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Nitrogen use efficiency and yield of broccoli crop fertilized with compost and synthetic fertilizer in arid region of Morocco

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Abstract

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Soils in arid regions and especially in Morocco are becoming increasingly degraded and polluted due to the heavy use of synthetic chemical fertilizers linked to population growth. The optimal dose is a key challenge for successful crop yield. Organic fertilizer such as compost remain a great potential to improve soil fertility and yield. Broccoli is a crop that is beginning to develop in Morocco. It is very nitrogen demanding crop; therefore, it is necessary to know nitrogen use efficiency of compost in broccoli.

In this field experimental conducted during 2016, different treatments were tested on broccoli as follows: $T_{C8t/ha}$: compost, 8 t/ha (equivalent 200 kg N /ha), $T_{C12t/ha}$: compost, 12 t/ha (equivalent 300 kg N/ha), T_{SYN}: Synthetic chemical fertilizer (200 kg N/ha), T_{C+SYN}: 50% compost, 4 t/ha+50% Synthetic fertilizer (equivalent 200 kg N/ha) and T0: control.

Our research showed that the combination of compost and synthetic fertilizer:T_{C+SYN} improved the growth and yield parameters of broccoli. The best main head yield of broccoli was 13.5 t/ha for T_{C+SYN}. Compost improved the chemical properties of soil. Total N content was 266 kg/ha for T_{C+SYN}, 253 kg/ha for TSYN, 244 kg/ha for $T_{C8t/ha}$ and 234 kg/ha for $T_{C12t/ha}$. For Nitrogen use efficiency. Apparent recovery efficiency (ARE) was higher with T_{SYN}: 0.91 and the last value was 0.48 with $T_{C12t/ha}$.

Keywords: compost; nitrogen use efficiency; synthetic fertilizer; yield; broccoli

Introduction

Population growth and industrialization have resulted in a steady decline in cultivated land. Cultivated land is gradually decreasing due to the irrational use of synthetic fertilizers and pesticides (Delang, 2017). Synthetic fertilization is still expensive and inaccessible to all farmers (Yannick et al., 2013). Its use is certainly beneficial because it increases the productivity of the crops, however, its polluting effect and high cost still farmers hinder its use by all (Bochman et al., 1990). Therefore, organic fertilizer could be an alternative to improve soil fertility (Nyembo et al., 2014) and improve yields of crops without harming the environment.

Broccoli (*Brassica oleracea* var. *italic*) is a crucifer family (Yoldas et al., 2008). Like other crucifers, broccoli has a potential anticancer property because it's a rich source of antioxidant, vitamin C, K and E, and beta-carotene (Nagraj et al., 2020). In Morocco, broccoli has become a very popular vegetable for consumers. The main difficulty with broccoli is related to fertilization in general and the high nitrogen needs in particular. Indeed, for a yield of 10 to 20 t/ha, the crop needs vary from 150-200 to 350-450 kg ha^{-1} (Silva et al., 2019).

The addition of organic matter such as compost has a positive effect on soil health and sustainability of production systems (Churchman & Landa, 2014; Jigme et al., 2015).

Organic Fertilization management is complex because the N in organic fertilizer is transformed to humic acid and then to mineral N available for absorption by plant (Zech et al., 1997). This mineralization is considered slow compared with synthetic fertilizers which are quickly absorbed. In addition, decisions must be based on local experiences on how different elements: N, P, K interact at different levels to improve yield. However, there is no universal solution that can be applied to broccoli.

Nitrogen use efficiency (NUE) is defined as the fraction of nitrogen applied which is absorbed and used by plant (Baligar & Fageria, 2015). Improving a plant's ability to use nitrogen is a key factor in improving yields and chemical soil parameters especially for organic fertilizers where NUE is not available. NUE is one of the research challenges for management of fertilizer and this parameter was investigated by many researchers (Dobermann, 2007; Fageria et al., 2008; Sharma et al., 2017).

Farmers lack data about the performance of organic fertilizers such as compost and manure, the timing and amount of fertilizer applied, and the evaluation tools to determine nitrogen use efficiency. Using NUE may result in high additional costs that must be offset by benefits, or small changes in fertilization can have a significant effect on increasing yields or profitability.

