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Impact of fertiliser application on cocoa yields in Ghana: An analysis of cocoa bean yields in farmers' plantations

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Abstract

Nutrient mining from cocoa plantations in Ghana occurs continuously as pods and beans are taken from cocoa farms. The effects of fertiliser application on yield of cocoa was investigated over a ten-year period by monitoring yields in the farms of 256 farmers in the Ashanti, Brong Ahafo, Central, Eastern and Western Regions of Ghana. Selection of farms was limited to farmers that planted recommended mixed-hybrid variety, and within the age class of 10 to 15 years. Data were taken from two separate field monitoring. In the first group of farms monitored over a ten-year period (2009/10 to 2018/19), only granular type of fertilisers was applied on the farms of 99 farmers. In the second set of data taken over a six-year period the (2013/14 to 2018/19), 157 farmers who applied both granular and foliar type of fertilisers were monitored. At each farm, a 0.2 ha plot was demarcated for each fertiliser type. A plot receiving no fertiliser application was included as a control for comparison. The experimental design was a randomised complete block with the locations (Farmers' plantations) in each region serving as blocks. That is, at each location, a Farmer's plantation is divided into the various treatments applied. Data on total number of pods was taken on each farmer's plantation for two or three years after fertiliser application. Data collected were subjected to Analysis of variance. The results showed significant impact of fertiliser application on cocoa production in Ghana. In the farms that received only granular type of fertilisers, the average yield increases across the five regions was 73%, whereas in the second that had both granular and foliar types, the yield increase was 98%. There was no interaction between fertiliser type and Region for bean yields, except when the data on fertilised plots were disaggregated into foliar-applied and granular-applied farms. The result implies that both granular and foliar type of fertilisers recommended by Ghana cocoa board will provide similar levels of yield increment in the majority of cocoa producing Regions in Ghana.

Keywords: Nutrient mining, Foliar-fertiliser, Cacao, Ghana.

Introduction

Cocoa growth and optimal production requires lands with substantial reserves of plant nutrients. Wessel (1971) demonstrated a steady decline in all nutrients in soils under cocoa production with increasing length of cultivation. According to Singh et al. (2019), a yield of approximately 1,000 kg ha^{-1} would represent the removal of approximately 40 kg of nitrogen, 6 kg of phosphorus, and 62 kg of potassium per hectare. Work done by Ahenkorah et al. (1974) showed that in Ghana unshaded cocoa yield declines within ten years without (especially) phosphorus fertilization. Kongor et al. (2018) found out that available phosphorus and low organic matter in the soil are among the main factors that reduce the soil quality of farms in the main cocoa producing regions of Ghana. With modeled potential yields of cocoa in Ghana estimated to be over 5,000 kg ha^{-1} (Zuidema et al., 2005), the country could produce one million tonnes of cocoa from only 400,000 ha of land if one-half of this estimate is achievable by farmers. Aneani and Ofori-Frimpong (2013) estimated a yield gap of more than 82% for the Ghanaian national average yield of 450 kg ha^{-1} in comparison with yields from experimental (fertilised) farms in Ghana of around 1,890 kg ha^{-1}. This large yield gap is the result of low adoption of cocoa production technologies, including pest and disease management and farm practices, of aged and moribund plantations and of widely ignored fertilizer recommendations leading to soil degradation and low soil fertility (Abdulai et al., 2020; Kongor et al. 2018; Snoeck et al. 2010).

Among these challenges, low soil fertility has been cited as a crucial contributor to the low productivity (Appiah et al., 1997; Danso-Abbeam and Baiyegunhi, 2017; Wessel and Quist-Wessel, 2015). To reverse the increasing trend of soil nutrient mining and improve soil quality, fertiliser application should be taken seriously. Fertiliser application had long been proven to have a significant positive impact on cocoa productivity (Danso-Abbeam and Baiyegunhi, 2017). An on-farm experiment conducted in Ghana and Cote d'Ivoire by Ruff and Bini (2011), reported that yields of cocoa were 1,890 kg ha^{-1} after two years of fertiliser application. However, without fertilizer application, yields were 765 kg ha^{-1}. Another study conducted in Cote d'Ivoire by Assiri et al. (2012) found that in

Table 1. Number of farmers in each of five regions whose farms were monitored for the effects of various types of granular or foliar fertilisers.

