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EFFECT OF CONTINUOUS CULTIVATION AND FERTILIZER APPLICATIONS ON YIELDS OF MAIZE AND SOIL CHARACTERISTICS OF A FERRALSOL-LUVISOL CATENA ON GNEISS IN N.E. TANZANIA

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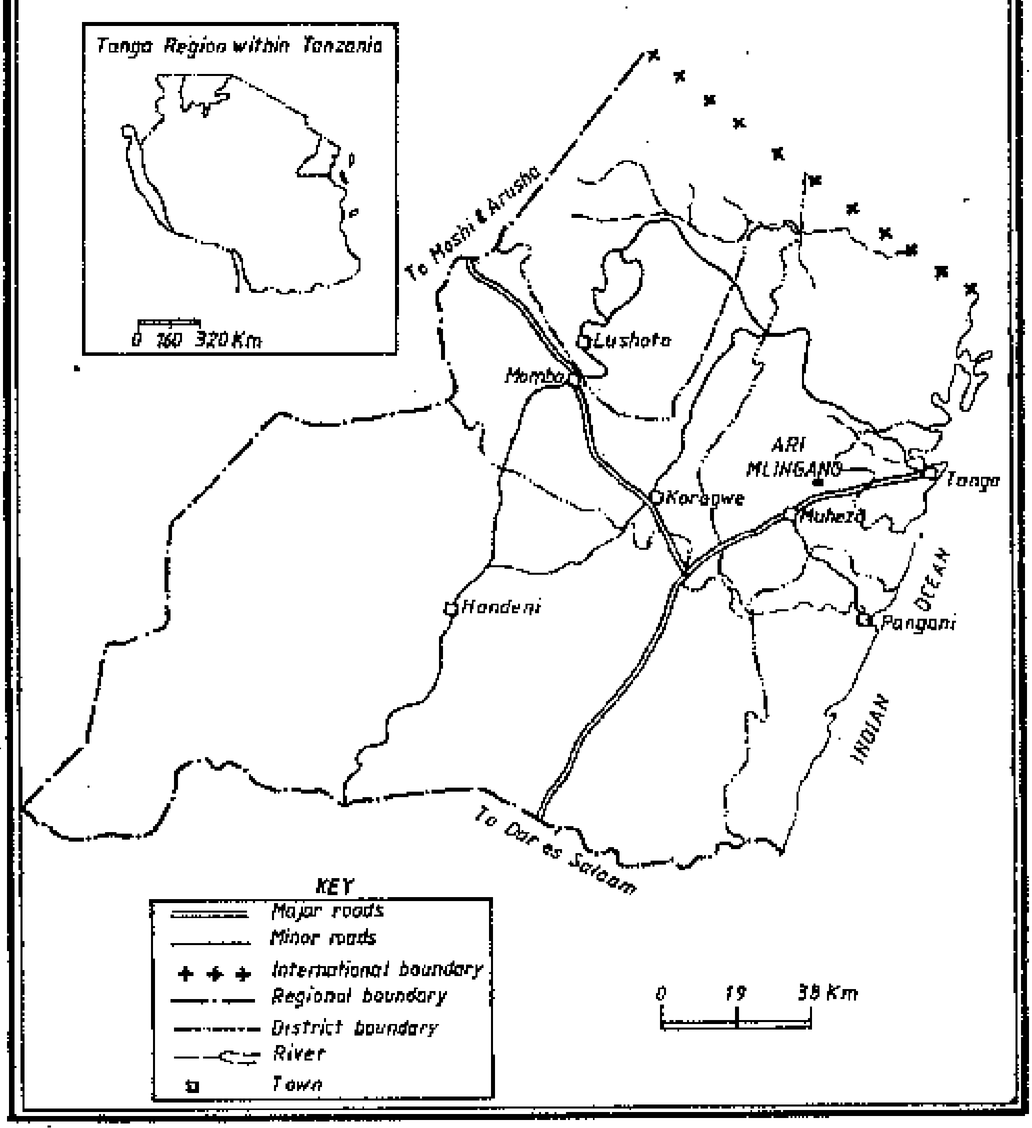
Preface

This Soil Fertility Report No. 5 presents the revised edition of a paper that was presented under the same title at the Inaugural Meeting of the All-Africa Soil Science Society which was held from 5-9 December 1988, at Kampala, Uganda.
The paper was prepared by Mr K.L. Haule (National Soils and Fertilizer Use Coordinator), Dr. E.I. Kimambo and Mr. J. Floor (Soil Fertility, Management and Conservation Section of National Soil Service).

