

## Full Length Research Paper

# Preliminary evaluation of the effects of carbonized chicken manure, refuse derived fuel and K fertilizer application on the growth, nodulation, yield, N and P contents of soybean and cowpea in the greenhouse

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Accepted 3 November, 2008

Carbonized organic materials have not traditionally been applied to grain legumes such as soybean (*Glycine max* L. Merrill) and cowpea (*Vigna unguiculata* L. Walp) although the potential for favourable agronomic responses exist because of their high contents of available P. We explored the effects of carbonized chicken manure and carbonized refuse derived fuel (RDF) from municipal organic waste with or without inorganic K fertilization on the growth, nodulation, seed yield, N and P contents of soybean and cowpea in a vinyl house pot experiment. Growth, nodulation, plant total N and P contents were evaluated at peak flowering stage of legume growth. The application of carbonized chicken manure only increased seed yield by 41 and 146% for soybean and cowpea respectively while the carbonized chicken manure with inorganic K fertilizer increased seed yield by 53 and 185% for soybean and cowpea respectively relative to the un-amended control. The application of carbonized RDF only increased seed yield by 20 and 59% for soybean and cowpea respectively while the application of carbonized RDF with inorganic K fertilizer increased seed yield by 45 and 126% for soybean and cowpea respectively relative to the absolute control. The application of both carbonized organic materials with inorganic K fertilizer increased number of nodules more than their sole application. Results suggested that the application of carbonized chicken manure and carbonized RDF improved the growth, nodulation, seed yield, N and P contents of both grain legumes due to their high content of P. The application of the carbonized organic materials with inorganic K fertilizer further increased seed yields of both grain legumes suggesting that K was limiting the response to P from the organic materials in the experimental soil.

**Key words:** Carbonization, chicken manure, grain legumes, refuse derived fuel, seed yield.

## INTRODUCTION

Soybean (*Glycine max* (L) Merrill) and Cowpea (*Vigna unguiculata* (L) Walp) are important grain legumes grown in the tropics and sub-tropics. Cowpea is particularly important in West Africa where it occupies 6 million hectares of agricultural land (Bationo et al., 1990) with over 9.3 million metric tons of annual production (Ortiz, 1998). The main limiting nutrients for legume production

in West Africa are N and P (Fox and Kang, 1977). The high cost and scarcity of inorganic fertilizers had renewed interest in the use of unorthodox organic soil amendment materials such as carbonized organic materials (Shinogi et al., 2003) and bio-char (Ishii and Kadoya, 1994) for cultivation of crops.

Carbonization has been proposed as a management tool for agricultural and municipal wastes producing fertilizer, renewable energy and bio-char. Carbonization is achieved through pyrolysis of organic wastes at temperatures ranging between 300 and 500°C and eliminates the bad smell, reduces the volume and weight of organic wastes (Popov et al., 2004). During carbonization, some

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amount of N is lost in the form of ammonia gas but the resulting carbonized material is higher in available P by up to 5 times compared to the original waste (Shinogi et al., 2003; Tagoe et al., 2008).

Carbonized organic wastes can be used as soil amendments to supply plant nutrients especially N and P. The application of carbonized organic wastes to soil improve the physical properties of the soil, improve soil fertility and nutrient retention (Sombroek et al., 1993; Lehmann and Rondon., 2005), stimulate microbial activities in soil (Tejada et al., 2006), increase mycorrhizal abundance and/or functioning (Warnock et al., 2007), increase nodule abundance in soybean (Tagoe et al., 2008) as well as improve biological N<sub>2</sub> fixation in common beans (Rondon et al., 2007).

No work has been reported in the scientific literature on the use of carbonized refuse derived fuel (CRDF) as soil amendment for legume growth while only one work had been reported on the use of carbonized chicken manure as soil amendment for soybean growth (Tagoe et al., 2008). In this study, we assess the effects of two carbonized organic soil amendment materials (chicken manure and RDF) on the growth, nodulation, yield, N and P concentrations of two grain legumes (soybean and cowpea) with or without inorganic K fertilizer. We hypothesized that the application of carbonized organic materials will improve the growth, nodulation, seed yield, N and P concentrations of grain legumes more with K fertilizer than without K fertilizer because K could limit the response of grain legumes to P from carbonized organic materials in low P status soils (Carsky, 2003) and also because of the low K content of the experimental soil. Our major objectives are to elucidate the effect of carbonized chicken manure and carbonized RDF on 1) the growth, nodulation and seed yield and 2) plant and seed concentrations of N and P of both crops.

## MATERIALS AND METHODS

### Plant culture

Experiments were conducted from May to October, 2007 at the greenhouse of Gifu University Experiment Farm (35° 27' N, 136° 46' E). Wagner pots (1/2000a) were filled with sandy loam soil with the following characteristics: pH; 5.62, EC; 0.28 mS cm<sup>-1</sup>, total N; 0.100%, total C; 0.88%, available P; 1.16 mg 100 g<sup>-1</sup>, available K; 13.3 mg 100 g<sup>-1</sup>, available Ca; 90.0 mg 100 g<sup>-1</sup>, and available Mg; 31.0 mg 100 g<sup>-1</sup>. The nutrient concentrations, pH and EC of the carbonized chicken manure and RDF used in the experiment are shown in Table 1. Carbonized chicken manure was obtained from Tokyo Yougyou Kabushiki Kaisha, Tajimi City, Gifu Prefecture, Japan. Carbonized chicken manure was produced from pelleted, dried chicken manure through pyrolysis at a temperature of 450°C for one hour in a furnace. Carbonized RDF was obtained from Kurimoto Tekkosho, In a City, Gifu Prefecture, Japan. Carbonized RDF was prepared from municipal organic waste through pyrolysis at a temperature of 500°C for 2 h in a kiln after drying the waste in a furnace for 10 h. The amounts of the carbonized organic materials applied per pot for the various treatments are shown in Table 2. Carbonized organic amendments were applied to the appropriate

treatments three weeks before sowing. Potassium fertilizer was applied as Muriate of Potash (KCl) at a rate of 83 kg K ha<sup>-1</sup> to the appropriate treatments at sowing. No chemical pesticides were used in this experiment. Five seeds of soybean (*Glycine max* (L) Merrill cv Akishirome) and cowpea (*V. unguiculata* (L) Walp cv Tsurushi sasage) were sown per pot on 7th June, 2007. After emergence, seedlings were thinned to two per pot. Plants were watered as when necessary. All pots were kept completely free of weeds within the duration of the experiment by hand-picking when they appear.

### Experimental design

The experiment was set up using two grain legumes (soybean and cowpea), two carbonized organic materials (carbonized chicken manure and carbonized RDF) with two rates of inorganic K fertilizer with or without K, 83 kg K ha<sup>-1</sup> and 0 kg K ha<sup>-1</sup> respectively in a factorial combination giving a total of 48 treatments (2 x 2 x 2 x 6) arranged in completely randomized design (CRD) of six replications. All data collected from the study were analyzed by using Duncan's Multiple Range Test (DMRT) (Excel Statistical Package Version 6.0) and mean separations were done by the same method.

### Measurements

Plant height and relative chlorophyll content (SPAD) were measured twice within the duration of the experiment. For both parameters, the first (pre-flowering) and second (post-flowering) samplings were done on 16th July and 31st July respectively. SPAD was measured with a chlorophyll meter model SPAD-502 (Minolta Co. Ltd., Japan). SPAD readings were taken from 12 randomly selected youngest and fully expanded leaves of plants in each pot. Each SPAD reading was taken on one side of the mid-rib of the leaf blade, midway between the leaf blade and tip.

Sampling for leaf area, dry matter weight, and number of nodules was done on 26th July for cowpea and 1st August for soybean when the plants were at peak flowering stage. Shoots were harvested by cutting the plants in each pot at the soil level. Roots were harvested by lifting the soil in each pot and washing off the soil under running water from a tap. The harvested shoots were separated into leaves, stems (including petioles), flowers etc. The roots were washed clean of soil and root nodules were separated and counted. The leaves were used to estimate leaf area by the core borer method after oven-drying harvested samples at 80°C for 72 h. The dried samples were then weighed to determine dry weights of leaves, stems, roots and nodules and finally total dry matter weight.