Region	Number of farmers		
	Granular type only (2009/2010 to 2018/2019)	Granular plus foliar type (2013/2014 to 2018/2019)	**Total**
Ashanti	24	43	**67**
B/Ahafo	20	48	**68**
Central	25	12	**37**
Eastern	16	22	**38**
Western	14	32	**46**
Total	**99**	**157**	**256**

the third year of fertilizer application, cocoa yield increased from 600 kg ha^{-1} to 1,000 kg ha^{-1}.

Soil applied fertilisers is the commonest method for supplying essential nutrients to plants. However, higher plants can also absorb mineral nutrients when applied via the leaves (Eichert and Fernández, 2012). According to Fernández et al*.* (2013), foliar fertilisation facilitates the rapid absorption of mineral elements and can be carried out throughout the growing season particularly during peak periods of nutrients demand without interaction with soil constituents, precipitation, adsorption onto soil surfaces or risk of loss through erosion and leaching. More recently, foliar fertilisation has been widely used and accepted as an essential part of cocoa production (Patil and Chetan, 2018). Foliar feeding today plays a pivotal role in crop production including cocoa with some farmers feeding their cocoa almost exclusively through the leaves in at least a season (Patil and Chetan, 2018).

In addition to the commonly used fertiliser type in Ghana with the formulation NPK 0-22-18+9CaO+6MgO+7S (Snoeck et al., 2009), more recent types usually applied in cocoa farms in Ghana are foliar (e.g. NPK 10-10-10+TE, NPK 10-8-10+TE, NPK 20-20-20+TE, NPK 6-0-20+TE) and granular (e.g. NPK 3-20-18+6CaO+7MgO+4S+0.5B+0.5Zn, NPK 5-16-15+16CaO+6S+3MgO+0.3B+0.7Zn). The effect of fertilizer application on yield of cocoa in Ghana has been reported by several authors (Appiah et al*.,* 2000; Ofori-Frimpong et al., 2013; Dossa et al, 2018). Several works have been done by researchers focused on the application of granular type fertilisers. For example, Appiah et al. (2000) reported yield increases of 61.7%, 99.8%, 116.0% and 106.6% in fertilizer treated plots over the unfertilized control after first, second, third and fourth years respectively, of fertilizer application. The focus of the current analyses is to demonstrate the impact of applying Ghana Cocoa Board recommended fertilisers (foliar and granular) on cocoa bean yields in the major cocoa producing Regions of Ghana.

Results

The results are disaggregated for granular type only and granular versus foliar type fertiliser effects on dry bean yields of cocoa, within regions and across the five regions.

Application of granular fertilisers only

For the 99 farmers whose farms were monitored from 2009/2010 to 2018/2019 for effects of granular type of fertilisers, fertiliser application increased cocoa dry bean yields by 73.5%, from 426 (±58) to 739 (±51) kg ha^{-1} $year^{-1}$ (Fig 1), which was statistically significant ($p < 0.05$).

There was no interaction between regions and fertiliser application ($p = 0.096$) indicating that regardless of the Region, application of granular type fertilisers had positive effects on cocoa bean yields. Between Regions, yield ranged from 427 kg ha^{-1} $year^{-1}$ for Brong Ahafo Region to 711 kg ha^{-1} $year^{-1}$ for Western Region, with significant differences ($p < 0.05$) between Regions (Fig 2). These values represent the combined effects of fertiliser and no fertiliser plots, and reflect the potential of the Regions for cocoa production based on the farmers monitored. Cocoa bean yield was highest in the Western and Central Regions and these were significantly higher than production in the Brong Ahafo, Eastern and Ashanti Regions.

The yield of plots fertilised with granular fertiliser compared to unfertilised plots in each of the five Regions is presented in Figure 3.0. Increase in yields in fertilised plots was 56% in the Brong Ahafo Region, 66% in the Eastern Region, 67% in the Ashanti Region, 71% in the Western Region and 101% in the Central Region.

