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A Flat kiln and utilization of sawdust charcoal:

Its capacity as a soil conditioner and for carbon storage

Gustan Pari
(Forest Product Technology Research and Development Center, FORDA)
Nobuo Ishibashi
(Japan International Cooperation Agency)
Kiyoshi Miyakuni
(University of Kyoto, Short-tern expert from JICA)

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I. Introduction

1. Background

It is said that 20 to 30 percent of wood material become sawdust in sawmill operations (Kikata, *et al.*, 1994). In Indonesia, a large amount of sawdust is left unused. Often it is piled up beside the sawmill and burned (Photo 1). It can also cause water pollution if the sawdust hill is located beside a river.

Whether or not the sawdust is left decomposed or burned, it causes carbon emission. Therefore, it is necessary to develop ways to utilize sawdust and reduce pollution and carbon dioxide emission.

Photo 1 Sawdust-hill beside sawmill (Bogor District, West Java)

Unused sawdust is often burned at the sawmill.

There are several ways to utilize sawdust. For example,

(1) Production of compost for agriculture
(2) Mushroom cultivation
(3) Material for activated charcoal (produced using a flat kiln)

(4) Briquette charcoal

Although the above methods have already been implemented in Indonesia, there is still a large amount of sawdust un-utilized because of a limited market, the difficulty in controlling the quality of products, and so on. Producing compost can be a good way to return nutrients in wood residue to the soil. This method, however, is still not common because fermentation of sawdust is difficult.

In Japan, charcoal is utilized as a soil conditioner that can improve the physical properties (water retention and water permeability) and chemical properties (nutrient retention) of soil, and activate microorganisms in the soil. In Indonesia, rice-husk charcoal has already been used in nurseries of tree seedlings. A trial in a maize field in Indonesia demonstrated that the application of rice-husk charcoal stimulated growth and resulted in a higher yield (AICAF, 2002).

On the other hand, there has been no trial for utilization of sawdust charcoal as a soil conditioner in Indonesia, and the capability of sawdust charcoal has not been proven.

Recommendations to utilize charcoal as a storage of carbon have already been stated (for example, Seifritz, 1993; Ogawa, 1997). Instead of burning sawdust at the sawmill, producing sawdust charcoal could limit carbon dioxide emission because pure carbon is stored inside charcoal.

2. Flat kiln

A flat kiln is a modified type for a traditional piling process (“Fuseyaki” in Japanese). Usually, it is used for producing materials for activated carbon, briquette charcoal and so on. Sawdust and tree bark are carbonized using this kiln.

The Appendix shows the process in building a flat kiln. In large-scale activated charcoal factories, many kilns are combined and flues are combined as a single large-sized chimney.

Because the kiln does not have roof, carbonization temperature is low (250 to 300℃, according to Mr. Sugai, Director of Hokuetsu Shoji Co. Ltd. Personal communication). The air enters into the kiln through an interstice of sawdust particles, goes to the kiln floor and finally it exits from the chimney. Carbonization starts at the bottom of the kiln, and proceeds to the top of the kiln (surface of sawdust). The speed of carbonization depends on the size of sawdust particles and intensity of the air suction in the chimney (according to Mr. Sugai. Personal communication).

3. Previous experiments in Japan

(1) Chemical properties of charcoal

In Table 1, chemical properties of charcoal from several types of kilns are compared. In a dry distillation furnace, sawdust was carbonized without an oxygen supply.

Generally, the higher the carbonization temperature, the higher the pH of charcoal. Ash content (oxidized minerals derived from wood material) also affects the pH of charcoal. Higher pH in charcoal can increase soil pH if mixed with acid soil. Konno and Nishikawa (1993) demonstrated the effects of charcoal on soil pH (in an experiment to examine the effects of charcoal on the growth of soybeans). The higher charcoal pH decreased exchangeable Al^{3+} and increased available phosphate if mixed with acid clay soil.

