The residual effect of soil amendments application on physical sandy soil properties and first ratoon sugarcane (*Saccharum officinarum* L.)

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Abstract. Sugarcane cultivation in sandy soil is quite difficult because the sandy soil properties are less suitable for this crop. Soil amendment application might be important as a growth medium for sugarcane. This study aimed to improve the physical properties of sand-texture soil due to the residue of soil amendments application and their effect on first ratoon sugarcane. The study was arranged in a randomized block design with ten treatments and three replication. The treatment was soil amendments residue which had been applied in 2013 includes 10 t ha⁻¹ of single soil amendment: sugarcane trash biochar (STB), sugarcane trash compost (STC), boiler ash (BA), cattle manure (CM); and 5+5 t ha⁻¹ of combinations: STB+STC, STB+CM; BA+STC, BA+CM, BA+filter cake (FC), and control. The results showed that the residue of soil amendment at 11 months after ratooning significantly improved soil physical properties such as aggregate stability, bulk density, total porosity, and available water content. The residue treatments of STB, CM, STB+CM, gave better effect on soil properties and increased growth, but they did not significantly increase the yield of the first ratoon sugarcane. Therefore, further research is needed with a dose of soil amendments >10 t ha⁻¹ in combination with nutrient treatments.

Keywords: soil physical property, amendment, sugarcane

1. Introduction

Sugarcane (*Saccharum officinarum* L.) plantations were also carried out on dry land with sandy textured soil. Agricultural problems in sandy soils include low aggregation, no structure or unstable structure, easy compaction, extreme temperatures, risk of drought, flooding, erosion, low water holding capacity, soil moisture deficit, low cation exchange capacity, nutrient deficiency, and low soil (micro)organisms population [1, 2]. Therefore, amendment of sandy soils as growth medium of sugarcane might be important.

Organic matter is known to have a positive role in improving soil quality. However, in tropical agriculture, organic matter application into the soil is rapidly degraded by soil microbes, so that C-organic rapidly decreases. Therefore, organic matter should be added at every planting season [3]. Another way to increase soil organic matter is by providing a more stable C source material, namely...
biochar [4]. By synergizing the function of organic matter such as compost or manure with biochar, it is expected that the combination would be able to provide a better synergistic effect on sustainable land management than compost and biochar individually [5].

Organic matter from sugar cane plantations and the sugar industry could be added to improve soil quality. The availability of the organic matter in the form of waste is around 6 to 8 t ha\(^{-1}\) [6, 7, 8]. Sugarcane waste can be processed into biochar or compost. The sugarcane industry produces waste in the form of filter cake (4%) and bagasse (28%) [9]. In addition, there is about 2.5% boiler ash from the burning of bagasse which was used for boiler fuel [10, 11].

The utilization of sugarcane trash and sugar factory waste is expected to improve sandy soil properties. Therefore, this study aimed to study the effect of organic matter on the physical properties of sandy soils associated with water-holding properties and their residual effect of organic matter on the growth of the first ratoon sugarcane.

2. Materials and methods

The study was performed at the Indonesian Sweetener and Fiber Crops Research Institute (ISFCRI) in Malang, Indonesia (7°54’26” S; 112°37’22” E; 522 m above sea level) from October 2014 to January 2016. The soil sample was analyzed at the Soil Laboratory of Brawijaya University, Malang.

Ten treatments were arranged in a randomized block design that were replicated three times. In this research, the treatment was a residual effect of soil amendments. Treatment included: sugarcane trash biochar (STB) 10 t ha\(^{-1}\), sugarcane trash compost (STC) 10 t ha\(^{-1}\), boiler ash (BA) 10 t ha\(^{-1}\), cattle manure (CM) 10 t ha\(^{-1}\), STB 5 t ha\(^{-1}\) + STC 5 t ha\(^{-1}\), STB 5 t ha\(^{-1}\) + CM 5 t ha\(^{-1}\), BA 5 t ha\(^{-1}\) + STB 5 t ha\(^{-1}\), BA 5 t ha\(^{-1}\) + CM 5 t ha\(^{-1}\), BA 5 t ha\(^{-1}\) + filter cake (FC) 5 t ha\(^{-1}\), and without soil amendment as control. Soil amendments were added at the previous year before sugar cane was planted (2013). Soil amendments added in each plot for a dose of 10 t ha\(^{-1}\) was equivalent to 754 g pot\(^{-1}\).

