input, management and yield data for each of the soil series analysed.
The 4th chapter presents the soil analysis results of pH(H2O), P-Olsen, K(HCl), and C-Kurmies per soil series. On basis of these results nutrient-limited grain yield per soil series is estimated by use of QUEFTS for fertilized and unfertilized sample fields.
The 5th chapter presents the plant analysis results of N, P, and K content of the plant samples collected from the sample fields. On basis of these results and the output data, actual uptake and removal of these 3 nutrients are estimated per cropping season per soil series.
The 6th chapter presents the results of a double pot experiment with 1 soil per soil series in the form of 'Sufficiency Quotients' of N, P, and K.
The 7th chapter presents the conclusions.

In this paper frequent use is made of the following abbreviations for the soil units/series:

A : Aluvial;
Bo : Bosque;
Cr : Cristina;
Mi : Milano;
Pa : Parismina;
Un : Union.

2 SAMPLING METHODS

In the following a brief account is given of the methods used in this research for field, plant, and soil sampling.

Sample field selection

The initial idea was to choose at random about 5 fields for the most common soil units in the subareas of Rio Jimenez and Neguev. Due to the large amount of soil units and the relatively little number of maize fields for many soil units a random sampling was quite difficult in the restricted area of the subareas. This led to the attempt of sampling as many fields as possible on the most common soil units, as long as maize was cultivated on them. This resulted in the unequal amount of sample fields per soil unit. This unequal amount can thus be seen as a reflection of the amount of maize grown on each soil unit as well as the extension of these soil units in the sample area. However, it is important to realize that the amount of maize grown on a soil unit is not solely dependant on the soil type, but also influenced amongst others by the farming system distribution over the soil units, the availability of better soil types on the farm and the location of the soil types on the farm. As maize is the more important cash crop, it will also be grown on marginal land if (sufficient) better land is unavailable to the farmer.

Only those soil units were analysed for which at least 3 sample fields were taken, each sample field being one small 100 m² area taken at random inside a homogenous part of a larger maize field, taking only one sample field per maize field per farmer. Care was taken to exclude as much as possible disturbing effects as borders, shade of nearby trees, presence of felled trees in the field, and severe weed problems.
The fields were all sampled after the maize crop had reached physiological maturity and before actual harvesting took place. The plant and soil samples were always taken from the same sample field on the same day.
For the background of each field the farmer was asked about land preparation, weed control, fertilizer application, variety used, average age of crop at harvest and average production of the field in question. The row and plant distance were measured in the sample field.

Plant sampling

A sample of 20 plants was gathered from each sample area of approximately 100 m² (10 rows X 10 m, each row normally at about 1 m from each other). These plants were sampled completely at random using random numbers to indicate row number and distance in row, till 20 or more plants were sampled.
The sample plants were cut off just above the ground. From the sampled plants, stem (plus leaf sheath), leaf (only blade), husk, grain and axe samples were seperated. All plant samples were

weighed fresh, and a sub-sample was dried for 48 hours at 80 °C to determine dry matter yield per sample field (see Annex 5). Due to the initial lack of drying facilities and later the restricted capacity of the available drying facilities, drying could be several days after sampling.
A sample of 200 g dry matter of each component of each sample field was send to the Netherlands for further analysis.

Soil sampling

From each sample area 9 soil (sub)samples were taken from the topsoil (top 20 cm), diagonally across the sample field. The 9 soil samples per sample field were mixed and air dried, resulting in one composite sample of approximately 3 kg of air dry soil per sample field. The soil samples were shipped to the Netherlands for further analysis and for the double pot experiment.

3 FIELD DATA

3.1 Introduction

For the sampled fields data were collected on management, input and yield levels of the respective fields. On basis of the plant sample data an estimation is given of the average dry matter production per soil series.

3.2 Field input and management data

In the local maize cropping system land is normally prepared using the 'machete' (long bladed knife) and herbicides (especially herbicides on the basis of paraquat), but also mechanically using harrow and or plough in combination with a pair of oxen or a tractor. The maize is sown manually in rows using a planting stick, with 3 to 4 seeds per hole. This gives on average 2 to 3 adult plants at harvest time, with a plant density normally varying from 35 to 45 thousand plants per ha. The maize crop is normally fertilized twice, the first application consisting of NPK- or N-fertilizers, the second of N-fertilizers. Weed growth is normally controlled by using machete and herbicides. The harvest of the crop normally occurs 4 months after sowing.
Most farmers practice double cropping, i.e. sowing in the beginning of the first and second half of the year (the 2 drier periods).

For a more detailed analysis of the local cropping system of maize the reader is referred to Brink (1987) or Erenstein (1987).

In Annex 2 some data about management and inputs are given for each of the sample fields. On basis of these data it can be said that :

* on each soil series a wide range of varieties is grown, mainly local varieties. Lacking exact background data on each variety it is assumed that they do not differ significantly on factors such as :
  - total dry matter production;
  - dry matter distribution over plant components;
  - nutrient uptake capability;
  - nutrient distribution over plant components;

* different methods of land preparation are practised on the different sample fields per soil series. Since the number of sample fields is to small to allow further differentiation for land preparation, it is assumed that the form of land preparation has no significant influence on production levels and the nutrient balances of the soil;

* nearly all weed control in sample fields is chemical with herbicides on basis of paraquat. Since all farmers practised similar forms of weed control and since all sample fields were chosen in relatively weed free areas, it is assumed that weed

control was satisfactory throughout the critical periods for all the sample fields concerned;

* the 90 % confidence intervals for the average amount of N applied during one cropping season show no significant (10 %) difference between the soil series. In Table 3.1 the average amounts of N applied are shown;

* the 90 % confidence intervals for the average amount of P and K applied during one cropping season show no significant (10 %) differences except for Pa and Un. All confidence intervals, except the one for Pa, include 0 due to the fact that the majority of the farmers only apply N fertilizers. All 3 Un farmers only applied N fertilizer. In Table 3.1 the average amounts of P and K applied are shown.

Table 3.1 Average quantity of N, P and K applied per soil series per cropping season in kg nutrient per ha

		Soil					
Nutrient		A	Bo	Cr	Mi	Pa	Un
N	x	97	66	63	53	65	67
	s	34	31	20	19	30	34
P	x	16	13	3	9	14	0
	s	28	23	9	14	20	0
K	x	8	6	2	4	6	0
	s	14	10	5	6	8	0
	n	3	5	7	6	8	3

3.3 Field output data

In Table 3.2 the average grain yield as estimated by the farmers is given. Also given is dry matter production as estimated from sample data.
In Table 3.3 a ranking in order of decreasing production for these data is given.
The average grain yield was estimated by the farmer in terms of sacks of maize cobs per ha. This quantity was transformed into grain yield (as kg dry matter per ha) by multiplication with the conversion factor 25.2. This factor implies an estimate of average 'filled sack' weight, and a correction for weight of 'empty sack', axe and humidity content (Erenstein, 1987).

Table 3.2 The average grain yield as estimated by farmers, and dry matter production as estimated from sample data per soil series in tons dry matter per ha

Source	Component		A	Bo	Cr	Mi	Pa	Un
			Soil					
Farmer	Grain	x	2.2	2.1	2.4	1.8	2.9	2.3
		s	0.2	0.7	0.8	0.8	1.0	0.4
		n	3	4	7	6	8	2
Sample	Grain	x	3.0	2.1	3.0	2.4	3.7	4.1
		s	1.0	0.9	1.2	0.8	0.9	1.3
		n	3	5	7	6	10	3
	Stalk	x	2.4	1.8	2.3	2.0	2.7	2.7
		s	0.7	0.9	0.6	1.1	0.6	0.9
		n	3	5	6	6	10	3
	Leaf	x	0.9	0.6	0.7	0.6	1.0	1.1
		s	0.5	0.3	0.3	0.3	0.3	0.3
		n	3	5	6	6	10	3
	Total (*)	x	7.7	5.6	7.5	6.1	9.1	9.5
		s	2.5	2.5	2.8	1.5	1.8	2.9
		n	3	5	5	6	10	3

* : Total = grain + stalk + leaf + husk + axe
See Annex 3 for husk and axe data

Table 3.3 Ranking of soil series in order of decreasing yield of grain as estimated by farmer, and dry matter production as estimated from sample data

Source	Component	1	2	3	4	5	6
		Rank number					
Farmer	Grain	Pa	Cr	Un	A	Bo	Mi
Sample	Grain	Un	Pa	A,Cr		Mi	Bo
	Stalk	Pa,Un		A	Cr	Mi	Bo
	Leaf	Un	Pa	A	Cr	Bo,Mi	
	Total (*)	Un	Pa	A	Cr	Mi	Bo

* : Total = grain + stalk + leaf + husk + axe

In Figure 3.1 the 90 % confidence intervals in tons dry matter per ha are shown for grain yield and total dry matter production. From Figure 3.1 it appears that on average farmers tend to underestimate levels of production. This could however well be explained by the fact that the samples were taken from a

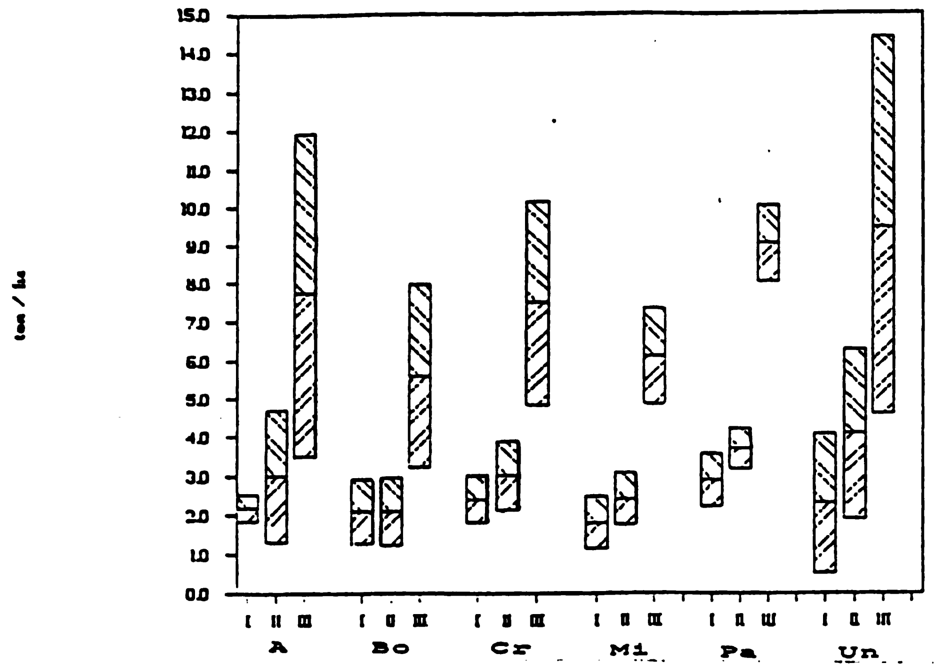

Figure 3.1 90 % confidence intervals in tons dry matter per ha per soil series for :
I : average grain yield as estimated by farmer;
II : average grain yield as estimated from sample data;
III : average total dry matter production as estimated from sample data.

homogenous sample area inside the sample field, whereas farmers base their estimations on the output of the entire sample field. The relative difference between farmer and sample-based estimates is however not equal for all soil units, resulting in a quite different ranking order of decreasing grain yield for the farmer based estimates in comparison to sample based estimates (see Table 3.3).

The sample based grain and dry matter yields as presented in Tables 3.2 and 3.3 suggest that 3 production level groups can be distinguished :

- 'High' : Pa, Un;
- 'Intermediate' : A, Cr;
- 'Low' : Bo, Mi.

Figure 3.1 shows however that the 90 % confidence intervals for average production per soil series overlap in a great deal making statistical proof of these production level groups on basis of these data impossible. For the average grain and average total dry matter production only Pa seems to be significantly (10 %) higher than Bo and Mi. If the other soil series in reality also differ from each other it is here masked by the quite high variation which in most of the cases is not compensated for by an adequate number of samples.

4 SOIL ANALYSIS

4.1 Introduction

All soil samples were analysed for several parameters. On basis of these results nutrient-limited grain yield was estimated.

4.2 Soil analysis results

The soil samples were analysed on pH(H2O), P-Olsen, K(HCl) and C-Kurmies according to the standard procedures as described in Houba et al. (1988). The average results per soil series are given in Table 4.1 (see Annex 4 for data per sample field).

Table 4.1 Average results of pH, P-Olsen, K(HCl) and C-Kurmies for the soil series

		Soil					
Parameter		A	Bo	Cr	Mi	Pa	Un
pH(H2O)	x	5.87	5.56	5.57	5.35	6.15	6.16
	s	0.08	0.13	0.10	0.37	0.21	0.20
P-Olsen	x	4.5	10.3	4.1	3.9	12.6	14.8
mg P / kg	s	1.9	4.5	1.0	2.3	4.8	9.3
K(HCl)	x	8.8	6.0	6.0	5.1	12.7	14.3
mmol K/kg	s	2.4	1.6	2.3	2.9	4.1	9.3
C-Kurmies	x	28.5	27.9	39.9	28.7	36.1	44.9
g C / kg	s	4.6	4.5	10.3	5.3	20.7	10.4
	n	3	5	7	6	10	3

In Figures 4.1, 4.2, 4.3, and 4.4 the 90 % confidence intervals are shown for the soil series averages of respectively pH(H2O), P-Olsen, K(HCl) and C-Kurmies.