The analysis of yields with different forms of organic fertilizer highlights the following main elements: an organic fertilizer can increase yields and quality compared to unfertilized soils when applied at an optimal dose, the yield results of organic fertilizers can approach the conventional in the long term (Hu et al., 2015). Compost with high organic carbon improves soil organic matter. The application of compost improves also organic carbon sequestration and maintain Aggregate stability (Zhao et al., 2009).

The need for more research in this area is primary at this time (Singh et al., 2003). Cereals have been extensively investigated (Dobermann, 2005; Agrama, 2006; Li et al., 2015; Mandolino et al., 2018). For vegetable crops, there is a lack of studies on growth and nitrogen uptake for vegetable crops, of which broccoli is one.

In order to optimize nitrogen fertilization, the main objective of this work was to study the growth and nitrogen use efficiency of compost at different doses in broccoli.

Materials and Methods

The present study was carried out at the horticultural complex of Agadir (30°35′ N, -9°47′ E, 3 m.a.s.l) in the Souss Massa region in the south of Morocco. The climate was semi-arid. The soil of the plot is sandy-loam type. The initial soil analysis before planting and the irrigation water analysis are presented in Tables 1 and 2. The experiment was conducted in a randomized block design with three repetitions per treatment. The treatments studied were as follows: $TC_{8t/ha}$: compost, 8 t/ha (equivalent 200 kg N/ha), $TC_{12t/ha}$: Vegetable compost, 12 t/ha (equivalent 300 kg N/ha), T_{SYN}: Synthetic chemical fertilizer on fertigation (200 kg N/ha), T_{C+SYN}: 50%Vegetable compost, 4 t/ha + 50% Synthetic fertilizer (equivalent 200 kg N/ha) and T0: control \50% of fertilizers quantities were applied before planting and 50% were applied at a flowering period near the roots at 50 days after planting (DAP). The synthetic chemical fertilizer was applied by fertigation at a rate of 200 kg N/ha. The compost used in this experiment was rich in organic matter (55%) with a NPK composition of 2.5-3-2.5 and a C/N ratio of 15. The experimental unit was 8.22 m^2 each containing 24 plants. The planting was on 20/03/2016 after tillage with a cover crop. The variety used was *italica*.

Table 1. Soil analysis

Elements	Units	Values
Organicmatter	%	0.7
pH	–	8.4
EC	Mmhos/cm	0.17
CEC	meq/100g	11.76
$N\text{-}NO_3^-$	%	0.22
P	mg/kg	9.6
K	mg/kg	94
B	ppm	0.7

Table 2. Irrigation water analysis results

Designations	Units	Values
pH	–	7.8
EC(at 25°C)	ms/cm	1.52
CO_3^-	meq/l	Traces
K^+	meq/l	0.04
Na^{+}	meq/l	1.35
Ca^{++}	meq/l	3.04
Mg^{++}	meq/l	3.7
Cl^-	meq/l	10.00
HCO_3^-	meq/l	5.4

The planting was done with a spacing of 40 cm between two plants and 60 cm between ridges. The plants were irrigated by drip irrigation. The cultivation cycle was 75 days. The impact of fertilizer on soil fertility was determined by soil analysis. Three samples were taken: before crop planting, 50 days after planting, and 75 days after planting. For each fertilization program, three soil samples were taken at random. Analyses were performed on: Soil pH was determined in a 1:2.5 soil/water suspension (Jackson, 1973). Organic matter: soil OM was determined by the method of Walkley & Black (1934), N content by the method of Kjeldahl, available P by the method of Olsen et al. (1954), available K by the method of Jackson (Jackson, 1973). Samples of three plants from each experimental plot were taken at 30 days from the date of transplanting to determine growth and yield parameters, namely: number of leaves per plant, leaf weight (g), main head length (cm) and main head weight (g). The total dry weight was determined after drying the samples in an oven at 70ºC for 48 hours. Total nitrogen was determined by the Kjeldahl method. The yield and nitrogen uptake parameters are used to calculate agronomic efficiency (AE), agro-physiological efficiency (APE) and Apparent recovery efficiency (ARE) according to the formulas mentioned in the Table 3 (Baligar et al., 2001; Mosier et al., 2004; Doberman, 2005).