### Table 1. Soil and soil-amendments properties

| Properties                  | Soil | STB | STC | BA  | FC  | CM  |
|-----------------------------|------|-----|-----|-----|-----|-----|
| Bulk density, g cm\(^{-3}\) |      | 1.23|     |     |     |     |
| Particle density, g cm\(^{-3}\) |      | 2.09|     |     |     |     |
| Total porosity, %           |      | 40.90|     |     |     |     |
| Water content;              |      |     |     |     |     |     |
| at pH 0                     |      | 41  |     |     |     |     |
| at pH 2.5                   |      | 35  |     |     |     |     |
| at pH 4.2                   |      | 5   |     |     |     |     |
| Texture                     |      | Sand|     |     |     |     |
| sand, %                     |      | 92.40|     |     |     |     |
| silt, %                     |      | 3.10|     |     |     |     |
| clay, %                     |      | 4.50|     |     |     |     |
| pH (H\(_{2}\)O)             |      | 6.7 | 9.1 | 7.6 | 9.2 | 7.1 |
| Organic-C, %                |      | 0.61| 35.2| 12.9| 2.80| 19.2| 4.50|
| Total-N, %                  |      | 0.1 | 0.92| 0.97| 0.08| 1.92| 0.77|
| Total-P, %                  |      | 2.75| 2.31| 4.05| 12.20| 0.16|
| Total-K, %                  |      | 3.19| 1.23| 2.83| 0.91| 0.24|
| Total-Na, %                 |      | 0.28| 0.45| 0.12| 0.27| 0.14|
| Total-Ca, %                 |      | 1.60| 1.21| 11.81| 42.32| 1.32|
| Total-Mg, %                 |      | 0.39| 0.33| 0.37| 0.25| 0.38|
| P\(_{2}\)O\(_{5}\) (Bray-I), mg kg\(^{-1}\) |      | 5.17|     |     |     |     |
| Exchangeable cation (NH\(_{4}\)OAc 1N pH7) |      |     |     |     |     |     |
| Exchangeable-K, cmol kg\(^{-1}\) |      | 0.09|     |     |     |     |
| Exchangeable-Na, cmol kg\(^{-1}\) |      | 0.35|     |     |     |     |
| Exchangeable-Ca, cmol kg\(^{-1}\) |      | 5.57|     |     |     |     |
| Exchangeable-Mg, cmol kg\(^{-1}\) |      | 0.48|     |     |     |     |
| Cation exchange capacity (CEC), cmol kg\(^{-1}\) |      | 11.54| 15.08| 22.83| 13.63| 53.48| 25.60|
The sugarcane seeds used were the first ratoon sugarcane of Bululawang variety. The seeds were grown in pots (diameter of 58 cm and height of 42 cm) of sandy soil which was collected from Asembagus Experimental Station, Situbondo (46 m asl; 7°45'35" S; 14°15' E). STB, STC, and CM were obtained from Karangploso Malang. BA and FC were obtained from Sugar Factory of Kebon Agung, Malang. Some soil and amendments properties are shown in Table 1. The pots were arranged similarly to the sugarcane plant spacing in the field, 200 cm distance between blocks/replications, 3 pots per unit treatment by 130 cm distance between pots, 60 cm distance between planting holes. Soil moisture was maintained by watering with tap water. Two weeks after ratooning, fertilizers were added at the dosage equivalent to 600 kg ha⁻¹ NPK 15:15:15. The second fertilization was executed at 3 months after ratooning with the dosage equal to 500 kg ha⁻¹ ZA). Cane stalks were harvested at 11 months old.

Soil samples were collected twice for laboratory analysis: 7 months after ratooning (grand growth phase) and at harvesting time. The soil parameters observed were aggregate stability (Vilensky technique), bulk density (cylinder method), particle density (pycnometer method), total porosity ((1 - (BD/PD)) x 100 percent), and accessible water content (pF2.5, sandbox) (pF4.2, pressure plate). Meanwhile, the plant growth parameters were plant height, stalk diameter (average of bottom, middle, and top part), stalk number, whereas the yield parameter was the harvested stalks weight. The data obtained were analyzed using Analysis of Variance (ANOVA) 5%, followed by Least Significance Difference (LSD) 5%.