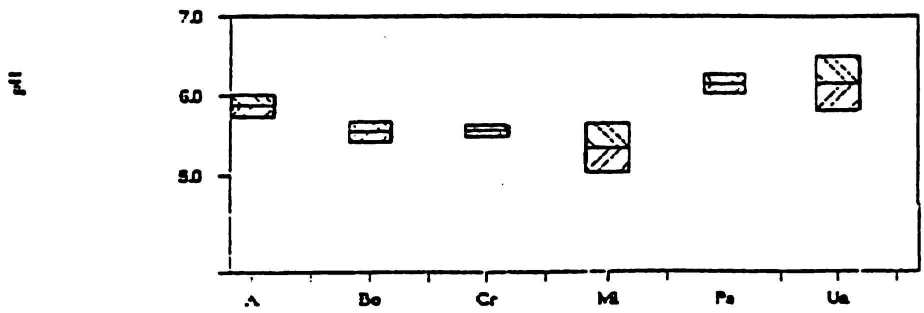

Figure 4.1 90 % confidence interval for the average pH(H2O) per soil series

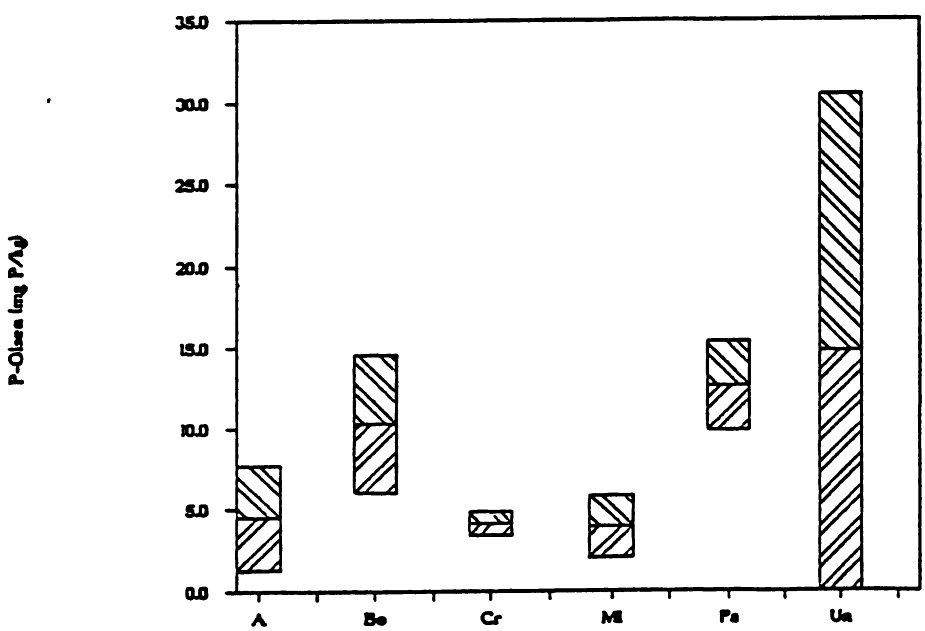

Figure 4.2 90 % confidence intervals for the average P-Olsen in mg P / kg per soil series

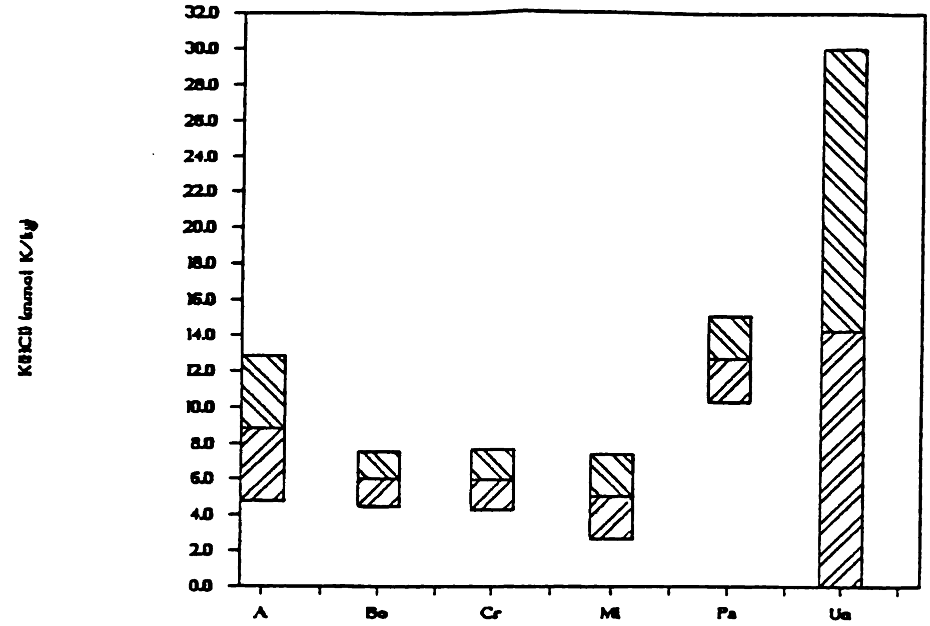

Figure 4.3 90 % confidence intervals for the average K(HCl) in mmol K / kg per soil series

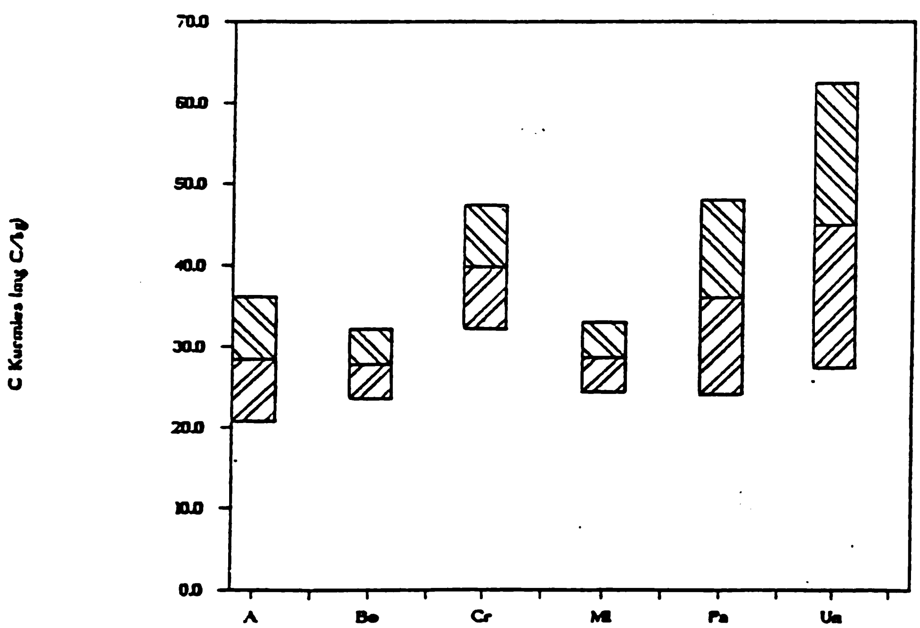

Figure 4.4 90 % confidence intervals for the average C-Kurmies in g C / kg per soil series

pH

The 90 % confidence intervals for average pH(H2O) show that the soil series can be divided into two significantly (10%) different groups according to pH :

- 'High' pH (> 5.7) : A, Pa, and Un;
- 'Low' pH (< 5.7) : Bo, Cr, and Mi.

Only 4 soil samples had pH(H2O) values below 5.4, the value below which aluminium toxicity could occur (Raij, van, 1982). 3 of those 4 samples were Mi samples, resulting in an average pH of 5.35 for the Mi series.

P-Olsen

The 90 % confidence intervals for average P-Olsen show that Pa and Bo have a significantly (10%) higher P availability than Cr and Mi, whereas Pa P availability is also significantly (10%) higher than A.
Classification (according to Landon, 1984) of the P-Olsen values for a maize crop (relatively low P demand) results in an, on average:

* too low P availability in Mi soils;
* too low to questionable P availability in A and Cr soils;
* adequate P availability in Bo, Pa and Un soils.

K(HCl)

The 90 % confidence intervals for average K(HCl) show that Pa has a significantly (10%) higher K availability than Bo, Cr and Mi.
Classification (according to Landon, 1984) of the K(HCl) values results in an, on average:

* intermediate K availability in Mi soils;
* intermediate to high K availability in Bo and Cr soils;
* high K availability in A, Pa and Un soils.

C-Kurmies

The 90 % confidence intervals for average C-Kurmies show that Cr has a significantly (10%) higher C content than Bo.
Classification of the C-Kurmies values by using the broad ratings of organic carbon measurements as presented by Landon (1984) results in an, on average:

* low C content in all investigated soils except Un;
* medium C content in Un soils.

4.3 Estimate of nutrient-limited grain yield

At the Department of Soil Science and Plant Nutrition of the AUW a method was developed to quantify soil fertility (QUEFTS or Quantitative Evaluation of the Fertility of Tropical Soils). The model estimates the nutrient-limited grain yield of maize on basis of soil fertility data and fertilization level.
Average grain yields per soil series as calculated with QUEFTS are given in Table 4.2 (see Annex 3 for per field data). Figure

4.5 shows the 90 % confidence intervals for the average nutrient-limited grain yield and average actual grain yield.
In Table 4.2 and Figure 4.5 a destinction is made between average unfertilized and average fertilized grain yield. For the unfertilized grain yield only the 4 investigated soil parameters (pH, P-Olsen, K(HCl) and C-Kurmies) were considered. Per sample field the nutrient-limited grain yield was estimated. These were then averaged per soil series.
For the fertilized grain yield the 4 investigated soil parameters and fertilizer application were considered. The fertilization level for each field was set at that level that the farmer applied on that specific field (see Annex 2). Since no actual recovery data are available the recovery factors of the fertilizers were set at an arbitrary 50 % for N and K, and at 10 % for P fertilizers. The so calculated fertilized grain yields were then averaged per soil series.

Table 4.2 Average nutrient-limited grain yield as estimated by QUEFTS in tons dry matter per ha

Soil		A	Bo	Cr	Mi	Pa	Un
Unfertilized grain yield	x	5.0	4.5	4.0	3.3	5.8	5.7
	s	0.8	0.6	1.2	1.0	1.4	1.6
	n	3	5	7	6	10	3
Fertilized grain yield	x	5.7	5.1	4.2	3.6	6.0	5.8
	s	1.3	0.6	1.2	0.9	1.5	1.7
	n	3	5	7	6	8	3

Ranking the soil series (in decreasing nutrient-limited grain yield) leads to Pa, Un, A, Bo, Cr and Mi for both unfertilized as fertilized grain yields. However when we look at the difference between average unfertilized and fertilized grain yields (see Table 4.2) it appears that some soil series respond stronger than others to fertilizer application. A, Bo, and to a lesser degree Mi, appear to respond stronger then Cr, Pa and Un. The 90 % confidence interval (see Figure 4.5) for the average nutrient-limited fertilized grain yield overlaps with the 90 % confidence interval for the average nutrient-limited unfertilized grain yield for each soil series. This implies that there is no significant (10%) difference between the average fertilized and average unfertilized nutrient-limited grain yield. It should however not be forgotten that fertilizer application is not the same for every soil nor for every soil series in terms of quantities of each nutrient applied.
It is remarkable that, except for A, the standard deviations of the two averages for each soil series are very alike.

The ranking of the soil series in decreasing nutrient-limited grain yield (see above) leads to a slightly different order than the one found when comparing average estimated actual grain

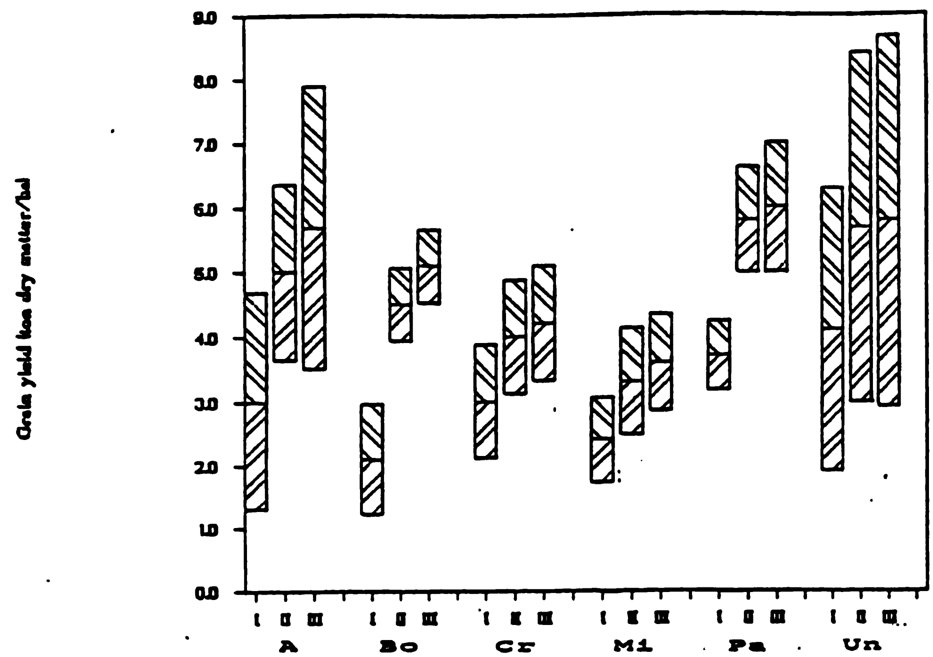

Figure 4.5 90 % confidence intervals in ton dry matter per ha per soil series for average :
I : actual grain yield as estimated from sample data;
II : nutrient-limited unfertilized grain yield as estimated by QUEFTS;
III : nutrient-limited fertilized grain yield as estimated by QUEFTS.

yield, which was Un, Pa, A, Cr, Mi, and Bo. The lower ranking of Bo soils for actual grain yield could be the result of the bad drainage qualities of these soils (field observation).