Table 1 Chemical properties of several types of charcoal

Type of kiln	Wood material	pH	CEC (me/100g)	Exchangeable cation (me/100g)		
				K_2O	CaO	MgO
Flat kiln	Larch (bark)	8.64	15.89	62.9	254.1	17.04
Block kiln	Larch (wood)	8.88	16.28	79.3	141.9	36.18
Flat kiln	Larch (sawdust)	8.86	14.77	107.5	158.0	20.25
Dry distillation furnace (under no-oxygen condition)	Larch (sawdust) (300℃, 10minutes)	4.15	8.60	7.5	10.7	2.53
	Larch (sawdust) (300℃, 60minutes)	4.18	9.89	9.9	3.2	0.54
	Larch (sawdust) (600℃, 10minutes)	6.24	1.85	33.1	5.3	0.73
	Larch (sawdust) (600℃, 60minutes)	6.38	0.99	32.2	4.5	0.58

Source: Hokkaido Central Agricultural Experiment Station (1990)

CEC (Cation Exchange Capacity) is the capacity to retain minerals (cation). CEC of charcoal becomes lower if carbonized temperature is high because functional groups (such as carboxyl and phenolic hydroxyl) on the surface of charcoal and volatile matter disappear. CEC of sawdust charcoal from a flat kiln was almost the same as bark charcoal. In this experiment, exchangeable cation in sawdust charcoal from a flat kiln was more than bark charcoal, although the mineral content of materials is higher in bark than in sawdust.

Sawdust charcoal produced under no oxygen supply showed a lower CEC and lower exchangeable cation. Flat kilns are open to the air, so some portion of the wood materials become ash and supply exchangeable cation (and it related to higher pH). Also, because the carbonized temperature is low, the CEC is still high.

From a chemical aspect, it seems that flat kilns can produce relatively suitable charcoal for a soil conditioner.

(2) Physical properties of charcoal

According to the Japan Soil Association (1986), the size of charcoal particles affects the water retention potential of charcoal. The smaller the particle, the more water retained (Table 2).

Table 2 Water retention capacity and size of charcoal particle

Diameter of particle	1 – 2 mm	< 0.2mm
Available water (Capillary water) (ml/100g) pF 1.5 – 2.7	5.7	58.1

Source: Japan Soil Association (1986)

Carbonization temperature also affects water retention capacity. According to the Hokkaido Central Agricultural Experiment Station (1993), sawdust charcoal (Japanese larch) made under temperatures of 500℃ to 600℃ was most suitable in increasing water retention capacity (Table 3). Water retention capacity mainly depends on the size of pores formed between charcoal particles (and soil grains) and also the surface of the charcoal. As carbonization temperature rises, the sawdust particle and the size of the pores will shrink. If, however, the size of pores is too small, charcoal absorbs soil water so strongly that the plants' roots cannot use it.

Data regarding the relationship between size of pores and water retention capacity is not available at the present and more research is needed. In this report, however, this factor was not considered because of a lack of equipment for measurement.

Experiments by the Japan Soil Association (1990) demonstrated that charcoal of 0.5 ~ 1.0mm particle size was most efficient for improving water permeability of soil (Fig.1). 0.25 ~ 0.5mm was also effective for the improvement.

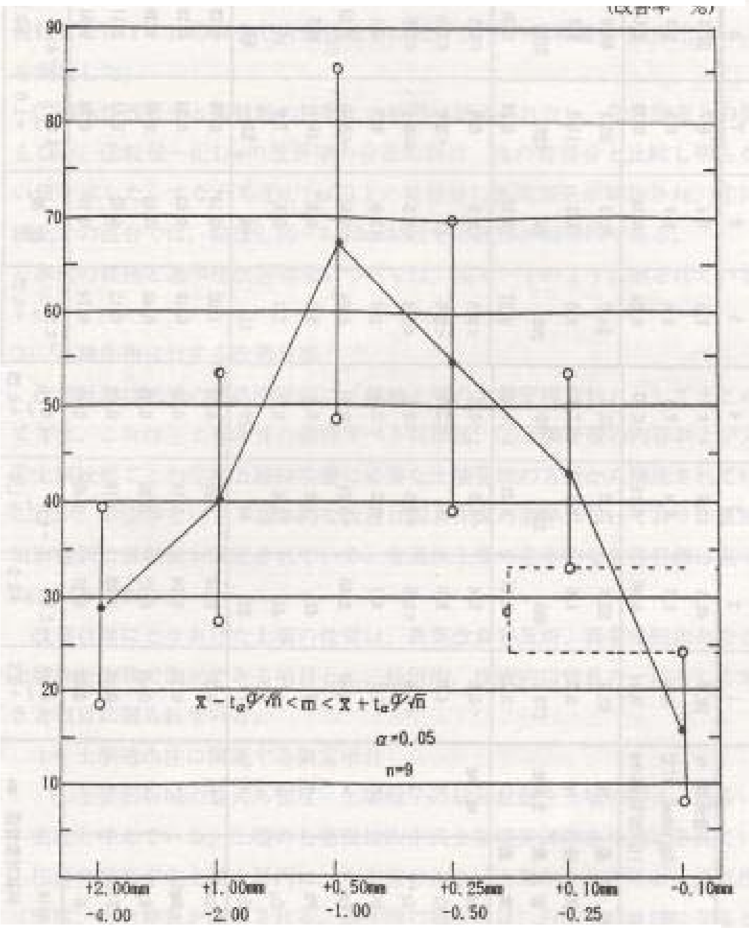
The particle size of sawdust charcoal needs to be measured to evaluate its capacity for improvement of the physical properties of soil.

