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Research Article

Identifying Limiting Nutrients for Wheat Production Through Omission Plot Experiment on Nitisols of East Gojjam Zone, North Western Ethiopia

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Abstract

A field experiment was conducted to identify the most yield limiting nutrients for wheat yield on Nitisols of D/Eliase District North western Ethiopia during 2021/22 main cropping season. The experiments were laid out in a completely randomized block design (RCBD) each with three replications. The treatments were control, NP, PKSZnB (-N), NKSZnB (-P), NPSZnB (-K), NPKZnB (-S), NPKSZn (-B), NPKSB (-Zn) and full fertilization (+NPKSZnB). The available data were collected and subjected to ANOVA using SAS 9.3 software. The LSD test was used to separate means at 5% level of significance. According to the results obtained, considerable reduced in plant height, spike length, grain and biomass yield was recorded due to omission of N and P nutrients compared with fully fertilized plots. The highest yield reduction was recorded due to omission of N followed by P in the study district. The highest grain yield of wheat (2835.20kgha^{-1}) was measured from recommended NP fertilized plots while the lowest grain yields (357.50kgha^{-1} and 545.90kgha^{-1}) were obtained from the control and N omitted plots respectively. Therefore, N and P were found to be the most yield limiting nutrients for wheat production indicating that the inherent N and P supplying capacity of soil is very low. Thus, N and P nutrients should be applied in optimum dose for efficient nutrient uptake which ultimately increases wheat productivity. The highest agronomic efficiency (19.08 kg grain/kg nutrient applied) was recorded from plots treated with recommended NP fertilizer. In addition the highest profits realized with application of recommended NP fertilizer compared with other treatments The economics of wheat cultivation therefore indicates that omission of (-N) and (-P) nutrients results in losses. Omission of nitrogen (-N) followed by omission of phosphorus (-P) has more impact on wheat yield and profits in the study area.

Keywords

Economic Return, Indigenous Nutrient Supply, Nutrient Omission

1. Introduction

The presence of variability of soil fertility status in smallholder farming systems in Ethiopia is currently a major factor that affects productivity and the suitability of crop and nutrient management recommendation for different locations at various spatial scales. Due to this, there is unbalanced fertilization to crops which ultimately results yield gaps in most areas of Ethiopia. Declining yield trend and yield gap between maximum observed and national average yield of

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wheat in Ethiopia required urgent research to determine fertilizer use in wheat producing areas. In such a case implementing nutrient omission experiment supports the development and dissemination of site-specific nutrient management (SSNM) options for crop production systems. Moreover, nutrient omission technique provides a systematic framework to identify the inherent nutrient supplying capacity of the soil and for applying site-specific nutrients of both macro and micro nutrients in heterogeneous production systems.

So far, fertilizer application in Ethiopia was mainly focused only two major plant nutrients, N and P in the form of DAP and urea, whereas very little attention has been given to other macro and micronutrients [12]. However, [2] revealed that in addition to (N and P), sulfur, potassium, copper, manganese, iron, boron and zinc deficiencies are widespread in Ethiopian soils. This analysis led to formulate variety of nutrients or blended fertilizers for a country-wide uses in Ethiopia. However, the decision made on the changing of fertilizer system took little or no consultation of information, particularly from research system. The demonstrations of the newly formulated blended fertilizers came before the research system made recommendation and the fertilizer materials, the blended nutrients used for the validations were not appropriate for research since the cause confounding effects.

Currently blended fertilizer is applied in Ethiopia based on blanket recommendation which assumes that the need of a crop for nutrients is constant over time and large areas without considering whether the soil is deficient for that formulated nutrients or not. However, the need for supplemental nutrients vary greatly among fields, seasons and years and a blanket dose of fertilizer will not fit to all fields. The nutrient requirement of a crop is therefore, depends upon the nutrient supplying capacity of particular soil. Determination of soil capacity to supply major nutrients (N, P, S, K, Zn and B) is therefore pre-requisite regarding increasing crop yield and nutrient use efficiency. Nutrient omission plot technique is therefore a useful tool to quantify nutrient supplying capacity of soil [9] where all the other major nutrients are supplied other than the nutrient in question.