Results and Discussion

***Growth and yield parameters of broccoli**:* The result for the number of leaves measured in the crop harvest showed a highly significant difference between fertilized treatments. T_{C+SYN} gave the higher number of leaves (30.66) followed by T_{SYN} (29.47) (Table 4). Regarding leaf weight for broccoli, significant differences were observed between a mixture of organic and synthetic fertilizers: T_{C+SYN} and T0. However, there was no significant difference between synthetic and compost treatments. The highest leaf weight was observed with T_{C+SYN}: 311 g, followed by T_{SYN}: 260 g, and the low value was observed by T0 with 133 g. The Head weight was showed a highly significant difference between organic and synthetic fertilizers and control. T_{C+SYN} showed the highest values with 326 followed by 324 g/plant with synthetic fertilizer: T_{SYN} (Table 4).

Concerning Head length of broccoli, it was varied significantly between control and fertilizers treatments. The high-

Table 3. Calculating of nitrogen use efficiency

	Nitrogen use Efficiency	Formulas	Designation
EA	Agronomic efficiency	EA = (Gf-Gu) /Na – Gf: yield of fertilized pot (kg) – Gu: yield unfertilized pot (kg) – Na: N amount of nutrient applied (kg)	Increase in yield per unit of N applied (kg.kg^{-1})
EAP	Efficiency Agro-physiological	EAP = (Gf-Gu)/(Nf-Nu) – Gf: yield of fertilized pot (kg) – Gu: yield unfertilized pot (kg) – Nf: amount of N absorbed on fertilized plot (kg) – Nu : amount of N absorbed on unfertilized plot (kg).	Economic output obtained per unit of N uptake (kg.kg^{-1})
ARE	Apparent use Coefficient	AUC = (Nf-Nu) / Na – Nf: amount of N absorbed on fertilized pot (kg) – Nu: amount of N absorbed on unfertilized pot (kg). – Na:amount of N applied (kg)	Quantity of N uptake per unit of N applied

Table 4. Yield Parameters of broccoli

Treatment	Number of leaf	Leaf weight, g	Head weight, g/plant	Head length, cm	Main head yield, T/ha	Head diameter, cm	Height of broccoli, cm
T_{SYN}: 200 N kg/ha of synthetic fertilizer (20-20-20)	29.47b	260b	324 a	11.3a	13.50a	12.9b	55.4
$T_{C8\ t/ha}$: 200 N kg/ha of compost (2.5-3-2.5)	28.41bc	244b	310 b	11.4a	12.92b	13.5b	51.4
$T_{C12\ t/ha}$: 300 N kg/ha of compost (2.5-3-2.5)	26.44 c	233b	306b	11.3a	12.75b	13.3b	50.9
T_{C+SYN}: 50% compost + 50% syntetic fertilizer (200 N kg/ha)	30.66a	311a	326 a	11.5a	13.58a	14.7a	66.6
T0: Control	18.21d	133c	217c	10.7b	9.04c	12.5b	49.5
SEm±	3.25	2.7	4.11	1.15	0.23	2.15	NS

*Values in each column for each treatment followed by different letters are significantly different using Duncan's multiple range test, at 0.05 level est value was observed with $T_{C8t/ha}$. The compost treatments and the type of fertilizer had no effect on this parameter.

The main head yield had the highest values for the treatment T_{C+SYN} followed by T_{SYN} (13.50 t/ha) with a high significant difference (P value 0.001) compared with control and compost fertilizers followed by $T_{C8t/ha}$ and $T_{C12t/ha}$ with 12.92 and 12.75 t/ha respectively. There was no significant difference between $T_{C8t/ha}$ and $T_{C12t/ha}$. The control recorded the lowest yield with 9.04 t/ha (Table 4).

Head diameter showed a significant difference between T_{C+SYN}, synthetic Tsyn, compost fertilizer: TC8 t/ha and TC12 t/ha and control T0. The T_{C+SYN} showed the highest values with 14.7 cm. Broccoli height varied from 49.5 cm to 66.56 cm for T_{C+SYN} and control respectively. However, there was no significant difference between all treatments (Table 4).