Figure 4.5 shows that in most cases the 90 % confidence intervals for nutrient-limited fertilized grain yield overlap, but that Bo and Pa appear to be significantly (10 %) higher than Mi.
The difference in nutrient-limited fertilzed grain yield of Mi and Pa coincides with the significant (10 %) difference between the actual yield levels of these soils. The difference found in actual grain yield for these 2 soils can thus be explained (in part) on basis of the 4 investigated fertility parameters.
The significant (10 %) difference between Bo and Mi nutrient-limited fertilized grain yield does however not coincide with the non-significant (10 %) difference in actual grain yield.

Only for Bo and Pa do the 90 % confidence intervals for average nutrient-limited fertilized grain yield not overlap with the 90 % confidence intervals for average actual grain yield of the same soil series. This suggests that other factors than the investigated soil fertility parameters (also) limit grain

production on Bo and Pa soils significantly (10 %). The fact that Bo soils are significantly (10%) limited by other than the 4 factors investigated helps to explain why the significant (10%) difference between Bo and Mi for nutrient-limited fertilized grain yield does not coincide with the non-significant (10%) difference in actual grain yield (see above).
The difference between nutrient-limited fertilized grain yield and actual grain yield is much bigger for Bo than for Pa. This suggests that Bo is more severely limited in its grain production by other than the 4 investigated soil fertility factors than Pa. This explains why the non-significant (10%) difference between Bo and Pa for nutrient-limited fertilized grain yield does not coincide with the significant (10%) difference between actual grain yield.
It thus appears that the 4 investigated soil parameters were insufficient to explain all the differences found in fertility.

In Figure 4.6 nutrient-limited fertilized grain yield is plotted against actual grain yield for the investigated sample fields. The figure shows a reasonably positive correlation between the two.
Results of Nieuwenhuyse (1988) suggest that a better relation between nutrient-limited and actual grain yield is obtained if total N and total P are used as well in QUEFTS (next to the other 4 soil fertility parameters). These data were however not analysed in this study.

For those soils where actual grain yields are very much lower than the nutrient limited grain yield (those soils below the 50 % line) other factors then the investigated soil parameters appear to be severely limiting maize dry matter production. In the case of Bo38 the very low actual grain yield can in part be explained by the extreme low planting density found in that sample field.

For those soils where actual grain yields are higher than the nutrient-limited grain yield (i.e. those soils above the 100 % line) no reasonable explanations can be given on basis of the collected data.

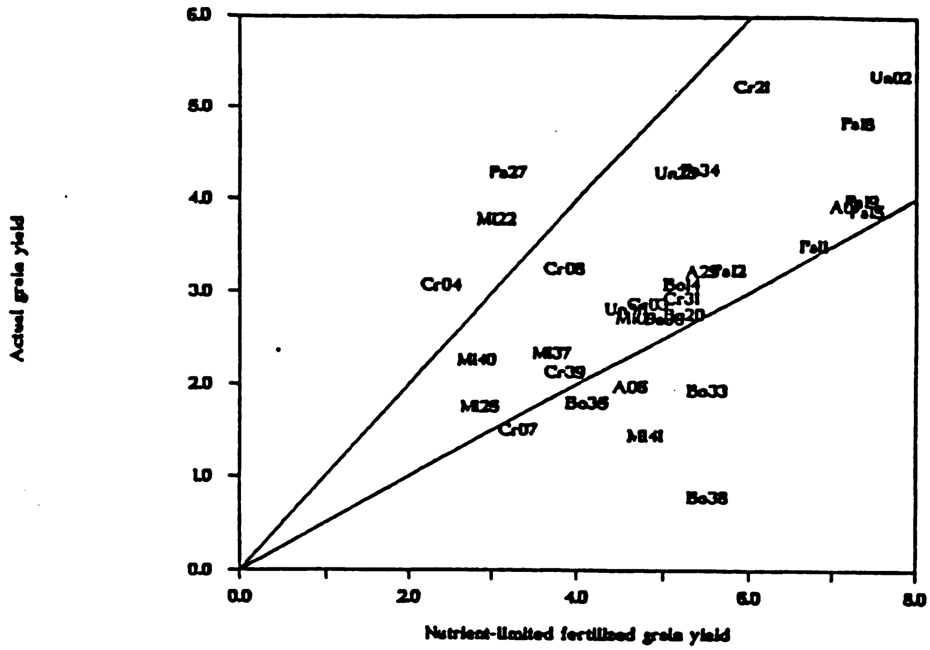

Figure 4.6 Nutrient-limited fertilized grain yield versus actual grain yield (both in tons dry matter per ha) per sample field. Top line represents line where nutrient-limited grain yield equals actual grain yield (100% line), bottom line represents line where 50 % of nutrient-limited grain yield equals actual grain yield

5 PLANT ANALYSIS

5.1 Introduction

Per sample all plant components were analysed seperately on N, P, and K content. Using these results and the actual dry matter production data, an estimation is given of the actual uptake and removal of these 3 nutrients per cropping season per soil series.

5.2 Plant analysis results

The different plant components per sample were analysed on N, P and K content according to the standard procedures as mentioned in Houba et al. (1985). In Table 5.1 the average N, P and K content are given for grain, stalk and leaf per soil series (see Annex 5 for per sample field data and data on nutrient content of axe and husk).

In Table 5.2 a ranking of the soil series is given for N, P, and K content of grain, stalk and leaf.

Table 5.1 Average N, P and K content (%) of grain, stalk and leaf per soil series

			Soil					
Nutrient	Sample		A	Bo	Cr	Mi	Pa	Un
N	Grain	x	1.82	1.58	1.89	1.78	1.82	1.81
		s	0.04	0.11	0.55	0.11	0.06	0.14
	Stalk	x	0.71	0.55	0.65	0.65	0.60	0.69
		s	0.13	0.27	0.17	0.13	0.12	0.09
	Leaf	x	1.02	1.29	1.40	1.34	1.40	1.42
		s	0.64	0.49	0.20	0.13	0.33	0.07
P	Grain	x	0.26	0.25	0.24	0.23	0.27	0.28
		s	0.02	0.04	0.03	0.03	0.02	0.05
	Stalk	x	0.10	0.08	0.07	0.06	0.09	0.09
		s	0.02	0.04	0.01	0.03	0.04	0.02
	Leaf	x	0.11	0.13	0.12	0.10	0.16	0.16
		s	0.07	0.06	0.02	0.02	0.05	0.02
K	Grain	x	0.36	0.35	0.32	0.33	0.36	0.37
		s	0.03	0.04	0.03	0.03	0.04	0.02
	Stalk	x	2.20	1.85	1.52	1.37	2.36	2.77
		s	0.28	0.33	0.50	0.43	0.41	0.66
	Leaf	x	0.81	0.64	0.66	0.47	1.22	1.37
		s	0.61	0.37	0.28	0.20	0.49	0.23
	Grain	n	3	5	7	6	10	3
	Stalk	n	3	5	6	6	10	3
	Leaf	n	3	4	5	6	10	3

Table 5.2 Ranking of soil series in order of decreasing average N, P and K content (%) of grain, stalk and leaf per soil series

Nutrient	Sample	Rank 1	2	3	4	5	6
N	Grain	Cr	A,Pa		Un	Mi	Bo
	Stalk	A	Un	Cr,Mi		Pa	Bo
	Leaf	Un	Pa,Cr		Mi	Bo	A
P	Grain	Un	Pa	A	Bo	Cr	Mi
	Stalk	A	Pa,Un		Bo	Cr	Mi
	Leaf	Pa,Un		Bo	Cr	A	Mi
K	Grain	Un	A,Pa		Bo	Mi	Cr
	Stalk	Un	Pa	A	Bo	Cr	Mi
	Leaf	Un	Pa	A	Cr	Bo	Mi

From Tables 5.1 and 5.2 it appears that :
* the Bo series had a relatively low N content for all plant components;
* the Mi series had a relatively low P content for all plant components. The Mi series is followed by Cr and than Bo;
* the Mi series had a relatively low K content for all plant components. The Un series had a relatively high K content for all plant components.

In Figures 5.1, 5.2 and 5.3 the 90 % confidence intervals for respectively N, P, and K content are shown for grain, stalk and leaf.

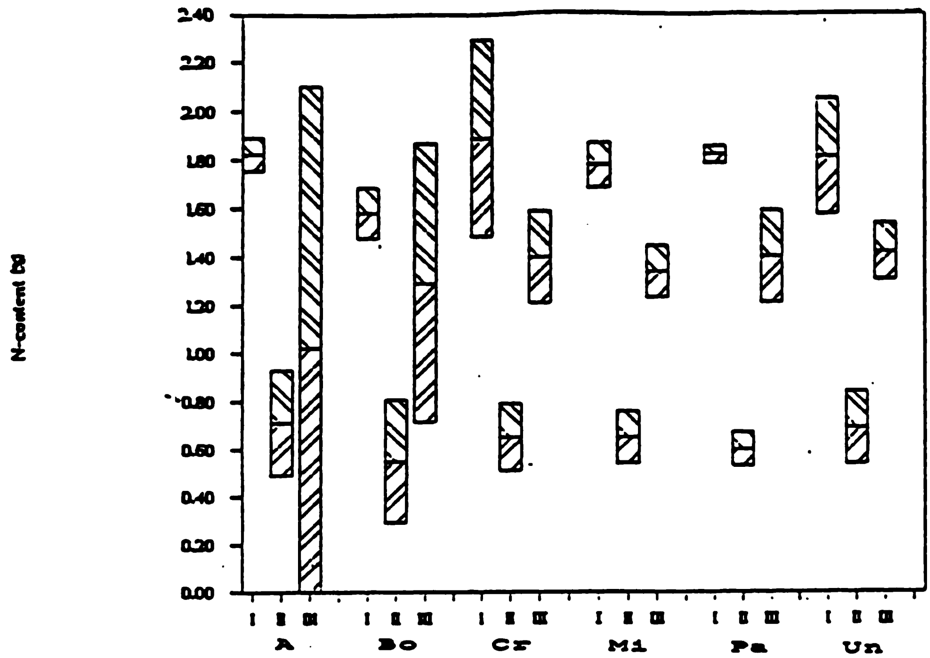

Figure 5.1 90 % confidence intervals (in %) per soil series for :
I : average grain N content;
II : " stalk " ;
III : " leaf " .

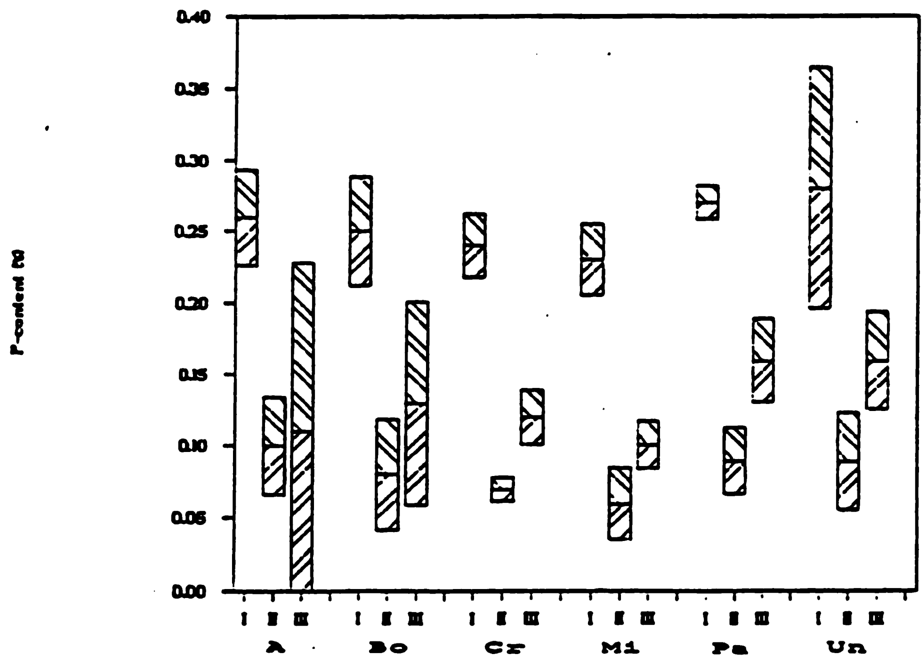

Figure 5.2 90 % confidence intervals (in %) per soil series for :
I : average grain P content;
II : " stalk " ;
III : " leaf " .

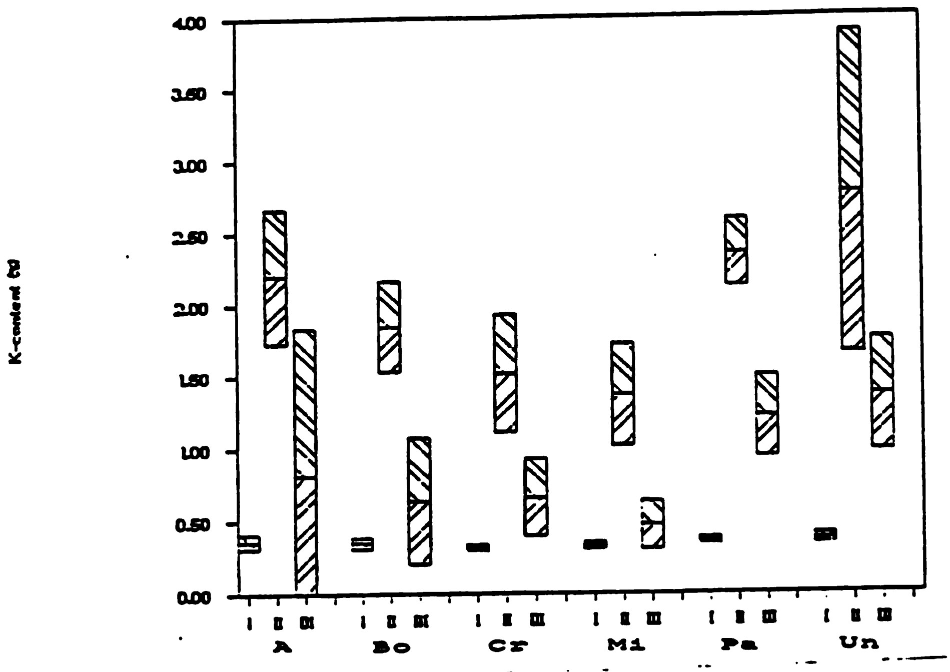

Figure 5.3 90 % confidence intervals (in %) per soil series for :
I : average grain K content;
II : " stalk " ;
III : " leaf " .

