OKRA RESPONSE TO SOIL AMENDED WITH RICE HUSK BIOCHAR AND PHOSPHATE FERTILIZERS

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ABSTRACT

This study was conducted at the School of Sustainable Agriculture, Universiti Malaysia Sabah, Sandakan Campus, Sabah for three months using polybags under rain shelter to investigate the okra response to soil amended with rice husk biochar and phosphate fertilizers. The objectives of this experiment were to determine the effect of rice husk biochar, Christmas Island rock phosphate (CIRP) and triple super phosphate (TSP) on the growth of okra and soil chemical properties. This factorial experiment was arranged in completely randomized design (CRD) with five replicates per treatment. The two factors involved were: (i) two types of phosphate fertilizers - CIRP (P1) and TSP (P2) and four biochar application rates – 0 (B1), 5 (B2), 10 (B3) and 20 (B4) t ha^{-1}. Plant height, total dry weight (TDW), soil organic matter (SOM), total organic carbon (TOC), soil pH_{H_2O}, soil pH_{KCL} and available phosphorus (AP) were measured and analyzed by two- way ANOVA at 5% level of significance using SPSS software version 20. Post hoc comparison was conducted using Tukey significant difference test. There was significant interaction between the types of fertilizers and the biochar application rates for SOM and TOC. B2 resulted in the highest mean for both SOM and TOC with the values of 5.97% and 4.33% respectively. P2 always showed significantly higher mean than P1 for TDW, soil pH_{KCl} and AP. Across biochar application rates, significant differences were observed for plant height, TDW, soil pH_{KCl} and AP. In comparison to the control treatment, the plant height, soil pH_{KCl} and AP for B4 were significantly increased by 48.0%, 1.3%, and 109.1% respectively. For TDW, B3 resulted in the highest mean of 37.95 g, which was 36.9% higher than B1. There was no significant effect of biochar application rates or types of phosphate fertilizers on soil pH_{H_2O}. It could be concluded that combination of biochar with phosphate fertilizer showed improvement in okra growth and soil chemical properties than fertilizer alone. Long term field experiment would be necessary to evaluate the interaction effect of biochar and phosphate fertilizers on crop productivity and on sustaining soil fertility.

RESPON TANAMAN BENDI TERHADAP PERAPI TANAH DENGAN BIOCHAR SEKAM PADI DAN BAJA-BAJA FOSFAT

ABSTRAK

Kajian ini telah dijalankan di Sekolah Pertanian Lestari, Universiti Malaysia Sabah, Kampus Sandakan, Sabah selama tiga bulan dengan menggunakan polibeg di bawah struktur lindungan hujan untuk mengkaji kesan perapi tanah dengan biochar dan baja-baja fosfat ke atas tanaman bendi. Objektif kajian ini adalah untuk mengenalpasti kesan biochar sekam padi, Christmas Island rock phosphate (CIRP) dan triple superphosphate (TSP) ke atas pertumbuhan bendi dan sifat kimia tanah. Eksperimen faktorial ini disusun dengan rekabentuk rawak lengkap (CRD) dengan setiap rawatan masing-masing mempunyai lima replikasi. Dua faktor yang dikaji adalah: (i) jenis baja fosfat - CIRP (P1) dan TSP (P2) dan empat kadar aplikasi biochar – 0 (B1), 5 (B2), 10 (B3) dan 20 (B4) tan per hektar. Ketinggian pokok, jumlah berat kering (TDW), bahan organik tanah (SOM), jumlah karbon tanah (TOC), keasidan tanah dalam larutan air (pH_{H2O}), keasidan tanah dalam larutan kalium klorida (pH_{KCL}) dan fosforus sedia ada (AP) telah diukur dan dianalisis dengan ANOVA dua hala pada aras keertian 0.05 menggunakan SPSS versi 20 dan ujian Tukey untuk membezakan min. Keputusan menunjukkan bahawa terdapat interaksi yang signifikan antara jenis baja fosfat dan kadar aplikasi biochar ke atas SOM dan TOC. B2 menghasilkan min yang paling tinggi bagi SOM dan TOC dengan nilai masing-masing 5.97% dan 4.33%. P2 sentiasa menunjukkan min yang lebih tinggi secara signifikan berbanding dengan P1 bagi TDW, pH_{KCL} dan AP. Bagi kadar aplikasi biochar pula, terdapat perbezaan signifikan ke atas ketinggian pokok, TDW, pH_{KCL} dan AP. Berbanding dengan B1, ketinggian pokok, pH_{KCL} dan AP pada B4 meningkat secara signifikan dengan masing-masing sebanyak 48.0%, 1.3% and 109.1%. Bagi TDW, B3 mempunyai min tertinggi iaitu 37.95 g, bersamaan dengan 36.9% lebih tinggi daripada B1. Manakala, tiada kesan kadar aplikasi biochar atau jenis baja fosfat ke atas pH_{H2O}. Ini dapat disimpulkan bahawa aplikasi biochar bersama baja fosfat secara signifikan menambahbaik pertumbuhan bendi dan sifat kimia tanah berbanding dengan baja sahaja. Kajian ladang dalam jangka masa yang panjang adalah diperlukan untuk memahami kesan interaksi biochar dan baja fosfat dalam produktiviti tanaman di samping mengekalkan kesuburan tanah.