The total dry material was milled to pass 0.5 mm mesh sieve using a wonder blender (Model WB-1). The milled plant samples were used for total N and total P analyses and determination. Total N was determined with an automatic high sensitive NC analyzer (Sumigraph NC-95A, Shimadzu Co. Ltd., Japan). Total P was determined colorimetrically (HITACHI-U-1800) according to Bray and Kurtz (1945) and Murphy and Riley (1962).

Residual experimental soil exchangeable cations (K<sup>+</sup>, Ca<sup>2+</sup>, and Mg<sup>2+</sup>) were measured with a Polarized Zeeman Atomic Absorption Spectrophotometer (HITACHI-180-60) after extraction of samples with 1.0N Ammonium acetate solution (pH 7.0).

## RESULTS

### Plant growth

At the pre-flowering sampling of the relative chlorophyll

**Table 1.** Nutrient composition of carbonized organic materials used in the experiment after pyrolysis.

Property	Carbonized chicken Manure	Carbonized refuse derived fuel
pH †	9.93	7.76
EC ( $\mu\text{S cm}^{-1}$ )	3.64	65.03
Total N ( $\text{g kg}^{-1}$ )	44.0	20.2
NO <sub>3</sub> -N ( $\text{mg kg}^{-1}$ )	1.90	-
Total C ( $\text{g kg}^{-1}$ )	497.5	500.9
C/N ratio	11.31	25.00
Na ( $\text{g kg}^{-1}$ )	2.37	3.38
P ( $\text{g kg}^{-1}$ )	24.6	5.22
K ( $\text{g kg}^{-1}$ )	37.00	3.45
Ca ( $\text{g kg}^{-1}$ )	7.67	30.28
Mg ( $\text{g kg}^{-1}$ )	1.93	2.10

† The pH and EC were measured in the extracts of carbonized organic materials in distilled water [1:20 (w/v)] on dry weight basis.

**Table 2.** Treatment details showing amounts of carbonized organic materials and inorganic K fertilizer applied per pot and treatment abbreviations.

Treatment	Amount of carbonized organic material applied (g)	Amount of K fertilizer applied as muriate of potash (KCl) (mg)	Abbreviation
No carbonized organic material (Control)	0	0	Control (Without K)
No carbonized organic material (Control)	0	830.0	Control (With K)
Carbonized chicken manure	11.40	0	CCM (Without K)
Carbonized chicken manure	11.40	410.0	CCM (With K)
Carbonized refuse derived fuel	24.75	0	CRDF (Without K)
Carbonized refuse derived fuel	24.75	740.0	CRDF (With K)

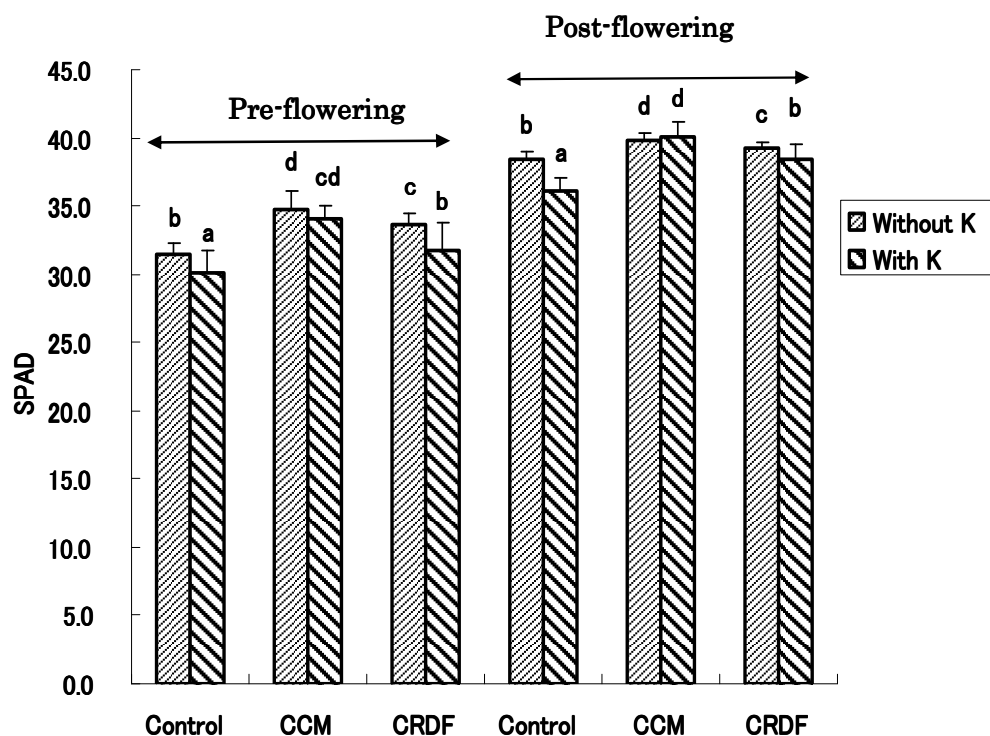
content (SPAD) leaves of soybean plants treated with carbonized chicken manure were the greenest. Leaves of soybean plants treated with carbonized RDF were of intermediate greenness while those of the control were the least green with or without K fertilizer. Generally, leaves of soybean plants without K fertilizer were greener than those with K fertilizer (Figure 1). The observed differences were significant according to DMRT at  $p < 0.05$ .

At the post-flowering sampling of SPAD, a similar trend was observed for the control and carbonized RDF treatments with or without K fertilizer. However, leaves of soybean plants treated with carbonized chicken manure were the greenest with or without K fertilizer (Figure 1). At the pre-flowering sampling of SPAD of cowpea, leaves of plants treated with carbonized chicken manure with or without K fertilizer were the greenest. Cowpea leaves of plants treated with carbonized RDF with or without K fertilizer were of intermediate greenness. Leaves of cowpea plants without any organic amendment (control) with or without K fertilizer were least green (Figure 2). For cowpea leaves of plants treated with carbonized chicken manure and carbonized RDF, no difference in greenness were observed for treatments with and without K fertilizer.

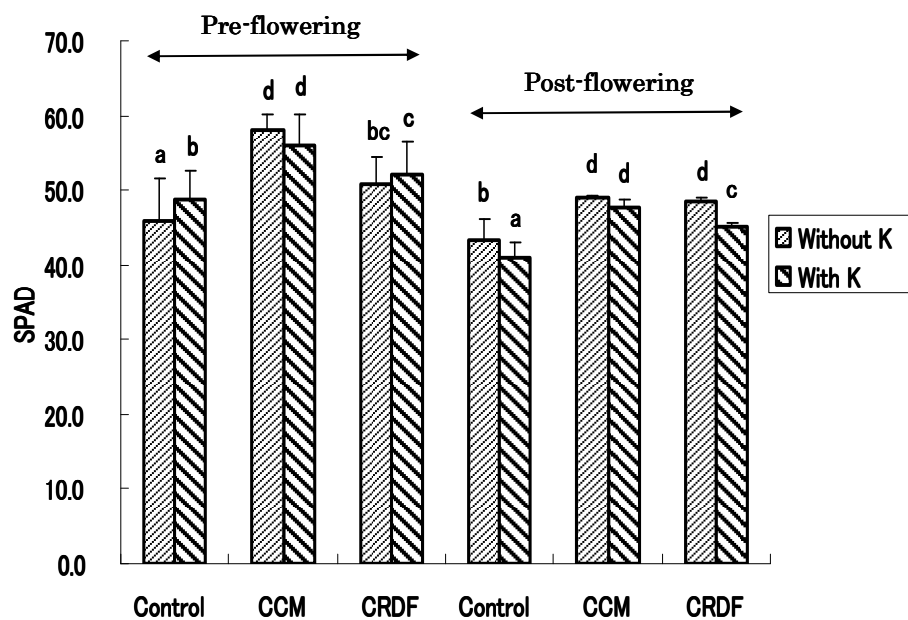
Leaves of control cowpea plants that received K fertilizer were greener than those that did not (Figure 2). At the post-flowering sampling of SPAD for cowpea, a similar trend to the pre-flowering SPAD was observed except that leaves of control cowpea plants without K fertilizer were greener than those with K fertilizer (Figure 2). The observed differences among treatments for both pre-flowering and post-flowering were significant at  $p < 0.05$  according to DMRT.