3. Result and discussion
In Table 2, it is presented the residual effect of organic matter on sandy soil aggregate stability in the second year. The application of 10 t ha⁻¹ biochar significantly increased the aggregate stability at 7 and 11 months after ratooning (MAR). This condition occurred due to C and CEC from soil amendments that bind soil particles. Interaction between soil minerals, metal/soil base and functional groups of soil amendments, and organic matter and soil microbes, caused the aggregate to become stable [12, 13, 14, 15].

On 11 MAR, there was a decrease in soil aggregate stability compared to 7 MAR in all treatments. These conditions indicated that the ability of soil amendments in aggregating soil particles could not retain up to 2 years since application. It appears that the application of the 10 t ha⁻¹ dose was insufficient.

The soil amendments did not significantly affect soil bulk density at 7 MAR, but they had a significant effect on soil bulk density at 11 MAR (Table 2). The treatments of STB 5 t ha⁻¹ + CM 5 t ha⁻¹, CM 10 t ha⁻¹, STB 10 t ha⁻¹, BA 5 t ha⁻¹ + STC 5 t ha⁻¹, and BA 5 t ha⁻¹ + CM 5 t ha⁻¹ significantly reduced soil bulk density compared to control. As in the plant cane (PC) in the first year, soil amendments reduced the bulk density of the sandy soil [16]. The decrease in soil bulk density indicated that the application of soil amendments reduced soil strength so that the roots are easier to penetrate the soil [15, 17, 18, 19]. Biochar possesses a low density due to its porous and large inner surface characteristics [4, 20, 21, 22, 23, 24]. However, in some treatments, bulk density increased at 11 MAR; due to soil compaction. Besides, the dense sugarcane roots biomass affected the overall soil mass density.

In the second year ratoon, the treatment of soil amendments in the first year had no significant residual effect on soil density at 7 and 11 MAR (Table 2). Soil particle density is the ratio between the total mass weight and the volume of the solid phase of the soil. Sugarcane root biomass increased over time caused soil mass increased. So that soil particle density at 11 MAR was higher than 7 MAR. The addition of organic matter into the soil affected the particle density of the soil [25, 26].

Total porosity is related to the aggregation of the soil, where there is more space between soil particles. The application of soil amendments in the first year did not show any residual effect on the
total porosity in 7 MAR, but it was significant in 11 MAR (Table 2). In 11 MAR, the treatment of CM 10 t ha\(^{-1}\) and STB 5 t ha\(^{-1}\) + CM 5 t ha\(^{-1}\) gave a better effect than other treatments, including control, although were not significantly different. Even though the total porosity in control was high, it was suspected that it was in the form of macropores that could not hold water, while in the soil amendments treatment, there assumed that more pores could hold water. The microporous nature of biochar increased the soil porosity that could hold water. Manure and compost could act as aggregating agents for soil particles to form aggregates and increased soil pores that can hold water [27, 28]. The application of biochar in sandy textured soils increased soil porosity [22, 24, 29].

The available soil water content is the amount of water in the soil that can be utilized or absorbed by plant roots. The water available for this plant is bound in soil particles/aggregates, in the soil pores, which is the water content between field capacity and permanent wilting point condition. In the sandy soil, the ability to store water was altered by changes in aggregate stability, bulk density, particle density, and porosity. The available soil moisture content at 7 MAR did not show any difference between treatments, while at 11 MAR, there was a significant difference (Table 2). The treatment of STB 5 t ha\(^{-1}\) + CM 5 t ha\(^{-1}\) showed the best effect at 11 MAR, or increased available water content by 37\% compared to control following the increase of porosity. The available water content of sandy soil increased in treatment of STB 5 t ha\(^{-1}\) + CM 5 t ha\(^{-1}\). The available soil water increased due to the presence of organic matter, micropores, and the specific surface area of biochar [15, 22, 30, 31, 32, 33], both of which play a role in improving soil aggregation and structure [34]. Soil amendments treatment could support plants to avoid water stress [35, 36].