Imbalanced fertilizer application will make depletion of soil nutrients leading to production decline as well as deterioration of soil physical and chemical properties. Apart from these, imbalanced fertilization increases cost of production because any amount more than the required type/does is nothing but a waste. Therefore, individual field has to be assessed for their nutrient supplying capacity so that fertilizer required for certain targeted yield can be developed. Thus, the current experiment was implemented to identify the most important yield limiting nutrient for wheat production at D/Eliase district.

2. Materials and Methods

2.1. Description of the Study Area

A field experiment was conducted on farmers' fields to estimate the native nutrient supplying capacity of soil on the Nitisols of D/Eliase District North-western Ethiopia during the main cropping season (2021/22). The experimental site was selected systematically to cover a wide range of major wheat growing areas in the district. Geographically, the experimental site was located between 07°40' 09 3" N latitude and 037°14' 41.5" E longitudes with an elevation of 2234 meters above sea level. According to the data obtained from D/Markose Meteorological Station (informal personal communication), the average minimum and maximum temperature and mean annual rainfall of the experimental sites were 12.64℃, 28.36℃ and 1198 mm, respectively. The predominant soil type of the study area, in particular, is Nitisols which have a reddish colour with moderately acidic in reaction.

2.2. Treatments and Experimental Design

Nine treatments of six single nutrients combinations (N_{120}, P_{40}, K_{50}, $S_{10.5}$, Zn_5 and B_1 kg ha^{-1}) were tested. Each rate of nutrient was set based on the recommendation given by reviewing scientific literatures. Even though farmers are not growing wheat without fertilizer, control treatment was included for comparison among the rest of the treatments. The treatments were laid out in a randomized complete block design with three replications. The gross plot area was $12m^2$ (4 m*3 m), which accommodated 20 rows while the net plot area was 10.8 m^2 (3.6 m*3 m).

Table 1. *Treatments of omission plot experiment.*

Treatments	Description of treatments
Control	Without any external application of nutrient sources
Reco. NP	To compare combination of nitrogen and phosphorus fertilizer with others
PKSZnB (-N)	To determine the indigenous N supplying capacity of the soil
NKSZnB (-P)	To determine the indigenous P supplying capacity of the soil
NPSZnB (-K)	To determine the indigenous K supplying capacity of the soil

Treatments	Description of treatments
NPKZnB (-S)	To determine the indigenous S supplying capacity of the soil
NPKSZn (-B)	To determine the indigenous B supplying capacity of the soil
NPKSB (-Zn)	To determine indigenous Zn supplying capacity of the soil
NPKSZnB	To determine the maximum attainable yield with application of full dose of nutrients

2.3. Experimental Materials and Planting Procedures

High yielding (Wanie) wheat variety was used as a test crop. Full doses of all nutrients in the respective treatments except the nutrient to be omitted were applied at planting. Nitrogen in the form of urea was applied in splits where half rate during planting and the remaining half rate was applied (3-4 weeks after planting). Urea, Triple Super Phosphate (TSP), Murate of Potash (KCl), Magnesium Sulfate ($MgSO_4.2H_2O$), Zinc Sulfate ($ZnSO_4$. $7H_2O$) and Borax ($Na_2B_4O_7.5H_2O$) were used as sources of N, P, K, S, Zn and B, respectively. All cultural practices were done uniformly for all plots, as per the recommendation set for wheat production in the area. Harvesting was done manually from the net plot area when the crop physiologically matured.

2.4. Measurement of Crop Parameters

Data on a plant basis was recorded from the central net harvestable rows/plots of 10.8 m^2 (3.6 m* 3 m). The collected data include plant height, spike length, grain yield and aboveground biomass yield. Plant height (cm) was recorded from 10 randomly selected plants at physiological maturity which was measured from the base of the stem of the main plant to the tip of the main shoot or spike, excluding awns. Spike length (cm) was measured from 10 randomly selected plants with scale from the basal joint of the spike till the terminal spike excluding awns. Grain yield (economic yield) was determined from the entire net plots and converted into kilogram per hectare where the actual grain yield was adjusted to 12.5% standard moisture level. Above-ground biomass yield (Biological yield) was measured from the weight of aboveground biomass for plants in a net plot area and converted to kilogram per hectare. Harvest Index (%) was determined as a ratio of grain yield to above-ground biological yield on a dry weight basis in percentage as described in the following formula.

