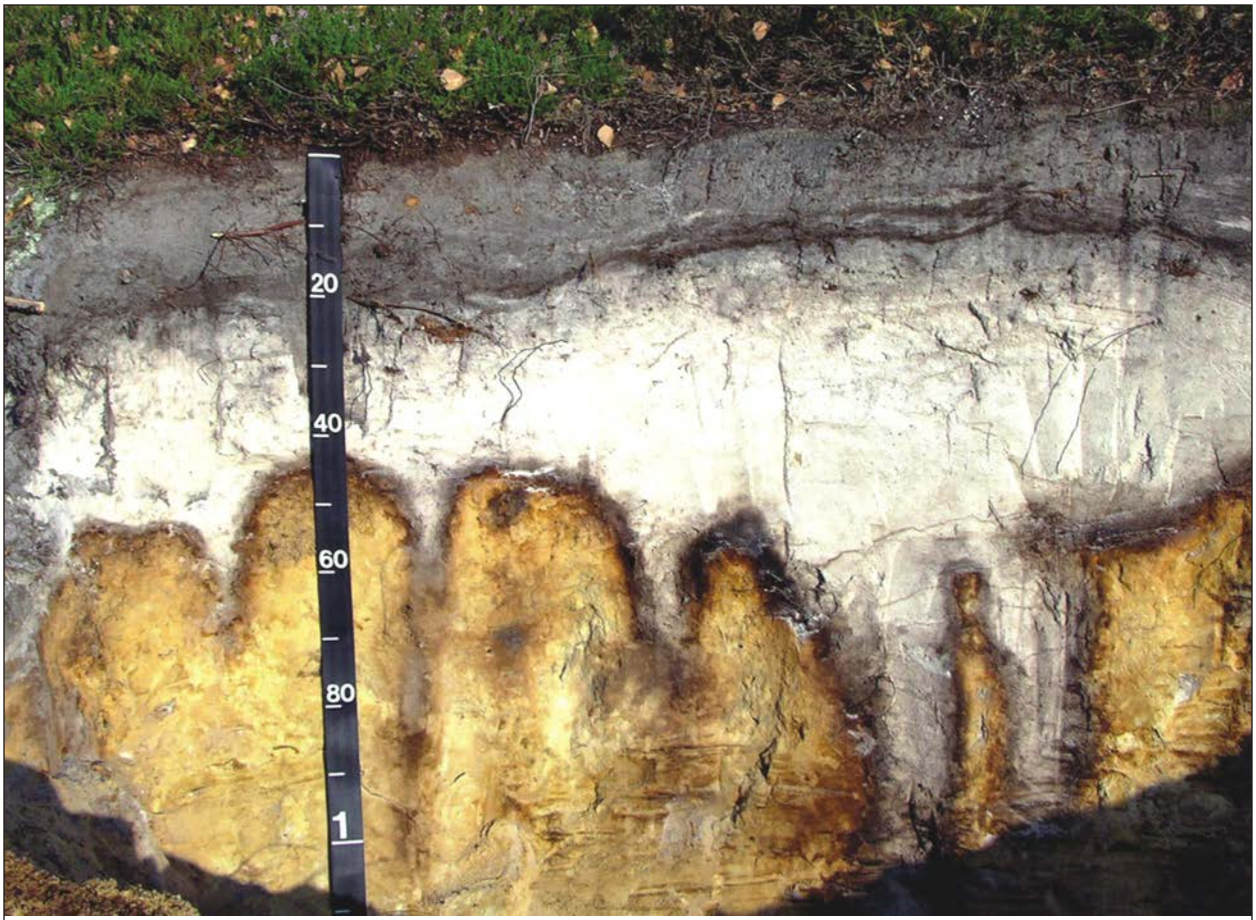

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Research Article
Subsoiling and Incorporation of Boiler Ash for Restoration of Degraded Red Yellow Podzolic for Sugarcane Plantation at Sulawesi, Indonesia