Table 2. The residual effect of soil amendments application on physical properties of sandy soil in first ratoon sugarcane.

| Treatment                                      | Aggregate stability | Bulk density | Particle density | Total porosity | Available water content % volume |
|-----------------------------------------------|---------------------|--------------|------------------|---------------|----------------------------------|
|                                                | Water droplet       |              |                  |               |                                  |
|                                                | breaking point      |              |                  |               |                                  |
| 7 months after first ratooning (grand growth phase) |                     |              |                  |               |                                  |
| 1. Sugarcane trash biochar (STB) 10 t ha\(^{-1}\) | 21.33 a             | 1.24         | 2.30             | 46.20         | 12.81                            |
| 2. Sugarcane trash compost (STC) 10 t ha\(^{-1}\) | 13.67 cd            | 1.27         | 2.50             | 44.72         | 13.12                            |
| 3. Boiler ash (BA) 10 t ha\(^{-1}\)            | 18.22 ab            | 1.26         | 2.30             | 45.40         | 12.55                            |
| 4. Cattle manure (CM) 10 t ha\(^{-1}\)         | 17.89 abc           | 1.24         | 2.26             | 45.01         | 11.37                            |
| 5. STB 5 t ha\(^{-1}\) + STC 5 t ha\(^{-1}\)   | 16.00 bc            | 1.30         | 2.25             | 42.28         | 11.59                            |
| 6. STB 5 t ha\(^{-1}\) + CM 5 t ha\(^{-1}\)    | 15.89 bc            | 1.30         | 2.24             | 42.03         | 12.65                            |
| 7. BA 5 t ha\(^{-1}\) + STC 5 t ha\(^{-1}\)    | 16.22 bc            | 1.26         | 2.26             | 44.34         | 12.28                            |
| 8. BA 5 t ha\(^{-1}\) + CM 5 t ha\(^{-1}\)     | 19.56 ab            | 1.28         | 2.32             | 44.86         | 12.41                            |
| 9. BA 5 t ha\(^{-1}\) + Filter cake (FC) 5 t ha\(^{-1}\) | 18.22 ab           | 1.21         | 2.26             | 46.63         | 12.09                            |
| 10. Control                                    | 10.56 d             | 1.31         | 2.35             | 44.07         | 10.57                            |
| LSD 5%                                         | 4.24 ns             | ns           | ns               | ns            |                                  |

| 11 months after first ratooning (harvest time)  |                     |              |                  |               |                                  |
| 1. Sugarcane trash biochar (STB) 10 t ha\(^{-1}\) | 9.00 a              | 1.16 bcd     | 2.28             | 41.73 c       | 9.35 bcd                         |
| 2. Sugarcane trash compost (STC) 10 t ha\(^{-1}\) | 3.00 c              | 1.31 a       | 2.41             | 45.48 bc      | 11.55 abc                        |
| 3. Boiler ash (BA) 10 t ha\(^{-1}\)            | 3.50 bc             | 1.23 abc     | 2.36             | 47.73 abc     | 9.05 cde                         |
| 4. Cattle manure (CM) 10 t ha\(^{-1}\)         | 5.00 bc             | 1.13 cd      | 2.37             | 52.50 a       | 9.95 bcd                         |
| 5. STB 5 t ha\(^{-1}\) + STC 5 t ha\(^{-1}\)   | 4.50 bc             | 1.32 a       | 2.38             | 44.48 bc      | 11.70 ab                         |
| 6. STB 5 t ha\(^{-1}\) + CM 5 t ha\(^{-1}\)    | 3.00 c              | 1.12 d       | 2.37             | 52.79 a       | 13.25 a                          |
| 7. BA 5 t ha\(^{-1}\) + STC 5 t ha\(^{-1}\)    | 4.00 bc             | 1.19 bcd     | 2.33             | 48.86 ab      | 6.60 e                           |
| 8. BA 5 t ha\(^{-1}\) + CM 5 t ha\(^{-1}\)     | 4.00 bc             | 1.19 bcd     | 2.37             | 49.84 ab      | 9.40 bcd                         |
| 9. BA 5 t ha\(^{-1}\) + Filter cake (FC) 5 t ha\(^{-1}\) | 4.50 bc             | 1.24 abc     | 2.34             | 47.01 abc     | 8.60 de                          |
| 10. Control                                    | 6.00 b              | 1.33 a       | 2.45             | 52.63 a       | 9.70 bcd                         |
| LSD 5%                                         | 2.65 ns             | 0.10 ns      | 6.57             | 2.51          |                                  |