The report summarizes the findings up to 1988 of a long-term NP fertilizer trial, started in 1981 under the supervision of Messrs. F. Miany, E.M. Shenkalwa and J.F. Harrop, along the Mlingano Catena. The trial is still being carried out yearly by the Soil Fertility, Management and Conservation Section of the National Soil Service.

FIG. 1:- LOCATION OF A.R.I. MLINGANO



1 SUMMARY

This Soil Fertility Report describes the results up to 1988 of a long-term NP fertilizer experiment that was started in 1981 along the so-called Mlingano Catena which is developed on metamorphic basement rocks, mainly gneiss, at the Agricultural Research Institute at Mlingano, Tanga Region, Tanzania. This still on-going experiment studies the effects of continuous cultivation of maize and application of N and P fertilizers at various rates on the performance and yield of maize, as well as on soil characteristics.

The results over the period 1981-1988 show that the position in the catena is of dominant importance is determining maize yield. Lowest yields are obtained on the crest position (Rhodic Ferralsol) and highest on the lower slope position (Chromic Luvisol) with intermediate yield levels at the mid slope position.

Responses to nitrogen, in the range 0-40 kg N/ha were obtained mainly on the crest and mid-slope position and amounted to, on average, about 25 to 30 kg grain per kg N applied.

Rainfall and number of years under cultivation turned out to have distinct influences on yield levels and the magnitude of crop response to nitrogen.

Responses to phosphorus were not recorded, although soil extractable P values are (very) low at all sites.

The effect of continuous cultivation with maize is obvious, and significant decreases in pH, organic matter and bases are recorded.

As the nitrogen is applied in the form of Sulphate of Ammonia, the monitoring of the acidifying effect of this type of fertilizer is part of the study. The results of this trial show that only in the Ferralsol a significant drop in pH can be detected, but still less than the drop as result of continuous cultivation.

2 INTRODUCTION

The concept of the soil catena was first developed in Tanzania in the 1930s (Milne, 1935). Since then this concept was used and found practical in many soil studies, especially those on aspects of soil genesis and classification, not only in Tanzania but also in other parts of Africa (Calton, 1953 and 1954; Moorman, 1981).

One of the obvious advantages of the application of this method is that soils occur in close proximity to each other, hence minimizing the effect of differences in climate, whilst at the same time offering the maximum degree of differentiation on the same parent material.

This concept can also be used in soil fertility and management research (Hanegraaf, 1985; Harrop, 1985; Mitchell, 1984; Kraus, 1988), but special care should be taken in site selection as topsoil properties are of utmost importance in soil fertility research and are influenced by many factors.

Soil fertility experimentation based on the catena concept has been put into practice by the National Soil Service since 1981 on a soil catena developed on gneiss in N.E. Tanzania.

The objective of the study was to monitor crop responses and changes in

soil characteristics resulting from continuous monocropping with maize and the addition of N and P fertilizers.
As nitrogen was applied in the (at least then) most commonly used form, i.e. as Sulphate of Ammonia, which is known for its acidifying effect, the monitoring of change in pH under relatively high application rates of this fertilizer could be studied as well.

3 MATERIALS AND METHODS

3.1 The catena

The soils in the catena under study, locally known under the name Mlingano Catena, are developed on metamorphic Precambrian Basement rocks, mainly gneisses. The catena is dominant on the undulating, slightly dissected peneplain at the foot of the Usambara Mountains. The crests of the ridges are broad and slightly convex and are at an altitude of about 200 m. The ridge slopes are convex in shape with slopes between 2 and 14 percent.
Soils on the crests and upper slopes classify as Rhodic Ferralsols (FAO, 1988); those on the lower slopes as Chromic Luvisols (FAO, 1988). In between intergrades of these two kinds of soil are present.
The Ferralsols are deep, well drained, clayey soils with having dark reddish brown over dusky red colours. The structures are friable, strong or moderate subangular blocky, underlain by subsoils with weak, granular structures.
The Luvisols on the lower slopes are deep or moderately deep, well drained and with sandy clay over clay textures. Colours are dark red over red and the structures of the subsoils are strong, subangular blocky.