N content
At harvest time the N nutrient content of the grain is the most representative for the N status of the plant.
The 90 % confidence interval for the average N content of grain for Bo is significantly (10 %) lower than for A, Mi, and Pa.

P content
At harvest time the P nutrient content of the grain is the most representative for the P status of the plant.
The 90 % confidence interval for the average P content of grain for Mi is significantly (10 %) lower than for Pa.

K content
At harvest time the K nutrient content of the stalk and leaves are the most representative for the K status of the plant.
For the 90 % confidence intervals for the average K content of stalks, Pa and Un appear to be significantly (10 %) higher than Mi, Pa also being significantly (10 %) higher than Cr.
For the 90 % confidence intervals for the K content of the leaves, Pa and Un appear to be significantly (10 %) higher than Cr and Mi, Un also being significantly (10 %) higher than Bo.

The conclusions related to these findings will be presented at the end of this chapter.

5.3 Estimate of actual nutrient uptake and removal

Using the actual dry matter production data (see Annex 3) and the N, P and K contents as found in the plant analysis (see Annex 5) actual uptake is calculated per plant component and per crop, as well as removal per cropping season for the different soil series (see Annex 6 for per sample field data).
In the calculation of the nutrient uptake only the above ground parts were considered. In the following the nutrient content of the grain initially sown to produce the crop was ignored.

Removal is here defined as the amount of nutrients that leaves the field per cropping season by means of that part of the crop that is harvested and removed (in this case grain and axe). The husks, stalks and leaves of the maize plants are left on the field, and nutrients in these parts may thus become available in subsequent cropping seasons.

The amount of nutrients removed by harvest, as well as those nutrients lost by leaching, erosion and other causes, should be compensated for by fertilizers to maintain actual fertility levels (as long as they are not compensated for by other means). Here only data of removal by crop are available, but it should not be forgotten that especially in humid lowland tropics a lot of factors contribute to the loss of nutrients from the rootzone.

Comparison of the actual removal of N, P and K (see Annex 5) with the actual fertlilizer input (see Annex 2) per sample field shows that :

* 11 of the 32 farmers do not apply enough N;
* 24 " " 32 " " " " " P;
* 27 " " 32 " " " " " K to compensate for removal.

It also appears that none of the 32 farmers that participated in this study apply secundary macro or micro-elements.

These data, which do not include losses of nutrients other than by crop removal, suggest that at this rate actual fertility levels will not be maintained and probably will deteriorate in most of the farms in the long run. Weathering and deposition will however always compensate some of the loss.

In Table 5.3 estimates are given for average actual N, P and K uptake per plant component and per crop, as well as removal per cropping season for the different soil series.

In Figures 5.4, 5.5 and 5.6 the 90 % confidence intervals for respectively N, P, and K are shown for supply, uptake and removal.

Table 5.3 Average N, P and K uptake for grain, stalk, leaf and all above ground parts, and removal per crop per soil series in kg nutrient per ha (Total=grain+stalk+leaf+axe+husk)

Nutrient	Plant			Soil A	Soil Bo	Soil Cr	Soil Mi	Soil Pa	Soil Un
N	Uptake	Grain	x	55.3	32.3	57.4	42.1	67.6	76.1
			s	18.2	13.6	28.2	13.7	16.5	28.3
		Stalk	x	17.4	8.7	14.6	11.8	16.0	18.7
			s	7.0	4.4	4.2	4.4	3.1	7.2
		Leaf	x	10.9	9.1	10.5	8.2	13.7	14.9
			s	9.2	7.8	4.6	4.3	5.7	4.3
		Total	x	88.4	44.6	82.6	66.1	103.2	114.6
			s	34.1	20.5	36.0	15.3	17.5	40.4
	Removal		x	57.4	33.7	59.2	43.7	69.7	78.0
			s	18.9	14.2	28.4	14.1	17.1	28.8
P	Uptake	Grain	x	8.1	5.0	7.2	5.4	10.1	11.9
			s	3.0	1.8	2.9	1.4	2.2	5.5
		Stalk	x	2.4	1.4	1.6	1.5	2.4	2.4
			s	0.9	0.6	0.5	1.7	0.9	1.2
		Leaf	x	1.2	0.8	0.9	0.6	1.6	1.7
			s	1.1	0.5	0.4	0.5	0.6	0.7
		Total	x	12.1	6.5	10.1	7.9	14.8	16.5
			s	4.6	2.5	4.3	2.1	2.1	7.3
	Removal		x	8.2	5.1	7.3	5.6	10.3	12.0
			s	3.0	1.8	2.9	1.4	2.2	5.5
K	Uptake	Grain	x	11.0	6.9	9.5	7.7	13.2	15.2
			s	4.2	2.5	3.3	2.7	2.8	5.4
		Stalk	x	53.8	34.3	37.0	27.2	63.2	76.1
			s	21.3	17.0	18.1	16.9	14.6	34.6
		Leaf	x	9.0	3.7	5.2	3.2	12.3	14.0
			s	8.2	2.0	2.7	2.3	6.6	3.3
		Total	x	81.4	51.3	58.8	44.3	98.9	113.7
			s	35.9	28.8	29.1	18.7	21.7	45.4
	Removal		x	14.0	9.7	12.1	10.0	16.4	18.1
			s	5.2	4.2	3.7	3.3	3.9	6.3
	Uptak	Grain	n	3	5	7	6	10	3
		Stalk	n	3	5	6	6	10	3
		Leaf	n	3	4	5	6	10	3
		Total	n	3	3	5	6	10	3
	Removal		n	3	5	7	6	10	3

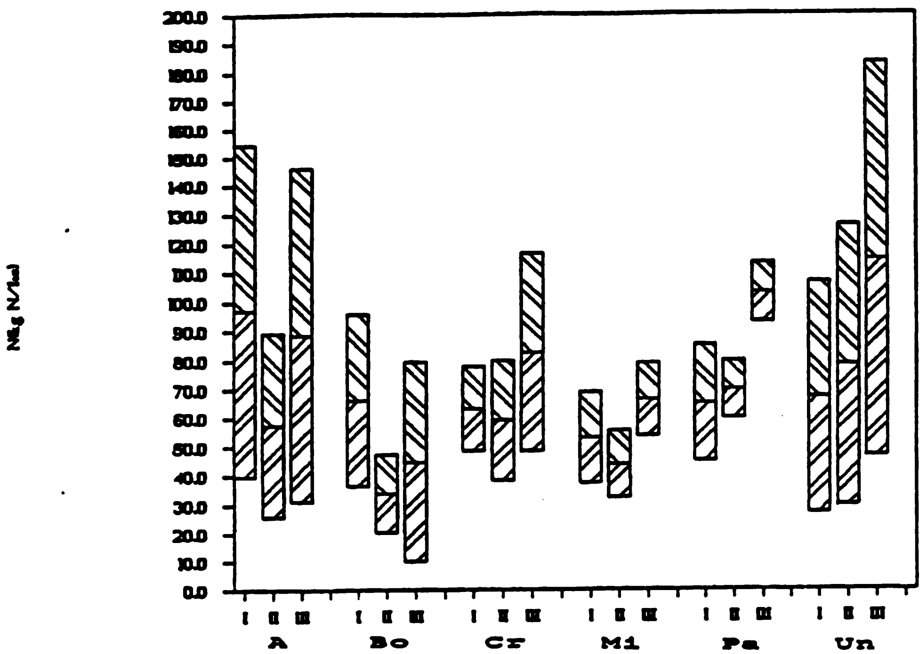

Figure 5.4 90 % confidence intervals (in kg N/ha) per soil series
for :
I : average N-supply by means of fertilizer;
II : average N-removal by harvest;
III : average N-uptake per crop.

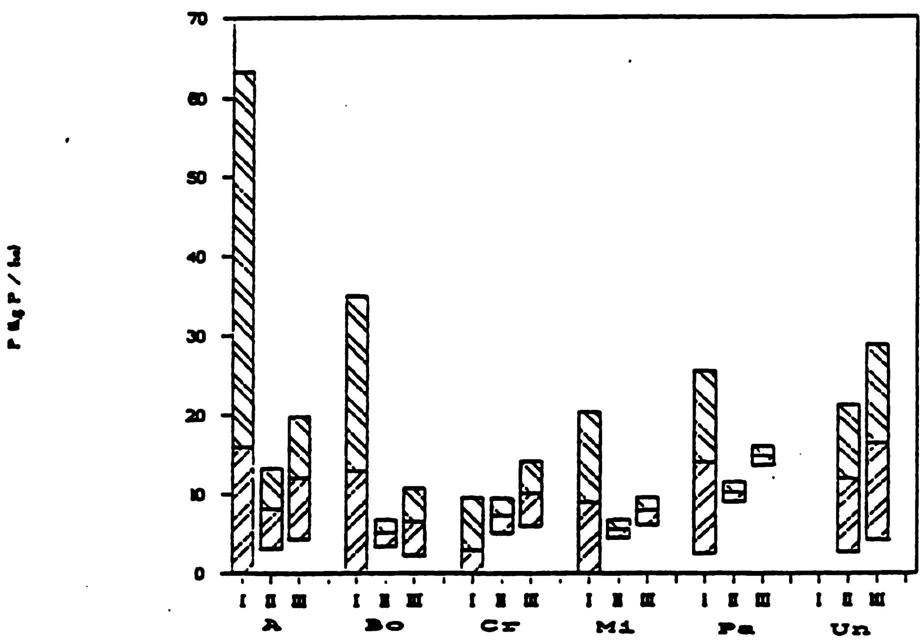

Figure 5.5 90 % confidence intervals (in kg P/ha) per soil series
for :
I : average P-supply by means of fertilizer;
II : average P-removal by harvest;
III : average P-uptake per crop.

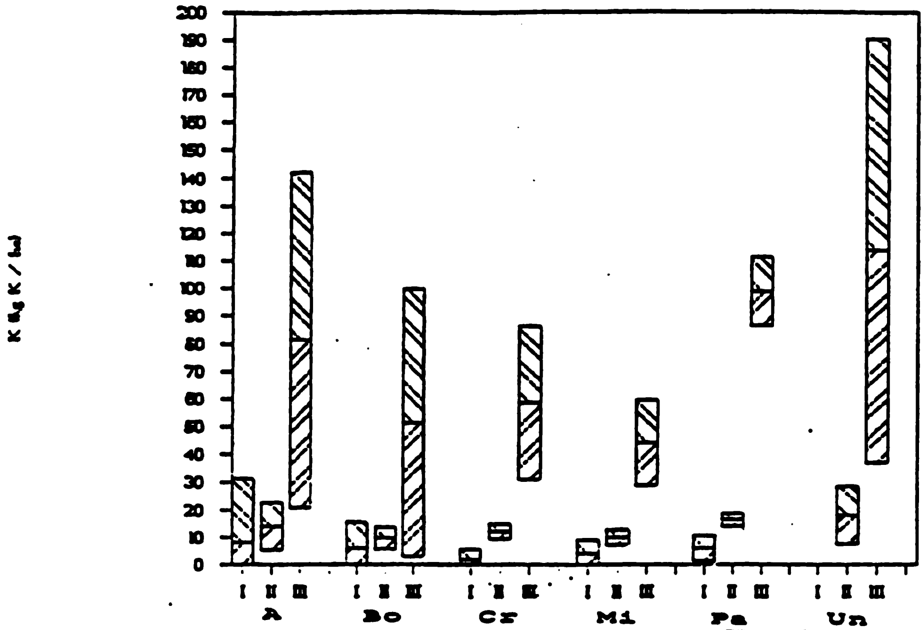

Figure 5.6 90 % confidence intervals (in kg K/ha) per soil series for :
I : average K-supply by means of fertilizer;
II : average K-removal by harvest;
III : average K-uptake per crop.

Uptake was calculated by multiplying above ground dry matter production by nutrient content. Therefore only in the cases where a low uptake is caused by a low level of both components, is the low uptake an indication of low nutrient availability.

N uptake

The 90 % confidence intervals for the average N uptake greatly overlap for the different soil series except for Bo and Mi, both of which appear to be significantly (10 %) lower than Pa.
Looking back at the dry matter production and N content data presented earlier, it appeared that both Bo and Mi had significantly (10 %) lower dry matter productions than Pa, but only Bo had a significantly (10 %) lower N content (of the grain). This suggests that another factor than N availability is responsible for the low dry matter production and consequent low N uptake in Mi soils.
It can be concluded that in comparison to the other Costa Rican soils N availability appears to be relatively low in Bo soils.

P uptake

The 90 % confidence intervals for the average P uptake greatly overlap except for Bo and Mi, which appear to be significantly (10 %) lower than Pa.
Looking back at the dry matter production and P content data presented earlier, it appeared that both Bo and Mi had significantly (10 %) lower dry matter productions than Pa, but only Mi had a significantly (10 %) lower P content (of the grain) than Pa. This suggests that another factor than P availability is responsible for the low dry matter production and consequent low P uptake in Bo soils.
It can be concluded that in comparison to the other Costa Rican soils P availability appears to be relatively low in Mi soils.

K uptake

As can be seen from Figure 5.6, K uptake is many times higher than K removal. Since K supply is not even enough to compensate for removal, the plants depend mainly on the K reserve in the soil for their K uptake.