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LIST OF SYMBOLS, UNITS AND ABRREVIATIONS

%	Percent
°C	Degree celcius
µg	Microgram
ANOVA	Analysis of Variance
C	Carbon
CIRP	Christmas Island rock phosphate
cm	Centimeter
$cmol_c\ kg^{-1}$	Centimoles of positive charge per kilogram
DAS	Days after sowing
DOA	Department of Agriculture
g	Gram
$g\ kg^{-1}$	Gram per kilogram
H_2O	Water
K	Potassium
KCL	Potassium chloride
kg	Kilogram
km^2	Kilometer square
m	Meter
mg	Miligram
Mg	Megagram
ml	Mililiter
mm	Milimeter
MT	Metric tonnes
N	Nitrogen
p	Probability
P	Phosphorus
ppm	Part per million
RM	Malaysia ringgit
SOM	Soil organic matter
$t\ ha^{-1}$	Tonne per hectare
TOC	Total organic carbon
TSP	Triple superphosphate
WAS	Weeks after sowing

CHAPTER 1

INTRODUCTION

1.1 Background

The problem of limited and degrading arable lands is a big challenge to agriculture, in addition to global warming, increasing world population, and rising food prices. This problem is more acute in tropical than in temperate countries. Therefore, ways have to be found to solve this problem of degrading land in order to achieve sustainable agriculture. Use of chemical fertilizers is one way but rising fertilizer prices is a major concern. Alternative methods are required to either replace or reduce the reliance on chemical fertilizers.

Amending soil with biochar is one of the feasible ways to enhance soil health and fertility apart from manure and compost. Lehmann and Rondon (2006) reported that biochar application has gained popularity as a sustainable technology to improve highly weathered or degraded tropical soils. An important aspect for improving crop growth in these areas is the liming effect of biochar that typically have a high pH (Yamato *et al.*, 2006) which can neutralize acid soils.

The interest in biochar application arose from research on anthropogenic soil discovered in the Amazonian region called Terra Preta de Indio which improves soil fertility for millennia (Lehmann *et al.*, 2003). Biochar is normally known as black carbon or charcoal. Biochar is a by-product of pyrolysis which can be produced from any biomass through incomplete combustion (Haefele *et al.*, 2009). Glaser *et al.* (2002) found that biochar can significantly improved soil tilth, nutrient availability to plants, and plant productivity as a soil additive, along with organic and inorganic fertilizers.

As one of the important food commodities in Malaysia, vegetables can be cultivated either in lowlands or highlands. The area of vegetable cultivation in Malaysia was 41,078 hectares in 2009. Meanwhile, production of vegetables rose from 572,687 MT in 2006 to 623,457 MT in 2009, whereby other than local consumption, the vegetables are also exported to other countries. The export value of vegetables increased from RM 510,882 million in 2006 to RM 633,552 million in 2009. Malaysia is also an importer of vegetables and the value of its vegetable imports increased from RM 1,828,371 million in 2006 to RM2,268,378 million in 2009 (DOA, 2010a).