Table 3 Carbonization temperature and water retention ability of charcoal
(Sawdust charcoal from Japanese larch)

Type of charcoal (Carbonization temperature and time)	Bulk density (g/ml)	Maximum water holding capacity (ml/100g)	Available water (Capillary water) (ml/100g) pF 1.5 – 2.7
300℃, 60min.	20.9	218	26
400℃, 60min.	21.1	484	131
500℃, 60min.	21.6	478	160
600℃, 60min.	23.3	441	170
700℃, 60min.	23.6	450	136

Source: Hokkaido Central Agricultural Experiment Station (1993)

Rate of improvement* (%)



Large ← Size of particle → Small

Fig.1 Relationship between size of charcoal particle and improvement of water permeability
Source: Japan Soil Association (1990)
Notes:
1) Soil:charcoal=10:1
2) * Improvement rate of saturated hydraulic conductivity

(3) Other factors not considered in this report

Charcoal can activate some kinds of microorganisms in the soil. Previous studies (experiments in Indonesia) stated that certain kinds of mycorrhiza are activated if charcoal is inside the soil (Ogawa, 1994; Mori, *et al.*, 2000). Konno and Nishikawa (1993) conducted experiments using soybean and observed an increase of root nodule for nitrogen fixation.

The mechanism to stimulate activities of microorganisms is very complicated and not fully understood. In this report, this aspect was not examined.

4. Good points of flat kiln

Reviewing previous studies, the advantages of flat kilns seem to be as follows:

(1) Although kiln temperature is low, it can produce charcoal with a higher pH. This contains more minerals.

(2) The charcoal still maintains a relatively higher CEC because of low carbonized temperatures.

(3) If wood charcoal is utilized as a soil conditioner, it needs to be crushed before applying it to soil. If sawdust is used as a raw material, no crushing is necessary. This can reduce costs.

According to the survey conducted in the *Shorea* experimental site (in RPH Ngasuh BKPH Jasinga of PT. Perhutani area, West Java) for this project, crushing cost (manual crushing) was about Rp.15,800 /sack of crushed charcoal (1 sack equals about 40 liters).

(4) In sawmills, a large amount of raw material is available. As long as the sawmill continues to operate, raw material will be supplied continuously.

(5) Large capacity: a large amount of charcoal can be produced at one time. The size of the kiln can be enlarged.

Data of sawdust charcoal in Indonesia, however, is still not sufficient to explain these aspects. Analysis should be conducted to examine the character of sawdust charcoal and the effectiveness of flat kilns.

5. Purposes of the trials in this project

The purposes of the trials were:

(1) To analyze properties of sawdust charcoal and examine whether sawdust charcoal is suitable as a soil conditioner.

(2) To calculate how much carbon can be stored in sawdust charcoal (what percentage of carbon originating from raw material can be maintained within produced charcoal).
(3) To calculate costs for building a flat kiln and producing sawdust charcoal.

II. Method

1. First and second trials in 2002

First trials were conducted under the guidance of Mr. Furumoto from Hyonen Kogyo Co. A plan for flat kilns in large-scale factories was provided by Mr. Sugai from Hokuetsu Shoji Co. Some modification was made to build small-scale kiln. The plan was shown in Fig.2. After the first trial, the ventilation system did not function properly and little smoke from the chimney was observed.

Mr. Furumoto and Mr. Salim (a technician from the Center) suggested that the size and location of the chimney should be modified.

A second trial was conducted immediately after the first trial. Charcoal yield was improved, but the condition of the ventilation was not improved.

2. Modification of kiln in 2003

To improve ventilation, following modifications were made.
(1) Size and location of chimney (see Fig.2 and Photo 5 and 15 in Appendix)
(2) Direction of firewood to be loaded (see Photo 8 and 16 in Appendix)

A modified ventilation system including the chimney functioned better (see Photos 13 and 18 in Appendix) and smoke from the surface of the sawdust was reduced.

3. Analysis

(1) Analysis of sawdust charcoal

i. Chemical properties

pH, available phosphate (Bray No.1), available potassium (not all samples were analyzed), CEC (Cation exchange capacity) and exchangeable cation were examined. Data analysis was conducted in the Soil and Agroclimate Research Center.