The 90 % confidence intervals for the average K uptake greatly overlap except for Cr and Mi, which appear to be significantly (10 %) lower than Pa.
Looking back at the dry matter production and K content data presented earlier, it appeared that only Mi had a significantly (10 %) lower dry matter production than Pa, but both Cr and Mi had a significantly (10 %) lower K content (of stalk and leaf) than Pa. This suggests that K availability is not a limiting factor for dry matter production in Cr soils.
It can be concluded that in comparison to the other Costa Rican soils K availability appears to be relatively low in Mi soils.

6 DOUBLE POT EXPERIMENT

6.1 Introduction

The principle of a double pot experiment (Janssen, 1974) is that young plants (in this case maize) can take up nutrients simultaneously from the soil to be investigated and from a nutrient solution. When a nutrient is omitted from the solution, plants can take it up from the soil only. The difference in growth between plants on a deficient and complete solution, expressed in the so-called 'Sufficiency Quotient' (SQ), is an estimate of the availability of the nutrient in the soil.
The sufficiency quotient of N is calculated by :

$$SQ\ N = \frac{(Rs)\text{-}N}{(Rs)C}$$

where (Rs)-N : relative increase in plant size per unit of time of plants on a solution only lacking N;
(Rs)C : relative increase in plant size per unit of time of plants on a complete solution (all nutrients added).

The parameter Rs is calculated by means of linear regression of the following function :

$$Rs = \frac{(\ln S[i+1] - \ln S[i])}{t[i+1] - t[i]}$$

where S[i] : sum of the lengths of the individual leaves (in cm) on the i-th measurement. Length being measured from plant base to leaf tip;
t[i] : day on which i-th measurement took place;
i : number of the measurement (i = 1,...,6).

Measurements must take place during the exponential growth phase of maize. In this case 6 measurements took place from 14 days up to 27 days after sowing, at a 2-3 days interval.

To keep the experiment within reasonable proportions only one soil of each of the 6 soil series (A, Bo, Cr, Mi, Pa and Un) was investigated. The selection of the soils to be investigated in the double pot experiment was based on the known field, soil and plant analysis data of the sampled fields. An attempt was made to select the most 'average' sample per soil series ('average' in terms of the dry matter production levels achieved, the analysed soil parameters, nutrient-limited grain yield, nutrient contents, and total nutrient uptake). The selected soil was also supposed to have an actual grain yield lying in between 50 % and 100 % of the nutrient-limited fertilized grain yield (see Figure 6.1).
This resulted in the selection of the following 6 soils : A29, Bo14, Cr03, Mi37, Pa15 and Un28. Standard soils were Eng and Loess.

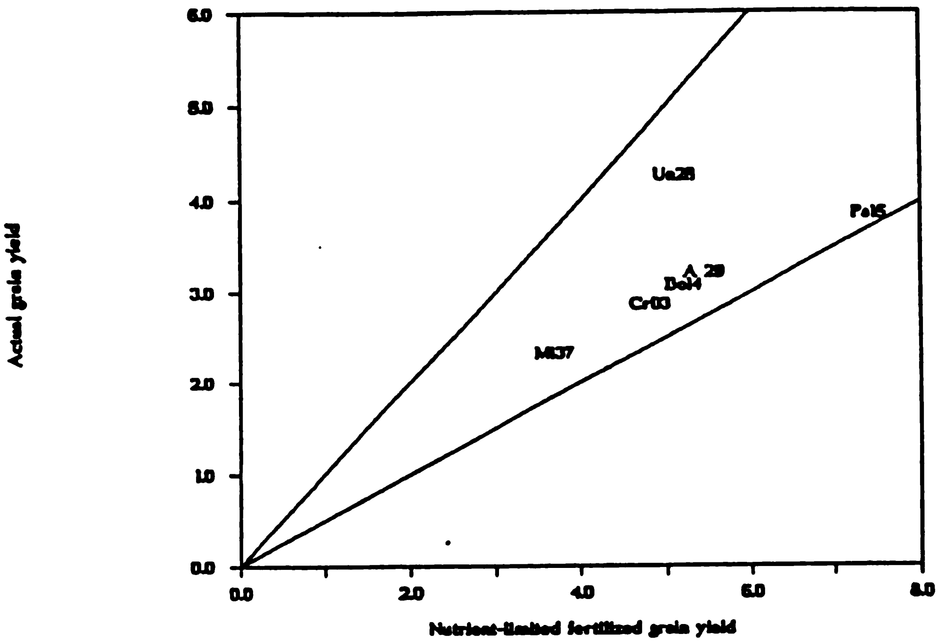

Figure 6.1 Nutrient-limited fertilized grain yield versus actual grain yield (both in tons dry matter per ha) for the selected soils. Top line represents line were nutrient-limited fertilized grain yield equals actual grain yield, bottom line represents line were 50 % of nutrient-limited fertilized grain yield equals actual grain yield

The experiment was set up in 3 blocks of 40 pots each. Per block each of the 8 soils had the following treatments :

- 2 pots with complete solution (control);
- 1 " " minus N " ;
- 1 " " " P " ;
- 1 " " " K " .

6.2 Results of double pot experiment

The results of the experiment are tabulated in Tables 6.1, for SQ N, SQ P, and SQ K (see Annex 6 for per block data). In the table the results of the statistical analysis according to Tukey are shown.

Table 6.1 SQ N, SQ P and SQ K values for the investigated soils and group forming according to Tukey at the 5 % level of significance

Soil	Mean SQ N (*)	(**)	Mean SQ P (*)	(**)	Mean SQ K (*)	(**)
Cr03	0.87	a	0.68	b	0.98	a
Mi37	0.86	a	0.76	a b	1.07	a
Pa15	0.83	a b	0.80	a b	0.96	a
A 29	0.79	a b	0.78	a b	1.03	a
Bo14	0.78	a b	0.73	a b	0.96	a
Loess	0.78	a b	0.81	a b	0.98	a
Un28	0.74	a b	0.74	a b	0.97	a
Eng	0.65	b	0.93	a	0.89	a

* : average of 3 replications;
** : any 2 means for the same SQ which have the same letter are not significantly different at the 5 % level of significance.

The results show that the Eng soil appears to have a significantly (5 %) lower SQ N than Cr03 and Mi37, and a significantly (5 %) higher SQ P than Cr03.
The results show no signifficant (5 %) differences between the investigated Costa Rican topsoils for neither SQ N, SQ P, or SQ K. The fact that no significant (5 %) differences were found as compared to the earlier found significant (10 %) differences between soil fertility parameters, nutrient content of plant samples, nutrient uptake, grain yield and dry matter production could have numerous explanations.
One explanation could be that the factors most limiting nutrient availability are not actually found in the topsoil but underneath. This could explain some of the differences related to the plant analysis, but is not relevant for the differences found between the nutrient limited yields, since these are entirely based on topsoil data. Another explanation could be that the undisturbed soils possess characteristics that worsen nutrient availability for the maize crop, for example imperfect drainage. It is however impossible to give the actual explanation on basis of the data collected for this study.

The results do however show that the investigated Costa Rican soils have SQ N values $\leq$ 0.90, SQ P values $\leq$ 0.80 and SQ K values $\geq$ 0.95. This suggests that insufficient N and P, but sufficient K, are available in these soils for maximum maize growth.

7 CONCLUSION

Based on the **soil analysis** the following can be concluded :

* nutrient-limited grain yield : Parismina soils have a significantly (10%) higher average nutrient-limited grain yield than Cristina and Milano soils;

* pH : Aluvial, Parismina and Union soils have a significantly (10%) higher average pH (>5.7) than Bosque, Cristina and Milano soils;

* P availability : Milano soils appear to have a deficient, whereas Aluvial and Cristina soils appear to have a deficient to questionable P availability. Bosque, Parismina and Union P availability apeared to be adequate. Parismina and Bosque P availability appeared to be significantly (10%) higher than that of Milano;

* K availability : Milano soils appeared to have an intermediate K availability, Bosque and Cristina soils an intermediate to high, and Aluvial, Parismina and Union a high K availability. Parismina K availability appeared to be significantly (10%) higher than those of Milano, Bosque and Cristina;

* organic C : All the investigated Costa Rican soils, except Union, had a low average C content. Union had a medium C content;

* other factors : Other factors than pH, P and K availability and organic matter content limit maize grain yield on Bosque and to a lesser degree Parismina soils, more than they limit the other investigated Costa Rican soils.

Based on the **plant analysis** the following can be concluded :

* actual grain and total dry matter production : Parismina soils have a significantly (10%) higher average grain yield and total dry matter production than Bosque and Milano soils;

* N availability : In comparison to the other Costa Rican soils investigated, N availability appeared to be relatively low in Bosque soils;

* P availability : In comparison to the other Costa Rican soils investigated, P availability appeared to be relatively low in Milano soils;

* K availability : In comparison to the other Costa Rican soils investigated, K availability appeared to be relatively low in Milano soils.

Based on the **double pot experiment** the following can be concluded :

* N availability : In all the investigated Costa Rican soils, N availability was insufficient for maximum maize growth;

* P availability : In all the investigated Costa Rican soils, P availability was insufficient for maximum maize growth;

* K availability : In all the investigated Costa Rican soils, K availability was sufficient for maximum maize growth.

However, no significant (5%) differences were found between the sufficiency quotients of N, P or K of the different Costa Rican soils investigated.

The **overall conclusions** of the soil and plant analysis and the double pot experiment can be summarized as follows :

* N availability : In all the investigated Costa Rican soils, N availability appears to be insufficient for maximum maize growth. Bosque soils appear to have the lowest N availability;

* P availability : In all the investigated Costa Rican soils, P availability appears to be insufficient for maximum maize growth. Milano soils appear to have the lowest P availability;

* K availability : In all the investigated Costa Rican soils, K availability appears to be sufficient for maximum maize growth. Milano soils appear to have the lowest K availability;

Based on the collected data it also can be concluded that the soil is being over-exploited by the current local maize cropping system : on average, except for N, the amount of nutrients that is removed by each harvest greatly exceeds the amount that is actually applied by means of fertilizer.

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SUMMARY

This study attempts to give a nutrient availability classification of 6 soil units (Aluvial, Bosque, Cristina, Milano, Parismina, and Union) used for maize (Zea mays) production in the Rio Jimenez and Neguev subareas in the Atlantic Zone of Costa Rica. The classification is based on 3 techniques, namely soil and plant analysis, and a pot experiment.
In the subareas a total of 34 fields were sampled. Sampling was done by means of a 100 m^2 sample field in a homogenous part of a maize field, from which 3 kg of topsoil was collected and at least 20 plants were sampled at random. As additional data some management and input data were collected on factors as variety used, land preparation, fertilizer application, weed control, duration cropping period, and average grain yield.

The soil samples were all analysed on pH(H20), P-Olsen, K(HCl), and C-Kurmies. Based on these results nutrient-limited grain yield was estimated by QUEFTS for situations with and without fertilizer application.
The more fertile soil, on basis of the parameters investigated, appeared to be Parismina (unfertilised nutrient-limited grain yield being significantly (10%) higher than that of Milano).

Based on the plant sample data estimations were given for average actual grain yield and total dry matter production per ha. The plant samples were split up into grain, axe, stalk, leaf and husk samples. For each plant component N, P, and K content was determined. Based on these data estimations were given for uptake and the eventual removal of these 3 nutrients per harvest. Comparison of nutrient removal with nutrient application (by means of fertilizer) learned that the soil, on average, is being over-exploited by the current local maize cropping systems for all nutrients except N.
Parismina soils appeared to have high actual production levels (significantly (10%) higher than Bosque and Milano).

To determine the nutrient supplying capacity of the investigated soil series a pot experiment based on the 'missing element technique' was conducted for one soil of each soil series. No significant (5%) differences between the soils for the availability of N, P or K were found.

From the results found in this study it can be concluded that all investigated Costa Rican soils appeared to have a N and P availability insufficient for maximum maize growth. K availability appeared to be sufficient for maximum maize growth.
Bosque soils appear to have the lowest N availability, whereas Milano soils appear to have the lowest P and K availability.

RESUMEN

Este estudio trata de dar una clasificion de la disponibilidad de nutrientes en 6 suelos (Aluvial, Bosque, Cristina, Milano, Parismina, y Union) usados para el cultivo de maíz (Zea mays) en las subareas de Río Jiménez y Neguev en la Zona Atlántica de Costa Rica. La clasificacion esta basada en 3 metodos, siendo análysis de suelo y de plantas, y un experimento de pote.
En las subareas se tomaron muestras de un total de 34 lotes. Las muestras se tomaron dentro de areas de unos 100 m² en una parte homogenea del lote de maíz. De estas areas se tomaron 3 kg de suelo de los primeros 20 cm de suelo y 20 plantas de maíz. Como información de fondo se colecionó datos acerca del manejo de los lotes (variedad usada, preparación del terreno, aplicación de abono, control malezas, duración de cultivo, y rendimiento promedio).

De las muestras de suelo se analisaron el pH(H2O), P-Olsen, K(HCl), y C-Kurmies. Basado en estos resultados se estimó el rendimiento limitado por nutrientes con QUEFTS para los lotes sin y con aplicación de abono. Los suelos más fertiles en cuanto a los parámetros analisados, parecio ser el suelo Parismina (nivel de rendimiento limitado por nutrientes (en situación no fertilisada) significadamente (10 %) más alto que el del suelo Milano).

Basado en las muestras de plantas se estimó el rendimiento de grano y de materia seca. De las muestras de plantas se separaron muestras de grano, olote, tallo, hoja y tuza. De todas las muestras de planta se analisaron el contenido de N, P y K. Basado en estos resultados se estimó la cantidad de nutrientes que el cultivo saca del terreno (entendido el abono aplicado) y la cantidad de nutrientes que se pierda con la cosecha. Comparación de la cantidad de nutrientes que se pierda con la cosecha, con la cantidad que se aplica (en forma de abono) muestra que el suelo es seriamente exploitado (en promedio para todos los nutrientes excepto N) por el sistema de cultivo de maíz que se practica actualmente en la Zona Atlántica. El suelo Parismina parece de tener un nivel de rendimiento actual bastante alto (significadamente (10 %) más alto que el de los suelos Bosque y Milano).