Vegetables can be divided into three types which include leafy, root and fruit vegetables. Okra is one of the fruit vegetables. According to DOA (2010b), the total vegetables producing area in Sabah was 2931.6 hectares with a production of 40,243.5 tonnes. Okra alone occupied 61.4 hectares with production of around 688.8 tonnes. In the Tenth Malaysia Plan, the aim was to increase the cultivation area of okra from 1,818 hectares in 2011 to 2,375 hectares by 2015 while the production is expected to increase from 22,394 MT to 52,433 MT respectively (DOA, 2010a).

Based on the statistics above, the import value of vegetables is greater than the export value. This indicates that there is a need to produce more vegetables for a better trade balance. However, there is a challenge in increasing the yield of vegetables due to the problem of land degradation among other constraints. Therefore, this study was undertaken with the hope of finding some solutions to overcome the problem of soil infertility and low land productivity.

1.2 Justification

Biochar application has many advantages in terms of economic, social and environmental aspects. Biochar improves soil fertility and thus reduces the usage of fertilizers which helps to lower the production cost of farmers and increase their profit. Apart from that, biochar also contributes in mitigating climate change by reducing greenhouse gas emissions and increasing soil carbon sequestration. Moreover, biochar can enhance crop yield which can subsequently help in achieving food security.

However, most of the studies on biochar effects on crops have focused on rice and maize. To my knowledge, there is no report on the effect of rice husk biochar on okra crop performance. Okra is chosen for this experiment as it is a multipurpose vegetable crop in Malaysia and it is important to evaluate the effect of biochar under local field conditions and agronomic practices.

1.3 Objectives

This study was undertaken with the following objectives:

(1) To determine the effect of rice husk biochar, Christmas Island rock phosphate and triple super phosphate on growth of okra.

(2) To determine the effect of rice husk biochar, Christmas Island rock phosphate and triple super phosphate on soil pH, organic matter, total organic carbon, and available phosphorus.

CHAPTER 2

LITERATURE REVIEW

2.1 Okra

2.1.1 Origin and distribution

Okra, with the botanical name *Abelmoschus esculentus L. Moench* or *Hibiscus esculentus*, belongs to the family Malvaceae. Okra originated in tropical Africa, was grown in the Mediterranean region, and wild forms are also found in India (Mahmood, 2008). To date, okra is well distributed in the temperate zones and tropics. It is known as gumbo or lady's finger in English-speaking countries, *bhindi* in India and *bamyah* or *bamiat* in Arabic-speaking countries (Peter and Abraham, 2007). In Malaysia, okra is called *kacang bendi* or *kacang lendir.*

2.1.2 Botany

Okra is an annual, erect herbaceous plant which can attain a height of one to two meters. The stem is green or with reddish tinge. The leaves are alternate, broadly cordate, palmately 3-7 lobed, hirsute; and serrate. The flowers are solitary, axillary with about 2 cm long peduncle. The fruit is a light green or red in colour, pyramidal oblong, beaked, longitudinally narrowed capsule about 10-30 cm long and dehiscing longitudinally when ripe. Ripe pods contain 30-80 green to dark brown rounded seeds (Rai and Yadav, 2005). Poincelot (2004) stated that immature pods are ready in 48-60 days and should be picked to ensure a continuing supply. If allowed to over-ripen, they become fibrous, woody and inedible pods containing hard round seeds (Loehrlein, 2008).

2.1.3 Climatic requirements

Okra is a seed propagated warm season crop sensitive to frost, low temperature, and waterlogging as well as drought conditions (Dhankhar and Mishra, 2005). Mahmood (2008) reported that okra will not thrive when there is continuous cold and the seeds will not germinate below 20 °C. It grows well at day temperatures of between 25-40 °C with night temperature over 22 °C (Peter and Abraham, 2007). Pollen formation fails at temperature below 24 °C and flowers subsequently drop off the plant (Loehrlein, 2008). Temperature higher than 42 °C may also cause flower drop (Rai and Yadav, 2005).

2.1.4 Soil and irrigation requirements

According to Mahmood (2008), okra will produce a satisfactory yield in any good soil if other conditions are favourable but it grows best in a well-manured and friable medium loam soil. It is only slightly tolerant to acidity and the optimum pH ranges from 6 to 6.8. Adequate and constant moisture is required for good growth and yields of okra. Too much water or too little during flowering can reduce yields and cause tough pods if this practice is continued. Water needs are 25 mm in two weeks and preferred minimal soil moisture is -0.70 Bars (Poincelot, 2004).