Some typical properties of the two kinds of soil are presented in Table 1.

	CVO			CV I			CV II			CV III			CV IV		
H 1:2,5	pH-H2O	pH-KCl		pH-H2O-	pH-KCl		pH-H2O	pH-KCl		pH-H2O	pH-KCl		pH-H2O	pH-KCl	
	6,6	5,7					6,7	5,9		6,6	6,0		6,5	6,0	
	6,0	5,0					6,5	5,5		6,4	5,8		6,4	5,8	
	5,8	4,7					6,3	5,0		6,4	5,8		6,0	5,7	
	5,9	4,9					5,9	4,9		6,5	6,0		6,4	5,8	
C - P ppm [illegible]	1,3	8,5					2,0	2,5		1,9	2,1		1,4	2,3	
	0,9	10,6					0,8	0,7		1,8	1,9		0,9	0,7	
	0,3	20,8					0,4	0,5		0,5	0,5		0,4	0,7	
	0,2	1,6					0,3	0,6		0,5	0,4		0,3	0,5	
- BS - CECc	11,7	76	24,9				19,0	100	31,7	17,5	96	36,5	17,4	96	41,4
	11,9	60	20,2				8,4	81	21,5	17,0	92	34,7	14,3	91	34,9
	6,2	61	10,5				6,8	75	12,4	11,4	92	20,4	11,5	75	20,9
	5,7	55	10,4				7,0	64	13,2	11,1	78	17,9	10,1	93	18,4
mg - K	7,6	0,8	0,4				6,7	4,0	1,4	13,4	2,1	1,2	12,6	1,8	2,1
	6,0	0,6	0,3				4,8	1,0	0,9	12,2	2,3	1,0	9,4	2,3	1,2
	3,0	0,6	0,1				2,4	1,8	0,8	7,0	2,8	0,6	6,2	2,0	0,4
	2,7	0,7	0,1				2,2	1,4	0,8	5,6	2,4	0,6	4,2	3,8	0,2

=0,1-0,2

Table 1. Chemical and physical properties of the Rhodic Ferralsol and Chromic Luvisol, Mlingano Catena.

	Rhodic Ferralsol		Chromic Luvisol	
	Ap (0-15)	Bws_1 (35-65)	Ap (0-12)	Bt_1 (30-75)
Clay (%)	53	61	39	53
Silt (%)	10	6	15	11
Sand (%)	37	33	56	36
$pH-H_2O$	6.3	5.4	7.1	6.6
pH-KCl	5.6	4.7	6.4	5.6
org C (%)	1.8	0.3	2.0	0.4
CEC (me/100g)	13.6	6.9	22.6	13.5
exch. K "	0.6	0.2	1.6	0.8
exch. Ca "	9.3	2.1	16.6	8.0
exch. Mg "	1.4	0.6	4.1	2.6
Base Sat. (%)	83	42	100	70
P-Bray I (mg/kg)	5	2	6	1

3.2 The experiment

The experimental sites are located within the Mlingano Agricultural Research Institute, about 30 km W. of Tanga Town, at an altitude of about 200 m (see map).
The rainfall pattern is bimodal with a long rainy season from March to June and a short rainy season from October to December. Annual rainfall is erratic, but, on average, amounts to about 1150 mm.

The experiments were conducted on sites, cleared from secondary bush, occupying a crest position (slope 2 percent), a mid-slope position (slope 5 percent) and a lower slope position (slope 9 percent) in the catena described above.
Maize (Zea mais) has been planted at the onset of each long rainy season since 1981 at a spacing of 75 x 30 cm (44,400 plants/ha).
Fertilizer applied included the addition of nitrogen at rates of 20, 40 and 80 kg N /ha, and phosphorus at 8.8, 17.6 and 26.4 kg P /ha. An absolute control treatment (no N, no P) was also included.
The nitrogen was applied in the form of Sulphate of Ammonia (SoA, 21 % N), half of the dose at planting and half when plants were about knee-high and the phosphorus as TripleSuperPhosphate (TSP, 46 % P_2O_5), as a single dose at planting. Both fertilizers were banded.
The statistical design was a complete randomized block design, 3 x 3 factorial plus one control, four times replicated.
On the sites standard crop management practices were carried out.
Composite soil samples were taken from the topsoil (0-20 cm) each year

before planting, and analyzed for the main soil fertility parameters, including pH-H_2O and pH-KCl (1:2.5), org C (Walkley & Black), P (Bray-I), exchangeable cations (Na, K, Ca and Mg) and CEC (pH:7.0, Ammonium Acetate).