Para determinar la capacidad de los suelos investigados de dar nutrientes se codujo un experimento de pote para un suelo de cada serie. La tecnica del experimento esta basado en no dar un nutriente para ver cuanto puede dar el suelo a la planta del mismo nutriente. No se encontraron differencias significativas (5 %) entre los suelos encuanto a la disponibilidad de N, P, y K.

Basado en los resultados encontrados en este estudio se puede concluir que todos los suelos Costa Riquenses investigados parecían no tener una disponibilidad de N y P sufficientemente alto para un crecimiento máximo de maíz. La disponibilidad de K sí parecía sufficientemente alto para un crecimiento máximo de maíz. El suelo Bosque parece tener la disponibilidad más baja de N, mientras que el suelo Milano parece tener la disponibilidad más baja de P y K.

SAMENVATTING

Deze studie probeert een classificatie te geven van de nutrientenbeschikbaarheid in 6 gronden (Aluvial, Bosque, Cristina, Milano, Parismina, en Union) die voor de verbouw van mais (Zea mays) gebruikt worden in de Rio Jimenez en Neguev subgebieden in de Atlantische Zone van Costa Rica. De classificatie is gebaseerd op 3 technieken, zijnde grond- en gewasanalyse, en een potproef. In de subgebieden zijn in totaal 34 velden bemonsterd. Bemonstering vond plaats via bemonsteringsveldjes van ongeveer 100 m^2 binnen een homogeen deel van een maisveld. Van deze bemonsteringsveldjes werd 3 kg bovengrond verzameld en ten minste 20 willekeurige planten geoogst. Als aanvullende gegevens werden enkele management en input gegevens verzameld over factoren als gebruikte varieteit, veldvoorbereiding, bemesting, onkruidbestrijding, veldperiode gewas en gemiddelde opbrengst.

De grondmonsters werden geanalyseerd op pH(H2O), P-Olsen, K(HCl), en C-Kurmies. Gebaseerd op deze resultaten werd de nutrientgelimiteerde graanopbrengst geschat door QUEFTS voor bemeste en onbemeste veldjes.
De meest vruchtbare grond op grond van de onderzochte parameters bleek Parismina te zijn (nutrient-gelimiteerde graan opbrengst was significant (10%) hoger dan die van Milano).

Gebaseerd op de gegevens over het gewas werd een schatting gegeven van de gemiddelde graanopbrengst en totale drogestofproduktie per ha. De gewasmonsters werden opgesplitst in graan, spil, stengel, en monsters van blad en schutblad. Voor elk onderscheden onderdeel van de plant werden N, P, en K gehalte bepaald. Gebaseerd op deze data werd een schatting gegeven van opname en uiteindelijke onttrekking van deze 3 nutrienten per oogst. Vergelijking van nutrientenonttrekking met bemesting (door middel van kunstmeststoffen) leerde dat de gronden, gemiddeld genomen, overgeexploiteerd worden door het huidige locale teeltsysteem van mais voor alle nutrienten behalve N.
Parismina gronden bleken hoge actuele opbrengsten te hebben (significant (10%) hoger dan Bosque en Milano).

Om van de onderzochte gronden de capaciteit om nutrienten te leveren te bepalen werd een grond per bodemserie meegenomen in een potproef. Deze potproef was gebaseerd op de 'techniek van het missende element'. Er bleken geen significante (5%) verschillen tussen de Costa Ricaanse gronden voor noch de beschikbaarheid van N, noch voor die van P of K.

Op basis van de resultaten gevonden in deze studie kan men concluderen dat alle onderzochte Costa Ricaanse gronden te lage N en P beschikbaarheden lijken te hebben voor een maximale groei van mais. K beschikbaarheid bleek hoog genoeg voor een maximale groei van mais.
Bosque gronden lijken de laagste N beschikbaarheid te hebben, terwijl Milano gronden de laagste P en K beschikbaarheden lijken te hebben.

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ANNEX 1 ABBREVIATIONS USED

Table A1.1 Abbreviations used

Abbre-viation	Meaning
A	Alluvial (name soil unit/series)
AUW	Agricultural University Wageningen
ASBANA	Asociacion Bananera Nacional
Bo	Bosque (name soil unit/series)
C	carbon
CATIE	Tropical Agronomic Research and Education Centre
cm	centimetre
Cr	Cristina (name soil unit/series)
fert	fertilizer
g	gram
gal	gallon (=3.79 l)
ha	hectare
IDA	Institute for Rural Development
K	kalium
kg	kilogram
l	litre
LUW	Landbouw Universiteit Wageningen (=AUW)
m	metre
MAG	Ministry of Agriculture and Livestock
Mi	Milano (name soil unit/series)
mmol	milimol
N	nitrogen
n	number of observations on which mean is based
P	phosphorous
Pa	Parismina (name soil unit/series)
QUEFTS	Quantitative Evaluation of the Fertility of Tropical Soils
s	standard deviation
SQ	Sufficiency Quotient
UAW	Universidad Agricola Wageningen (=AUW)
Un	Union (name soil unit/series)
x	mean

ANNEX 2 INPUT AND MANAGEMENT DATA PER SAMPLE FIELD (also see 3.2)

Table A2.1 Planting densities and varieties used in sample fields. Variety names are mainly names for local varieties. Where variety was unknown to farmer "?" is given. All sampled varieties had white grain.

Soil	Distance in row (m)	Distance between rows (m)	Average number of plants per planthole	Number of plants (1000) per ha	Variety
A 01	0.63	1.08	2.11	31	Semi-enano
A 06	0.53	0.94	1.62	32	Maicena
A 29	0.62	1.11	3.14	46	Enano
Bo14	0.57	1.19	2.86	42	?
Bo20	0.62	0.79	2.86	58	Enano
Bo33	0.62	0.89	2.56	47	Rocamec
Bo35	0.71	1.03	3.11	43	Tico B7
Bo38	0.80	1.17	1.71	18	?
Cr03	0.60	0.98	4.13	70	Semi-enano
Cr04	0.68	1.21	2.86	35	Tico B7
Cr07	0.63	0.89	2.50	35	H 5
Cr08	0.63	1.14	2.86	40	Criollo
Cr21	0.56	1.13	3.00	48	?
Cr31	0.56	1.06	2.18	37	Rocamec
Cr39	0.64	1.11	2.75	39	Enano
Mi09	0.71	0.96	2.63	39	?
Mi22	0.49	1.01	2.40	49	Diamantes
Mi25	0.63	1.02	2.00	31	Criollo
Mi37	0.49	1.03	2.20	43	Maicena+Rocamec
Mi40	0.82	0.75	2.40	39	Maicena
Mi41	0.53	0.90	2.08	44	Maicena+?
Pa11	0.83	1.03	2.67	31	Rocamec
Pa12	0.63	1.00	2.10	33	Semi-enano
Pa15	0.50	1.09	2.86	52	Enano
Pa16	0.58	1.11	2.75	43	Enano X Maicena(*)
Pa18	0.59	1.14	2.86	43	Eto blanco
Pa19	0.81	1.05	3.00	35	?
Pa26	0.57	0.89	2.86	56	?
Pa27	0.69	1.04	3.83	53	Criollo
Pa34	0.67	1.00	1.67	25	Maicon
Pa36	0.62	1.06	2.44	37	Rocamec
Un02	0.49	1.14	2.63	47	Criollo
Un28	0.59	1.14	3.43	51	Hibrido(**)
Un30	0.56	1.00	1.69	30	Maicena

* : hybrid seed from parents Enano and Maicena

** : this was said to be hybrid seed but was already used for 3 consecutive harvests without renewal of the seed

Table A2.2 Fertilizer application (N-P-K) in sample fields in kg granuled fertilizer. The number in brackets refers to the age of maize in days after sowing at day of application. 2 numbers refer to the days of application for half the quantity mentioned.

	Compound fertilizer			Nutran (*)	Urea
Soil	10-30-10	12-24-12	unknown to farmer if 10-30-10 or 12-24-12	33.5-0-0	46-0-0
A 01		200(13)		200(27-35)	
A 06				400(15,50)	
A 29				200(20,35)	
Bo14				200(15,30)	
Bo20			200(30)	200(60)	
Bo33				150(27)	
Bo35				300(15,45)	
Bo38		50(8)		50(30)	
Cr03					125(27)
Cr04				70(10),150(45)	
Cr07				200(27,45)	
Cr08		100(8)		100(38)	
Cr21				150(?,?)	
Cr31				300(20,60)	
Cr39					100(30)
Mi09				200(27,75)	
Mi22		100(0)		100(27)	
Mi25				250(20,35)	
Mi37				125(35)	
Mi40	100(8)			100(30)	
Mi41				100(14,60)	
Pa11				100(30)	100(60)
Pa12		100(?,?)			
Pa15			200(0)	200(60)	
Pa16	?(13)			?(35)	
Pa18	100(9)			100(52)	
Pa19				200(15,45)	
Pa27				300(20,35)	
Pa34				115(45)	
Pa36				150(20),100(105)	
Un02				100(0,30)	
Un28				300(30,60)	
Un30				200(20,35)	

* : Nutran = ammonium nitrate

Table A2.3 Land preparation in sample fields. For mechanical land preparation the number of passages is mentioned between brackets. The manual land preparation by means of a machete is normally before chemical land preparation and only in the case thet weeds are high and dense. For chemical land preparation the dosis applied is mentioned between square brackets. If more than one chemical application, the dosis is preceded by the number of applications (when applying same dosis), or more than one dosis is mentioned.

	Mechanical		Manual	Chemical (*)			Physical
Soil	plough passages	harrow passages	machete	paraquat [gal/ha]	2,4-D [gal/ha]	diuron [kg/ha]	burning
A 01			+	+[1.5,1]		+[2,0]	
A 06		+(2)					
A 29		+(2)					
Bo14			+	+[2]		+[.5]	
Bo20		+(2)					
Bo33		+(3)					
Bo35			+	+[2*.8]	+[2*.5]		
Bo38			+	+[1]			
Cr03			+	+[1,.5]			
Cr04		+(2-4)					
Cr07		+(?)					
Cr08		+(2)					
Cr21			+	+[1]			
Cr31			+	+[2*<.5]			
Cr39		+(2)					
Mi09		+(2)					
Mi22		+(4)					
Mi25		+(2)					
Mi37			+	+[.25]			+
Mi40	+(1)	+(2)					
Mi41			+	+[2]		+[1]	
Pa11			+	+[2]			
Pa12		+(2)					
Pa15			+	+[2]			
Pa16			+	+[1]			
Pa18		+(?)	+	+[1]			
Pa19			+	+[2*2]			
Pa27			+	+[2]	+[1.1]		
Pa34			+	+[1,1]		+[1,0]	
Pa36		+(3)					
Un02			+	+[?]			
Un28			+	+[1,1]		+[1.5,0]	
Un30			+	+[2*.8]			

* active concentration paraquat 28%, 2,4-D 70%, diuron 80%

Table A2.4 Weed control in sample fields and average duration of cropping period. For chemical weed control the dosis applied is mentioned in between square brackets. If more than one chemical application, the dosis is preceded by the number of applications (when applying same dosis), or more than one dosis is mentioned.

	Weed Control					Average duration cropping period
	Manual	Chemical (*)				
Soil	machete	paraquat [gal/ha]	2,4-D [gal/ha]	amma (**) [gal/ha]	atrazine [gal/ha]	(monthes)
A 01		+[1]				4
A 06		+[2]				4
A 29		+[.66]				3.5
Bo14		+[2]				4
Bo20		+[2*2]				4
Bo33		+[.5]				5
Bo35		+[.6]	+[.4]			4.5
Bo38		+[1]				3
Cr03	+					4
Cr04		+[.6,.4]				4.5
Cr07		+[?]				4
Cr08		+[?]	+[?]	+[?]		3.5-4
Cr21		+[1]				3.5-4
Cr31		+[1]				4
Cr39		+[2*1]				4
Mi09		+[.3]				4.5
Mi22		+[.5]				4
Mi25		+[1]				4
Mi37	+					4
Mi40					+[1]	5
Mi41		+[1]				5
Pa11		+[1]				3.5-4
Pa12		+[1]				4
Pa15		+[1]				3.5
Pa16		+[1.5]				4
Pa18		+[.5]				3
Pa19		+[2]				4
Pa27		+[.75]	+[.5]			3-4
Pa34		+[.5]				5.5
Pa36		+[2*1]				5.5
Un02		+[1]				3.5
Un28		+[1]				3.5
Un30		+[.2]				4.5

* active concentration paraquat 28%, 2,4-D 70%, amma 48%, atrazine 46%
** amma : arsenic monosodic methane acid

ANNEX 3 OUTPUT DATA PER SAMPLE FIELD (also see 3.3 and 4.3)

Table A3.1 Nutrient-limited grain yield with and without fertilizer apllication as estimated by QUEFTS , average (expected) grain yield as estimated by farmer, and actual dry matter production as estimated from sample data. All productions in kg dry matter per ha.