2.1.5 Consumption

Okra is a hot weather crop grown for its edible and young fleshy fruits. It is a very popular, tasty and gelatinous vegetable. Okra can be eaten raw as salad or cooked in curries, stews, and soups. It is also steamed, boiled, microwaved, fried and sautéed. Fruits are dried under the sun and stored for a long period while leaves are also used as a vegetable or dried (Peter and Abraham, 2007). Apart from that, okra can be preserved by canning or freezing (Loehrlein, 2008).

2.1.6 Economic importance

Okra has good nutritional values which benefits people suffering from renal coilic, leucorrhoea and general weakness. Okra contains a fair source of vitamin A, B, C and K, as well as protein, minerals such as calcium and iron, and also iodine which is considered useful to control goiter (Poincelot, 2004; Mahmood, 2008). Okra also has high fiber content which can help to prevent constipation. Other than that, the crude fibre of mature fruits and stems are used in the paper industry. In Turkey, leaves of okra are used for preparation of medicine to reduce inflammation while roasted ripe seeds are used as a substitute for coffee. The roots and stem of okra are used for clearing the cane juice from which gur or brown sugar is prepared. Apart from that, the plants are soaked in water and the resulting solution is used as clarifier in the manufacture of jiggery (Rai and Yadav, 2005).

2.1.7 Nutritional values

Table 2.1 Nutritional value of the edible portions of okra

Components	Content per 100 g
Water content	89.90%
Protein	1.7 g
Carbohydrate	5.9 g
Fat	0.1 g
Fiber	1.0 g
Calcium	77.0 mg
Iron	1.3 g
Beta-carotene	200 µg
Thiamin	0.1 mg
Nicothiamin	0.7 mg
Riboflavin	0.2 mg
Ascorbic acid	19.3 mg
Phosphorus	32.0 mg

Source: FAMA, 2005

2.2 Biochar

2.2.1 Types and properties of biochar

Biochar can be produced from biomass such as animal manure, crop residue, food waste, paper sludge and others. According to McElligott (2011), biochars produced from biomass are predominantly composed of recalcitrant organic C with contents of micro and macro nutrients in the starting feedstock. However, different biomass feed stocks and pyrolysis conditions create biochars with different physical and chemical properties (Keiluweit *et al.*, 2010). Freshly produced biochar consists of a crystalline phase with graphene layers and an amorphous phase of aromatic form which is resistant to decomposition when added as a soil amendment (Lehmann *et al.*, 2006).

Carbon (C) contents of biochar ranges between 172 g kg^{-1} and 905 g kg^{-1}. Nitrogen (N) content can range from 1.8 g kg^{-1} to 56.4 g kg^{-1}; total phosphorus (P) from 2.7 g kg^{-1} to 480 g kg^{-1} and total potassium (K) from 1.0 g kg^{-1} to 58 g kg^{-1} (Lehmann *et al.*, 2003; Chan *et al.*, 2007). Other elements contained in biochar with varying concentrations are oxygen (O), hydrogen (H), sulfur (S), base cations, and heavy metals. Lehmann (2007) stated that biochar has a range of pH values between 4 and 12 in which low pyrolysis temperatures of less than 400 °C produced acidic biochar while rising pyrolysis temperatures produce alkaline biochar.

Charcoal is not only present as large pieces in soils but also as fine particles of less than 20 micrometer (Glaser *et al.,* 2000). The size of the charcoal pieces amended to soil had only minor effects on nutrient uptake and biomass production of cowpea. This phenomenon suggests that either the surface area or the amount of nutrients supplied with the charcoal were sufficient and available with larger pieces (Lehmann *et al.,* 2003).

2.2.2 Production and application of biochar

Biochar is created by heating organic material under conditions of limited or no oxygen to optimize its useful characteristics in agriculture, such as high surface area per unit volume, low amounts of residual resins, and its ability to persist in soils with very little biological decay (Lehmann and Rondon, 2006). Different types of materials heated under different temperature greatly affect the yield and quality of biochar (Kwapinski *et al.*, 2010). Normally, biochar is incorporated into the soil manually or with machinery, unless the situation does not permit, for example in fruit orchards, biochar can be applied to the soil surface and covered with other organic materials or mixed with compost (Hunt *et al.*, 2010).