$$\text{HI (\%)} = \left(\frac{\text{Grain yield}}{\text{Aboveground biomass yield}}\right) * 100$$

Agronomic efficiency (AE): refers to the additional produce obtained in kg kg^{-1} of an applied nutrient which was calculated using the formula of [3] as follows:

$$AE = \frac{Grain\ yield\ of\ fertilized\ plot - grain\ yield\ of\ unfertilized\ plot}{Quantity\ of\ fertilizer\ applied}$$

Data Analysis

The collected data were subjected to analysis of variance (ANOVA) appropriate to RCBD using SAS Institute [11] 9.3 version software and the interpretations were made following the procedure described by Gomez and Gomez [5]. The least significant difference (LSD) test at 5% probability level was used for treatment mean comparison when the ANOVA showed significant differences among treatments.

Economic Analysis

Economic analysis was done to investigate the economic feasibility of treatments that would give acceptable returns at low risk to farmers following the procedures [1]. While doing the economic analysis, the average grain yield obtained from each plot was adjusted to 10% downward to reflect the difference between researchers experimental plot yield and the yield farmers will expect from the same treatment because researchers are using small plot sizes and applying better crop management practices during experimentation.

3. Results and Discussion

Effect of Nutrient Omission on Growth and Yield Attributes

The ANOVA table showed there was highly significant variations observed among treatments on plant height, spike length, grain yield, above ground biomass yield and harvest index of wheat due to nutrient omission at all locations as indicated (Table 2).

The data revealed that N omitted plot has produced the shortest plant height (56.29 cm) and spike length (4.46 cm) followed by P omitted plots whereas the tallest plant height (86.31 cm) was recorded from NP fertilized plots which was stastically similar with fully fertilized plots. A plant height recorded from N missed plot was statistically similar with unfertilized (control) plots indicating the inherent supplying capacity of the study soil was too low and N is the most important plant nutrient followed by P. Application of NP fertilizer significantly increased plant height by 77.08%, 53% and 21.26% over control, N omitted and P omitted plots respectively. The variation in plant height due to different nutrient combinations was considered to be due to variation in the availability of major nutrients in the soil. Chemical fertilizer offers nutrients which are readily soluble in soil solution and thereby instantaneously available to plants. The data thus indicates that majority of plant growth in terms of height was controlled by N fertilization due to its role in cell division. A similar reduction in plant height of rice and BT cotton was reported by [6, 8] respectively due to omission of nitrogen.

Major plant nutrient elements significantly affected the spike length of wheat where application of NP produced the highest spike length (6.99 cm) whereas the shortest spike length (3.83 cm) was recorded from the control plots. Omission of N and P from fully fertilized plots significantly reduced the number of spike length by 49.78% and 16.99% respectively whereas omission of S, K, Zn and B produced statistically similar result compared with fully fertilized plots indicating application of the above mentioned nutrients (S, K, Zn and B) have no significant contribution rather than a wastage in the study area. On the other hand omission of N produced significantly lower spike length followed by P compared with others indicating N and P nutrients are the two most important nutrients in the study area. An important advantage of commercial N and P fertilizers is that these nutrients made in a form that can absorbed by plants easily and immediately after fertilization, which enhanced vegetative growth of the crop, high Photosynthetic activity and vigorous vegetative growth of the crop. Therefore, adequate application of N and P increased the total dry matter and probably favored the cellular activity during spikelet formation and development which is in conformity with the finding of [7].

Table 2. *Effect of nutrient omission on plant height and spike length at each testing kebele.*