Total dry weight was significantly highest according to DMRT at  $p < 0.05$  in soybean plants treated with carbonized chicken manure followed by those treated with carbonized RDF. Control soybean plants were least heavy in total dry weight (Table 3). For all treatments, soybean plants with K fertilization produced heavier dry matter than the corresponding treatments without K fertilization (Table 3). There was a strong and significant positive relationship between total dry weight and plant total N content of soybean ( $R^2 = 0.79^{**}$ , Figure 3a). A strong and significant positive relationship was observed between soybean total dry weight and plant total P content ( $R^2 = 0.90^{**}$ , Figure 3b).

Total dry weight of cowpea followed a similar trend as that of soybean. Cowpea plants treated with carbonized



**Figure 1.** Effects of carbonized organic materials supply on the pre-flowering and post-flowering SPAD values of soybean. Data show the means  $\pm$  SD of three independent replications.



**Figure 2.** Effects of carbonized organic materials supply on the pre-flowering and post-flowering SPAD values of cowpea. Data show the means  $\pm$  SD of three independent replications.

chicken manure produced significantly the highest dry matter followed by those treated with carbonized RDF according to DMRT at  $p < 0.05$ . Control cowpea plants

produced the least dry matter (Table 4). For all treatments, cowpea plants that received K fertilizer produced heavier dry matter than those that did not

**Table 3.** Growth, nodulation, total N and P contents of soybean as affected by the application of carbonized organic materials.

Treatment	K fertilizer	Total dry weight (g)	Number of nodules	Plant total N content (g kg <sup>-1</sup> )	Seed total N content (g kg <sup>-1</sup> )	Plant total P content (g kg <sup>-1</sup> )	Seed total P content (g kg <sup>-1</sup> )
Control	Without K	38.0 a	380.7 a	27.8 a	66.1 a	0.35 a	0.09 a
	With K	49.3 b	428.3 b	27.2 a	66.8 a	0.38 b	0.11 b
CCM	Without K	64.2 c	529.3 c	31.9 c	72.8 d	0.44 d	0.27 c
	With K	81.8 d	611.0 d	33.0 d	73.8 e	0.47 f	0.34 e
CRDF	Without K	54.1 b	437.3 b	30.4 b	70.8 b	0.43 c	0.26 c
	With K	69.2 c	567.0 c	30.8 b	71.8 c	0.45 e	0.31 d

Within each column, means having a common letter(s) are not significantly different according to DMRT at  $p < 0.05$ .

**Table 4.** Total dry weight, number of nodules, total N and P contents of cowpea as affected by the application of carbonized organic materials.

Treatment	K fertilizer	Total dry weight (g)	Number of nodules	Plant total N content (g kg <sup>-1</sup> )	Seed total N content (g kg <sup>-1</sup> )	Plant total P content (g kg <sup>-1</sup> )	Seed total P content (g kg <sup>-1</sup> )
Control	Without K	17.5 a	103.3 a	23.1 a	40.3 a	0.54 a	0.12 a
	With K	31.7 bc	140.0 b	22.9 a	41.3 b	0.56 b	0.14 b
CCM	Without K	34.8 c	122.0 ab	27.3 c	46.6 e	0.64 d	0.18 d
	With K	38.3 d	215.0 d	31.9 d	47.9 f	0.67 e	0.21 f
CRDF	Without K	29.3 b	113.0 a	24.9 b	43.5 c	0.62 c	0.16 c
	With K	37.7 d	189.0 c	28.0 c	44.9 d	0.64 d	0.19 e

Within each column, means having a common letter(s) are not significantly different according to DMRT at  $p < 0.05$ .

(Table 4). There was a significant positive relationship between total dry weight and plant total N content of cowpea ( $R^2 = 0.56^*$ , Figure 4a). A strong and significant positive relationship was observed between total dry weight and plant total P content of cowpea ( $R^2 = 0.70^{**}$ , Figure 4b).

Number of nodules of soybean was significantly highest in soybean plants treated with carbonized chicken manure followed by those treated with carbonized RDF according to DMRT at  $p < 0.05$ . Control soybean plants produced the least number of nodules. For each carbonized organic amendment treatment, soybean plants that received K fertilizer produced more nodules than those that did not (Table 3). There was a strong and significant positive relationship between number of nodules and plant total N content of soybean ( $R^2 = 0.75^{**}$ , Figure 5a). Also, a strong and significant positive relationship was observed between number of nodules and plant total P content of soybean ( $R^2 = 0.83^{**}$ , Figure 5b).

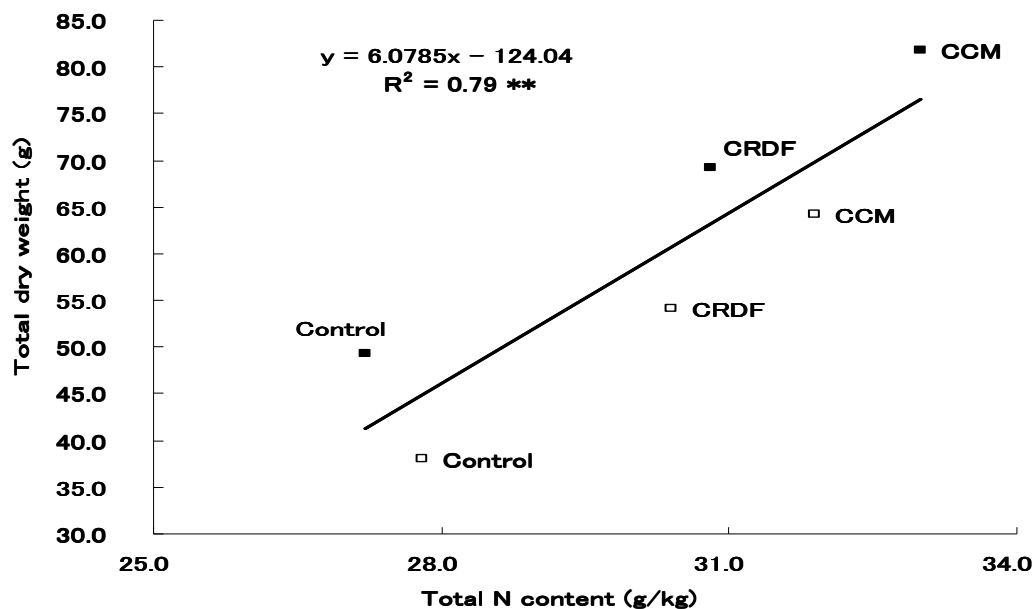
Cowpea plants of both carbonized organic amendment treatments without K fertilization produced similar number of nodules. However, cowpea plants treated with carbonized chicken manure and K fertilizer produced significantly the greatest number of nodules followed by cowpea plants treated with carbonized RDF and K fertilizer according to DMRT at  $p < 0.05$ . Control cowpea plants with K fertilizer produced the least number of

nodules (Table 4). There was a significant positive relationship between number of nodules and plant total N content of cowpea ( $R^2 = 0.68^*$ , Figure 6a). No significant positive relationship was observed between number of nodules and plant total P content of cowpea ( $R^2 = 0.43$  ns, Figure 6b).