Granular fertiliser, foliar fertiliser and unfertilised plots compared for yield

For the 157 farms treated with various types of granular or foliar fertilisers, fertiliser treated plots (regardless of type) gave an average yield of 792 (± 64.4) kg ha^{-1} $year^{-1}$ compared with 399 (± 70.1) kg ha^{-1} $year^{-1}$ ($LSD_{0.05} = 75.8$) for unfertilised plots from 2013/14 to 2018/19 across the five Regions (Figure 4.0). This corresponds to a yield increase of 98% following the use of fertilisers. When yield was disaggregated into unfertilised, foliar-fertilised or granular-fertilised, there was no significant difference between granular fertiliser and foliar fertiliser treated plots (Figure 4).

There was no interaction between Region and Fertiliser type for dry bean yields. The cocoa bean yields within each Region, averaging both fertilised and unfertilised plots showed that yields were highest in the Central Region (Figure 5). Dry bean yields in the other Regions were not significantly different from each other and ranged from 486 kg ha^{-1} $year^{-1}$ in the Ashanti Region to 584 kg ha^{-1} $year^{-1}$ in the Brong Ahafo Region. When the effects of the two fertiliser types are combined within the Regions, fertiliser application increased cocoa bean yields by 77% in the Eastern Region, 83% in the Central Region, 113% in

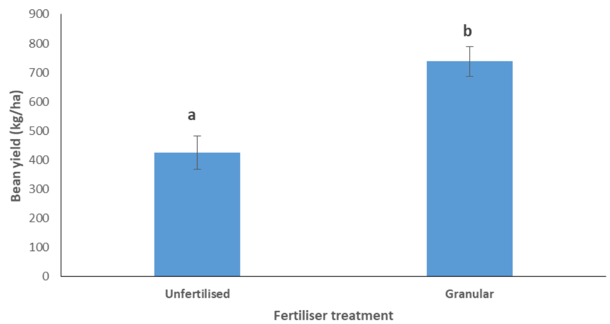

Fig 1. Effect of granular fertilisers on cocoa bean yields on ninety-nine farmers' plantations across five regions in Ghana from 2009/10 to 2018/19. Different letters indicate significant difference (LSD test: $p < 0.05$).

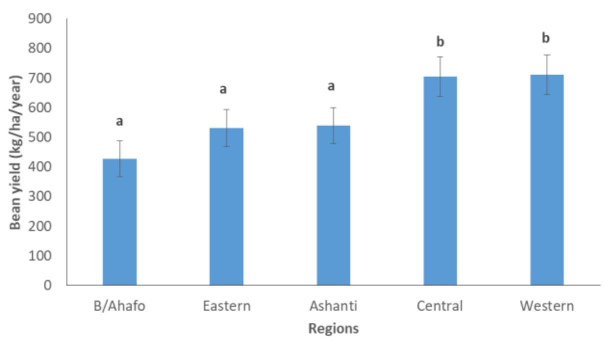

Fig 2. Average cocoa bean yields from farmers' plantations in each of five Regions in Ghana over a ten-year period (2009/10 to 2018/19). Different letters indicate significant difference (LSD test: $p < 0.05$).

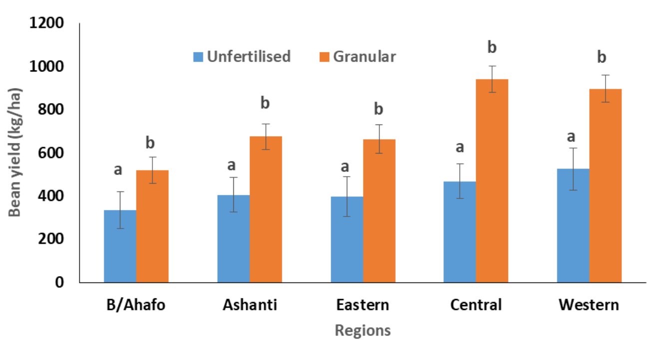

Fig 3. Cocoa bean yields of farmers' plots treated with granular fertilisers compared with unfertilised plots in each of five Regions in Ghana over a ten-year period (2009/10 to 2018/19). Different letters indicate significant difference (LSD test: $p < 0.05$).

the Brong Ahafo Region, and 117% in the Ashanti and Western Regions.

A significant interaction between fertiliser type and Region was observed when the fertiliser effects were disaggregated into foliar and granular types (Fig 6). The interaction was due to the observed effects in the Brong Ahafo Region. In the four other Regions, there was no significant difference between the effects of foliar or granular type of fertilisers on yield. It is only in the Brong Ahafo Region that granular type of fertilisers had significant increases in yield over foliar fertiliser treated plots.