4 RESULTS

4.1 Rainfall

As rainfall is erratic in the bimodal rainfall areas of Tanzania, rainfall characteristics have a specific effect on crop yield and fertilizer response.
Table 2 presents the monthly rainfall figures for the main growing months of maize during the experimental period (1981 -1988).

Table 2. Monthly rainfall (in mm) for March to July.
Mlingano Agricultural Research Institute (1981-1988)

Year	March	April	May	June	July	total
1981	350	133	108	38	38	667
1982	77	209	229	80	105	700
1983	80	91	301	44	55	571
1984	53	539	105	132	62	891
1985	36	165	232	8	59	500
1986	82	470	332	29	18	931
1987	48	108	458	2	82	698
1988	73	93	86	140	12	404

The rainfall figures show a large variation from season to season, both in total amount and in distribution. The generally low rainfall in June often puts the crop under stress, especially when moisture storage has been little in the previous month.

4.2 Unfertilized maize yields

Table 3 gives the maize yields of the unfertilized treatments per year and per soil type.

Table 3. Unfertilized maize yields (in kg/ha) in Mlingano Catena, (1981 - 1988).

	Rhodic Ferralsol	Intergrade soil	Chromic Luvisol	Mean
1981	240	1760	3355	1785
1982	1110	3225	5780	3370
1983	555	2290	2890	1910
1984	990	1735	4670	2465
1985	595	1465	2965	1670
1986	815	1020	2370	1400
1987	crop failure	crop failure	2445	-
1988	620	1250	2720	1530
Mean	615	1595	3400	

Unfertilized maize yields depended on soil type, rainfall characteristics of the season and length of cultivation period as shows from the data in Table 3.

Maize yields were lowest in all seasons on the Ferralsol, followed by the yields on the intergrade soil, whereas highest yields were obtained on the Luvisol. The latter being 5.5 times as high as the yield on the Ferralsol.

Yield levels in seasons with good rainfall (in terms of amount and distribution, e.g. 1982 and 1984) were highest.

Yields in the last few years of the experiment tended to be lower than those in the first years, especially on the intergrade soil and on the Luvisol (e.g. compare yield of 1982 with that of 1984, and the 1981 and 1983 yields with those of 1986 and 1988).

4.3 Response to fertilizer

No significant differences were found between the three levels of P, but responses to N were observed.

Table 4 gives the mean responses to N (averaged over the three P treatments) at the three sites.

For comparison the absolute control yields are also presented. Data are based on results from the total period of the experiment, except for 1987 when a crop failure was recorded due to drought.

Table 4. Mean yield response (in kg/ha) to nitrogen at Mlingano Catena (1981 - 1986,1988).

	N=20	N=40	N=80	N=0
Rhodic Ferralsol	1680 b	2170 a	2040 ab	705 c
Intergrade soil	2820 b	3045 ab	3360 a	1820 c
Chromic Luvisol	3945 a	4130 a	4225 a	3535 b

Figures followed by the same letter do not differ significantly at P=0.05 according to the New Duncan Multiple Range Test.

At all sites the yields with fertilizer were significantly higher than the absolute control treatment yield. Highest responses were recorded on the chemically relatively poor Ferralsol and on the intergrade soil. It appears that the highest yield increments occurred at the low application rate of 20 or 40 kg N /ha; rates higher than 40 kg N /ha did not result into a significantly higher yield.

The response to 40 kg N/ha is worked out in more detail in Table 5.

Table 5. Absolute and percentage response to 40 kg N/ha per soil type and per season, Mlingano Catena (1981 - 1988).