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Abstract
Background and Objective: Due to mismanagement, the red yellow podzolic of Bone sugarcane plantation has experienced degradation due to soil compaction. To overcome this problem an experiment was conducted to study the possibility of restoring this degraded red yellow podzolic by subsoiling and incorporation of boiler ash into the sub soil. The experiment was also aimed to study the effect of reducing tillage operation on cane yield and sugar content. **Materials and Methods:** The experiment was carried out on bone sugarcane plantation, South Sulawesi, Indonesia. The experiment treatments were: (T1) Conventional tillage (plowing-plowing-harrowing-furrowing), (T2) Reduced tillage (plowing-harrowing-furrowing), (T3) Minimum tillage (plowing-furrowing), (T4) Subsoiling-furrowing and (T5) Subsoiling-furrowing and incorporation of boiler ash. These 5 treatments were arranged in a randomized block design with 4 replications. **Results:** Subsoiling alone did not enough to restore the degraded red yellow podzolic of Bone sugarcane plantation. The highest cane and sugar yield was obtained by subsoiling combined with incorporation of boiler ash (T5). This treatment (T5) produced the highest sugar yield (8.96 t ha^{-1}). The highest yield of T5 treatment was associated with a better rooting system due to improvement of soil qualities. Boiler ash incorporation increased soil pH and decreased Al saturation. Reduction of tillage operation did not decrease the cane and sugar yield. **Conclusion:** Restoration of degraded red yellow podzolic of Bone sugarcane plantation could only be done by a combination of subsoiling with incorporation of boiler ash (T5). It was suggested that boiler as can be used as replacement of lime material for acid soil. Reducing tillage operation (plowing-harrowing-furrowing) could be suggested as the best tillage system for light texture of red yellow podzolic at bone sugar plantation.

Key words: Ultisols, acid soil, conservation tillage, biochar, soil organic matter, liming, soil qualities, sugarcane

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Historically, in Indonesia, sugarcane plantation was only concentrated in Java island. However, due to a competition with food crops, the area of sugarcane plantation decreased continuously. Therefore, since the early of 1980 Indonesian government expands sugar cane plantation to other islands of Indonesia. These include Bone, Caming and Takalar which are located in South Sulawesi. Planting sugarcane in these areas is not easy because the soil condition in these areas is much different compared to Java soil, which in turn needs a different management than that has been practiced in Java sugarcane plantation. The dominant soil in this sugar plantation area is red yellow podzolic or named as ultisols in soil taxonomy.

The red yellow podzolic soil is known as one of the marginal soil with a lot of limitation, such as low in soil pH, low clay content, low aggregate stability and low nutrient content and susceptible to compaction[1]. The only fertility sources of these soils are organic matter. The tillage practiced done in this plantation, which is done by plowing–plowing-harrowing-furrowing with heavy machinery would promote soil compaction, especially in the layer beneath tillage layer[2]. A preliminary measurement showed the soil in tillage layer had a bulk density of 1.28 mg m^{-3}; the bulk density of the subsoil was around 1.40. It has been widely known that increasing soil bulk density will hinder root growth[3]. Excessive tillage, of course, will spend more cost. Intensive tillage also break soil aggregate, which in turn will speed up soil organic matter decomposition[4] with a consequence of decreasing soil aggregate stability and decreasing chemical fertility. Due to a more traffic of agriculture implements, intensive tillage will also cause soil compaction. All of these phenomena had caused a steadily decrease in cane yield. When the plantation is just operated, the cane yield could as high as 100 mg ha^{-1} with sugar content[5] of about 9%, now the yield in this plantation is only around 50 mg ha^{-1} with sugar content of about 5%.

Actually intensive tillage is not always required for the growth of the cane[6]. As far as the growth of weeds can be controlled, intensive tillage is not necessary. On heavy clay soil, intensive tillage is probably required[7,8]. On light loamy soil, showed that the cane planted with reduced tillage could grow well and gave a yield as high as the intensive tillage[8]. The effect of zonal tillage (tilled was done on cane row only) on cane yield had been studied by Haris[9] and the result showed that the yield did not different with intensive tillage.