### Yield and yield components

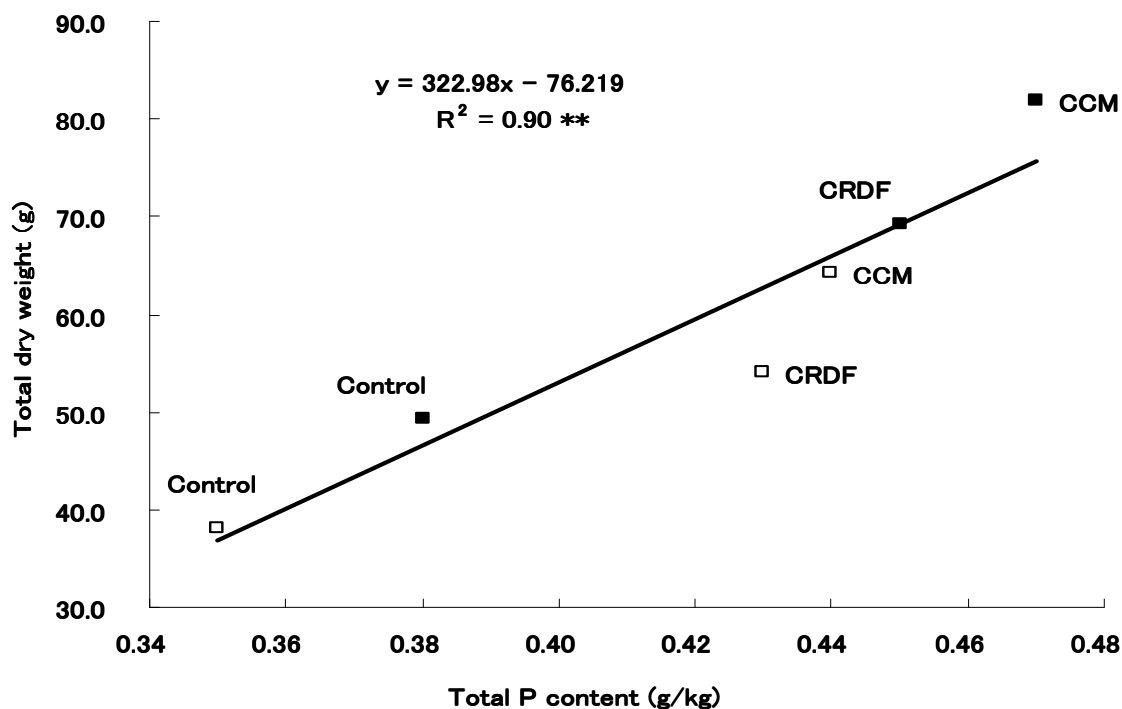
Dry pod yield and seed yield of soybean followed a similar trend. Soybean seed yield was heaviest in treatments amended with carbonized chicken manure with or without K fertilizer followed by carbonized RDF amended treatments with or without K fertilizer. Soybean seed yield was least in control treatments with or without K fertilizer (Table 5). Generally, carbonized organic amendment treatments that received K fertilizer produced better dry pod and seed yields than those without K fertilizer. The application of carbonized chicken manure only increased soybean seed yield by 41% while the application of carbonized RDF only increased soybean seed yield by 20%. The application of carbonized chicken manure and K fertilizer increased soybean seed yield by 53% while the application of carbonized RDF and K fertilizer increased soybean seed yield by 45%.

Dry pod yield and seed yield of cowpea followed a similar trend. Cowpea plants treated with carbonized



□ = Without K fertilizer; ■ = with K fertilizer; \*\* = significant at 1%.

(3a)



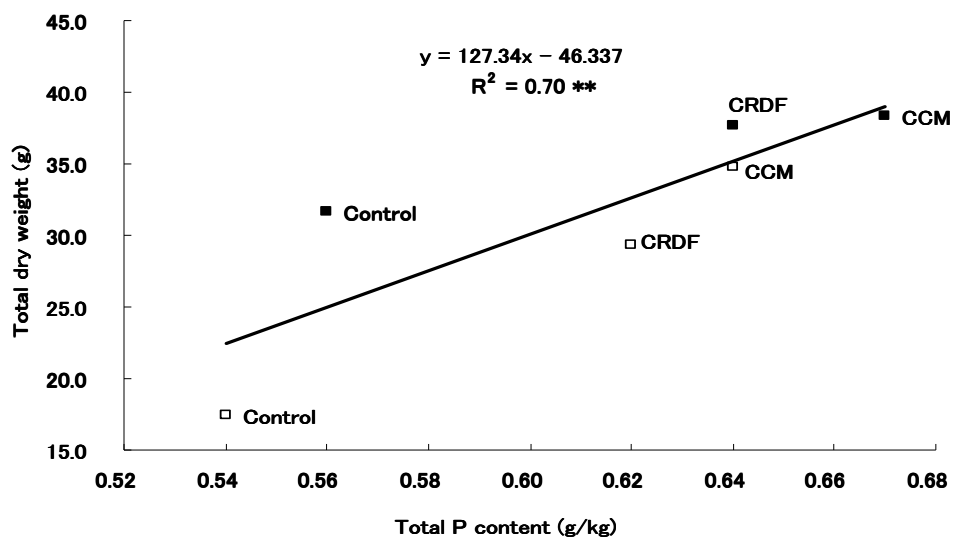
□ = Without K fertilizer; ■ = with K fertilizer; \*\* = significant at 1%.

(3b)

**Figure 3.** Relationship between total dry weight, plant total N content and plant total P content of soybean at peak flowering.

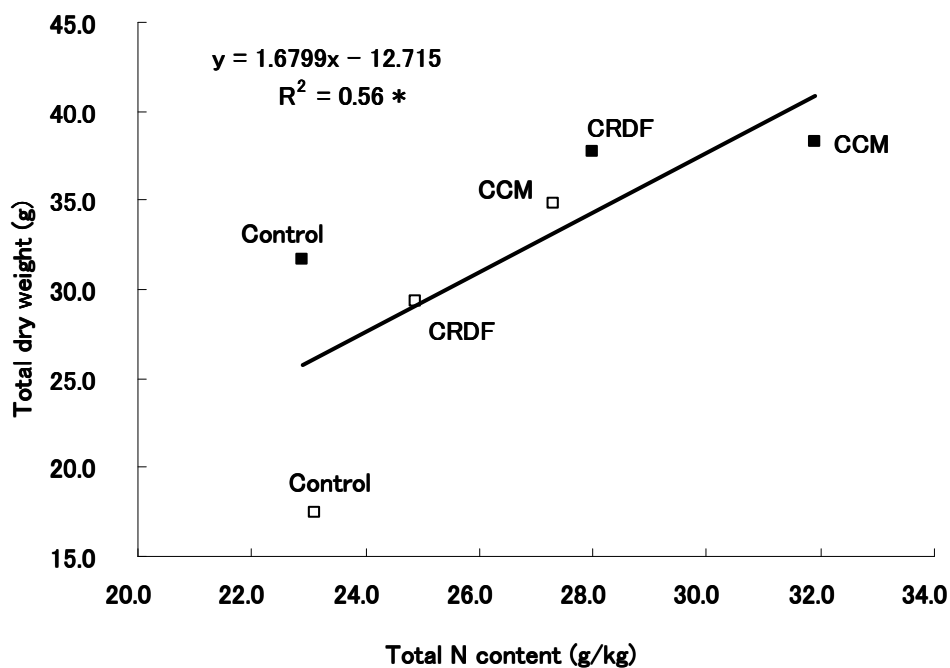
**3a.** Relationship between total dry weight and plant total N content of soybean at peak flowering stage

**3b.** Relationship between total dry weight and plant total P content of soybean at peak flowering stage



□ = Without K fertilizer; ■ = with K fertilizer; \*\* = significant at 1%.

(4a)



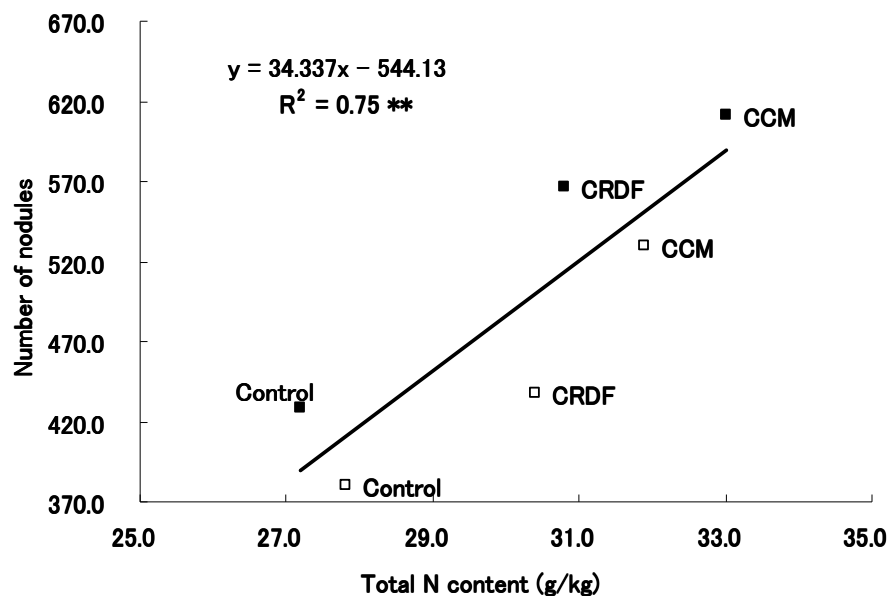
□ = Without K fertilizer; ■ = with K fertilizer; \* = significant at 5%.