Note: Numbers in the same column followed by the same letters were not significantly different at LSD 5% test; ns: not significant.
Improvement of the sandy soil physical properties (aggregate stability, porosity, water holding capacity) promoted the growth of first ratoon sugarcane (RC1) at 11 MAR (Table 3). The treatments of BA 5 t ha⁻¹ + STC 5 t ha⁻¹, CM 10 t ha⁻¹, BA 5 t ha⁻¹ + FC 5 t ha⁻¹, and STB 10 t ha⁻¹ had a residual effect on increasing the height of RC1 sugarcane. Although STB has lower nutrient content than CM, STC, and FC; however, it could have a residual effect equivalent to other treatments at 11 MAR sugarcane plant height.

Sandy soils that were treated with soil amendments had no significant residual effect on the stalks diameter of the first ratoon sugarcane at 7 and 11 MAR (Table 3). Consistently, treatment of BA 5 t ha⁻¹ + STC 5 t ha⁻¹ achieved the best results, resulting in a stalk diameter of 30-31 mm. The residual effect of this treatment was not different from the treatments of STB 10 t ha⁻¹ and CM 10 t ha⁻¹. Stalk diameter is affected by the soil availability of P [37], however, the application of soil amendments containing little P had not increased stalk diameter.

There was no increase in the number of sugarcane stalks at 11 MAR. The number of sugarcane stalks formed in the tillering phase (up to 4 MAR) and stable at 7-9 MAR. The number of sugarcane stalks of RC1 was not affected by the application of soil amendments (Table 3). Improvement of sandy soil properties did not increase the number of sugarcane stalks to be harvested. The number of sugarcane stalks formed is more determined by the adequacy of soil P and N nutrients than other factors, especially in the tillering phase [37]. The soil amendments given did not provide significant additional nutrients, so they could not increase the number of stalks compared to the control.

**Table 3.** The residual effect of soil amendments application on growth and yield of first ratoon sugarcane.

| Treatment | Plant height | Stalk diameter | Number of stalks harvested | Cane yield |
|-----------|--------------|----------------|----------------------------|------------|
|           | 7 months after first ratooning (grand growth phase) |               |                            |            |
| 1. Sugarcane trash biochar (STB) 10 t ha⁻¹ | 195.89 cm | 29.07 mm | 11.67 pot⁻¹ | 11.67 t ha⁻¹ |
| 2. Sugarcane trash compost (STC) 10 t ha⁻¹ | 206.39 cm | 28.56 mm | 11.67 pot⁻¹ | 11.67 t ha⁻¹ |
| 3. Boiler ash (BA) 10 t ha⁻¹ | 201.53 cm | 26.57 mm | 11.67 pot⁻¹ | 11.67 t ha⁻¹ |
| 4. Cattle manure (CM) 10 t ha⁻¹ | 218.97 cm | 28.93 mm | 12.17 pot⁻¹ | 12.17 t ha⁻¹ |
| 5. STB 5 t ha⁻¹ + STC 5 t ha⁻¹ | 191.97 cm | 27.45 mm | 11.83 pot⁻¹ | 11.83 t ha⁻¹ |
| 6. STB 5 t ha⁻¹ + CM 5 t ha⁻¹ | 230.69 cm | 29.68 mm | 11.50 pot⁻¹ | 11.50 t ha⁻¹ |
| 7. BA 5 t ha⁻¹ + STC 5 t ha⁻¹ | 219.86 cm | 30.29 mm | 12.00 pot⁻¹ | 12.00 t ha⁻¹ |
| 8. BA 5 t ha⁻¹ + CM 5 t ha⁻¹ | 178.69 cm | 29.37 mm | 11.50 pot⁻¹ | 11.50 t ha⁻¹ |
| 9. BA 5 t ha⁻¹ + Filter cake (FC) 5 t ha⁻¹ | 213.94 cm | 27.16 mm | 11.50 pot⁻¹ | 11.50 t ha⁻¹ |
| 10. Control | 203.33 cm | 25.11 mm | 11.50 pot⁻¹ | 11.50 t ha⁻¹ |