Treatments	Dejiba Kebele		Genet Kebele		Guay Kebele		Yetenter Kebele		Yekegat Kebele		Degolima Kebele	
	Ph (cm)	SL (cm)	Ph (cm)	SL (cm)	Ph (cm)	SL (cm)	Ph (cm)	SL (cm)	Ph (cm)	SL (cm)	Ph (cm)	SL (cm)
Control	53.87^{f}	3.47^{c}	57.80^{f}	4.60^{e}	46.50^{d}	4.10^{c}	50.60^{d}	3.90^{b}	40.33^{d}	2.50^{f}	43.30^{e}	4.33^{d}
-N	61.77^{e}	4.37^{bc}	62.83^{e}	5.20^{e}	54.00^{c}	4.50^{c}	54.90^{d}	4.00^{b}	52.93^{c}	3.50^{e}	51.30^{d}	5.20^{cd}
-P	70.57^{d}	5.17^{b}	76.67^{d}	6.10^{d}	70.90^{b}	5.60^{b}	78.80^{c}	6.10^{a}	68.68^{b}	5.20^{d}	61.47^{c}	6.10^{bc}
Reco. NP	93.87^{a}	6.87^{a}	90.60^{ab}	8.00^{a}	80.50^{a}	6.40^{ab}	89.80^{a}	7.00^{a}	85.00^{a}	6.40^{abc}	78.07^{a}	7.30^{a}
-S	85.47^{c}	6.47^{a}	85.27^{c}	6.60^{cd}	79.80^{a}	6.73^{a}	85.60^{ab}	6.20^{a}	85.00^{a}	5.80^{cd}	72.00^{ab}	6.60^{ab}
-K	86.87^{bc}	7.27^{a}	87.07^{bc}	7.10^{bc}	80.80^{a}	6.30^{ab}	85.80^{ab}	6.30^{a}	83.73^{a}	6.20^{abc}	69.77^{b}	6.20^{bc}
-Zn	90.27^{ab}	6.60^{a}	88.30^{abc}	6.80^{bc}	83.90^{a}	6.70^{a}	84.50^{b}	6.50^{a}	86.67^{a}	7.00^{a}	73.00^{ab}	6.70^{ab}
-B	88.43^{bc}	7.17^{a}	91.40^{a}	7.27^{b}	83.40^{a}	6.40^{ab}	86.10^{ab}	6.90^{a}	83.20^{a}	6.10^{bc}	74.30^{ab}	6.70^{ab}
All	85.90^{bc}	6.83^{a}	90.87^{ab}	6.90^{bc}	83.60^{a}	6.30^{ab}	88.10^{ab}	6.70^{a}	87.93^{a}	6.73^{ab}	76.40^{ab}	6.50^{ab}
CV (%)	3.45	11.98	2.74	5.12	5.84	9.39	3.81	9.97	4.98	8.61	6.48	9.52
LSD (0.05)	4.75	1.25	3.85	0.58	7.45	0.96	5.16	1.03	6.45	0.82	7.47	1.02
P - value	***	***	***	***	***	***	***	***	***	***	***	**

Effect of nutrient omissions on grain yield was highly significant. Among all the treatments, the highest grain yield (2835.20 kgha^{-1}) was obtained from NP fertilized plots and the lowest grain yield (357.5 kgha^{-1} and 545.9 kgha^{-1}) was recorded from control and N missed plots respectively followed by P omitted plots which was (1505.9 kgha^{-1}). The lowest grain yield obtained from N omitted plots indicates N cannot be substituted by any other nutrient and has the highest contribution in wheat yield. This confirms that N is the most limiting nutrient for crop production in many areas of the world and its efficient use is not only important for the economic sustainability of cropping systems, but also for safeguarding environment from pollution. It could be due effect of N on chlorophyll formation, photosynthesis and assimilated production because N deficiency reduces crop photosynthesis by reducing leaf area development and leaf photosynthesis rate by accelerating the leaf senescence [8]. Moreover, under N deficiencies, a considerably large proportion of dry matter is partitioned to roots than shoots, leading to reduced shoot/root dry weight ratio [10] and consequently the grain yield.

Table 3. Impact of nutrient omission on grain yield and biomass yield at each testing kebele.