(4b)

**Figure 4.** Relationship between total dry weight, plant total N content and plant total P content of cowpea at peak flowering.

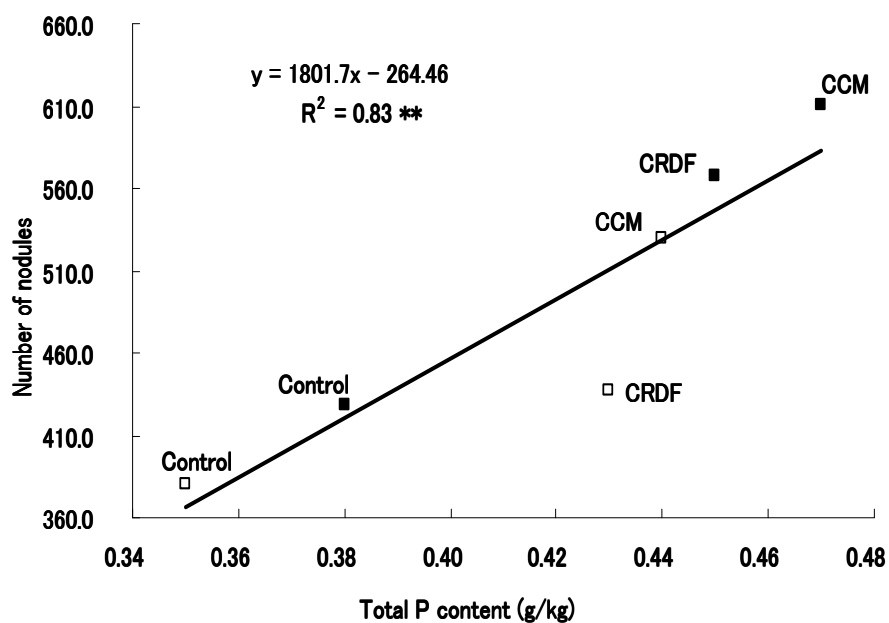
**4a.** Relationship between total dry weight and plant total N content of cowpea at peak flowering stage.

**4b.** Relationship between total dry weight and plant total P content of cowpea at peak flowering stage.



□ = Without K fertilizer; ■ = with K fertilizer; \*\* = significant at 1%.

(5a)



□ = Without K fertilizer; ■ = with K fertilizer; \*\* = significant at 1%.

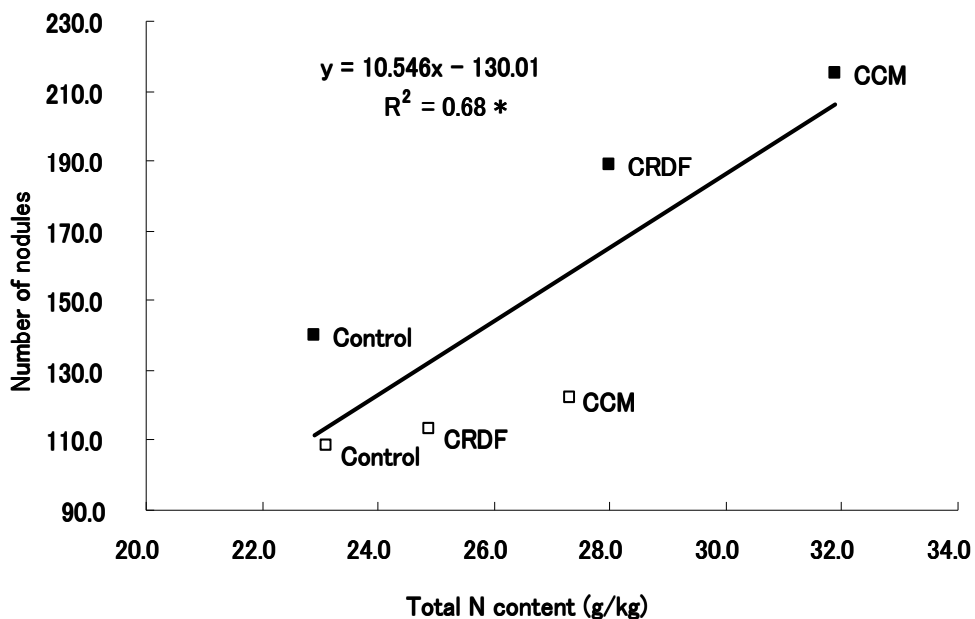
(5b)

**Figure 5.** Relationship between number of nodules, plant total N content and plant total P content of soybean at peak flowering.

**5a.** Relationship between number of nodules and plant total N content of soybean at peak flowering stage.

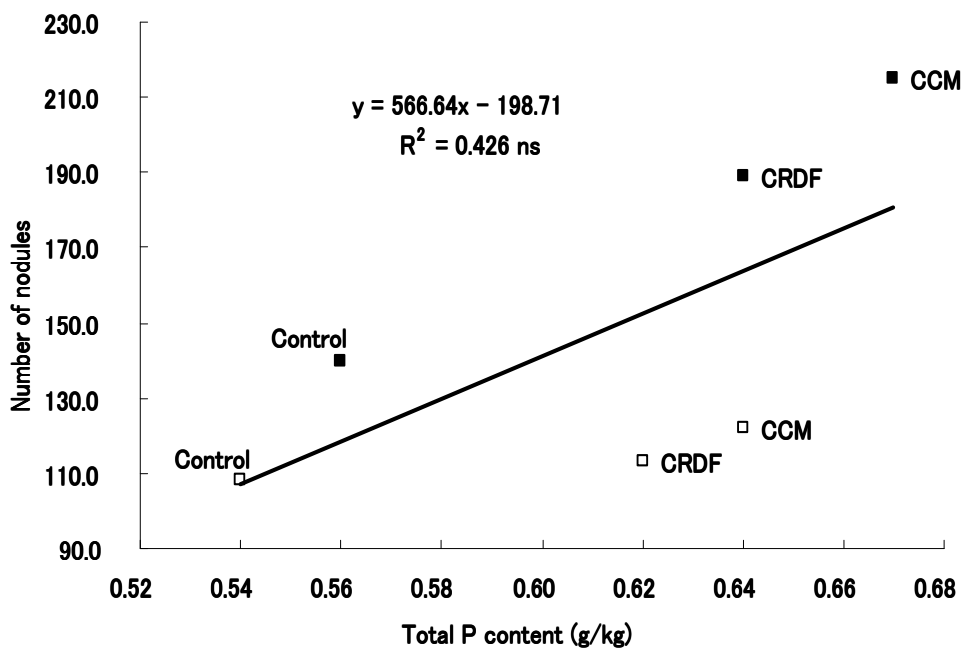
**5b.** Relationship between number of nodules and plant total P content of soybean at peak flowering stage.





□ = Without K fertilizer; ■ = with K fertilizer; \* = significant at 5% .

(6a)



□ = Without K fertilizer; ■ = with K fertilizer; ns = not significant .

(6b)

**Figure 6.** Relationship between number of nodules, plant total N content and plant total P content of cowpea at peak flowering.

**6a.** Relationship between number of nodules and plant total N content of cowpea at peak flowering stage.

**6b.** Relationship between number of nodules and plant total P content of cowpea at peak flowering stage.

**Table 5.** Yield and yield components of soybean as affected by the application of carbonized organic materials.

Treatment	K fertilizer	Dry pod yield (g)	Seed yield (g)	No. of pods plant-1	No. of seeds pod-1	100 seed wt (g)	Harvest index
Control	Without K	49.5 a	38.1 a	50.4 a	1.8 a	26.4 a	0.54 ab
	With K	68.7 c	52.9 c	108.7 c	1.8 a	28.0 b	0.63 e
CCM	Without K	69.8 c	53.7 c	79.0 c	1.9 b	28.9 c	0.57 bc
	With K	71.9 cd	58.4 d	137.5 d	2.0 c	29.9 e	0.59 bc
CRDF	Without K	59.7 b	45.9 b	68.9 b	1.9 b	27.8 b	0.67 e
	With K	75.8 d	55.4 cd	103.7 d	1.9 b	29.6 d	0.52 a

**Table 6.** Yield and yield components of cowpea as affected by the application of carbonized organic materials.

Treatment	K fertilizer	Dry pod yield (g)	Seed yield (g)	No. of pods plant-1	No. of seeds pod-1	100 seed wt (g)	Harvest index
Control	Without K	26.1 a	14.2 a	9.4 a	11.7 ab	17.4 a	0.66 d
	With K	40.6 c	27.6 c	12.0 bc	11.3 ab	17.3 a	0.60 ab
CCM	Without K	47.9 d	34.9 e	11.9 b	12.0 b	19.8 b	0.61 bc
	With K	54.9 e	40.5 f	14.9 d	12.3 b	20.2 b	0.63 c
CRDF	Without K	35.6 b	22.6 b	11.4 b	10.7 a	18.1 a	0.59 ab
	With K	47.1 d	32.1 d	13.0 c	11.3 ab	19.6 b	0.58 a

chicken manure with or without K fertilizer produced the heaviest seed yield followed by those treated with carbonized RDF. Control cowpea plants with or without K fertilizer produced the least heavy seed yield. Generally, cowpea plants that received K fertilizer produced heavier seed yield than those that did not receive K fertilizer (Table 6). Cowpea seed yield increased 146% by the application of carbonized chicken manure only while it increased by 49% as a result of the application of carbonized RDF only. The application of carbonized chicken manure and K fertilizer increased cowpea seed yield by 185% while the application of carbonized RDF and K fertilizer increased it by 126%.