	Ferralsol		Intergrade		Luvisol		Mean	
	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%
1981	+1045	+435	+685	+39	+570	+17	+830	+43
1982	2390	213	1465	45	900	16	1585	47
1983	880	158	1370	60	-70	-2	775	40
1984	1305	132	1330	77	495	11	1045	42
1985	935	157	225	15	735	25	630	38
1986	1850	226	1515	148	1235	52	1535	110
1987	crop	failure	crop	failure	165	7	-	-
1988	1850	298	1980	158	315	12	1380	90
Mean	1280	182	1070	59	595	15		

Table 5 shows again that absolute responses were highest on the Ferralsol, on average about twice as high as those on the Luvisol. Expressed as percentage response, the differences become even more pronounced.
Highest responses were in general obtained in years with good and/or well distributed rains (1984, 86 and 88). This holds particulary true for the Ferralsol and for the intergrade soil. But also in years with a moderate and/or rather poorly distributed rainfall, the response to N on these two soils was significant and amounted to 600 to 1000 kg maize grains per ha.
It is interesting to note that responses since 1986 have increased drastically compared to responses obtained in the years before, indicating a decrease in soil fertility and consequently a higher need for added nutrients. As will be seen later this observation is supported by the soil analytical data.

4.4 Effect of continuous cultivation on soil chemical parameters.

Table 6 presents a summary of the effects of continuous cultivation on soil pH-H_2O and organic carbon content in the unfertilized treatment.

Table 6. Effect of continuous cultivation on soil pH and organic carbon content in top soil, Mlingano Catena (1981 - 1988).

	Ferralsol		Intergrade soil		Luvisol	
	pH-H_2O	% C	pH-H_2O	% C	pH-H_2O	% C
1981	5.9	2.3	5.7	2.5	6.4	3.6
1982-83	5.8	2.3	5.4	2.2	5.9	2.9
1984-85	5.7	2.1	5.6	2.0	6.3	3.0
1986-88	5.3	1.6	5.2	1.5	6.0	2.2

A general trend of declining organic matter and pH values is present in all soils, with strongest decreases occurring in the last years. Erosion might partly be held responsible for this as extremely heavy downpours were experienced in the 1986 and 1987 seasons.
Exchangeable bases follow the same trend, although some contradicting results were obtained, especially on the Luvisol (Table 7).

Table 7. Effect of continuous cultivation on exchangeable bases content, Mlingano Catena (1981 - 1988).

	Ferralsol			Intergrade soil			Luvisol		
	K	Ca	Mg	K	Ca	Mg	K	Ca	Mg
	---me/100g---			---me/100g---			---me/100g---		
1981	0.42	6.1	2.7	1.04	4.9	2.3	0.77	8.9	4.2
1982-83	0.46	4.8	2.5	0.65	3.2	2.4	0.34	8.5	4.5
1984-85	0.35	5.1	1.8	0.66	3.1	2.4	0.64	10.1	4.8
1986-88	0.35	4.2	1.2	0.66	2.8	1.6	0.46	9.5	3.6

Extractable P values did not show a consistent trend at all three sites.

4.5 Effect of application of Sulphate of Ammonia on soil-pH values

As has been mentioned above the nitrogen was administered in the form of Sulphate of Ammonia and soil pH values were monitored over the experimental period.
Table 8 summarizes the pH effect resulting from the yearly application of 380 kg SoA (=80 kg N) /ha.

Table 8. Soil pH-H_2O change as result of application of 0 and 80 kg nitrogen per ha per year, Mlingano Catena (1981 - 1988).

	Ferralsol		Intergrade soil		Luvisol	
	0 kg	80 kg	0 kg	80 kg	0 kg	80 kg
1982-83	- 0.1	- 0.1	- 0.3	- 0.3	- 0.5	- 0.4
1984-85	- 0.2	- 0.4	- 0.0	- 0.1	- 0.0	- 0.0
1986-87	- 0.5	- 0.9	- 0.5	- 0.7	- 0.4	- 0.5
pH mid-1988	5.1	4.6	4.9	5.0	5.8	5.7

It appears that the yearly addition of the SoA had little effect on the soil pH on the intergrade soil and Luvisol, and that the observed decrease is mainly due to the continuous cultivation with maize. On the Ferralsol which has the lowest CEC, however, a fairly remarkable decrease was found after 8 years of SoA application, and it is expected that maize performance will be affected by these low pH values in due course. This was not yet experienced in the 1988 crop.
The application of SoA did not cause a difference in organic matter values at any site.