To overcome the sub-soil compaction, the conventional technique employed is done by sub-soiling[10]. Sub-soiling indeed will loosen the soil and make easier the plant root to grow. The results of the sub-soiling experiments, however, varied a lot. Some studies showed that sub-soiling increase cane yield[7]. Hashemi and Shokuhfar[11], however, showed different result; in this case the yield of cane planted with sub-soiling technique did not significantly different with that of panted with conventional tillage. Even if there is a significant effect, it is suggested that the effect sub-soiling is temporary. If there no other involved in loosening the soil, the soil will soon again compact. To maintain the porous condition there should be another process, such as soil aggregation. Since organic matter content in the sub-soil is usually very low, the addition of organic materials is important. These can be done on site, such as planting of leguminous cover crops[12,13], modified cropping system[14], or addition of organic materials such as manure and compost.

A lot of waste produced during milling the cane; these include filter muds (or filter cake) and boiler ash. The preliminary observation, boiler ash has a characteristic similar to biochar, i.e., high pH and high resistant organic matter content (Table 1). It has been widely known that biochar is a prospective soil amendment with multi functions[15,16]. Therefore, it was thought that boiler ash would be very valuable if can be used as a soil amendment. The possibility of boiler ash for improving soil productivity in calcareous soil has been studied by Khan and Qasim[17].

The experiment described here was aimed to study the possibility of restoring the degraded red yellow podzolic of Bone sugarcane plantation by sub-soiling and incorporation of boiler ash into the sub soil. The experiment was also aimed to study the effect of reducing soil tillage operation on cane yield and sugar content.

MATERIALS AND METHODS

Location: The experiment was done on Bone sugarcane plantation, at Bone, South Sulawesi, Indonesia (04°9'722" South, 120°13'338" East) which located at 133 m from the sea level. The soil is red yellow podzolic (classified as ultisols in soil taxonomy) with silt loam soil texture. pH of the soil is 4,94 (measured in H_2O), with organic-C of 1.72%, total-N of 0.16%, available P of 8.07 ppm and exchangeable K of 0.25 cmol kg^{-1} and Cation Exchange Capacity (CEC) of 13.02 cmol kg^{-1}.

Experimental treatments: The treatments tested in this experiment were: (T1) Conventional tillage (plowing-plowing-harrowing-furrowing/P-P-H-F), (T2) Reduced tillage

Table 1: Some characteristics of the boiler ash used in the experiment

Characteristics	Values
pH (H_2O)	7.25
Total-C (%)	36.42
Total-N (%)	0.03
P (%)	0.32
K (%)	0.53
Ca (%)	2.20
Mg (%)	0.55
Na (%)	0.37
CEC (cmol kg^{-1})	22.20

(plowing-harrowing-furrowing/P-H-F), (T3) Minimum tillage (plowing-furrowing/P-F), (T4) Sub soiling (subsoiling-furrowing/S-F) and (T5) Subsoiling and incorporation of boiler ash (S-F+BO). Subsoiling was done by plowing to a depth of 40 cm and boiler ash was applied at cane row at a rate of 20 t ha^{-1}. These 5 treatments were arranged in a randomized block design with 4 replications, with plot size of 30$\times$20 m.

The boiler ash used in the experiment is relatively bases (pH of 7.25) with total carbon content of 36.42% and high Cation Exchange Capacity (CEC) (Table 1). The boiler ash also has a high content of K, Ca and Mg.

Cuttings of (about 40 cm length) of PS 881, an early maturity high yielding sugarcane variety were planted at a distance of 1.35 m (between rows). Planting was done in March, 2013 and harvested in January 2014. The cane was fertilized with 100 kg ha^{-1} ammonium sulfate, 300 kg ha^{-1} urea, 300 kg super phosphate (36% P_2O_5) and 200 kg KCl. Weed control was done with pre and post emergence herbicides.