Treatments	Dejiba Kebele		Genet Kebele		Guay Kebele	
	GY ($kgha^{-1}$)	AGBY ($kgha^{-1}$)	GY ($kgha^{-1}$)	AGBY ($kgha^{-1}$)	GY ($kgha^{-1}$)	AGBY ($kgha^{-1}$)
Control	235.0f	696.3d	421.5c	9997.5d	284.2d	563.0c
-N	526.6f	1592.6c	621.8c	1584.0d	611.8d	1512.3c
-P	1407.8e	2969.1b	1918.1b	4321.0c	1896.4c	4312.3b
Reco.NP	2693.0a	5493.8a	2751.5a	6148.1a	3246.2a	5685.2a
-S	2034.4d	4799.4a	2128.5ab	4482.7bc	1981.2c	4314.8b
-K	2403.5abc	5024.7a	2252.0ab	4959.1abc	2540b	5114.8ab
-Zn	2129.9cd	4682.7a	2423.1ab	4938.3abc	2674.2b	5413.6ab
-B	2235.9bcd	4938.3a	2691.2a	5901.2ab	2381bc	5388.9ab
All	2494.7ab	5046.3a	2667.6a	5459.9abc	2608.8b	5498.8ab
CV (%)	10.29	12.19	20.87	20.39	13.89	17.72
LSD (0.05)	319.89	826.56	717.39	1521.5	486.83	1288.4
P-Value	***	***	***	***	***	***

Table 3. Continued.

Treatments	Yetenter Kebele		Yekegat Kebele		Degolima Kebele	
	GY ($kgha^{-1}$)	AGBY ($kgha^{-1}$)	GY ($kgha^{-1}$)	AGBY ($kgha^{-1}$)	GY ($kgha^{-1}$)	AGBY ($kgha^{-1}$)
Control	328.3e	1042c	288.8d	622.2d	490.0f	1308.6e
-N	519.5e	1481.5c	505.5d	1306cd	587.0f	1765.4e
-P	1994.1d	4506.2b	866.4c	1790.1c	951.5e	3129.6d
Reco.NP	2882.3a	6864.2a	2500a	5108ab	2938.5a	6174.1a
-S	2625.4ab	5246.9b	2113.4b	4166.7b	2037bcd	3943.2cd
-K	2404.6bc	5419.8b	2557.8a	5235.8a	2295.4bc	5005abc
-Zn	2030.1cd	5185.2b	2131.9b	4611ab	1896.7d	4124.7cd
-B	2214.3cd	4901.2b	2553.6a	4556ab	1951.2cd	4456.8bc
All	2425.7bc	5370.4b	2250.1ab	5424.7a	2306.9b	5493.8ab
CV (%)	12.23	17.15	11.72	15.48	11.69	17.21
LSD (0.05)	409.97	1320.2	355.41	977.38	347.3	1171.5
P-Value	***	***	***	***	***	***

The differences in grain yield expressed as penalties (%) on grain yield were somehow similar (4.04-78.25%) with biological yield (4.72%-72.80%). Omission of N resulted on highest grain yield declines (78.25 %) followed by P (40.00 %) which was far greater than the yield obtained due to application of all nutrients. Compared among each treatments, yield reduction were ranked as omission of N > P > S > Zn > B > K indicating N was the most yield limiting nutrient, followed by P and S while K is the least important nutrient for wheat yield in the study area. The reduction of photosynthetic area due to absence of N and hampered energy relations due to omission of P together have more damaging effects than the individual function impairment effects. Similar differential reductions in grain and straw yield of maize were reported by [4] due to -N and -P plots which are in conformity with the current result. Omission of N and P has caused identical reductions trend in grain and biological yields. The trend in biological yield was the same as that of grain yield.

Table 4. Impact of nutrient omissions on growth, yield and harvest index of Wheat (Combined analysis).

Nutrient (s) Omitted (-)	Plant height (cm)	Spike Length (cm)	Grain Yield (kgha^{-1})	Biomass Yield (kgha^{-1})	Harvest Index (%)
Control	48.74e	3.83e	357.50f	947.70g	38.28d
-N	56.29d	4.46d	545.90f	1464.10f	39.99cd
-P	71.18c	5.71c	1505.70e	3504.70e	43.70bc
Reco. NP	86.31a	6.99a	2835.20a	5912.20a	48.76a
-S	82.19b	6.41b	2153.30d	4492.30d	48.48a
-K	82.34b	6.55b	2408.90bc	5128.20bc	47.02ab
-Zn	84.44ab	6.71ab	2214.30cd	4825.90cd	46.83ab
-B	84.48ab	6.74ab	2287.30	5023.70bc	46.07ab
All	85.47a	6.68ab	2509.60b	5382.30b	46.95ab
CV (%)	5.15	9.81	16.56	18.61	14.65
LSD (0.05)	2.57	0.38	203.85	499.78	4.35
P-value	**	**	**	**	**

Table 5. Impact of nutrient omissions on yield, yield response and Yield penalty of Wheat.