Discussions

The improvement of cocoa productivity through fertiliser application is crucial for increasing dry bean yield, income levels of farmers among others (Ali et al*.,* 2018). Fertiliser is frequently recommended as a key strategy to improve yields of cocoa beans (Abdulai et al., 2020; Kongor et al., 2018). However, most cocoa farmers are smallholders with limited access to inputs, who use little or no fertiliser. Additionally, many smallholder farmers seem unconvinced of the need and effect of fertiliser on cocoa bean yield (Kenfack Essougong et al., 2020). This is most likely the result of the highly variable effects of fertiliser application; ranging from a doubling of the yield to no effect in some instances (Dossa et al., 2018), and there is lack of clear fertiliser recommendations with solid scientific base. Nevertheless, continuous cropping of cocoa without inputs from fertilisers results in nutrient imbalance, which eventually leads to soil degradation and nutrients depletion and severe yield decline in older plantations (Abdulai et al., 2020; Kongor et al., 2019; Snoeck et al., 2010). Results from this study clearly showed that plots treated with fertilisers had significantly higher pod production than unfertilised plots. This result is in line with that reported by Effendy et al. (2019) who have shown that the use of fertiliser in rural Indonesian cocoa farms has a positive impact on cocoa yields and therefore farmers 'incomes. In Duekué, West Côte d'Ivoire, average cocoa bean yields were 765 kg ha^{-1} without fertiliser, but 1,890 kg ha^{-1} after two years of fertiliser application (Ruf and Bini, 2011). Jadin and Snoeck (1985) applied fertilisers to smallholder farmers' fields in Côte d'Ivoire. The amounts of nutrients added differed among the fields and were calculated through the soil diagnostic method. Their results clearly showed that the application of fertilisers increased the yield of cocoa beans in those fields. Gockowski and Sonwa (2011) in their survey found average cocoa yields in Ghana to be more than double those of Ivoirian farmers which they ascribed largely to more fertiliser use in Ghana. Wessel (1971) reported positive responses to fertiliser application, although the degrees of response differed from location to location, with no response at some locations. A limited response of cocoa to fertiliser application (i.e. little difference between fertilised and unfertilised plots at the same location) may be explained in part by the fact that the trees were sited on relatively fertile soils (Appiah et al., 2000). A low cocoa bean yield from fertiliser application was reported by Asare et al. (2016). The authors ascribed the low yield to inherently low soil nutrients status especially phosphorus which could not sufficiently be ameliorated by the recommended fertiliser application. The non-significant interaction effect between fertilisers and regions on cocoa bean yield maybe ascribed to the fact that the trees were planted on soils of similar characteristics across the different regions. It has been established by some researchers that Acrisols are the dominant soil types in the cocoa landscape of Ghana (Dossa et al., 2018; Ameyaw et al., 2020). The use of foliar fertilisers to increase the yield of cocoa bean has been reported by some researchers. Kouadio et al*.* (2017) found out that foliar application of boron improved foliar density and induced production of pods of normal shape thereby reducing the appearance of this misshapenness due to CSSV. Boron also

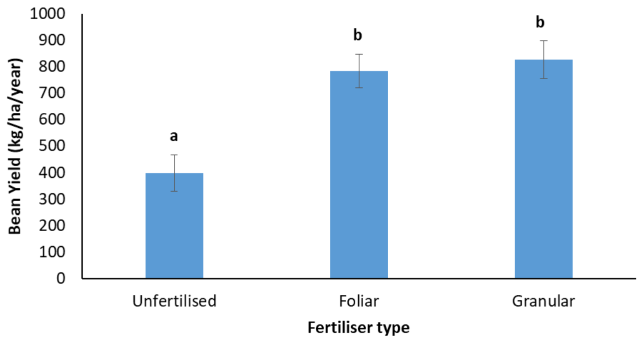

Fig 4. Average cocoa bean yields of unfertilised plots, foliar fertiliser and granular fertiliser treated farmers' plantations in each of five regions in Ghana over a six-year period (2013/14 to 2018/19). Different letters indicate significant difference (LSD test: $p < 0.05$).