The data collected included plant height, plant diameter, numbers of plant per meter, root length, cane yield, sugar content and soil characteristics. Twenty plants of each plot were selected randomly used for plant height and plant diameter measurement. Plant diameter was measured at 50 cm height.

The soil characteristics measured were: soil pH, organic soil-C, total-N, available P, Cation Exchange Capacity (CEC), exchangeable K, Ca and Mg. The soil was sampled before experiment and after harvesting the plant cane. Sampling before experiment was done by zigzag system to a depth of about 20 cm. After harvesting soil sampling was done similar to the first sampling, except the point of sample was at the row of sugar cane; the samples were taken at a depth of 0-20 cm and 20-40 cm. Undisturbed soil samples were taken for soil bulk density, water content at 0 and -33 kPa matric potential and penetrometer resistance measurements.

Soil characteristics were determined in accordance with the method developed by Sulaeman *et al.*[18]. Soil pH was measured in water (1:5) and read with Atago Digital pH Meter DPH-2; soil Organic-C with the Walkley and Black Method; available P with Olsen method; Cation Exchange Capacity (CEC) determination was prepared with blue idophenol method and the absorbance of C, N, available P and CEC was read with Spectrophotometer Hitachi U-1100 at wave length of 561, 636, 693 and 636 respectively. Available-K was extracted with 25% HCl solution and the K concentration was read with Flamephotometer BWB XP.

RESULTS AND DISCUSSION

Soil characteristics: The experimental result presented in Table 2 show that the physical characteristics of soil tilled with reduced tillage (P-H-F) and minimum tillage (P-F) systems did not significantly different with the conventional tillage (P-P-H-F). This phenomenon can be explained from soil tensile strength point of view. It has been suggested that intra aggregate tensile strength related to soil texture[19] and Lehrsch *et al.*[20] found that tensile strength of loamy sand was much lower compared to heavier soil texture. Tensile strength itself is the easiness of soil to break up under applied stress[21]. The soil for this experiment has a silt loamy texture and therefore would be easy to break up. This result indicated that, from point of view soil physical properties especially in 0-20 cm layer, intensive tillage in red yellow podzolic soil was not necessary. This finding was in agreement with the suggestion of McIntyre and Barbe[8] and the finding of Braunack *et al.*[22].

Intensive tillage of course will require more cost. In addition, intensive tillage could have a detrimental effect because as shown in Table 2, this system tends to increase soil bulk density and penetration resistance of the sub soil (20-40 cm depth). The increase in soil bulk density and penetration resistance with increasing traffic of agricultural machinery is a consequence of more pressure works on the soil. The increase of soil bulk density with machinery traffic has been reported by many researchers[23]. The increase in soil bulk density and soil penetration resistance could also be due to the decrease in soil aggregation. Utomo and Dexter[4] had shown that tillage would speed up soil aggregate deterioration with a consequence of decreasing the resistance to compaction.

The result in Table 2 shows that subsoiling (S-F) did not much help to restore the quality of degraded red yellow podzolic soil. The bulk density and penetration resistance of the top layer (0-20 cm) in this tillage system (S-F) did not significantly different with the conventional tillage (P-P-H-F). At the deeper layer (20-40 cm) soil bulk density and penetration resistance of subsoiling treatment (S-F) did not

Table 2: Some physical properties of red yellow podzolic as influenced by tillage system and boiler ash incorporation

