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Integrated Soil Water and Nutrient Management for Late Season Crop Production Systems in the Nigerian Savanna

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Abstract: The agronomic, ecological and economic aspects of some organic waste application along with water harvesting techniques on the performance of off-season tomatoes and late season roselle and cotton in a dry land savanna agroecosystem were investigated. Different organic materials were applied as amendments to soil for tomato production under soil residual moisture condition. In addition, roselle and cotton were cultivated using tied ridge moisture conservation technique and different nutrient sources in a savanna Alfisols at Samaru, Nigeria. The use of organic amendments produced similar fruit yield with those tomato receiving mineral fertilizer amendment. Organic amendments produced tomato fruit with 70 to 80% marketable yield while, 84% of the fruit yield were marketable under mineral fertilizer application. Net income from sales of tomato under organic amendments showed that they could produce comparative profit margin with those produced from mineral fertilizers. Trace and heavy metal accumulation in tomato leaves were generally within the critical concentrations of those elements in plants. The tied ridge technique significantly increased cotton yield by 54% when compared with the conventional open ridge technique. In addition, cowdung amendment produced 42% more seed cotton than the recommended practice of using mineral fertilizer. Cost-benefit ratio revealed that the use of organic waste material in cotton production resulted in a positive net returns. Hence, application of organic waste to soils is potentially an important means of recovery of soil organic matter and an essential disposal method.

Key words: Soil water conservation, organic material, soil amendment, tied ridge

INTRODUCTION

In Nigeria, much of the arable crop production falls within the savanna region, which is characterized, by limited and unpredictable rainfall and poor variable soils. Water is fast becoming an economically scarce resource. This, along with soil nutrient imbalance, have been described as the two most important biophysical constraints to crop production in the region (Bationo *et al*., 1997). Fibre and vegetable production systems in Nigeria are intensive, because they are high-value economic crops. Mineral fertilizers are commonly applied by growers to maximize yields. However, for a variety of socio-economic and political reasons, this became difficult. There is now an urgent need for the implementation of alternative methods to reduce dependence on use of mineral fertilizers, which are not readily available and when available, beyond the reach of the resource poor farmers.

The use of organic amendments is one cheap and readily available alternative if the trend of soil degradation is to be reversed (Bationo and Mokwunye, 1991). In the Nigerian savanna, large quantity of livestock (cattle, sheep, goat and poultry) wastes are dumped at disposal sites where their offensive odour is of environmental concern. Information on the agronomic potentials of these waste have shown that they possess potentials to increase soil and crop productivity (Asiegbu and Oikeh, 1995; Anikwe *et al*., 2002). One major benefit of the use of organic wastes as soil amendments is their ability to contribute soil organic matter, nitrogen and other nutrients via decomposition to soil. Most recent research work on manuring have focused on staple crops like maize, sorghum, etc. (Uyovbisere and Elemo, 2002). In the case of maize production in the savanna agroecology, organic amendments must complement mineral fertilizer for optimum yield. With crops like vegetables, organic amendments can totally substitute mineral

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fertilizer. Tomato yields under green manure in the wet season have been reported to compare favourably with mineral fertilizer at 38 to 120 kg N ha^{-1} (Thonnissen *et al*., 2002).

Cash crop production is usually delayed in Nigeria because priority is usually given to food crop production at the commencement of the cropping season (Ogunlela *et al*., 1986). This, has made soil moisture insufficient for these economic crops resulting in very poor yield. Crops like roselle (*Hibiscus sabdariffa*) and cotton (*Gossypium hirsutum* L.) can improve performance under proper soil water management conditions. Ogunwole (2004) has reported 80% yield increase in seed cotton when the tied ridge soil moisture conservation technique was adopted.

The objective of this study was therefore to:

- Compare the effect of substituting mineral fertilizer with organic amendments on soil properties, yield, nutrient uptake and economics of late sown tomato (*Lycopersicon lycopersicum*).
- Determine the effect of integrating various nutrient sources with tied ridge moisture conservation techniques on roselle and cotton yield in a savanna agroecology.