Nutrient (s) omitted (-)	Yield (kgha^{-1}) over no nutrient omission		Yield Response		Yield penalty (%) over no nutrient omission	
	Biological	Grain	Biological	Grain	Biological	Grain
Control	947.70	357.50	4434.60	2152.10	-82.39	-85.75
-N	1464.10	545.90	3918.20	1963.70	-72.80	-78.25
-P	3504.70	1505.70	1877.60	1003.90	-34.88	-40.00
Reco. NP	5912.20	2835.20	-530.10	-325.60	9.85	129.74
-S	4492.30	2153.30	890.00	356.30	-16.54	-14.20
-K	5128.20	2408.30	254.10	101.30	-4.72	-4.04
-Zn	4825.90	2214.30	556.40	295.30	-10.34	-11.77
-B	5023.70	2287.30	359.30	222.30	-6.68	-8.86
No omission	5382.30	2509.60				

*Yield response: grain yield in no omission plot - grain yield of omission plot
** Yield penalty (%) = (yield in no omission plot - yield of omission plot)*10

Table 6. Impacts of nutrient omission on economics of wheat cultivation.

Nutrient (s) omitted (-)	GY (kgha^{-1})	Adj. GY (kgha^{-1})	Economics			Benefit cost ratio (ETB ha^{-1})
			Cost of Cultivation (ETB ha^{-1})	Gross income (ETB ha^{-1})	Net income (ETB ha^{-1})	
Control	357.50	321.75	0.00	9652.50	9652.50	-
-N	545.90	491.31	13531.62	14739.30	1207.68	1.09
-P	1505.70	1355.13	13966.40	40653.90	26687.50	2.91
Reco. NP	2835.20	2551.68	20434.78	76550.40	56115.62	3.75
-S	2153.30	1937.97	23409.11	58139.10	34729.99	2.48
-K	2408.90	2168.01	21854.40	65040.30	43185.90	2.98
-Zn	2214.30	1992.87	23347.13	59786.10	36438.97	2.56
-B	2287.30	2058.57	23723.34	61757.10	38033.76	2.60
No omission	2509.60	2258.64	23966.40	67759.20	43792.80	2.83

Where; Adj. GY = Adjusted Grain Yield down to 10%, GY = Grain Yield, ETB = Ethiopian Birr.

Agronomic Efficiency (AE): The data revealed that AE of wheat was highest in recommended NP fertilizer treated plot but the lowest in N omitted plots followed by P omitted plots. Thus if single and double nutrients are to be applied, it should be N and P in the study area.

Economic analysis: The economics analysis showed that under different nutrient omission treatments cost of cultivation was highest (23966.40 ETB ha^{-1}) in fully fertilized (+NPKSZnB) treated plots and least (13531.62 ETB ha^{-1}) in N omitted (-N) plots. No nutrient omission plots have incurred (3531.62 ETB ha^{-1}) or 17.28% higher cost of cultivation compared with plots received only recommended NP fertilizers. The lowest (1.09) and highest (3.75) benefit to cost ratio were recorded due to omission of N and application of recommended NP fertilized plots.

4. Conclusion

From the present result we can conclude that N and P nutrients are the most important yield limiting nutrients in the study area where the inherent N and P supplying capacity of soil is too low and highly limits grain yield of wheat. Use of optimum dose of nitrogen and phosphorus should be used for efficient nutrient uptake which ultimately increases overall productivity. Therefore, rational fertilizer promotions and recommendations based on actual limiting nutrients for a given crop is not only revealed to supply adequate plant nutrients but also helped to understand the long-term ecological and economic benefits of the studied crop. Therefore, the use of an optimum dose of N and P should take great attention to efficient nutrient uptake, which ultimately increases wheat productivity.

Apart from these, imbalanced fertilization increases cost of production because any amount more than required does not help in producing higher crop yields. Thus, the consumption of more than required quantity of elements is called luxury consumption, which is nothing but a waste. This type of loss is in addition to leaching, washing and other losses of elements.

Data Availability Statement

The data that support the findings of this study are availa ble from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

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