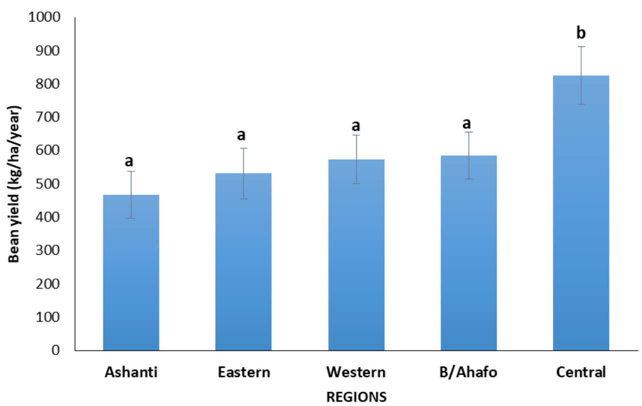

Fig 5. Average cocoa bean yields from a combination of fertilised and unfertilised farmers' plantations in each of five Regions in Ghana over a six-year period (2013/14 to 2018/19). Different letters indicate significant difference (LSD test: $p < 0.05$).

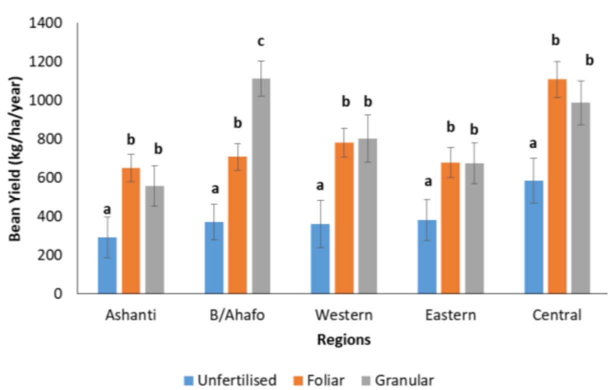

Fig 6. Average cocoa bean yields from unfertilised plots, and farms treated with either granular or foliar fertilisers from farmers' plantations in each of five regions in Ghana over a six-year period (2013/14 to 2018/19). Within a Region, different letters indicate significant differences (LSD test: $p < 0.05$).

increased number of flowers, cherelles and pods. Moreover, weight and size of fresh cocoa beans per pod were positively correlated to boron dosage. Lallié et al. (2021) reported that plots that received the application of biostimulant Banzai had significantly produced more pods than the control plots that were without application of the biostimulant. The similarity in yield performance of foliar and granular fertiliser supports the argument raised by Toscano et al. (2002) that applications of foliar fertiliser are considered an alternative to supply plant nutrients when soil conditions may hamper root uptake or during stages of rapid growth when requirements may exceed supply by the root. Plant health is very important in any form of fertilisation. Foliar fertilisers can perform their role via foliar sprays with utmost efficiency only when they are applied at an optimal time (phenological phase), right site, and in correct application rate with uniform distribution (Srivastava et al., 2007; Fernández-Escobar et al., 2009). The relatively high dry cocoa bean yield obtained at Central region could be explained by the relatively younger cocoa plantations in the region. Cocoa trees with age class between 8-10 years old have been reported to be more responsive to fertilizer application than older plantations, 20 years and above (Dossa et al., 2018).

Materials and Methods

Study area

The study was carried out in the semi deciduous forest and rain forest agroecologies in five cocoa growing regions of Ghana (Fig 7). The areas are characterized by weak temperature amplitudes (26–30 ^{0}C), high relative humidity (80–90%) and a bimodal rainfall pattern. The major rainy season starts from March–July and the minor season is from September–November. There is a short dry spell in August. The semi deciduous zone receives mean an annual rainfall of 1500 mm, and 2000 mm in the rain forest zone. The soils are leached, highly weathered and consist of Acrisols, Lixisols, Nitisols and Ferralsols with the Acrisols accounting for about 70% (Dossa et al., 2018).

Plot demarcation

Selected plantations were healthy mature cocoa farms >3.0 acres with light or no shade. The ages of the cocoa trees used ranged from 8 to 15 years and were of mixed hybrid cocoa. On each farm, a 0.2 ha plot was demarcated for each fertiliser treatment. The number of cocoa trees in each 0.2 ha plot was recorded.