2.2.3 Biochar and soil properties

a) Soil physical properties

Asai *et al.* (2009) found that wood biochar application improved not only soil water permeability but also soil water holding capacity and subsequently increased plant water availability. This result indicates that high wood biochar application amounts lead to higher saturated hydraulic conductivity (SHC) and xylem sap flow (XSF) of upland rice. Similar improvements due to biochar application were reported by Glaser *et al.* (2002). On the other hand, Zhang *et al.* (2011) stated that wheat straw biochar amendment decreased soil bulk density. Graber *et al.* (2010) reported that there was no improvement in water holding capacity of the soilless mixture at any amendment level of wood biochar despite the porous nature of biochar.

b) Soil chemical properties

In addition, biochar application increased plant available P (Lehmann *et al.*, 2003; Glaser *et al.*, 2002; Yamato *et al.*, 2006; Asai *et al.*, 2009) but resulted in negative effects to grain yield because biochar application can limit N availability. Nitrogen uptake of plant decreased in response to the effect to N immobilization caused by the high C/N ratio of the applied wood biochar (Lehmann *et al.*, 2003). The results were again confirmed by a decrease in leaf SPAD values and decreased yield of upland rice following application of wood biochar amendment without N fertilization in soils with a low indigenous N supply in the study of Asai *et al.* (2009).

Zhang *et al.* (2011) stated that wheat straw biochar amendment increased soil organic carbon and total N but had no effect on soil mineral N and pH in treatments both with and without fertilization. Improvements in pH or nutrient retention observed for many other locations with poorer soils did not have a large effect on crop growth especially at high application rates (Lehmann *et al.,* 2003; Steiner *et al.*, 2007; Van Zwieten *et al.,* 2010; Rajkovich *et al.,* 2011). In contrast, biochar application promoted better use of applied nutrients including P, K, Calcium (Ca), Zinc (Zn), and Copper (Cu) by the plants with increased charcoal additions. Leaching of applied fertilizer N was also significantly reduced by charcoal while Ca and Magnesium (Mg) leaching was delayed (Lehmann *et al.*, 2003; Steiner *et al.*, 2007).

c) Soil biological properties

In addition to the observed increases in plant growth and productivity, the rhizosphere of biochar-amended pepper plants had significantly greater abundances of culturable microbes belonging to prominent soil-associated groups. This was attributed to the biochar stimulating shifts in microbial populations towards beneficial plant growth promoting rhizobacteria or fungi, due to either the chemical or physical attributes of the biochar (Graber *et al.*, 2010). In addition, biochar is highly recalcitrant to microbial decomposition and thus guarantees long term benefits for soil fertility (Steiner *et al.*, 2007).

2.2.4 Biochar effects on crop growth and yield

The actual effects of biochar are highly dependent on various factors such as fertility management and cultivated genotype (Asai *et al.,* 2009). Regional conditions including climate, soil chemistry and soil condition also influence the agronomic benefits of biochar (Graber *et al.*, 2010). Various studies have shown that plants performed better with the application of biochar. Asai *et al.* (2009) reported that grain yield was significantly higher in plots treated with wood biochar and non-phosphorus fertilizer than in non-biochar plots. Zhang *et al.* (2011) reported that wheat straw biochar amendment significantly increased maize production. Lehmann *et al.* (2003) also stated that charcoal addition significantly increased plant growth and nutrition.

In another study by Graber *et al.* (2010), they found that that pepper plant development in pots treated with wood biochar was significantly enhanced in terms of plant height, number of nodes, canopy, leaf area, leaf length, buds, flowers and fruits as compared with the un-amended controls. For tomato plants, biochar treatment increased plant height and leaf size, but had no effect on flower and fruit yield. There were no significant difference between treated and non-treated plants in terms of leaf nutrient content indicating that the positive impacts of biochar on pepper and tomato plant response were not due to direct or indirect effects on plant nutrition.

Lehmann *et al.* (2003) reported that increasing the amount of wood charcoal further increased the above ground and below ground biomass production. Additionally, plant roots were found to be clustered around the charcoal pieces or even sometimes grow into charcoal pieces indicating that nutrient availability in the charcoal was high and plants could access them. It is not surprising that nutrients may have been moved by diffusion from the inside of the charcoal pieces into the rhizosphere.