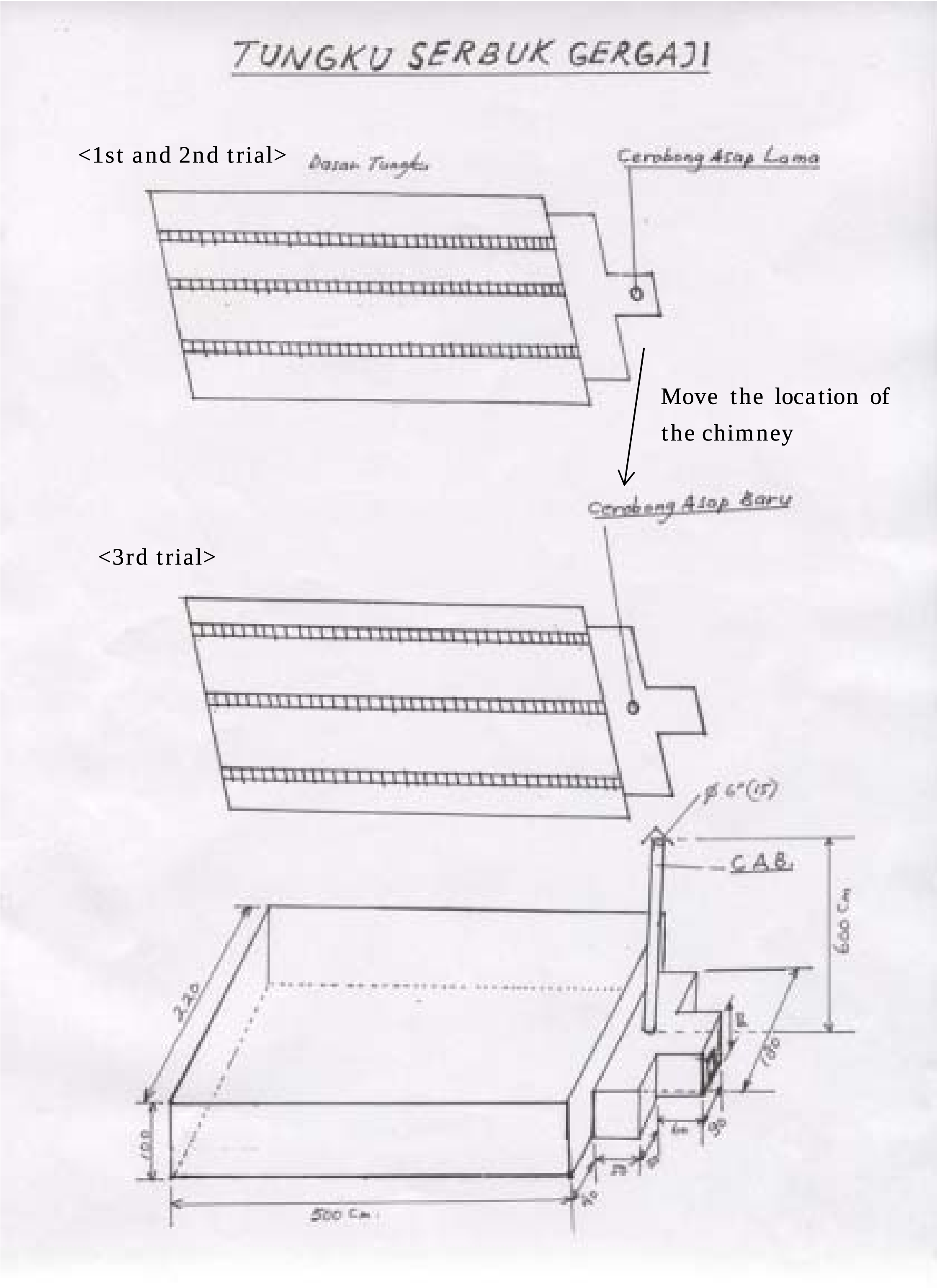


Fig.2 Description of a flat kiln

ii. Size of particles

Several types of sieve were prepared and sieved charcoal was weighed. 400g of charcoal was prepared and analyzed. This analysis was conducted in the Forest Product Technology Research and Development Center.

(2) The amount of carbon stored in sawdust charcoal: what percentage of carbon originating from the raw materials can be maintained within produced charcoal?