The increase in vegetative growth and yield for the combination of compost and synthetic fertilizer can be attributed to the role of microorganisms that convert some insoluble nutrients into available soluble forms. In addition, organic fertilization could improve the root system of plants and increase nutrient uptake for better vegetative growth of plants (Singh et al., 2010; Kumar et al., 2012). The type of fertilizer significantly affects the yield where plant nutrient requirements were covered (Issoufa et al., 2019; Abdrabbo et al., 2015). A high dose of compost can negatively affect the yield and growth parameters of broccoli. Main head yields of broccoli were affected by the rate of nitrogen applied. Indeed, the application of 200 kg/ha of N with compost and the combination recorded higher main head yields than 300kg/ha of N. Similar results were reported by (Yoldas et al., 2008) with an application of 150 kg/ha N with synthetic fertilizer: ammonium nitrate (26%), the higher main head yields were observed by synthetic fertilizer and the combination of compost and synthetic one in a sandy-loamy soil. The low yield recorded by $T_{C12t/ha}$ could be explained by the amount of nitrogen applied, which negatively affected the nitrogen uptake (Ambrosini et al., 2015). The yield responses of broccoli to nitrogen application rates vary with soil type, season of crop, cultivar and crop management (Zhang, 2017)0.75, 1.00 and 1.25. In our experiment, broccoli produced its maximum yield when the nitrogen fertilizer application rate was 200 kg N ha^{-1}. The same result was observed in California, it was between 200-250 kg N ha^{-1}(Kim et al., 2021)magnitude, and duration of extreme weathers (e.g. drought. Other research in the Mediterranean area in Spain has shown that the optimum content of N ranges from 211 to 373 kg ha^{-1} N (Oliveira et al., 2016; Silva et al., 2019; Cecílio Filho et al., 2018).

Available Soil Nutrients: pH decreased throughout the crop cycle for all treatments. This decrease was -7.14% for TC12t/ha (Table 5). No significant difference was recorded between the treatments studied (Table 5). The values ranged from 8.04 to 7.8 for T0 and$T_{C12t/ha}$ respectively. Compost and synthetic fertilizer and their combination had no significant effect on soil pH which is similar to the findings of (Bhangoo et al., 1988). The results showed that the soil pH values decreased due to the application of organic fertilizers compared to the control which is due to the gradual accumulation of H+ ions (Akanza et al., 2014). The decrease in pH in synthetic

Table 5. Soil chemical parameters after fertilizer application

Treatment	pH		ECmS/cm		MO%	
	50DAP	75DAP	50DAP	75DAP	50DAP	75DAP
$T_{C\ 8\ t/ha}$: 200 N kg/ha of compost (2.5-3-2.5)	8.02a	7.9a	1.44a	1.65a	1.41a	2.15a
$T_{C\ 12\ t/ha}$: 300 N kg/ha of compost (2.5-3-2.5)	7.97a	7.7a	1.67a	1.75a	1.42a	2.34a
T_{C+SYN}: 50% compost + 50% syntetic fertilizer (200 N kg/ha)	8.12a	7.8a	1.52a	1.63a	1.33a	2.23a
T_{SYN}: 200 N kg/ha of synthetic fertilizer (20-20-20)	8.22a	8.02a	0.8b	0.85b	1.41a	2.25a
T0: Control	8.11a	8.04a	0.9b	1.05b	1.31a	2.01a
SEm±	NS	1.33	0.07*	0.35*	NS	NS
	Nitrogen, kg ha^{-1}.		Phosphorus, kg ha^{-1}		Potassium, kg ha^{-1}	
	50DAP	75DAP	50DAP	75DAP	50DAP	75DAP
$T_{C\ 8t/ha}$: 200 N kg/ha of compost (2.5-3-2.5)	210.8c	113.5b	45.2	33.5b	305.9b	215.2a
$T_{C\ 12t/ha}$: 300 N kg/ha of compost (2.5-3-2.5)	230.4c	125.1b	48.6	35.8b	317.5b	222.8a
T_{C+SYN}: 50% compost+50% syntetic fertilizer (200 N kg/ha)	267.2b	136.3a	33.1	40.6 a	321.1b	215.1a
T_{SYN}: 200 N kg/ha of synthetic fertilizer (20-20-20)	287.6a	147.1a	42.5	39.2a	332.3a	300.7a
T0: Control	77.6d	51.2c	25.9	22.5b	116.0c	189.2b
SEm±	2.03*	6.01*	NS	3.6*	0.78*	10.5*

DAP – Days after planting; *Significant at $P \leq 0.05$; NS – Non Significant at $P > 0.05$

treatment could be attributed to the efficient uptake of nutrients by soil microorganisms, which leads to the production of acidic metabolites such as organic acids (He & Suzuki, 2004) and the nitrification process (Hu et al., 2010).