2.2.5 Biochar and the environment

Atmospheric carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are released into the atmosphere as organic materials decay. These greenhouse gases are the main cause of global warming. According to Hunt *et al.* (2010), methane is 21 times more potent than CO_2 as a greenhouse gas. Through pyrolysis, the carbon in the organic matter will become a more stable form and will be effectively sequestered after application to the soil (Liang *et al.*, 2008). As a result, biochar is found to be a potential means for increasing carbon sequestration and reduce greenhouse gas emission (Glaser *et al.*, 2002) apart from improving soil properties and crop productivity.

The potential of biochar in combating climate change has been indicated by a few studies. Lin *et al.* (2011) reported that methane (CH_4) emission was reduced by 51.1% and 91.2% when paddy soil was amended with bamboo biochar and rice straw biochar as compared to without biochar. In addition, biochar addition significantly decreased nitrous oxide (N_2O) emissions in paddy fields by 73.1% on average while the inhibition ranged from 51.4% to 93.5% during the 60-day period (Wang *et al.*, 2011).

Zhang *et al.* (2011) also found that biochar amendments of 20 t ha^{-1} and 40 t ha^{-1} in calcareous loamy soil poor in organic carbon decreased the total global warming potential (GWP) of methane (CH_4) and nitrous oxide (N_2O) by 9.8% and 41.5% without N fertilization, and by 23.8% and 47.6% with N fertilization, respectively.

2.3 Fertilizers

Malaysian has a total land area of 327,733 km^2. The soils are highly leached infertile acid tropical soils and therefore fertilizer plays an important role in Malaysian agriculture (Zainal, 2008). Fertilizer is a substance which is added to the soil to provide more nutrients to the plants for better plant growth. Fertilizers can be either organic or inorganic in form.

2.3.1 Types of fertilizer

a) Mineral fertilizers

In all types of farming systems in Malaysia, mineral fertilizers account for more than 90% of the fertilizers used. The common fertilizers used, both imported and locally manufactured, are urea, ammonium sulphate, calcium ammonium nitrate, phosphate rocks, super phosphates, potassium chloride, ammonium phosphates, potassium sulphate, NPK, NP and PK compound fertilizers (FAO, 2004).

The total value of imported fertilizers in 2004, 2005 and 2006 averaged about RM 2.50 billion. When the prices of fertilizers increased in 2007 and 2008, the value of the imported fertilizers increased significantly to RM 5.83 billion and RM 9.17 billion, respectively (Mohamed Ali Sabri, 2009).

b) Organic fertilizers

According to FAO (2004), the usage of organic fertilizers is being promoted by the Malaysian government for more sustainable use and better management of natural resources. Organic agriculture is also identified as a niche market opportunity for vegetables and fruits under the Third National Agricultural Policy of Malaysia. The government encourages the recycling and use of agricultural wastes and other biomass to reduce dependence on mineral fertilizers which are more expensive. These materials which include rice straw and husk, empty oil palm fruit bunches, animal droppings, saw dust and palm oil mill effluent (POME) will improve soil fertility in the long term.

The use of organic fertilizers for various crops has gained popularity due to the active promotion of organic farming by the Ministry of Agriculture through their certification programs under Standard Organic Malaysia and target to increase the organic production areas in the country. The number of local manufacturers of these organic fertilizers has also increased over the last few years to supply the vegetable and fruit crops areas. More recently, organic fertilizers fortified with chemical fertilizers have also been marketed to the plantation crop sectors (Zainal, 2008).

2.3.2 Effects of fertilizer on crop growth and yield

The yield of maize was highest under inorganic fertilizer treatment because nutrients are readily released from this source and thus maize as a short duration crop and an aggressive feeder was able to utilize it for its growth and yield. Maize and melon planted in the early season did not seem to benefit much from organic fertilizer added probably due to the low mineralization of nutrient from organic fertilizers. Highest yields of cowpea and cassava were recorded where a combination of inorganic and organic fertilizer was applied because they are late season crops and benefited from the organic fertilizer applied (Ayoola and Olukemi, 2006).

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