Data was collected in the Forest Product Technology Research and Development Center.

i. Charcoal yield

Charcoal yield is calculated by the formula below:

$$\text{Charcoal yield (\%)} = \frac{\text{(Weight of produced charcoal)}}{\text{(Dry weight of wood material)}} * 100$$

ii. Charcoal analysis → Carbon content → Carbon yield

Analysis of moisture content, ash content, volatile matter content and fixed carbon content was conducted according to SNI (Standard Nasional Indonesia). Fixed carbon inside charcoal indicates the amount of pure carbon (not easily decomposed). Volatile matter is half-carbonized organic material that can be more easily decomposed. Using this data, carbon yield was calculated. Carbon yield indicates the percentage of carbon derived from wood material was preserved in charcoal produced.

Carbon yield is calculated by the formula below:

$$\text{Carbon yield (\%)} = \frac{\text{(Weight of produced charcoal)}}{0.5*\text{(Dry weight of wood material)}} * \frac{\text{(Fixed carbon content)}}{100} * \frac{\text{(100-Moisture content)}}{100} * 100$$

Carbon yield of sawdust charcoal from a flat kiln was calculated and compared with other types of charcoal (charcoal from a drum kiln and piling process which had already been tried in this project).

After calculation, the question of how to increase carbon yield was discussed.

(3) Cost estimation

i. Costs to build a flat kiln

ii. Costs for producing sawdust charcoal

Using data obtained from these trials, costs for producing sawdust charcoal were estimated.

III. Results and Discussion

1. Analysis of sawdust charcoal

(1) Chemical properties of sawdust charcoal

Table 4 shows results of the chemical analysis of charcoal. Data of sawdust charcoal was compared with wood charcoal produced using other types of kilns.

The pH of sawdust charcoal from the 2nd trial was relatively high (8.60). On the other hand, that from the 3rd trial was low (7.37).

It is clear that sawdust charcoal contained relatively large amount of minerals (especially CaO). The CEC of sawdust charcoal was 9.64 for the 2nd trial and 24.47 for the 3rd trial.

From the relatively lower pH and higher CEC, it was assumed that the carbonization temperature of the 3rd trial was lower than the 2nd trial. The quality of sawdust charcoal was not stable in these trials. If, however, technicians get used to charcoal production using flat kilns, it is assumed that the quality will be stabilized.

Charcoal from drum kiln showed the lowest CEC. This means that the carbonization temperature was the highest in drum kilns. Charcoal made by local people (Piling process in Table 4) contained more minerals and higher CEC. This means that the carbonization temperature was relatively low and ash content was higher. Higher Mg content seems to originate from leaves used as a roof for the kiln.

To evaluate the capacity for improvement of soil property, chemical properties of soil at three experimental sites in West Java established by this Project was presented in Table 5. Comparison of data in Table 5 and chemical properties of sawdust charcoal shows that:

i. Sawdust charcoal has a limited potential to improve CEC. At *Acacia mangium* and *Shorea leprosula* experimental sites, CECs were higher than that of sawdust charcoal. It is assumed that sawdust charcoal could improve nutrient retention capacity only when it is applied to soil with very low CEC such as sandy soil.

ii. Sawdust charcoal can add Ca^{2+} and K^{+} and also increase available phosphate. Soil such as Ultisol (Acrisol, Nitosol, etc.) usually shows low pH and available phosphate and charcoal could contribute its improvement.

Table 4 Results of charcoal analysis

Type of charcoal	pH (H_2O) 1:5	Available phosphate (Bray1, P_2O_5) (ppm)	Exchangeable cation (me/100g)					CEC (me/100g)
			Ca	Mg	K	Na	Total	
<Sawdust charcoal produced using a flat kiln[2)]>								
2nd trial	8.60[1)]	14.6	21.56	1.90	8.96	0.41	32.83	9.64
3rd trial (Average)	7.37	189.50	19.22	1.42	4.69	0.71	26.04	24.47
Front	7.2	202.40	20.49	1.26	4.80	0.69	27.24	27.28
Rear	7.8	237.70	28.60	2.04	6.01	0.97	37.62	23.24
Top+bottom	7.1	128.40	8.57	0.97	3.26	0.46	13.26	22.90
<Wood charcoal produced using other types of kilns>								
Drum kiln[3)]	9.0	153.8	7.42	1.54	6.41	0.28	15.65	6.66
Piling process[4)]	8.8	28.9	15.55	3.16	10.39	0.46	29.56	19.06

Notes: 1) pH (H_2O) 1:10. It is assumed that charcoal powder absorbed water too strongly.