		Treatment				
Soil characteristics	Soil depth (cm)	P-P-H-F	P-H-F	P-F	S-F	S-F+BO
Water holding capacity (%ww)	0-20, 20-40	45.22^{ab}	45.00^{a}	46.29^{ab}	48.30^{bc}	51.20^{c}
		43.45^{a}	44.26^{a}	43.64^{a}	44.32^{a}	51.26^{b}
Water content at Field capacity (%ww)	0-20, 20-40	30.74^{a}	31.07^{a}	30.54^{a}	32.38^{ab}	34.23^{b}
		27.45^{a}	28.00^{a}	29.34^{a}	28.55^{a}	36.12^{b}
Available water (%ww)	0-20, 20-40	14.01^{a}	15.68^{ab}	16.17^{ab}	18.12^{bc}	20.64^{c}
		12.55^{a}	13.46^{ab}	14.50^{b}	14.12^{ab}	19.35^{c}
Water aggregate stability (MWD, mm)	0-20, 20-40	1.12^{a}	1.05^{a}	1.20^{a}	1.15^{a}	2.30^{b}
		1.00^{a}	0.95^{a}	1.10^{a}	1.18^{a}	2.35^{b}
Soil bulk density (mg m^{-3})	0-20, 20-40	1.37^{b}	1.38^{b}	1.34^{b}	1.29^{ab}	1.22^{a}
		1.45^{b}	1.42^{ab}	1.44^{b}	1.38^{ab}	1.24^{a}
Penetration resistance (kg cm^{-1})	0-20, 20-40	1.50^{bc}	1.55^{bc}	1.48^{b}	1.56^{c}	1.37^{a}
		1.89^{c}	1.78^{c}	1.65^{b}	1.55^{ab}	1.45^{a}

P: Plowing, H: Harrowing, F: Furrowing, S: Sub-soiling, BO: Boiler ash, means followed by the same letters in the same row is not significantly different (p = 0.05)

significantly different with that of minimum tillage (P-F). It seems that the loosening process during subsoiling had no long effect, so that at the time of harvesting (about 10 months after sub soiling) the soil again compact. If subsoiling was combined with boiler ash incorporation (S-F+BO), the experimental result showed that the positive effect of subsoiling last for a longer time. The result in Table 2 shows that the subsoiling with boiler ash incorporation (S-F+BO) had a lower soil bulk density and penetration resistance than the other treatments. This treatment also had a higher water holding capacity and available water. This result show the importance of organic matter, especially boiler ash, for restoration of degraded red yellow podzolic of bone.

The positive effect of boiler ash on soil bulk density and penetration resistance could be explained from soil aggregate formation and stability. Table 1 shows, boiler ash incorporation with subsoiling increased soil organic-C. The result in Table 2 shows that subsoiling with boiler ash incorporation (S-F+BO) treatment had a higher Mean Weight Diameter soil aggregate (2.30 mm) compare to the other treatments. With its high soil organic-C, boiler ash would play an important role in soil aggregate formation and stability[24] and in turn it will increase soil porosity and lower both of soil bulk density and penetration resistance. The increase in available water of this treatment indeed was due the occurrence of inter aggregate soil pore as a result of soil aggregate formation.

Tillage system did not significantly influence chemical properties of red yellow podzolic soil (Table 3). Incorporation of boiler ash in subsoiling system, however, significantly improved the chemical properties of red yellow podzolic. It increased soil pH and increased soil organic-C. The increase of soil pH with boiler ash incorporation is reasonable, because as has been shown on Table 1, boiler ash has a high a high pH, Ca and Mg content. Masulili *et al.*[25] observed the increase of pH West Kalimantan acid soil with application of high pH biochar.

The results in Table 3 also shows that incorporation of boiler ash in subsoiling increased Cation Exchange Capacity (CEC) and some plant nutrients such as P, K, Ca and Mg and decreased Al-saturation. The decrease of Al-saturation is a logic consequence of increasing soil pH and bases content, especially Ca and Mg. The high concentration of Ca and Mg would replace Al in the adsorption surface.

With this result, it was suggested that boiler ash of sugarcane factory can be used as a replacement of lime material for increasing the pH and decreasing Al-saturation of acid soil. To some extent, due to its high K content, it was suggested that boiler ash can be used as replacement or at least will minimize the K fertilizer requirement.