MATERIALS AND METHODS

Experiment 1 involves the cultivation of tomato to survive on the residual soil moisture after cessation of rain as there would be no provision made for supplemental irrigation. The justification for such cultivation is vested largely on economic reasons that include low-level inputs particularly in crop protection practices and high market prices attraction since the crop will be harvested as off-season produce. Experiment 2 involves cultivation of roselle and cotton under the tied ridge water harvesting technique. All the experiments were conducted at the Experimental farm of the Institute for Agricultural Research (IAR), Samaru (11°11'N, 07° 38'E, alt. 686 m), Nigeria. Long term mean annual rainfall is 1050 mm (Table 1) with the rainy season extending from May to October.

Experiment 1: The experimental site is made up of Alfisols; Typic Haplustalf, loam with a pH (water) 5.5, cation exchange capacity of 5.6 cmol (+) kg^{-1} with total nitrogen (microkjeldahl method) of 0.8 g kg^{-1} and moderate Bray-1 phosphorus of 12.2 mg kg^{-1}. The study involves five organic soil amendments namely; cowdung, poultry litter, urban waste, goat-and rabbit-droppings. These materials were tested with mineral fertilizer (NPK) and a control (i.e., no amendment). The treatments were arranged in a Randomized Complete Block Design with three replications. Before the treatments were imposed, they were analysed for total nitrogen (Bremner and Mulvaney, 1982). and available phosphorus (Olsen and Sommer, 1982). The nitrogen content was used to calculate for 100 kg N ha^{-1} of each treatment. However, for the organic materials, a 60% adjustment factor to compensate for the nitrogen availability was included (Keeling *et al*., 1995). Seedlings of tomato variety, TI106 at five weeks old were transplanted in the first week of September into the various treatment microplot of 6 m^2 each and crop spacing was 0.6 × 0.45 m. The crop was rainfed for the first six weeks of field life as there was no provision for any form of irrigation after cessation of the rains, the crop matured thereafter on soil residual moisture. Soil analysis determined include organic carbon, total nitrogen, available phosphorus and soil reaction. Plant uptake of selected heavy metals like nickel, lead, cadmium and chromium (Page *et al*., 1982) was determined along with growth and yield parameters. Data collected were subjected to analysis of variance using the GLM procedure of the SAS version 6.0 (SAS Institute Inc., 1987). The cost benefit ratio of the various

Table 1: Long term (60 years) mean meteorological data of Samaru, northern Nigeria

			Air temperature (°C)		
Months	Rainfall (mm)	Relative humidity (%)	Minimum	Maximum	Sunshine (h)
January	0.1	16.6	21.6	30.0	8.5
February	0.9	13.5	24.0	32.4	9.0
March	6.0	20.1	27.2	35.1	8.1
April	34.5	32.8	28.5	35.8	7.9
May	119.3	54.2	27.3	33.1	8.1
June	153.9	66.2	25.4	30.7	7.7
July	221.2	74.3	19.5	28.5	6.2
August	273.8	76.9	19.2	27.9	5.0
September	208.3	70.9	15.1	29.4	7.0
October	36.7	51.7	17.6	31.3	8.0
November	1.0	25.0	15.2	31.6	9.0
December	0.2	19.4	13.6	30.2	8.7

amendment-based systems was also calculated to determine the effect of application of synthetic and organic manures on the expenditure profile of the systems.

Experiment 2: A factorial combination of nutrient sources and water harvesting techniques were laid out in a Randomized Complete Block Design with three replications. The treatments include three nutrient sources, namely; cowdung, poultry litter and mineral fertilizer along with three water harvesting techniques (i.e., open ridge, alternate ridge-tie and all ridge-tie). All nutrient sources were equivalent of 100 kg N ha^{-1} in the first year (2003). Mineral fertilizer was applied in two equal split doses at 3 and 5 weeks after crop emergence. Tied ridge treatments were imposed when the crops were fully established at 4 weeks after emergence. Tied ridge involves the construction of earthen bunds at right angle to the ridges at intervals of 1-2 m for all- and alternate-ridges as the case may be. Roselle was sown on August 13, 2003 in a plot size of 30 m^2. In the second year of the trial, upland cotton (*Gossypium hirsutum* L.) was sown on July 6, 2004. In this report, only result of roselle calyx weight, seed cotton yield and lint quality will be reported. Soil analysis such as bulk density, moisture content, total nitrogen, available phosphorus and organic carbon contents of the various nutrient sources after incorporation and at harvest were highlighted. Data were statistically analysed using GLM procedure of SAS with the Duncan's Multiple Range Test being adopted for mean comparisons. Yield of all crops, account of cost of production and returns were recorded and analysed.