The decrease in pH of soil fertilized with compost may be due to the increase of nitrogen in the soil by microorganisms (Zhu et al., 2016) in the form of NH_4^+ soil ammonium (Zhao et al., 2009). NH_4^+ is the form of N taken up by the plant, so the plant releases H^+ which leads to a decrease in soil pH (Hammad et al., 2020). Regarding Electrical conductivity, an increase was observed between 50 and 75 DAP for all treatments (Table 5). The highest values at 75 DAP were observed in the compost $T_{C12t/ha}$ and T_{SYN} with 2.34 and 2.25 mS/cm respectively. No significant difference was observed between treatments. The possible explanation for the increase in EC may be due to the large amounts of soluble salts and HCO_3 contained in the compost and the decrease of pH in the soil (Abdrabbo et al., 2015).

Organic matter increased significantly in all plant's growth stages. Indeed. It increased by 138% and 105% for TC12 t/ha and TC8t/ha respectively (Table 5). At 75 DAP, statistical analysis revealed highly significant differences between compost treatment and a synthetic one. Soil OM content increased at 75 DAP. This increase was highest with $T_{C12T/ha}$, reaching 1.75%. At 50 DAP, the highest Total soil N content was observed for T_{SYN} and T_{C+SYN} with 287.6 kg/ha and 267.2 kg/ha respectively (Table 5). Then, the values decreased to 75 DAP. Statistical analysis revealed significant differences between different treatments tested. The evolution of the total nitrogen content of the soil was influenced by the type of fertilizer. The values dropped at the end of broccoli cycle, which was explained by the high nitrogen requirements of broccoli. Our results are consistent with those of Purakayastha et al. (2015) who reported that the combination of manure and inorganic fertilizer increased OM and total soil nitrogen.

Available phosphorus was showed a significant difference between compost and synthetic fertilizers and control. The T_{SYN} and T_{C+SYN} showed the highest values with 40.6 and 39.2 kg/ha respectively at 75DAP (Table 5). The soil fertilized with compost alone had the lowest soil phosphorus levels. Towards the end of the crop cycle, phosphorus levels dropped significantly. This could be explained on the one hand by the low phosphorus content in the compost (Lahav, 1976) and on the other hand by the presence of limestone in the soil which blocks the availability of phosphorus for broccoli.

Soil potassium content varied significantly between control compost and synthetic treatments. The highest value was observed with $T_{SYN: 332.3}$ kg/ha followed by $T_{C+SYN:}$ 321.1 kg/ha. The lowest value was observed with T0: 116 kg/ha. Exchangeable potassium levels in the soil decreased between the beginning and the end of the crop cycle (Table 5). The released potassium was probably absorbed by the broccoli.

N uptake and nitrogen use efficiency*:* Total plant N uptake is presented in Table 6. N content for broccoli was 273 kg/ha for T_{SYN} followed by T_{C+SYN}, $T_{C8t/ha}$ and $T_{C12t/ha}$ with 266 kg/ha, 244 kg/ha and 234 kg/ha respectively. The control had the lowest N content with 90 kg/ha (Table 6).

Agronomic efficiency (AE) was significantly affected by fertilizer type ($p < 0.005$). The highest values were recorded by T_{C+SYN} and T_{SYN}: about 22 kg/kg (Table 6). The agronomic efficiency for the synthetic fertilizer was higher compared to compost alone which in agreement with the results of Kirchmann et al. (2009). These results are comparable with those of Musyoka et al. (2017) for the cabbage crop, agronomic efficiency of compost 20 t/ha gave 14 kg/kg and 20.8 kg/kg for the conventional treatment. High nitrogen input in $TC_{12t/ha}$ decreased AE. This result was in agreement with (Ren et al., 2022). A high correlation ($r = 0.97$; $p < 0.01$) was observed between AE and yield of broccoli (Figure 1). AE depends also on the level of organic matter in soil, nitrogen application rate, soil pH, soil types, and fertilizer types (Ren et al., 2022).