2) Sawdust charcoal (experiment in Forest Product Technology Research and Development Center, flat kiln), wood material: *Paraserianthes*, *Maesopsis*, and other tree species

3) Drum kiln, Wood material: *Schima*, *Maesopsis* and other tree species in secondary forests (produced in the *Shorea* experimental site in RPH Ngasuh BKPH Jasinga of PT. Perhutani area, West Java),

4) Piling process (produced in the *Shorea* experimental site in RPH Ngasuh BKPH Jasinga of PT. Perhutani area, West Java), Wood material: *Schima*, *Maesopsis* and other tree species in secondary forests. After carbonization, charcoal was crushed manually.

Table 5 Results of soil analysis in three experimental sites in West Java

Type of charcoal	pH (H_2O) 1:5	Available phosphate (Bray1, P_2O_5) (ppm)	Exchangeable cation (me/100g)					CEC (me/100g)
			Ca	Mg	K	Na	Total	
Acacia mangium experimental site (Acrisol)	4.4	7.05	4.06	3.08	0.21	0.15	7.50	31.37
Shorea leprosula experimental site (Ferralsol)	4.6	5.95	0.80	0.52	0.15	0.09	1.55	18.21
Pinus merkusii experimental site (Nitosol)	4.4	2.06	1.48	0.36	0.24	0.13	2.20	32.68

Notes: Soil from 0-30cm deep (after litters were removed). In each site, four samples (except *Pinus merkusii* experimental site: 5 samples) were collected. The figures shown in this table are the averages of 4 (5 in *Pinus merkusii* experimental site) samples.

(2) Size of charcoal particles

Fig.3 shows the distribution of particle size of sawdust charcoal produced in the 3rd trial. Apparently, the size of particles was categorized as "sand" (>0.05mm for USDA, >0.02mm for ISSS). The large portion of sawdust charcoal (87.4%) was less than 1.00mm, and 15.5% was less than 0.20mm. The size of particles was suitable for improving the water permeability capacity of soil, as shown in Fig.1, especially it is applied to soil with higher clay content.

From the aspect of water retention capacity, sawdust charcoal could contribute to improvement. The effects, however, seems to be limited. To raise improvement capacity, carbonization temperature needs to be higher. The size of pores on the surface of charcoal should be measured for complete analysis of water retention capacity. This aspect, however, was not conducted because of a lack of equipments.

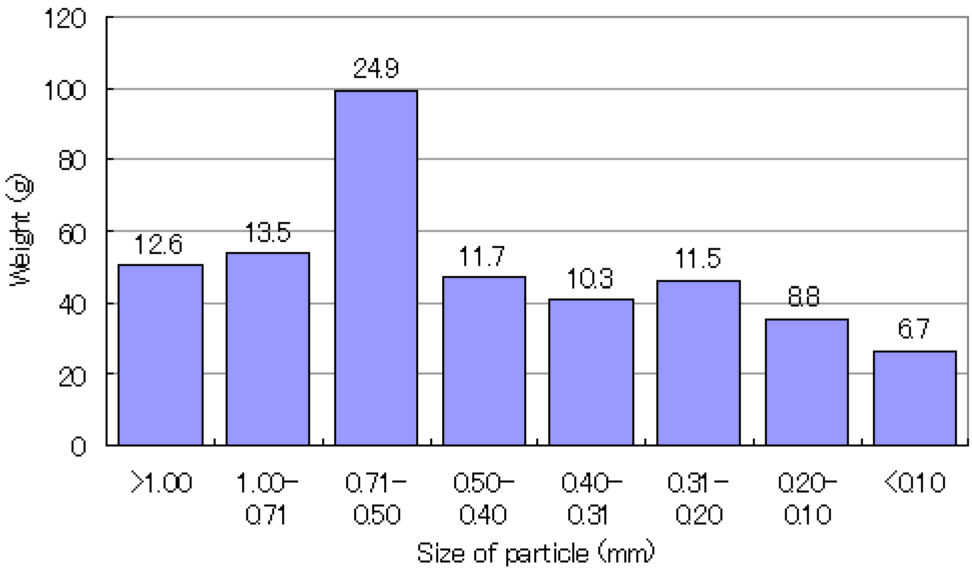


Fig.3 Distribution of particle size (charcoal from 3rd trial)

Note: The numbers written above the bars indicate percentage.

2. Amount of carbon stored in sawdust charcoal

Table 6 shows charcoal yield and carbon yield of each trial. Carbonization time for the 3rd trial was longer than 2nd trial, although the amount of charcoal produced in the 2nd trial was larger. This is because of the carbonized method shown in Photo 17 in the Appendix. For controlling the ventilation, the operation was conducted very carefully. It is assumed that quality of charcoal is stabilized and carbonization time will be shortened after technicians and workers get used to the technique.