RESULTS

Experiment 1: Rabbit and goat droppings produced significantly higher number of branches per tomato plant. They also produced significantly wider stem girth and larger canopy spread than the other soil amendments (Table 2). These two organic soil amendments also recorded significantly more days to tomato flowering under soil residual moisture. The control (zero amendment) and the urban waste amendment recorded the lowest number of days to flowering, lowest value of plant height, low leaf area index, canopy spread, stem girth and number of leaves per plant (Table 2). In all the vegetative growth indices considered, mineral fertilizer as a soil amendment performed significantly lower than the rabbit and goat droppings. Cowdung and poultry litter recorded comparatively similar values for number of branches per plant, stem girth, leaf area index and canopy spread (Table 2).

Mineral fertilizer amendment recorded the highest tomato fruit yield of 13.2 t ha^{-1}, this was similar to tomato yield from the other amendments (Table 3). Similar trend was recorded for marketable tomato yield. Among the various soil amendments investigated, more rotten tomato fruits were recorded under the mineral fertilizer amendment while, urban waste amendment and control produced significantly lower rotten fruits. The others fall between the values for the control and those of mineral fertilizer in the weight of rotten fruits produced. Green and rotten fruits form the non-marketable tomato fruits, which amount to losses for the tomato grower. Highest fruit volume was recorded under the urban waste amendment while, poultry litter and control recorded the lowest fruit volume in that order (Table 3).

Application of the various soil amendments significantly altered the concentration of heavy metals in tomato leaves. Poultry litter, cowdung and mineral fertilizer recorded significantly ($p = 0.001$) higher nickel (Ni) concentration than the others. Those tomato plants growing under urban waste soil amendment recorded significantly higher ($p<0.001$) lead (Pb) and cadmium (Cd) concentrations in their leaves (Table 4). The application of soil amendments also influences the uptake by tomato leaves of nitrogen (N), phosphorus (P) and potassium (K). There was no significant difference in tomato leaf uptake of N and K. However, P uptake was greatly influenced by the various amendments. Highest P uptake was recorded in tomato leaves that were treated with goat droppings while rabbit droppings produced the lowest P concentration in tomato leaves (Table 4).

The various soil amendments influenced to a large extent the properties of the soil. Rabbit and urban waste amendments recorded the highest soil moisture content while, the control had significantly lower soil moisture content than the amended soils. The rest amendments produced soil moisture values which fall between the two extremes (Table 5). Soil pH was highest under urban waste and poultry litter treatments recorded significantly ($p<0.01$) higher total soil organic carbon (SOC) than all the other treatments. The control and mineral fertilizer amended soils recorded the lowest SOC concentration. Soils with cowdung had the highest ($p = 0.01$) value of available P, this was followed by soils that received rabbit dropping. Lowest soil P was recorded in soils that were amended with urban waste (Table 5).

Experiment 2: The tied ridge treatment (i.e., all ridge tie) produced the highest calyx weight in roselle. Even though, the differences in calyx weights among the various water harvesting techniques were not significant. Among the nutrient sources, mineral fertilizer produced the highest calyx weight, this was followed by cowdung and lastly poultry litter (Table 6).

Table 2: Effect of soil amendments on vegetative growth of tomato growing under residual soil moisture at Samaru, northern Nigeria

Amendments	No. of branches/plant	*Stem girth (cm)	*Plant height (cm)	*Canopy spread (cm)	Leaf area index	Days to flowering (days)	No. of leaves/plant
Mineral fertilizer	34.2b	1.1c	69.0bc	39.4bc	1.37b	39.7dc	115.5bcd
Rabbit dropping	40.8a	2.1a	87.1a	46.8a	2.28a	47.0a	150.6a
Goat dropping	42.9a	1.7ab	76.6b	44.3ab	1.66b	46.0ab	125.6bc
Cowdung	30.8bc	1.3c	60.0c	35.6cd	0.82cd	38.7de	106.8cd
Poultry litter	34.2b	1.4bc	71.7b	41.3abc	1.25bc	43.0bc	130.2b
Urban waste	19.2d	1.1c	60.9c	32.2d	0.65d	37.3de	104.4d
No amendment	26.0c	1.3c	58.9c	32.4d	0.51d	35.0e	95.5d
SE	1.93	0.13	3.26	2.03	0.16	1.22	6.05