	QUEFTS								
	-fert	+fert	Farmer	Sample					
	Grain	Grain	Grain	Grain	Axe	Stalk	Leaf	Husk	Total
A 01	5,700	7,100	2,080	3,919	703	2,527	891	1,043	9,083
A 06	4,100	4,600	2,520	1,975	329	1,601	436	469	4,810
A 29	5,100	5,400	2,140	3,232	677	3,039	1,362	793	9,103
Bo14	4,800	5,200	-	3,091	588	2,758	723	941	8,101
Bo20	4,000	5,200	3,020	2,758	680	2,411	1,131	786	7,766
Bo33	4,900	5,500	2,010	1,943	335	1,378	508	498	4,662
Bo35	3,700	4,100	1,460	1,796	435	2,099	663	650	5,643
Bo38	5,100	5,500	2,010	777	190	555	221	240	1,983
Cr03	4,600	4,800	2,010	2,870	475	2,527	-	745	-
Cr04	2,400	2,400	2,800	3,070	509	-	416	675	-
Cr07	3,300	3,300	2,520	1,497	424	1,404	355	391	4,071
Cr08	3,200	3,800	3,780	3,247	580	2,734	780	757	8,098
Cr21	5,800	6,000	1,510	5,216	967	3,178	1,067	1,234	11,662
Cr31	4,800	5,200	1,760	2,943	544	1,894	737	803	7,465
Cr39	3,700	3,900	2,270	2,133	533	2,089	759	575	6,089
Mi09	4,400	4,700	3,150	2,722	501	1,749	535	584	6,091
Mi22	2,400	3,000	2,010	3,782	778	1,728	771	753	7,812
Mi25	2,600	2,800	1,760	1,750	411	1,204	461	400	4,226
Mi37	3,600	3,700	1,130	2,332	423	1,509	388	545	5,620
Mi40	2,200	2,800	1,390	2,259	355	1,373	353	505	4,845
Mi41	4,600	4,800	1,160	1,450	410	4,242	1,129	733	7,964
Pa11	6,800	6,800	2,140	3,496	616	2,070	526	840	8,164
Pa12	5,200	5,700	2,520	3,244	487	2,175	1,026	730	7,662
Pa15	5,900	7,400	-	3,871	726	3,257	1,296	1,244	10,394
Pa16	7,300	-	2,900	4,826	1,010	2,748	839	1,322	10,745
Pa18	6,700	7,300	3,020	4,816	883	2,684	1,156	1,169	10,708
Pa19	7,100	7,300	5,040	3,973	661	2,849	774	1,081	9,338
Pa26	6,500	-	-	1,810	350	2,678	1,102	645	6,585
Pa27	3,100	3,200	1,890	4,267	909	3,842	1,330	1,188	11,536
Pa34	5,200	5,400	2,900	4,303	638	2,653	767	1,306	9,667
Pa36	4,300	5,000	2,770	2,708	417	1,968	720	556	6,369
Un02	7,600	7,700	-	5,345	823	3,073	1,194	1,208	11,643
Un28	5,000	5,100	2,520	4,265	668	3,262	1,299	1,048	10,542
Un30	4,600	4,600	2,010	2,819	473	1,703	672	528	6,195

- : missing

Table A3.2 Total dry weight of sample (g) and humidity content (%) of fresh sample for each plant component per sample

	Grain (g)	Grain (%)	Axe (g)	Axe (%)	Stalk (g)	Stalk (%)	Leaf (g)	Leaf (%)	Husk (g)	Husk (%)
A 01	2400	27.1	431	48.0	1550	51.5	546	13.3	639	10.6
A 06	1280	21.0	213	31.4	1040	12.4	283	9.9	304	11.0
A 29	1560	21.2	327	25.9	1470	22.0	659	9.8	383	38.6
Bo14	1470	16.0	280	22.4	1310	13.0	344	12.5	447	17.2
Bo20	945	21.9	233	32.1	826	19.5	388	10.7	270	24.2
Bo33	960	10.1	165	13.6	681	16.0	251	13.0	246	15.4
Bo35	1180	9.8	286	13.4	1380	17.6	436	11.4	428	15.5
Bo38	1010	12.8	249	21.9	725	16.9	289	14.4	314	17.1
Cr03	1350	25.7	224	43.6	1190	73.5	-	-	351	13.9
Cr04	1760	19.4	292	39.1	-	-	238	59.1	387	10.9
Cr07	862	16.3	244	15.1	808	12.9	205	12.9	225	14.4
Cr08	1630	21.0	292	34.1	1380	12.9	393	12.6	381	17.0
Cr21	2300	12.2	427	19.2	1400	12.7	470	11.1	544	16.8
Cr31	1910	12.6	353	20.2	1230	13.6	479	13.2	522	21.3
Cr39	1210	15.9	303	30.2	1190	36.8	431	14.7	327	19.6
Mi09	1480	19.2	272	24.3	950	13.4	291	12.4	317	16.0
Mi22	1850	10.9	381	15.6	847	12.2	378	14.3	369	16.2
Mi25	1230	9.5	289	12.6	847	13.8	324	14.8	282	16.2
Mi37	1190	10.7	216	17.2	769	20.3	198	14.4	278	16.2
Mi40	1380	9.6	217	11.7	837	13.7	216	14.6	308	15.1
Mi41	819	16.7	232	28.6	2400	46.7	638	14.3	414	18.6
Pa11	2670	18.1	471	28.0	1580	20.5	402	9.5	642	12.7
Pa12	2040	25.1	307	47.5	1370	23.3	647	11.9	460	30.2
Pa15	1490	23.4	279	38.9	1250	18.1	498	12.9	478	22.2
Pa16	2470	18.8	517	20.3	1410	22.6	430	12.4	677	16.7
Pa18	2260	27.1	414	43.9	1260	13.9	542	14.0	548	28.5
Pa19	2360	21.6	393	34.4	1700	23.6	460	14.0	643	21.8
Pa26	646	28.2	125	27.0	955	16.4	393	17.2	230	49.9
Pa27	1840	10.5	393	15.0	1660	19.6	575	11.4	514	16.2
Pa34	3450	17.0	512	25.8	2130	17.8	616	11.8	1050	21.8
Pa36	1610	13.9	248	19.9	1170	15.0	428	15.9	331	16.9
Un02	2390	27.8	368	48.5	1374	67.0	534	21.1	540	9.7
Un28	2000	21.7	313	34.6	1529	20.8	609	12.2	491	23.8
Un30	2060	17.2	345	25.5	1241	15.5	490	13.2	385	24.6

- : missing

ANNEX 4 SOIL ANALYSIS DATA PER SAMPLE FIELD (also see 4.2)

Table A4.1 Results of pH(H2O), P-Olsen, K(HCl) and C-Kurmies

Soil	pH(H2O)	P-Olsen mg P / kg	K(HCl) mmol K / kg	C-Kurmies g C / kg
A 01	5.93	4.4	10.88	33.8
A 06	5.78	2.6	6.20	25.2
A 29	5.90	6.4	9.40	26.5
Bo14	5.60	8.8	6.36	29.8
Bo20	5.50	10.2	4.50	34.0
Bo33	5.71	15.6	7.87	21.7
Bo35	5.38	3.8	4.24	27.6
Bo38	5.63	12.9	7.15	26.2
Cr03	5.43	4.4	6.66	44.8
Cr04	5.54	4.0	3.41	49.2
Cr07	5.62	4.8	3.52	32.5
Cr08	5.73	4.4	4.59	46.4
Cr21	5.47	5.2	9.91	48.5
Cr31	5.62	2.4	7.05	36.5
Cr39	5.57	3.3	6.79	21.2
Mi09	5.88	1.2	8.02	27.4
Mi22	5.02	6.8	2.34	36.4
Mi25	4.87	4.7	3.43	28.8
Mi37	5.41	3.3	8.53	20.4
Mi40	5.33	1.4	1.92	27.5
Mi41	5.59	5.8	6.08	31.7
Pa11	6.11	22.6	16.46	91.3
Pa12	6.05	11.3	10.42	22.4
Pa15	6.40	7.0	14.98	30.6
Pa16	6.16	13.2	16.77	38.4
Pa18	6.36	12.2	15.44	33.2
Pa19	6.41	12.7	16.26	36.9
Pa26	6.20	18.0	11.35	30.3
Pa27	5.72	12.0	3.63	36.5
Pa34	6.05	6.7	11.04	25.6
Pa36	6.08	10.2	10.94	15.5
Un02	6.17	12.6	25.05	33.7
Un28	5.96	6.7	8.38	46.8
Un30	6.35	25.0	9.55	54.2

ANNEX 5 PLANT ANALYSIS DATA PER SAMPLE FIELD (also see 5.2)

Table A5.1 N content (%) of different components of plant samples

Sample	Grain	Axe	Stalk	Leaf	Husk
A 01	1.85	0.32	0.85	1.35	0.36
A 06	1.84	0.30	0.58	0.27	0.33
A 29	1.77	0.40	0.71	1.42	0.36
Bo14	1.52	0.28	0.27	0.97	0.26
Bo20	1.61	0.40	0.67	1.82	-
Bo33	1.52	0.28	0.42	-	0.49
Bo35	1.50	0.25	0.42	0.79	0.29
Bo38	1.77	0.39	0.96	1.59	0.51
Cr03	1.47	0.44	0.50	-	0.26
Cr04	3.10	0.30	-	-	0.30
Cr07	1.69	0.31	0.71	1.34	0.37
Cr08	1.77	0.28	0.48	1.13	0.34
Cr21	1.84	0.27	0.62	1.63	0.34
Cr31	1.77	0.29	0.65	1.36	0.31
Cr39	1.60	0.36	0.95	1.54	0.44
Mi09	1.74	0.26	0.52	1.23	0.29
Mi22	1.74	0.34	0.66	1.55	0.55
Mi25	2.01	0.32	0.86	1.37	0.46
Mi37	1.75	0.32	0.67	1.36	0.35
Mi40	1.71	0.37	0.68	1.18	0.28
Mi41	1.74	0.35	0.49	1.34	0.40
Pa11	1.87	0.27	0.48	1.18	0.26
Pa12	1.89	0.32	0.71	1.62	0.38
Pa15	1.83	0.27	0.58	1.67	0.28
Pa16	1.78	0.30	0.66	0.70	0.34
Pa18	1.74	0.30	0.70	1.55	0.34
Pa19	1.85	0.25	0.58	1.16	0.27
Pa26	1.83	0.40	0.75	1.61	0.98
Pa27	1.71	0.48	0.40	1.44	0.39
Pa34	1.89	0.27	0.49	1.27	0.42
Pa36	1.79	0.26	0.71	1.82	0.34
Un02	1.97	0.29	0.79	1.38	0.35
Un28	1.74	0.30	0.65	1.40	0.32
Un30	1.74	0.28	0.62	1.50	0.27

- : missing

Table A5.2 P content (%) of different components of plant samples

Sample	Grain	Axe	Stalk	Leaf	Husk
A 01	0.27	0.02	0.08	0.12	0.04
A 06	0.24	0.02	0.11	0.03	0.03
A 29	0.27	0.02	0.11	0.17	0.07
Bo14	0.23	0.02	0.03	0.08	0.02
Bo20	0.21	0.03	0.07	0.14	-
Bo33	0.27	0.04	0.13	-	0.10
Bo35	0.24	0.02	0.07	0.09	0.05
Bo38	0.30	0.07	0.12	0.20	0.10
Cr03	0.28	0.06	0.09	-	0.02
Cr04	0.18	0.02	-	-	0.02
Cr07	0.23	0.03	0.08	0.10	0.02
Cr08	0.26	0.02	0.06	0.12	0.03
Cr21	0.24	0.01	0.07	0.14	0.03
Cr31	0.24	0.02	0.06	0.11	0.03
Cr39	0.24	0.03	0.07	0.13	0.05
Mi09	0.20	0.01	0.04	0.08	0.01
Mi22	0.21	0.01	0.03	0.09	0.04
Mi25	0.27	0.02	0.08	0.10	0.05
Mi37	0.23	0.03	0.06	0.11	0.05
Mi40	0.22	0.04	0.05	0.07	0.02
Mi41	0.27	0.06	0.11	0.13	0.08
Pa11	0.28	0.02	0.12	0.15	0.05
Pa12	0.27	0.04	0.11	0.19	0.07
Pa15	0.26	0.02	0.07	0.18	0.02
Pa16	0.26	0.04	0.05	0.06	0.03
Pa18	0.25	0.02	0.06	0.15	0.03
Pa19	0.29	0.01	0.06	0.13	0.05
Pa26	0.33	0.05	0.13	0.21	0.19
Pa27	0.25	0.07	0.06	0.17	0.06
Pa34	0.27	0.03	0.16	0.21	0.07
Pa36	0.27	0.02	0.09	0.21	0.04
Un02	0.33	0.02	0.11	0.17	0.03
Un28	0.26	0.02	0.09	0.17	0.03
Un30	0.24	0.02	0.06	0.13	0.02

- : missing

Table A5.3 K content (%) of different components of plant samples

Sample	Grain	Axe	Stalk	Leaf	Husk
A 01	0.37	0.49	2.37	1.07	0.43
A 06	0.32	0.57	1.88	0.11	0.56
A 29	0.38	0.54	2.35	1.24	0.86
Bo14	0.29	0.51	2.02	0.39	0.64
Bo20	0.34	0.87	1.28	0.59	-
Bo33	0.36	0.56	1.89	-	1.04
Bo35	0.33	0.40	2.08	0.41	0.51
Bo38	0.41	0.62	1.99	1.19	0.81
Cr03	0.36	0.75	1.39	-	0.46
Cr04	0.29	0.46	-	-	0.52
Cr07	0.29	0.57	0.65	0.25	0.44
Cr08	0.32	0.51	1.80	0.69	0.64
Cr21	0.29	0.34	1.92	0.67	0.70
Cr31	0.31	0.31	1.38	0.65	0.36
Cr39	0.36	0.47	1.97	1.04	0.65
Mi09	0.29	0.48	1.89	0.58	0.61
Mi22	0.34	0.45	1.16	0.70	0.82
Mi25	0.34	0.48	1.63	0.52	0.76
Mi37	0.31	0.53	1.56	0.30	0.68
Mi40	0.31	0.45	0.65	0.16	0.56
Mi41	0.36	0.50	1.37	0.56	0.59
Pa11	0.35	0.40	1.89	0.56	0.41
Pa12	0.36	0.56	2.54	1.51	0.59
Pa15	0.34	0.59	2.64	1.40	0.56
Pa16	0.34	0.42	2.39	0.41	0.74
Pa18	0.37	0.54	2.95	1.50	0.67
Pa19	0.35	0.49	2.42	1.13	0.82
Pa26	0.47	0.43	2.77	1.92	1.17
Pa27	0.32	0.65	1.65	1.31	0.76
Pa34	0.33	0.42	2.01	0.78	0.67
Pa36	0.36	0.39	2.39	1.68	0.72
Un02	0.39	0.41	3.54	1.43	0.51
Un28	0.34	0.50	2.44	1.12	0.65
Un30	0.36	0.36	2.34	1.56	0.71