LSD 5% ns ns

| Treatment | 11 months after first ratooning (harvest time) |               |                            |            |
|-----------|---------------------------------------------|----------------|----------------------------|------------|
| 1. Sugarcane trash biochar (STB) 10 t ha⁻¹ | 283.00 ab cm | 29.57 mm | 13.67 pot⁻¹ | 94.70 t ha⁻¹ |
| 2. Sugarcane trash compost (STC) 10 t ha⁻¹ | 280.83 abc cm | 29.24 mm | 14.00 pot⁻¹ | 97.73 t ha⁻¹ |
| 3. Boiler ash (BA) 10 t ha⁻¹ | 267.67 abc cm | 29.66 mm | 14.17 pot⁻¹ | 87.53 t ha⁻¹ |
| 4. Cattle manure (CM) 10 t ha⁻¹ | 296.67 a cm | 29.36 mm | 14.33 pot⁻¹ | 100.58 t ha⁻¹ |
| 5. STB 5 t ha⁻¹ + STC 5 t ha⁻¹ | 248.00 bc cm | 28.47 mm | 13.67 pot⁻¹ | 87.29 t ha⁻¹ |
| 6. STB 5 t ha⁻¹ + CM 5 t ha⁻¹ | 251.67 bc cm | 30.07 mm | 14.17 pot⁻¹ | 91.75 t ha⁻¹ |
| 7. BA 5 t ha⁻¹ + STC 5 t ha⁻¹ | 304.17 a cm | 31.00 mm | 13.67 pot⁻¹ | 99.30 t ha⁻¹ |
| 8. BA 5 t ha⁻¹ + CM 5 t ha⁻¹ | 248.67 bc cm | 30.00 mm | 13.50 pot⁻¹ | 85.64 t ha⁻¹ |
| 9. BA 5 t ha⁻¹ + Filter cake (FC) 5 t ha⁻¹ | 290.33 a cm | 28.48 mm | 14.33 pot⁻¹ | 100.79 t ha⁻¹ |
| 10. Control | 244.50 c cm | 27.64 mm | 13.50 pot⁻¹ | 82.71 t ha⁻¹ |

LSD 5% ns ns ns

Note: Numbers in the same column followed by the same letters were not significantly different at LSD 5% test; ns: not significant. *) average of the bottom, middle, and top of stalks diameter.

Sugarcane yield is determined by the number of stalks, plant height (stalk length), and stalk diameter. The residual effect of soil amendments did not significantly increase the yield of the first
The highest yield was obtained in BA 5 t ha⁻¹ + FC 5 t ha⁻¹ and CM 10 t ha⁻¹ treatments. The treatment of STB 10 t ha⁻¹ increased the yield of the first ratoon sugarcane by an addition 12 t ha⁻¹ (14%) compared to the control. This result had not in line with the other studies which state that sugarcane production on sandy soils was significantly affected by the application of organic soil amendments [38], although the effect of organic matter also depends on the source of organic matter and the plant cycle. According to the Indonesian Sugarcane Statistics [39], the national sugar productivity in 2015 was 5.56 t ha⁻¹. With a sugar content of 8%, the productivity was equivalent to 70 t ha⁻¹ of sugarcane.

In this study, improvement of soil physical properties alone was not correlated to sugarcane yields. Soil chemical fertility factors namely very low organic C and exchangeable K, low total-N, P₂O₅, exchangeable Ca, exchangeable Mg, and CEC (Table 1) were insufficient to increase sugarcane yields, need to be supported by adequate fertilization [40]. However, compared to the control, the treatment of soil amendments could increase the yield of first ratoon sugarcane by 3-18 t ha⁻¹ (4-22%). The results of this study proved that sugarcane waste and waste of a sugar factory can be utilized to improve sandy soil properties.

Conclusions
The application of soil amendments in the first year improved the sandy soil properties which was expressed by aggregate stability until the second year on the first ratoon sugarcane. The treatments of sugarcane trash biochar 5 t ha⁻¹ + cattle manure 5 t ha⁻¹, sugarcane trash biochar 10 t ha⁻¹, and cattle manure 10 t ha⁻¹ resulted in a better residual effect on improving soil physical properties in holding water. Improving the physical properties of the soil in holding water could increase the growth of the first ratoon sugarcane. Further studies need to be done with a dose of soil amendment >10 t ha⁻¹ combined with nutrient treatments.

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