Values having the same or no alphabets within the same column are not significantly different at p = 0.05 by DMRT, *Reading taken at 10 weeks after transplanting tomato seedlings on the field

Table 3: Effect of soil amendments on fruit yield and quality of tomato growing under residual soil moisture at Samaru, northern Nigeria

			Weight of unmarketable yield			
Amendments	Total Frui yield (t ha^{-1})	Market-able yield (t ha^{-1})	Green fruit (t ha^{-1})	Rotten fruit (t ha^{-1})	Fruit volume (cm)	*Earliness to fruiting (t ha^{-1})
Mineral fertilizer	13.2	11.1	1.7	0.98a	96.7abc	2.14ab
Rabbit dropping	10.3	8.4	1.5	0.71ab	95.0abc	1.59ab
Goat dropping	10.4	8.3	1.2	0.76ab	98.3abc	2.53a
Cowdung	8.7	6.2	1.8	0.48ab	106.7ab	1.48ab
Poultry litter	6.7	5.2	0.7	0.51ab	86.7bc	0.92b
Urban waste	7.5	5.6	1.8	0.31b	123.3a	1.46ab
No amendment	3.8	2.6	0.8	0.35b	73.3c	0.92b
SE	3.6	3.0	0.65	0.18	8.25	0.37

Values having the same or no alphabets within the same column are not significantly different at p = 0.05 by DMRT, *Earliness is determined as the weight of the first three pickings

Table 4: Effect of soil amendments on elemental concentrations of tomato leaves in Samaru, northern Nigeria

Soil amendment	Nitrogen (g kg^{-1})	Phosphorus (g kg^{-1})	Potassium (g kg^{-1})	Nickel (mg kg^{-1})	Lead (mg kg^{-1})	Cadmium (mg kg^{-1})
Mineral fertilizer	0.27	7.73ab	38.9	140.4ab	163.7b	0.23b
Rabbit dropping	0.29	6.30b	36.6	80.2c	77.3bcd	0.50b
Goat dropping	0.22	9.07a	52.7	78.9c	43.7cd	0.33b
Cowdung	0.40	8.40ab	57.0	134.5ab	129.4bc	0.30b
Poultry litter	0.31	6.87ab	44.9	164.0a	129.4bc	0.47b
Urban waste	0.36	6.43ab	42.7	108.3bc	261.8a	1.03a
No amendment	0.27	7.90ab	48.7	73.5c	7.0d	0.23b
SE	0.98	0.8	7.3	12.34	26.3	0.09

Values having the same or no alphabets within the same column are not significantly different at p = 0.05 by DMRT

Table 5: Effect of soil amendments on selected properties of soils at Samam, northern Nigeria

Soil amendment	Moisture content (g g^{-1})	Soil pH	Soil organic carbon (g kg^{-1})	Total nitrogen (g kg^{-1})	Available phosphoms (mg kg^{-1})
Mineral fertilizer	0.23b	6.7ab	60.0c	1.7	182.0b
Rabbit dropping	0.26a	0.7ab	64.0bc	1.6	196.0ab
Goat dropping	0.25ab	6.8ab	73.7ab	1.5	168.0bc
Cowdung	0.25ab	6.8ab	83.0a	1.4	119.0bc
Poultry litter	0.25ab	6.6b	77.0a	1.6	266.0a
Urban waste	0.27a	6.9a	78.0a	1.4	94.7c
No amendment	0.23b	6.8ab	58.7c	1.1	175.0bc
SE	0.016	0.07	3.83	0.19	25.73

Values having the same or no alphabets within the same column are not significantly different at p = 0.05 by DMRT

Table 6: Effect of Water Harvesting Techniques (WHT) and Nutrient Sources (NS) on performance of roselle at Samaru, northern Nigeria