Agrophysical efficiency varied from 24.37 to 25.79 kg/kg for T_{SYN} and T_{C+SYN} respectively (Table 6). There was a

Table 6. Total nitrogen up take after harvesting of broccoli crop and nitrogen use efficiency

Treatment	Total Plant uptake	NUE		
	Nitrogen, kg/ha	AE, kg/kg	APE, kg/kg	ARE
T_{SYN}: 200 N kg/ha of synthetic fertilizer (20-20-20)	273b	22.30a	24.37b	0.91 a
$T_{C8\ t/ha}$: 200 N kg/ha of compost (2.5-3-2.5)	244b	19.40b	25.19b	0.77 b
$T_{C12\ t/ha}$: 300 N kg/ha of compost (2.5-3-2.5)	234b	12.36c	25.76a	0.48 c
T_{C+SYN}: 50% compost+50% synthetic fertilizer (200 N kg/ha)	266a	22.7 0a	25.79a	0.88 a
T0: Control	90c	–	–	–
SEm±	8.23*	5.02*	NS	0.04*

*Values in each column for each treatment followed by different letters are significantly different using Duncan's multiple range test, at P < 0.05 level.

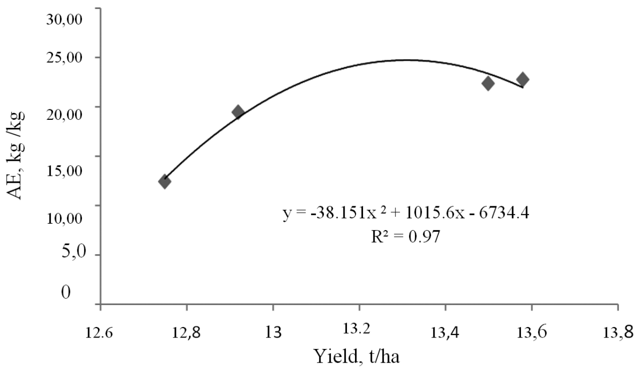

Fig. 1. Relation between yield and Agronomic efficiency under synthetic and compost treatments

significant difference between compost doses. This result is in agreement with Fageria et al. (2014) who found that N rate affects significantly APE.

For Apparent recovery efficiency (ARE), which represents the quantity of N uptake per unit of N applied, the values varied from 48% for $T_{C12t/ha}$, 77% for $T_{C8t/ha}$, 88% for T_{C+SYN} to 91% for T_{SYN}. The ANOVA analysis showed significant variations between treatments. The highest value was observed with T_{C+SYN} et T_{SYN} (Table 6).

NUE parameter showed that the use of compost with synthetic fertilizer reduces the amount of mineral nitrogen provided by 50% (Zhang et al., 2021). NUE of compost has also given satisfactory results for broccoli. The use of compost and synthetic fertilizers significantly increased N use efficiency (Plaza-Bonilla et al., 2021; Widnyana et al., 2021; Baligar & Fageria, 2015; Hirel et al., 2007). Which it depends on several parameters: soil type, fertilizer, amount applied, and climatic conditions (Fageria et al., 2014).

The dose 200 kg N/ha of a combination of organic and synthetic fertilizer gave better nitrogen use efficiency than synthetic fertilizer. For compost 200 kg of N/ha was significantly higher in nitrogen use efficiency results than 300 kg of N/ha. The combination of synthetic fertilizer with compost increases the chemical properties of soil for better nutrient uptake, especially nitrogen. These results are similar to those of Chattha et al. (2018) who demonstrated better yields and improved soil properties and uptake of wheat with the combination of synthetic and organic fertilizer.

Conclusion

The effect of two doses of compost, synthetic fertilizer, and their combination on soil chemical parameters and yield of broccoli crop was studied. Using compost with synthetic fertilizer achieved the highest yield and improved growth parameters. The use of 300 kg N/ha dose of compost decreased the main head yield, agronomic efficiency and nitrogen use efficiency. The 200 kg N/ha dose of compost and its combination with synthetic fertilizer achieved satisfactory and efficient results that are similar or superior to the use of synthetic fertilizer alone.

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