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ANNEX 6 ACTUAL NUTRIENT UPTAKE AND REMOVAL PER SAMPLE FIELD (also see 5.3)

Table A6.1 N uptake and removal in kg N per ha

	Uptake						
Sample	Grain	Axe	Stalk	Leaf	Husk	Total	Removal
A 01	72.5	2.2	21.4	12.1	3.8	112.0	74.8
A 06	36.2	1.0	9.4	1.2	1.6	49.3	37.2
A 29	57.2	2.8	21.6	19.4	2.9	103.9	60.0
Bo14	46.9	1.6	7.5	7.0	2.5	65.4	48.6
Bo20	44.3	2.7	16.2	20.6	-	-	47.0
Bo33	29.5	1.0	5.8	-	2.4	-	30.5
Bo35	27.0	1.1	8.7	5.2	1.9	43.9	28.1
Bo38	13.7	0.8	5.3	3.5	1.2	24.5	14.5
Cr03	42.1	2.1	12.6	-	1.9	-	44.2
Cr04	95.2	1.5	-	-	2.0	-	96.7
Cr07	25.2	1.3	10.0	4.8	1.4	41.3	26.6
Cr08	57.5	1.6	13.0	8.8	2.6	83.5	59.1
Cr21	96.0	2.7	19.8	17.4	4.2	140.0	98.6
Cr31	51.9	1.6	12.3	10.0	2.5	78.3	53.5
Cr39	34.1	1.9	19.8	11.7	2.5	70.1	36.0
Mi09	47.4	1.3	9.1	6.6	1.7	66.2	48.7
Mi22	65.7	2.7	11.4	11.9	4.1	95.7	68.3
Mi25	35.1	1.3	10.4	6.3	1.9	55.0	36.4
Mi37	40.8	1.4	10.1	5.3	1.9	59.4	42.2
Mi40	38.6	1.3	9.3	4.2	1.4	54.8	39.9
Mi41	25.2	1.5	20.7	15.1	3.0	65.4	26.6
Pa11	65.2	1.7	9.9	6.2	2.1	85.1	66.9
Pa12	61.2	1.6	15.4	16.6	2.8	97.5	62.7
Pa15	70.8	2.0	18.9	21.6	3.5	116.7	72.7
Pa16	85.8	3.1	18.1	5.9	4.6	117.3	88.9
Pa18	83.5	2.6	18.7	17.9	4.0	126.7	86.2
Pa19	73.5	1.6	16.4	9.0	2.9	103.5	75.2
Pa26	33.1	1.4	20.0	17.7	6.3	78.6	34.6
Pa27	73.1	4.3	15.3	19.2	4.7	116.6	77.5
Pa34	81.4	1.7	13.1	9.7	5.5	111.4	83.1
Pa36	48.4	1.1	13.9	13.1	1.9	78.3	49.4
Un02	105.3	2.4	24.4	16.4	4.2	152.8	107.8
Un28	74.0	2.0	21.1	18.2	3.3	118.6	76.0
Un30	48.9	1.3	10.6	10.1	1.5	72.3	50.2

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Table A6.2 P uptake and removal in kg P per ha

	Uptake						
Sample	Grain	Axe	Stalk	Leaf	Husk	Total	Removal
A 01	10.6	0.1	2.0	1.1	0.4	14.2	10.7
A 06	4.8	0.1	1.7	0.1	0.1	6.8	4.9
A 29	8.8	0.2	3.4	2.3	0.5	15.2	9.0
Bo14	7.1	0.1	0.9	0.6	0.1	8.8	7.2
Bo20	5.9	0.2	2.1	1.6	-	-	6.1
Bo33	5.2	0.1	1.8	-	0.5	-	5.3
Bo35	4.3	0.1	1.4	0.6	0.3	6.7	4.4
Bo38	2.4	0.1	0.7	0.5	0.2	3.9	2.5
Cr03	7.9	0.3	2.3	-	0.2	-	8.2
Cr04	5.6	0.1	-	-	0.1	-	5.7
Cr07	3.4	0.1	1.1	0.4	0.1	5.1	3.5
Cr08	8.5	0.1	1.6	0.9	0.2	11.3	8.6
Cr21	12.5	0.1	2.1	1.5	0.4	16.6	12.6
Cr31	7.1	0.1	1.1	0.8	0.3	9.4	7.2
Cr39	5.1	0.2	1.6	1.0	0.3	8.2	5.3
Mi09	5.6	0.1	0.7	0.4	0.0	6.9	5.7
Mi22	8.1	0.1	0.5	0.7	0.3	9.7	8.2
Mi25	4.7	0.1	1.0	0.4	0.2	6.4	4.8
Mi37	5.3	0.1	0.9	0.4	0.3	7.0	5.4
Mi40	4.9	0.2	0.7	0.3	0.1	6.2	5.1
Mi41	4.0	0.2	4.9	1.5	0.6	11.2	4.2
Pa11	9.9	0.1	2.5	0.8	0.4	13.7	10.0
Pa12	8.8	0.2	2.3	1.9	0.5	13.7	9.0
Pa15	10.0	0.1	2.4	2.3	0.3	15.1	10.1
Pa16	12.7	0.4	1.4	0.5	0.4	15.4	13.1
Pa18	12.1	0.2	1.7	1.7	0.4	16.1	12.3
Pa19	11.7	0.1	1.7	1.0	0.5	15.0	11.8
Pa26	6.0	0.2	3.5	2.3	1.2	13.2	6.2
Pa27	10.6	0.6	2.4	2.2	0.7	16.5	11.2
Pa34	11.7	0.2	4.3	1.6	0.9	18.7	11.9
Pa36	7.4	0.1	1.8	1.5	0.2	11.0	7.5
Un02	17.7	0.2	3.2	2.1	0.4	23.6	17.9
Un28	11.2	0.1	3.0	2.2	0.3	16.8	11.3
Un30	6.8	0.1	1.1	0.9	0.1	9.0	6.9

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Table A6.3 K uptake and removal in kg K per ha

Sample	Uptake						Removal
	Grain	Axe	Stalk	Leaf	Husk	Total	
A 01	14.5	3.5	59.9	9.5	4.5	91.9	18.0
A 06	6.3	1.9	30.1	0.5	2.6	41.4	8.2
A 29	12.3	3.6	71.3	16.9	6.8	110.9	15.9
Bo14	9.1	3.0	55.7	2.8	6.0	76.6	12.1
Bo20	9.4	5.9	35.2	6.6	-	-	15.3
Bo33	7.0	1.9	26.0	-	5.2	-	8.9
Bo35	6.0	1.7	43.7	2.7	3.3	57.4	7.7
Bo38	3.2	1.2	11.1	2.6	1.9	20.0	4.4
Cr03	10.4	3.5	35.2	-	3.4	-	13.9
Cr04	9.0	2.3	-	-	3.5	-	11.3
Cr07	4.3	2.4	9.1	0.9	1.7	18.4	6.9
Cr08	10.4	3.0	49.2	5.4	4.9	72.9	13.4
Cr21	15.3	3.3	61.1	7.1	8.6	95.4	18.6
Cr31	9.1	1.7	26.1	4.8	2.9	44.6	10.8
Cr39	7.7	2.5	41.1	7.9	3.7	62.9	10.2
Mi09	8.0	2.4	33.0	3.1	3.6	50.1	10.4
Mi22	12.9	3.5	20.1	5.4	6.2	48.1	16.4
Mi25	6.0	2.0	19.6	2.4	3.0	33.0	8.0
Mi37	7.1	2.2	23.5	1.2	3.7	37.7	9.3
Mi40	7.1	1.6	8.9	0.6	2.8	21.0	8.7
Mi41	5.2	2.1	57.9	6.3	4.3	75.8	7.3
Pa11	12.2	2.5	39.1	2.9	3.5	60.2	14.7
Pa12	11.8	2.7	55.2	15.5	4.3	89.5	14.5
Pa15	13.2	2.9	85.8	18.2	7.0	127.1	16.1
Pa16	16.6	4.2	65.8	3.5	9.7	99.8	20.8
Pa18	17.9	4.7	79.2	17.3	7.8	126.9	22.6
Pa19	13.8	3.2	68.8	8.7	8.9	103.4	17.0
Pa26	8.5	1.5	74.2	21.2	7.5	112.9	10.0
Pa27	13.7	5.9	63.2	17.4	9.0	109.2	19.6
Pa34	14.1	2.7	53.3	6.0	8.7	84.8	16.8
Pa36	9.7	2.5	47.0	12.1	4.0	75.3	12.2
Un02	20.9	3.4	108.8	17.0	6.1	156.2	24.3
Un28	14.7	3.4	79.7	14.5	6.8	119.1	18.1
Un30	10.1	1.7	39.8	10.5	3.7	65.8	11.8

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ANNEX 7 DOUBLE POT EXPERIMENT DATA (also see 6.2)

Table A7.1 Sufficiency Quotients (SQ) for N, P, and K for each block for the investigated soils A 29, Bo14, Cr03, Mi37, Pa15, Un28 and the standard soils Eng and Loess

Soil	Block	SQ N	SQ P	SQ K
A 29	I	0.798	0.748	1.043
	II	0.769	0.833	1.141
	III	0.791	0.769	0.910
Bo14	I	0.630	0.641	0.851
	II	0.778	0.802	1.066
	III	0.944	0.750	0.958
Cr03	I	0.784	0.614	0.943
	II	0.871	0.682	0.841
	III	0.961	0.750	1.158
Mi37	I	0.790	0.691	1.111
	II	0.871	0.761	1.067
	III	0.910	0.814	1.021
Pa15	I	0.827	0.778	0.926
	II	0.893	0.933	1.027
	III	0.765	0.685	0.926
Un28	I	0.765	0.679	0.951
	II	0.709	0.663	0.903
	III	0.748	0.877	1.045
Eng	I	0.663	0.907	0.872
	II	0.627	0.951	0.897
	III	0.655	0.933	0.909
Loess	I	0.670	0.715	0.883
	II	0.807	0.919	1.080
	III	0.851	0.797	0.986

ANNEX 8 LOCATION SAMPLE SITES AND FARMERS NAMES

Table A8.1 Location of sample sites and farmer/owners name

Soil	Northern latitude	Western longitude	Farmer/owners name
A 01	10° 15' 48"	83° 37' 58"	Victor, Jorge y Oscar Ruiz
Un02	10° 15' 11"	83° 37' 53"	Rafael Sanchez
Cr03	10° 15' 06"	83° 37' 04"	Victor Manuel Gonzalez Aries
Cr04	10° 15' 27"	83° 37' 23"	Don Checo
A 06	10° 15' 29"	83° 36' 59"	Carlos Barrantes
Cr07	10° 15' 24"	83° 37' 14"	Carlos Hernandez
Cr08	10° 16' 00"	83° 38' 42"	Efran Lobo Rivera
Mi09	10° 14' 35"	83° 36' 10"	Urpiano Fagardo Fagardo
Pa11	10° 15' 14"	83° 34' 39"	Heriberto Picon Martinez
Pa12	10° 14' 23"	83° 34' 59"	Mario Rodriguez Zamora
Bo14	10° 15' 17"	83° 34' 47"	Elodia Villegas Valderramos
Pa15	10° 13' 51"	83° 32' 54"	Danian Torres Martinez
Pa16	10° 14' 10"	83° 32' 02"	Juan Alvarez Morales
Pa18	10° 14' 44"	83° 33' 30"	Jose Segura Jimenez
Pa19	10° 14' 54"	83° 33' 14"	Jose Sanchez Sanchez
Bo20	10° 15' 04"	83° 34' 54"	Maria Francisca Ugalde Sibaja
Cr21	10° 15' 35"	83° 37' 37"	Enrique Obregon Castillo
Mi22	10° 11' 02"	83° 34' 34"	Olman Alfaro Esquivel
Mi25	10° 14' 23"	83° 36' 11"	Gerardo Castillo Chinchila
Pa26	10° 14' 15"	83° 35' 58"	Jezus Sanchez Pereira
Pa27	10° 14' 23"	83° 36' 18"	Carmelino Godinez
Un28	10° 15' 35"	83° 37' 30"	Rafael Angel Delgado
A 29	10° 15' 43"	83° 37' 36"	Don Guido (Papillo)
Un30	10° 15' 32"	83° 37' 25"	Luis Cordero (Hijo Don Checo)
Cr31	10° 15' 20"	83° 37' 22"	Jose Arias Mesa
Bo33	10° 14' 35"	83° 35' 14"	Eliu Artavia Conejo
Pa34	10° 14' 28"	83° 34' 59"	Olivier Alvrez Guillen
Bo35	10° 15' 17"	83° 34' 51"	Garcia Valencia Jose Domingo
Pa36	10° 14' 15"	83° 34' 54"	Mario Rodriguez Zamora
Mi37	10° 11' 09"	83° 35' 55"	Jesus Solano Leandro
Bo38	10° 14' 40"	83° 35' 10"	Felix Ruiz
Cr39	10° 15' 12"	83° 37' 40"	Hilario Hidalgo Lascarez
Mi40	10° 11' 12"	83° 34' 54"	Ponciano Barquero
Mi41	10° 11' 04"	83° 35' 51"	Jose Chavaria Solis