Treatment	Plant height (cm)	Shoot diameter (g)	Leaf area index (LAI)	Canopy spread (cm)	Calyx weight (kg ha^{-1})
WHT					
Open ridge	24.90	40.5	2.660	28.400	17.03
Alternate ridge tie	26.20	25.6	4.090	26.300	15.27
All ridge tie	24.30	46.3	5.350	29.300	18.87
SE	1.10	4.6	0.574	0.671	2.50
NS					
Cowdung	24.10	19.3b	3.18b	25.8	16.33
Poultry litter	24.20	17.7b	4.32b	26.1	14.10
Mineral fertilizer	27.30	75.4a	5.60a	32.0	20.73
SE	1.098	4.60	0.574	0.671	2.50
Interaction	NS	NS	NS	NS	NS

Values having the same or no alphabets within the same column are not significantly different at p = 0.05 by DMRT

Table 7: Effects of Water Harvesting Techniques (WHT) and Nutrient Sources (NS) on performance of cotton at Samaru, northern Nigeria

Treatment	Seed cotton (kg ha^{-1})	Cotton lint (kg ha^{-1})	Cotton seed (kg ha^{-1})	Span length 50% (cm)	Span length 2.5% (cm)	Ginning uniformity ratio (%)	Percentage (%)	Bundle micronaire g/in	Strength g/tex
WHT									
Open ridge	273.3b	102.7b	167.8b	12.30	23.70	52.00	37.90	3.20	15.00
Alternate ridge tie	373.7a	141.9a	234.5a	12.60	24.40	51.80	38.00	3.30	15.10
All ridge tie	420.2a	153.0a	258.5a	12.60	24.40	51.80	38.50	3.30	15.10
SE	30.84	11.66	18.98	0.23	0.23	0.63	0.46	0.06	0.54
NS									
Cowdung	408.3a	152.0a	252.9a	12.60	24.30	51.80	37.60	3.20	15.60
Poultry litter	371.9ab	139.3ab	235.6a	12.60	24.40	51.70	38.00	3.20	14.70
Mineral fertilizer	287.0b	111.2b	172.2b	12.40	23.80	52.10	38.80	3.20	14.80
SE	30.84	11.66	18.98	0.23	0.23	0.63	0.46	0.06	0.54
Interaction (WHT×NS)	NS	NS	NS	NS	NS	NS	NS	NS	NS

Values having the same or no alphabets within the same column are not significantly different at p = 0.05 by DMRT

Table 8: Economics of different amendments on tomato and cotton production at Samaru, northern Nigeria

Particulars for tomato	Marketable tomato yield (t ha^{-1})	*Gross returns ($)	Cost of cultivation	Net returns
Mineral fertilizer	11.1	4269.23	1415.60	2853.63
Rabbit dropping	8.4	3230.77	901.52	2329.25
Goat dropping	8.3	3192.31	910.09	2282.22
Cowdung	6.2	2384.62	946.76	1437.86
Poultry litter	5.2	2000.00	996.70	1003.30
Urban waste	5.6	2153.85	867.54	1286.31
No amendment	2.6	1000.00	929.45	70.55
Particulars for cotton	Seed cotton yield			
Cowdung	408.3	266.97	177.32	89.65
Poultry litter	371.9	243.17	182.51	60.66
Mineral fertilizer	287.0	187.65	196.00	-8.35

*Gross returns for tomato was at the rate of $384.6 per ton, **Gross returns for cotton was at the rate of $653.9 per ton

Water harvesting techniques did not influence significantly, the yield parameters measured in roselle (i.e., plant height, shoot dry matter, LAI, etc.). However, mineral fertilizer produced significantly higher LAI and shoot dry matter values than all the other nutrient sources (Table 6).

In upland cotton, the tied ridge treatments supported significantly (p = 0.01) higher seed cotton and cotton lint yield than the open ridge treatment (Table 7). However, lint quality was generally not affected by the water harvesting techniques. Cowdung, when used as a nutrient source recorded significantly higher (p<0.05) seed cotton and cotton lint yield than those of poultry litter and mineral fertilizers. Lowest yield was recorded in cotton plants that received mineral fertilizer (Table 7). The various nutrient source did not influence lint quality in this trial.