Number of pods/plant of soybean followed a similar pattern to dry pod and seed yields of soybean. In all treatments, number of pods/plant of soybean was better for treatments that received K fertilizer than for those without K fertilizer (Table 5).

Number of pods/plant was highest in cowpea plants that received K fertilizer than those that did not for all treatments. Number of pods/plant was significantly highest in cowpea plants treated with carbonized chicken manure followed by carbonized RDF. Number of pods/plant was least in control cowpea plants. Number of seeds per pod was only slightly increased by K fertilizer in soybean plants treated with carbonized chicken manure (Table 5).

Number of seeds/pod of cowpea was neither affected by carbonized organic amendment material supply nor K fertilizer application (Table 6).

100 seed weight of soybean was increased by K fertilizer

in all organic amendment treatments. 100 seed weight was significantly heaviest in carbonized chicken manure treated plants according to DMRT at  $p < 0.05$  followed by carbonized RDF treated plants. 100 seed weight was least heavy in control soybean plants (Table 5).

100 seed weight of cowpea was not affected by K fertilizer application in control and carbonized chicken manure treated plants but was increased slightly in carbonized RDF treated plants. 100 seed weight of cowpea was highest in plants treated with carbonized chicken manure with or without K fertilizer and similar to plants treated with carbonized RDF and K fertilizer (Table 6).

Harvest index was increased by K fertilizer application in control soybean plants and reduced in carbonized RDF treated soybean plants. K fertilizer application did not affect harvest index in carbonized chicken manure treated soybean plants (Table 5).

Harvest index of cowpea did not follow any particular trend but was highest in control cowpea plants without K fertilizer and lowest in carbonized RDF treated plants with K fertilizer (Table 6).

## N contents

Plant total N content of soybean was highest in carbonized chicken manure amended plants followed by carbonized RDF amended plants. Control soybean plants were least in plant total N content (Table 3). K fertilizer

only slightly increased plant total N content of carbonized chicken manure amended soybean plants while it had no effect on plant total N content of carbonized RDF amended soybean plants (Table 3). Seed total N content of soybean followed a similar trend as plant total N content of soybean. The only difference is that K fertilizer application increased seed total N content of carbonized chicken manure and carbonized RDF amended soybean plants while it had no effect on seed total N content of control soybean plants (Table 3). There was a significant positive relationship between seed total N content and seed yield of soybean ( $R^2 = 0.50^*$ , Figure 7).

Plant total N content of cowpea was highest in plants treated with carbonized chicken manure with or without K fertilizer followed by plants treated with carbonized RDF with or without K fertilizer. Control cowpea plants were lowest in plant total N content with or without K fertilizer (Table 4). K fertilizer application increased plant total N content in carbonized chicken manure and carbonized RDF amended cowpea plants but not in control cowpea plants (Table 4). Seed total N content of cowpea followed a similar trend (Table 4). However, K fertilizer application increased cowpea seed total N content in all treatments (Table 4). There was a strong positive relationship between plant total N content and seed yield of cowpea ( $R^2 = 0.72^{**}$ ) as well as between seed total N content and seed yield of cowpea ( $R^2 = 0.81^{**}$ , Figure 8).

## P contents

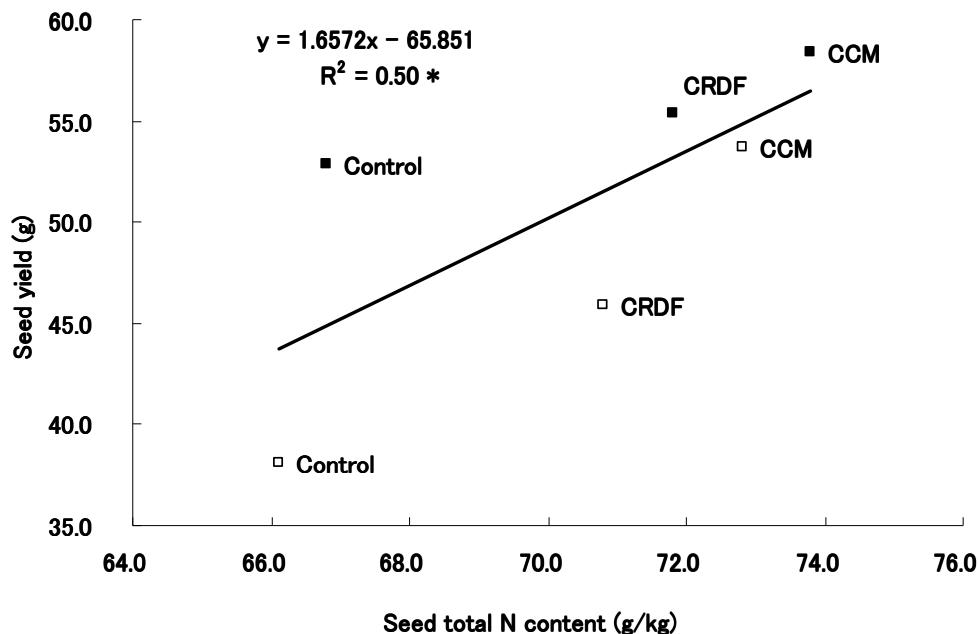
Plant total P content of soybean was affected by both carbonized organic amendment supply and K fertilizer application. Plant total P content of soybean was highest in plants amended with carbonized chicken manure with or without K fertilizer followed by carbonized RDF treated plants with or without K fertilizer. Control soybean plants were lowest in plant total P content (Table 3). K fertilizer application increased plant total P contents of all treatments (Table 3). Seed total P content of soybean followed a similar trend as plant total P content of soybean (Table 3). There was a positive relationship between plant total P content and seed yield of soybean ( $R^2 = 0.62^*$ , Figure 9).

Plant total P content of cowpea was affected by both carbonized organic amendment and K fertilizer application. Plant total P content of cowpea was highest in carbonized chicken manure amended cowpea plants with or without K fertilizer followed by carbonized RDF amended plants with or without K fertilizer. Plant total P content was lowest in control cowpea plants (Table 4). K fertilizer application increased plant total P contents of cowpea in all treatments. Seed total P content of cowpea followed a similar trend as plant total P content of cowpea (Table 4). There was a strong positive relationship between plant total P content and seed yield of cowpea ( $R^2 = 0.71^{**}$ , Figure 10). There was a strong positive relationship between seed total P content and seed yield

of cowpea ( $R^2 = 0.83^{**}$ , Figure 10).