5 DISCUSSION AND CONCLUSIONS

The results of this long-term trial clearly show that valuable information can be extracted on the effects of continuous cultivation and different fertilizer applications on crop yields when trials are located along a catena.
Yield levels were strongly influenced by the position of the site in the catena with lowest yields obtained on the Rhodic Ferralsol on the crest and highest yields on the Chromic Luvisol on the lower slope.
Ferralsols responded strongly to the addition of N fertilizer, whereas responses on the Luvisol were slight and in general not significant. This indicates that, although low soil fertility is one of the main reasons for the low yields realised on the Ferralsol, the potential for higher yields is present. Yields on the Luvisol without the addition of fertilizers were, however, still significantly higher than the yields on the Ferralsol with fertilizer. It is therefore recommended in farming systems were land scarcity is not the case to take these Luvisols in production first.
It was found that responses to N were highest in years with relatively high and well distributed rainfall, but contrary to the general belief, significant and attractive responses were also obtained in years characterized by sub-optimal rainfall conditions.
Responses to added fertilizer on the Ferralsol and intergrade soil became more pronounced in later years, probably as a result of the strong decline in the soil fertility status. This observation supports the opinion that long-term experiments of this kind are often more useful than (many) short-term trials.
The response to P was not significant at all sites, a fact that was also found in previous experiments carried out at the same station. This is

surprising as extractable P values are low. One reason might be that, as previous studies have shown that 60 to 80 per cent of the total-P in these soils is in organic form, through the mineralization of organic matter enough phosphorus has been released to obtain the present yield levels. Another reason might be that P applied is strongly fixed by the soil. However, on soils with pH values around 6.0, which happened to be the case at all sites in the first years of the experiment, this is not very likely, as is also shown by the data of Shirima (1988). As the experiment is still running future results might give an answer, and the 1988 results indicated that responses to P are forthcoming. Also in the TSP-Minjingu Rock Phosphate long-term experiment (NSS, 1989) responses to P became significant only after a number of years of cultivation.

The soil data show a significant decrease in both pH values and organic matter contents (on average 0.5 pH-unit and 35 per cent of the organic matter) and, at most sites, also in exchangeable bases after eight years of continuous maize cultivation. In general the decreases were most pronounced in the second half of the experimental period. This might explain the larger decreases found in this experiment compared to decreases obtained by Stephens (1969)in Uganda, whose experiments were run for 4 years only. On the other hand, Jones (1972) working on ferrallitic soils in Uganda reported a large decrease in organic matter content already after three years of cultivation. In Tanzania, Anderson (1970) found a decrease of about 30 per cent in organic matter content and a drop in pH of 0.9 unit already after five years of maize cultivation on a soil derived from a similar parent material, but having a coarse sandy loam texture and being chemically poorer than the soils studied in this experiment.
The strong decrease in organic matter content and other soil parameters as result of continuous cultivation, show that when long term cultivation on especially Ferralsols is envisaged, a careful soil management policy has to be followed in order to avoid mining and rapid degradation of the soil fertility status with special emphasis put on soil organic matter.

The effects of repeated applications of 80 kg N/ha as SoA on soil pH was only noticeable on the Ferralsol. Studying the same soils, Leuteneger (1956) observed a decrease of 0.3 pH-unit after one year when the soils were treated with 1000 kg SoA/ha (=210 kg N/ha). This decrease is higher than found in this experiment ,but the results of the present study show that the decrease per year does not follow a straight line as probably rainfall, and consequently leaching and conditions for nitrification, which magnitude differs from year to year, plays a role as well. He, as well as Smith (1962), also found that the negative effect of SoA on pH could be reduced by the application of mulch. On soils mentioned before, Anderson (1970) found a decrease in pH of almost one full unit after five years due to the application of, in total, about 300 kg N/ha which was applied as Ammonium sulphate nitrate.
In the present study, the acidifying effect of SoA could not be detected on the soils with higher CEC and base saturation values.
The results of this and the other studies mentioned above shows that care should be taken in the use of SoA, especially on Ferralsols and on soils that have already a pH value around 5.0. In those cases the use of less acidifying types of N fertilizers should be recommended.

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