The result presented in Table 4 shows that plant height, plant diameter and plant numbers per meter were not influenced by tillage system, but it was significantly influenced by incorporation of boiler ash into the sub soil (treatment S-F+BO).

The result in Table 4 also shows that subsoiling (S-F) increased plant root length and incorporation of boiler ash together with subsoiling (S-F+HO) further increased the length of plant root. Looking the soil physical properties data (Table 2) it can be thought that the increase of the plant root length in subsoiling (S-F) and incorporation of boiler ash with subsoiling (S-F+BO) treatments was due to the decrease of soil bulk density and penetration resistance. The increase of available soil water in the incorporation of boiler ash with subsoiling (S-F+BO) treatment indeed would improve cane growth.

Table 3: Some chemical properties of red yellow podzolic as influenced by tillage system and boiler ash incorporation

		Treatment				
Soil characteristics	Soil depth (cm)	P-P-H-F	P-H-F	P-F	S-F	S-F+BO
pH (H_2O)	0-20, 20-40	4.94^{a}	4.98^{a}	4.96^{a}	4.92^{a}	5.90^{b}
		5.01^{a}	5.00^{a}	4.86^{a}	4.92^{a}	6.12^{b}
C-organic (%)	0-20, 20-40	1.59^{b}	1.67^{b}	1.77^{ab}	1.92^{ab}	2.29^{a}
		1.05a	1.55a	1.10^{a}	1.12^{a}	2.25^{b}
Total N (%)	0-20, 20-40	0.18^{a}	0.24^{a}	0.18^{a}	0.16^{a}	0.21^{a}
		0.08^{a}	0.10^{a}	0.12^{a}	0.15^{a}	0.22^{b}
Available P (ppm)	0-20, 20-40	3.33^{a}	3.80^{a}	3.92^{a}	4.65^{a}	7.30^{b}
		2.75^{a}	3.10^{a}	3.42^{a}	3.05^{a}	5.40^{b}
Cation exchange capacity (cmol kg^{-1})	0-20, 20-40	12.50^{a}	12.12^{a}	11.20^{a}	13,8 5^{ab}	16.12^{b}
		15.56^{a}	16.12^{a}	14.55^{a}	15.25^{a}	18.17^{b}
Exchangeable K (cmol kg^{-1})	0-20, 20-40	0.25^{a}	0.28^{a}	0.21^{a}	0.25^{a}	1.46^{b}
		0.32^{a}	0.30^{a}	0.32^{a}	0.30^{a}	0.96^{b}
Exchangeable Ca (cmol kg^{-1})	0-20, 20-40	0.29^{a}	0.34^{a}	0.30^{a}	0.33^{a}	1.96^{b}
		0.44^{a}	0.38^{a}	0.40^{a}	0.42^{a}	2.12^{b}
Exchangeable Mg (cmol kg^{-1})	0-20, 20-40	0.53^{a}	0.48^{a}	0.45^{a}	0.50^{a}	2.05^{b}
		0.50^{a}	0.52^{a}	0.55^{a}	0.52^{a}	2.12^{b}
Exchangeable Na (cmol kg^{-1})	0-20, 20-40	0.23^{a}	0.28^{a}	0.30^{a}	0.40^{a}	1.05^{b}
		0.33^{a}	0.36^{a}	0.40^{a}	0.38^{a}	0.96^{b}
Al saturation (%)	0-20, 20-40	45.52^{a}	48.46^{a}	44.25^{a}	46.20^{a}	36.25^{b}
		39.30^{a}	44.50^{a}	40.26^{a}	40.50^{a}	36.05^{a}

P: Plowing, H: Harrowing, F: Furrowing, S: Sub-soiling, BO: Boiler ash, means followed by the same letters in the same row is not significantly different ($p = 0.05$)

Table 4: Effect of tillage system on plant height, plant diameter and root length