Experimental design and treatments

The experiment was laid out in a randomized complete block deign with each location in a region serving as replicate. At each farmer's site, a control plot (no fertiliser) and granular and/or foliar type fertilisers were applied. The types of granular (NPK 0-30-20; NPK 0-22-28+9CaO+6MgO+7S; NPK 3-20-18+6CaO+7MgO+4S+0.5B+0.5Zn; NPK 5-16-15+16CaO+6S+ 3MgO+0.3B+0.7Zn and foliar types (NPK 10-10-10+TE; NPK 10-8-10+ TE; NPK 20-20-20+TE; NPK 6-0-20) used were those recommended by Ghana Cocoa Board over different time scales for use on cocoa farms in Ghana. A total of 256 farmers' farms were monitored from the 2009/10 to 2018/19 season. The breakdowns of the number of farmers whose farms were monitored for either the granular type only or for both granular and foliar types are provided in Table 1. Each farmer received between two to five types of fertilisers, and was monitored for two to three years after fertiliser application. All

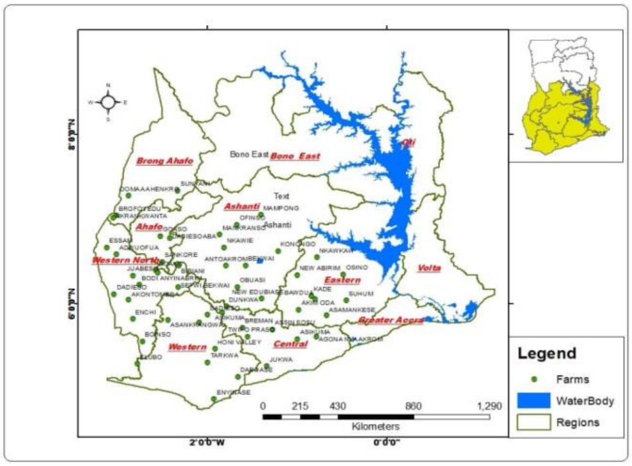

Fig 7. Map showing the regions and towns where the study was carried out over a ten-year period (2009/10 to 2018/19).

CRIG recommended agronomic practices (Opoku-Ameyaw et al., 2010) were followed at each of the sites.

Method and rate of fertiliser application

Granular type fertilisers were applied by broadcasting at the rate of 375 kg ha^{-1} at the beginning of the rainy season, in single pplication at each monitored site. Application rate of foliar type fertilisers followed the manufacturers' recommendations, but typically at monthly intervals from May to October. The foliar fertilisers were applied with a mist blower spraying machine.

Data collection

Mature pods were periodically harvested, categorized into good, diseased (black pod), immature ripe pods and malformed pods. Pod number was taken per treatment plot, and the yield was estimated based on a conversion factor of 28 pods to 1 kg dry cocoa beans. Dry bean yields of farmers' plots monitored from 2009/10 to 2018/19 in the five regions were used to estimate the effects of granular and foliar type fertilisers on cocoa bean yields in Ghana. Plots were monitored in two tiers. First, groups of farmers who received only granular fertilisers from 2009/10 to 2018/19 were monitored separately. Second, farms that received both granular and foliar fertilisers from 2013/14 to 2018/19 were then analysed.

Statistical analysis

Data collected on dry cocoa bean yield were subjected to analysis of variance (ANOVA). Treatment means that show significant differences were compared using the least significant difference (LSD) method. All statistics were performed using GenStat statistical package (edition 12, Lawes Agricultural Trust, Rothamsted Experimental Station, http://www.vsni.co.uk).

Conclusion

The analyses of the data have shown that fertiliser application had a positive impact on cocoa bean yield across the various cocoa growing regions. Application of granular and foliar fertiliser types showed similar effect on cocoa bean yield. Yield was highest in the Central region probably due to relatively young plantations in that region and high fertiliser response by the cocoa trees. The non-significant interaction between fertilisers and Regions suggest that majority of the plantations were planted on soils of similar characteristics. Farmers are encouraged to apply only COCOBOD approved fertilisers to ensure that they obtain high yield from fertiliser application. To obtain maximum benefit from fertiliser application, agronomic practices such as weeding, removal of chupons, mistletoes and pruning should be carried out as recommended.

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