Cost benefit ratio: The cost benefit ratio of the various soil amendment used in tomato production was calculated (Table 8) to see the effect of expenditure on application of mineral fertilizers and the organic amendment. This is with the aim of determining whether this expenditure compensated the yield reduction in the organic amendment. Accordingly, in tomatoes that were amended with mineral fertilizer, the expenditure incurred was $1416 ha^{-1}, whereas return from marketable tomato yield sold at $385 ton^{-1} was $4269, in this way net income was $2854 ha^{-1}. The net income of tomatoes receiving rabbit dropping amendment (highest yield of all organic amendment) was $2329 ha^{-1}. In the case of seed cotton, return from sales at about $654 per ton gave $267, $243 and $188 for seed cotton amended with cowdung, poultry litter and mineral fertilizer, respectively (Table 8). While, expenditure incurred was $177, $182 and $198 ha^{-1} for cowdung poultry litter and mineral fertilizer.

DISCUSSION

The yield of tomato was very low compared to what is obtainable under a well watered condition. This was principally due to the fact that the crops grew under a moisture stressed condition (i.e., residual soil moisture). Bodunde and Ogunwole (2000) reported tomato yield ranging from 20-40 t ha^{-1} under well watered condition and 10-13 t ha^{-1} when the crops were stressed. Tomato performance under rabbit and goat dropping amendment were comparable to those under mineral fertilizer. Where mineral fertilizer amended plots recorded 84% of the total yield as marketable, the rabbit and goat dropping amended plot recorded 80% of the total yield as marketable. A probable reason for the high performance of tomato fruits under these organic amendments could be their large surface area, which facilitate rapid decomposition and nutrient release.

Most of the changes in soil chemical properties observed are largely explained by differences in soil organic amendments. Higher soil organic carbon levels were found in soils managed with organic amendment. An indication that soil quality can be improved with the introduction of organic fertilization programme in the farming system of the savanna. Studies have shown that soil organic carbon responds linearly to changes in the rate of organic matter input (Rasmussen and Collins, 1991). The relative abundance of available P content in poultry litter amended soils adds to its merit as a good organic amendment that can replace mineral fertilizers in phosphorus deficient soils. High concentration of nitrogen (N) and phosphorus content have been reported in poultry litter from works done at Saudi Arabia (El-Nadi *et al.*, 1995). Under an acid soil in the humid forest of Cameroon, 83% increase in maize yield was recorded under a poultry litter amended soil (Zonkeng and The, 2001).

Total tomato N and potassium (K) uptake patterns mirrored treatment effects on tomato dry matter and yield. This was similar to the findings of Cooperband *et al.* (2002), where no significant difference was observed in corn N uptake between raw poultry litter and mineral fertilizer-treated plots. The low cadmium (Cd) uptake by tomato in all the treatment is an indication that major organic waste within the area contain very minimal Cd except for urban waste treatment, which has tendency to favour accumulation of Cd in tomato leaves. The uptake of lead (Pb) ranged from 1004% in rabbit dropping to 3640% in urban waste relative to the control. However, the highest Pb concentration of 262 mg kg^{-1} observed underwaste amended plot, is still within the permissible concentration of 30- 300 mg kg^{-1} reported by Kabata-Pendias and Pendias (1984). In addition, high nickel (Ni) uptake was recorded for poultry litter and mineral fertilizers. The use of vitamin-mineral premix in poultry production could be a source of Ni in the poultry litter. For mineral fertilizers, it has been established that they contain high levels of Ni particularly, those made from ammonium salts and rock phsophate (Senesi and Polemio, 1981). Economically, replacing mineral fertilizer with organic amendment will not significantly affect the returns expected by the growers.

The all ridge-tie treatment favours significantly higher yield in seed cotton. This water harvesting technique ensures zero runoff, which cannot be the case under the other treatments. Consequently more water is retained on-site which infiltrates into the soil for plant use. The water harvesting technique seems ideal, when a high water demanding crop like cotton is sown late.

CONCLUSIONS

- Tomato yield was not affected by the type of soil amendment used under a residual soil moisture condition. The implication of this finding is that some of these organic amendments can effectively substitute mineral fertilizers in fibre and vegetable production systems.
- The use of organic amendments in soils improves the quality of the soil than when mineral fertilizer amendments are used.
- Yield of late sown, moisture demanding crops like cotton was significantly increased ($p<0.05$) by adopting a tied ridge water harvesting technique.

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