Treatments	Plant height (cm)	Plant diameter (cm)	Plant numbers m^{-1}	Root length (m)
P-P-H-F	1.76^{a}	2.36^{ab}	12.98^{b}	34.10^{c}
P-H-F	1.74^{a}	2.29^{a}	12.76^{ab}	28.47^{a}
P-F	1.70^{a}	2.26^{a}	11.33^{a}	27.85^{a}
S-F	1.84^{ab}	2.36^{ab}	13.11^{bc}	40.98^{b}
S-F+BO	1.95^{b}	2.39^{b}	13.38^{c}	51.20^{d}

P: Plowing, H: Harrowing, F: Furrowing, S: Sub-soiling, BO: Boiler ash, means followed by the same letters in the same row is not significantly different ($p = 0.05$)

Table 5: Effect of tillage system on cane yield, sugar content and sugar yield

Treatments	Cane weight (g plant^{-1})	Cane yield (t ha^{-1})	Sugar content (%)	Sugar yield (t ha^{-1})
P-P-H-F	10.29^{ab}	86.94^{ab}	6.27^{ab}	5.67^{b}
P-H-F	9.74^{a}	80.84^{ab}	6.45^{ab}	5.21^{b}
P-F	9.05^{a}	61.98^{a}	5.65^{a}	3.50^{a}
S-F	10.35^{ab}	97.69^{bc}	6.60^{bc}	6.44^{b}
S-F+BO	11.44^{b}	122.79^{c}	7.30^{c}	8.96^{c}

P: Plowing, H: Harrowing, F: Furrowing, S: Subsoiling, BO: Boiler ash, means followed by the same letters in the same row is not significantly different ($p = 0.05$)

The experimental result presented in Table 5 shows that both the cane and P-H-F) sugar yield of reduced tillage did not significantly difference with that of the conventional tillage. However, minimum tillage (P-F) had the lowest sugar yield compared to the other treatments. Braunack *et al.*[22] found that in yellow podzolic soil of Bundaberg, Australia, the tillage system did not decrease the cane yield, but it seems that in the red yellow podzolic of bone minimum tillage (P-F) did not enough for sugarcane cultivation. Probably the compaction in this soil had so severe, so plowing and harrowing only did not able to restore them. Looking the result in Table 5, the low sugar yield of this treatment was a consequence of both of low cane yield and sugar content. Although, plant height; plant diameter and plant number (m) in the minimum tillage (P-FP) did not significantly different with that of the conventional tillage (Table 4), but simultaneously, the effect of these 3 variables on cane yield was significant.

The sugar yield of reduced tillage (P-H-F), subsoiling (S-F) did not significantly different with that of the conventional tillage (P-P-H-F). Therefore, it was suggested that one plowing, one harrowing and then followed by furrowing is enough for cane cultivation in red yellow podzolic of bone, South Sulawesi, Indonesia. Intensive tillage (P-P-H-F) did not always necessary, even could have a detrimental effect because it could increase soil bulk density and soil penetration resistance. These phenomena have also been found anywhere[6,10,22].

Incorporation of boiler ash with subsoiling significantly increased cane yield, sugar content and indeed sugar yield. The result in Table 5 show that the incorporation of boiler ash with subsoiling (S-F+BO) possesses a sugar yield of 8.96 t ha^{-1}, which is far higher compared to the other treatments. This high yield is un-doubly was a result of the improvement of both soil physical and chemical characteristics with incorporation of boiler ash into the subsoil as presented in Table 2 and 3.

CONCLUSION

The experiment discussed here showed that reduced tillage (P-H-F) could minimize the degradation rate of red yellow podzolic of Bone sugarcane plantation. This practice could produce sugar yield as high as the conventional tillage (P-P-H-F).

Subsoiling (S-F) was not enough to restore the degraded red yellow podzolic of Bone. It should be practiced by the incorporation of organic materials. Incorporation boiler ash with subsoiling improved soil qualities and increased both cane and sugar yield. It was thought that boiler ash could be used as a replacement of lime material for red yellow podzolic. Boiler ash also thought could minimize fertilizer requirement, especially K.

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