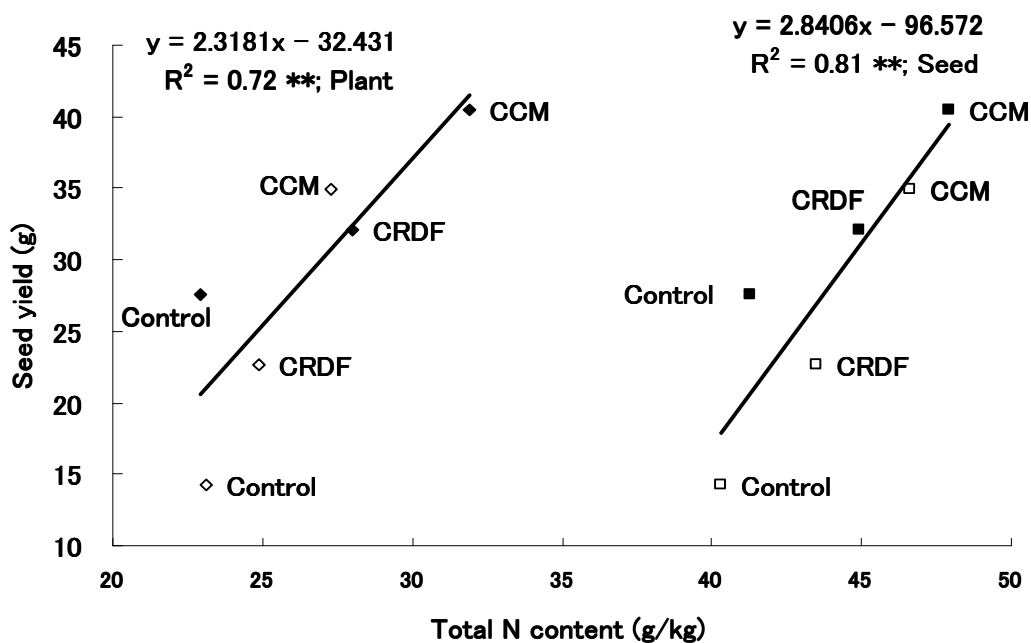
## DISCUSSION

The effects of two carbonized organic materials that is, chicken manure and refuse derived fuel (RDF) with or without inorganic K fertilizer on the growth, nodulation, yield, N and P contents of two grain legumes i.e. soybean and cowpea were explored in this greenhouse trial. The application of carbonized chicken manure only increased seed yield by 41 and 146% in soybean and cowpea respectively while the application of carbonized chicken manure and inorganic K fertilizer increased seed yield by 53 and 185% in soybean and cowpea respectively. The application of carbonized RDF only increased seed yield by 20 and 59% in soybean and cowpea respectively while the application of carbonized RDF and inorganic K fertilizer increased seed yield by 45 and 126% in soybean and cowpea respectively. The trends for dry pod yield and total dry weight of both grain legumes were similar to that of their respective seed yields. This result is consistent with that reported by Rondon et al. (2007) who observed a 46% increase in common bean yield over the control in response to bio-char application. Chan et al. (2007) observed in their work that in the absence of N fertilizer, green-waste bio-char application to soil did not increase radish yield even at higher rates but reported significant bio-char and N fertilizer interaction highlighting the role of bio-char in improving N fertilizer use efficiency of the plant. Although few works are available for comparison with the results of this study, our results are consistent with previous works done using ordinary un-carbonized chicken manure. Garcia and Blancaver (1983) reported that the application of poultry manure increased soybean seed yield by 62% over the control. Schmidt et al. (2001) found that soybean seed yield increased linearly with increasing swine manure rate. Several researchers have reported soybean seed yield increases with applied commercial N fertilizer (Lamb et al., 1990; Wesley et al., 1998). The higher seed yields of both grain legumes in response to the application of carbonized organic materials especially carbonized chicken manure suggest that both N and P are important nutrients that influence the growth and yield of soybean and cowpea. Carbonized chicken manure and carbonized RDF contain high levels of macro-nutrients especially N and P as well as micro-nutrients that would be available to plant roots and soil biota. Hariston et al. (1990) and Schmidt et al. (2001) observed that soybean not only requires a considerable amount of N to produce a crop, but also a constant supply of available P to maintain rapid growth and development. Carbonized chicken manure and carbonized RDF are particularly rich in both total and available P and their application to soil at high rates can supply a considerable amount of available P for plant uptake. Again, carbonized organic materials such as



□ = Without K fertilizer; ■ = with K fertilizer; \* = significant at 5%.

Figure 7. Relationship between seed total N content and seed yield of soybean.

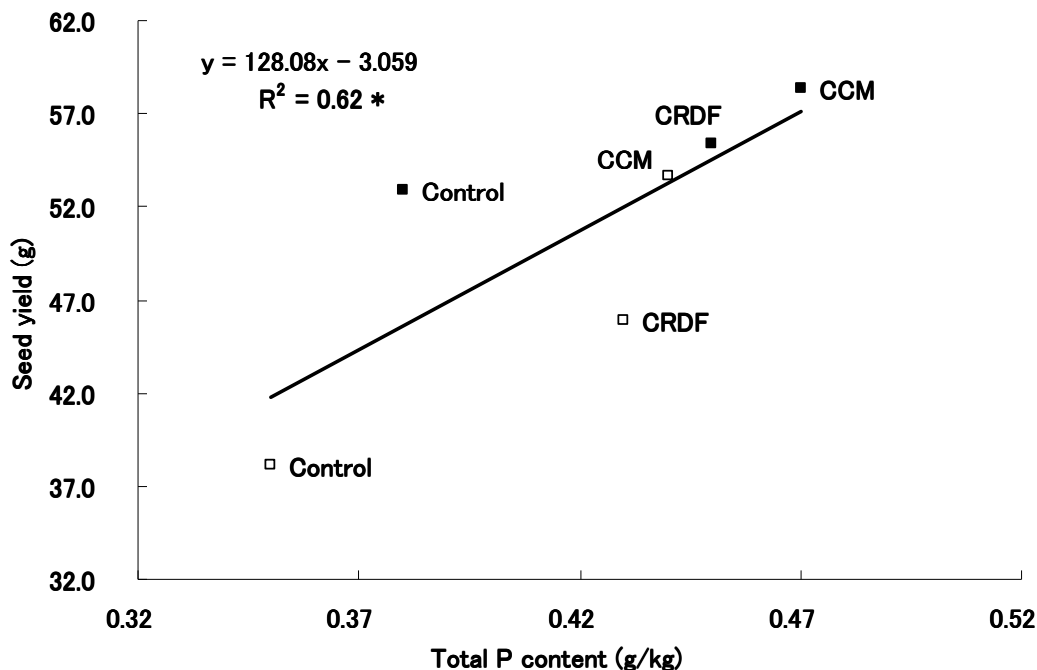


□ = Seed TN Without K; ■ = Seed TN With K; ◇ = Plant TN without K; ◆ = Plant TN with K; \*\* = significant at 1%.

Figure 8. Relationship between plant total N content, seed total N content and seed yield of cowpea.

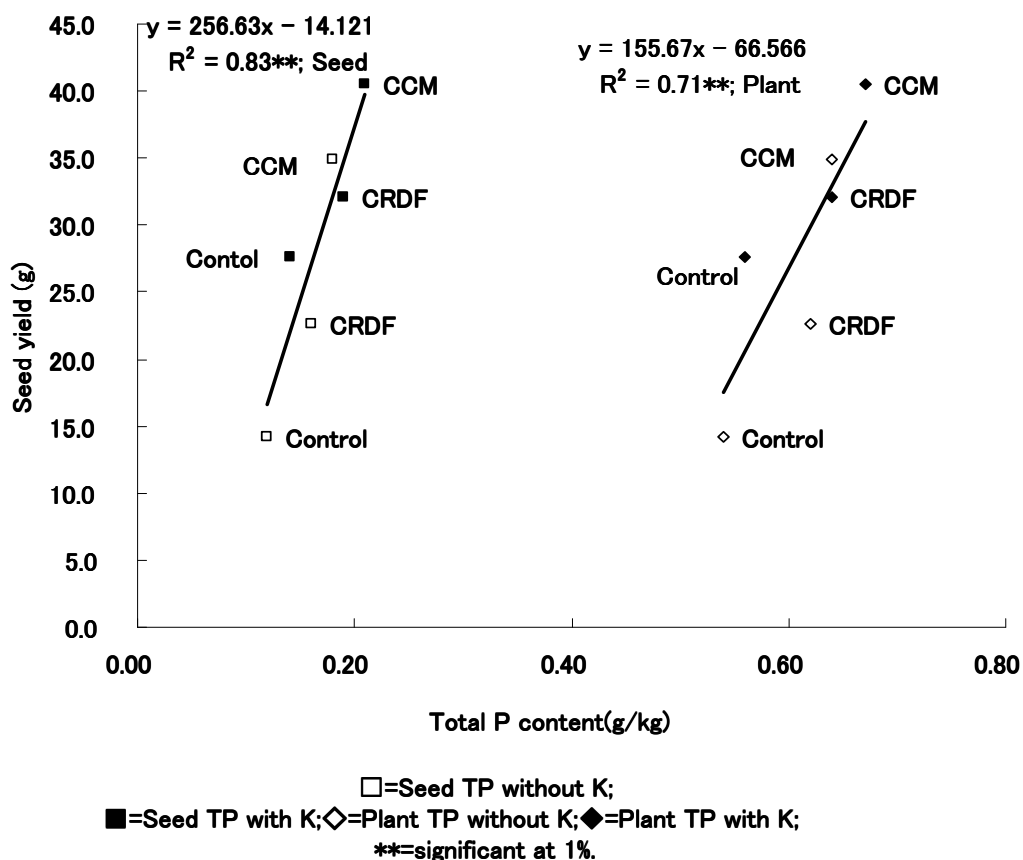
carbonized chicken manure, carbonized RDF and bio-char can act as soil conditioners to enhance plant growth by supplying macro and micro-nutrient elements,

retaining nutrients and improving soil physical and biological properties (Glaser et al., 2002; Lehmann and Randon, 2005). Abdelhamid et al. (2004) found increased



□ = Without K fertilizer; ■ = with K fertilizer; \* = significant at 5%.