The amount of carbon fixed in Table 6 was calculated using data shown in Table 7. Fixed carbon content and carbon yield reached 72.65% and 26.01%, respectively. This means that 74% of the carbon inside wood materials was emitted or stored inside volatile matter that is easily decomposed.

Table 6 Charcoal yield and carbon yield

Trial		1st trial	2nd trial	3rd trial
Date		September 19 - 20, 2002	September 24-27, 2002	June 3 - 6, 2003
Amount of wood material (sack[1])		70	154	147
Dry weight of wood material (kg)	A	569.9	1434.4	1249.98
Weight of charcoal produced (kg)	B	64.81	254.6	229.5
Charcoal yield (%)	C[2]	11.37	17.74	18.36
Carbonization time (hour)		36	60	72
Amount of half-carbonized charcoal (sack)		10	3	12
Weight of carbon fixed (kg)	D	44.64	176.79	162.53
Carbon yield (%)	E[3]	15.67	24.65	26.01

Notes: [1] 1 sack contained 12kg of sawdust

[2] C = 100*B/A

[3] $E = \frac{B}{0.5*A} * \frac{G}{100} * \frac{(100-F)}{100} * 100$ (F and G: refer to Table 6)

Table 7 Charcoal analysis according to SNI (Standard Nasional Indonesia)

Trial		1st	2nd	3rd
Moisture content (%)	F	3.51	4.01	2.52
Ash content (%)		3.99	4.08	6.35
Volatile matter content (%)		24.62	23.58	21.00
Fixed carbon content (%)	G	71.39	72.34	72.65

Note: This data was contrary to that from Table 4 (the quality of charcoal from the 3rd trial was lower than that from the 2nd trial). It is supposed that the difference came from sampling because of the uneven quality of charcoal inside the kiln.

Fig.4 shows the relationship between charcoal yield and carbon yield. Data obtained from previous experiments in this project was combined (Data for drum kilns and the piling process). As shown in the Figure, charcoal yield of a flat kiln was still low (only 18%, almost the same as in the piling method).

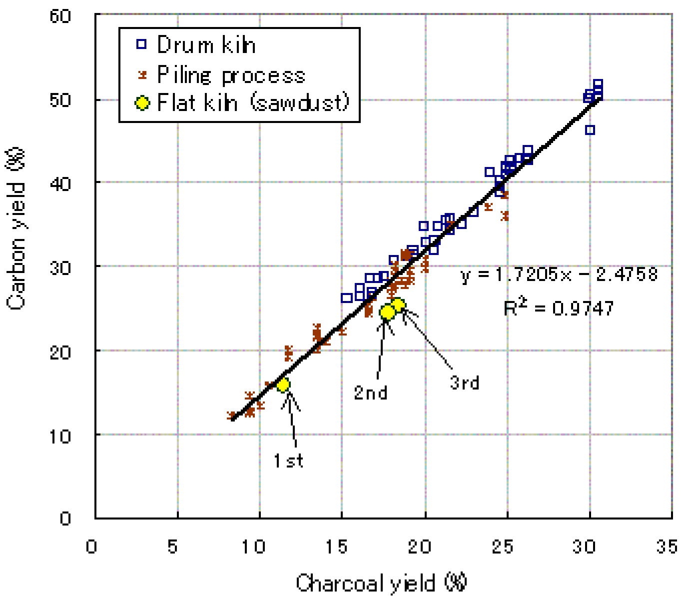


Fig.4 Relationship between charcoal yield and carbon yield:

A comparison of drum kiln, traditional kiln (piling process), and flat kiln

Notes: This is a combination with data from Gustan, *et al.* (2003): Charcoal produced in the three experimental sites in PT. Perhutani area, West Java.

To achieve 50% of carbon yield, charcoal yield must be 30%. The drum kiln was more efficient than other types of kilns.

3. Cost estimation

(1) Costs to build a flat kiln

The flat kiln for these trials was built at a cost of about 6 million Rupiah (Table 8).

(2) Costs for producing sawdust charcoal

Production costs were calculated under an assumption shown in Table 9. This analysis is only one example because these figures shown in Table 9, especially wages of workers, can vary from place to place.