Figure 9. Relationship between plant total P content at peak flowering and seed yield of soybean.



□ = Seed TP without K; ■ = Seed TP with K; ◇ = Plant TP without K; ◆ = Plant TP with K; \*\* = significant at 1%.

Figure 10. Relationship between plant total P content, seed total P content and seed yield of cowpea.

dry weight of faba bean as a result of chicken manure supply. Cowpea responded positively to the application of carbonized chicken manure and CRDF in this study in terms of growth parameters and seed yield. This response underscores the importance of P as a critical nutrient element influencing the performance of cowpea and soybean. Several researchers have reported significant responses of cowpea and soybean to P application (Tenebe et al., 1995; Ankomah et al., 1995; Okeleye and Okelana, 1997). They observed significant increases in total dry matter yield, number of flowers, pod and seeds per plant, seed yield and nodulation as a result of P application. Rondon et al. (2007) reported a 39% increase in biomass production of common bean in response to bio-char application which they attributed to greater availability of K, Ca and P. Chan et al. (2007) observed additional increase in dry matter of radish in the presence of N fertilizer varied from 95% in the control to 266% in the 100 t/ha bio-char amended soils. Carsky (2003) working on the response of cowpea and soybean to P and K on *terre de barre* soils in southern Benin, reported that soybean and cowpea grain yield increased by 147% and 95% respectively in response to P application.

Number of nodules of soybean and cowpea increased with the application of carbonized organic materials. This observation is consistent with that of Tagoe et al. (2008) who reported increased nodule abundance of soybean as a result of carbonized chicken manure application and attributed it to the high available P content of carbonized chicken manure. The application of carbonized chicken manure increased nodule abundance of both grain legumes more than carbonized RDF. This observation can be attributed to the high P content of carbonized chicken manure relative to carbonized RDF. Rondon et al. (2007) also observed that biological N<sub>2</sub> fixation of common bean increased with bio-char application. They reported that the proportion of fixed N increased from 50% without bio-char addition to 72% with 90 g kg<sup>-1</sup> bio-char added and attributed this observation to greater availability of B, and Mo and to a lesser extent K, Ca and P availability. The application of the carbonized organic materials plus K fertilizer further increased the number of nodules of both legumes thus confirming the hypothesis that K could limit the response of P from the carbonized organic materials in low P status soils (Carsky, 2003). P fertilization has been shown to increase number of nodules and their weight in soybean (Cassman et al., 1993; Jones et al., 1977) and in cowpea (Wan Othman et al., 1991). This is because P is known to initiate nodule formation, increases the number of nodule primordia and is essential for the development and functioning of formed nodules (Waluyo et al., 2004). Nodules are known to be a strong sink for P and P concentration in nodules can be three times higher than in other plant organs with a minimum effect from P deficiency (Vadez et al., 1999). Several researchers have reported that the supply of P

plays important roles in establishment, growth and function of nodules (Israel, 1987; Beck and Munns, 1984; Leung and Bottomley, 1987) and growth of host plants (Munns et al., 1981). Number of nodules is important because a positive correlation has been reported between nodule number and total nitrogenase activity of soybean (Singleton and Bohlool, 1984) and alfalfa (Porter, 1983).

According to Gates and Muller (1979) the application of fertilizer containing N, P and S to soybean contributed to forming a stronger symbiotic mechanism and more active N<sub>2</sub>-fixation. Since the carbonized organic materials used in this experiment especially carbonized chicken manure contain N, P and S (Sharpley et al., 1993) their application to soybean and cowpea could be beneficial to the symbiotic N<sub>2</sub>-fixing mechanism. Low P availability is especially problematic for leguminous crops because legume nodules responsible for N<sub>2</sub>-fixation have high P requirement (Vance, 2001). P is essential for plant growth, nodulation and N<sub>2</sub>-fixation (Pereira and Bliss, 1989). Nodule number as well as nodule dry weight is greatly reduced by P deficiency (Ribet and Drevon, 1995) and nitrogenase activity varies with P availability (Israel, 1987). Acute P deficiency is known to prevent nodulation of grain legumes. P deficiency is more likely to affect N<sub>2</sub>-fixation legumes than other species because symbiotic N<sub>2</sub>-fixation is an energetically expensive process which requires more P than does plant growth (Olivera et al., 2004). The strong positive relationship between number of nodules and plant total P content of soybean confirms the importance of P in legume nodulation.

Total N and total P contents of plant and seed of soybean and cowpea increased with the application of carbonized organic materials with or without inorganic K fertilizer. This observation is consistent with that reported by Jassen (1998) that nutrient uptake requires N, P and K in balance to reach maximum values. Adeli (2005) observed increased N concentration in the above ground biomass of soybean in response to poultry manure application. The application of chicken manure to faba bean increased total N contents in roots, shoots and the whole plant (Abdelhamid et al., 2004). Belle (2006) reported significant increases in the uptake of N and P in common bean as a result of the application of N and P fertilizers. Barker and Sawyer (2005) observed that N concentration in plant dry matter of soybean was increased significantly with applied N. Studies with several legumes have consistently shown a positive response to P application; whole plant N concentration and plant dry matter were found to increase in response to phosphate in the growth media (Pereira and Bliss, 1987). P application has been reported to influence the contents of other nutrients in cowpea leaves (Kang and Nangju, 1983), shoots (Bagayoko et al., 2000) and seed (Omueti and Oyenuga, 1970). Seed total N content of soybean was positively correlated with seed yield. Also plant total N and seed total N contents of cowpea were

correlated with seed yield of cowpea. These observations suggest the importance of N in the seed yields of these grain legumes due to the high protein contents of their seeds especially soybean. Plant total P content of soybean was positively correlated with soybean seed yield. Also, plant total P and seed total P contents were positively correlated with seed yield in cowpea. These observations underscore the importance of not only N, but P as well in increasing the growth and seed yield of these grain legumes.

Bio-char addition can result in elevated quantities of bio-available nutrients such as N, P and metal ions, in the soil (Tryon, 1948; Lehmann et al., 2003; Gundale and DeLuca, 2006; DeLuca et al., 2006). Addition of bio-char to soil alters important soil physical and chemical properties such as pH (Lucas and Davis, 1961) and typically increase soil cation exchange capacity (CEC) (Glaser et al., 2002), and can lead to greater water holding capacity (WHC) while generally decreasing bulk density (Tryon, 1948) as well as increase bio-available P and cations in soils. Improvement in physical properties of the soil as a result of the addition of carbonized chicken manure and carbonized RDF to a lesser extent, may have contributed to the increased growth and yield of the grain legumes.

## Conclusion

The growth, nodulation, seed yield, total N and P contents of plant and seed of soybean and cowpea all increased with the supply of carbonized chicken manure and carbonized RDF due to their high available P contents. The application of carbonized organic materials and inorganic K fertilizer increased grain yield and other parameters in both crops more than the sole application of the carbonized organic materials thus suggesting that it is a good potential option to be evaluated for use in the field and home garden for grain legume production.

## ACKNOWLEDGEMENT

The authors would like to express their profound gratitude to the Ministry of Education, Culture, Sports, Science and Technology, Japan for financial support without which this research would not have been possible.

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