Table 8 Costs to built a kiln

Item	Amount	Price (Rupiah)
Galvanized iron sheet (Zink)	34 sheet	1,088,000
Scantling		1,336,000
Nail	6kg	45,000
Cement	15 sacks	420,000
Sand	$2.5m^3$	437,500
Sieve (For sieving sand)		10,000
Bricks	4,000	1,600,000
Iron pipe for the chimney (Diameter: 6 inch)	6m	625,000
Wages of workers	Rp.35,000[1)] x 11 person*day + Rp.25,000[2)] x 8 person*day	585,000
Total		**6,146,500**

Note: The size and structure of the kiln is indicated in Fig.2.
Costs for modification was not included.
[1)] Wages for skilled worker (3 workers)
[2)] Wages for non-skilled worker (2 workers)

Table 9 Assumptions for analysis

Item	Amount
Initial cost to build kiln (a)	Rp. 6,146,500
Days for one time carbonization (b)	3 days
Charcoal produced at one time carbonization (c)	0.255 t[1)]
Carbon produced at one time carbonization (d)	0.177 tC[1)]
Numbers of workers (e)	2 workers
Wages of workers (f)	Rp.600,000/month
Labor cost at one time carbonization (g)	Rp.118,356[2)]

[1)] Data obtained in the 2nd trial

[2)] $$g = \frac{f*e*12\text{months}}{365\text{ days (1 year)}} * b = \frac{\text{Rp.600,000} * 2\text{ workers} * 12\text{ month}}{365\text{ days}} * 3\text{ days}$$

Table 10 shows calculated costs using the assumption of Table 9. After repeating production, the costs per ton (carbon and charcoal) will be reduced. If production is repeated 50 times, costs for producing carbon will be 1.36 million Rp./tC (equivalent to 161 US$/tC, using exchange rate on December 10, 2003, 8,490 Rp./US$). After 100 times, 1.02 Rp./tC (equivalent to 120 US$/tC).

Costs for producing charcoal will be 0.95 Rp./t after 50 times and 0.71Rp./t after 100 times.

These costs seem to be much higher than expected price of carbon (for example, estimation by Tanujaya (2002) varies from 0.55 to 4.68 US$/tC depending on restriction of amount of hot air.)

Those costs can be reduced by:

(1) Enlargement of kilns to produce a large amount of charcoal at one time
(2) Higher yield: modification of kiln
(3) Reduction of labor cost: Efficient arrangements for workers

Table 9 Costs for production of charcoal and carbon

Times	Accumulated cost (Rp.)[1)]	Accumulated carbon (tC)	Cost (Rp./tC)	Accumulated charcoal (t)	Cost (Rp./t)
h	i=a+g*h	j=d*h	i/j	k=c*h	l=i/k
1	6,264,856	0.1770	35,394,668	0.2550	24,568,063
10	7,330,062	1.7700	4,141,278	2.5500	2,874,534
20	8,513,623	3.5400	2,404,978	5.1000	1,669,338
30	9,697,185	5.3100	1,826,212	7.6500	1,267,606
40	10,880,747	7.0800	1,536,829	10.2000	1,066,740
50	12,064,308	8.8500	1,363,199	12.7500	946,220
60	13,247,870	10.6200	1,247,445	15.3000	865,874
70	14,431,432	12.3900	1,164,764	17.8500	808,484
80	15,614,993	14.1600	1,102,754	20.4000	765,441
90	16,798,555	15.9300	1,054,523	22.9500	731,963
100	17,982,116	17.7000	1,015,939	25.5000	705,181

Note: [1)] Costs for repairing kiln were not included.

IV. Conclusions

In this report, a potential of sawdust charcoal as a soil conditioner was demonstrated. On the other hand, the efficiency for carbonization (percentage of carbon stored in charcoal) was still low and production costs were still high.

Concretely, several facts were found by these experiments:

1. Sawdust charcoal (in this experiment, wood material was soft wood such as *Paraserianthes* and *Maesopsis*) can add Ca^{2+} and K^{+} to soil and also increase amount of available phosphate.
2. A potential of sawdust charcoal for improvement of nutrient retention capacity is

limited. Only when the charcoal is applied to soil with very low CEC (for example, sandy soil), it could contribute to improvement of nutrient retention capacity.

3. Sawdust charcoal has a potential for improving the water permeability of soil. On the other hand, it showed a limited capacity for improving the water retention capacity of soil.
4. Charcoal yield and carbon yield of flat kilns were still low because of the structure of the kiln (for example, no roof).
5. Costs for producing sawdust charcoal were still high compared with expected price of carbon. Enlargement and further modification of the kiln are necessary so that this method can contribute to carbon sequestration.

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