Effect of biochar application to soil on komatsuna growth and nutrient leaching

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ABSTRACT

We evaluated the effect of the application of two biochar materials (rice husks and coconut shells) to soil. These materials were agricultural waste in rural areas in developing Asian countries. Komatsuna (*Brassica rapa* var. *perviridis*) was grown in sandy-soil pots treated with different biochar materials in a greenhouse from 25 April to 31 May 2012 in Okayama, Japan. Application of biochar materials led to increased uptake of nitrogen (N) and phosphorus (P) by the komatsuna. This is probably because soil water retention was improved with the incorporation of biochar. Coconut-shell biochar reduced total P leaching while it increased total nitrogen leaching due to less denitrification. Our results indicated that biochar has a great deal of potential as a soil additive but further studies should be undertaken to clarify the N dynamics in soil.

KEYWORDS

Biochar, komatsuna, leaching, nitrogen, phosphorus

INTRODUCTION

Agricultural wastes are increasing due to the economic growth in developing Asian countries. One possible way to recycle those wastes is the production of biochar materials for soil additives. Biochar is preferably produced from local agricultural wastes from viewpoints of treatment and material costs. Unused crop residues can be raw materials in rural areas in the countries because of sufficient and constant supply.

Biochar is defined as a solid material obtained from the carbonisation of biomass (International Biochar Initiative, 2012). Benefits of biochar application to soil are: i) increased soil carbon content (carbon sequestration), ii) improved physical properties (increased water retention and drainage), iii) decreased nutrient leaching, iv) improved fertility (nutrients release), v) reduced emissions of green house gases. However, contrasting results were reported on the effect of biochar on crop growth and nutrient leaching (Clough and Condron, 2010; Nelson et al., 2011).

The objective of the present study was to determine the influence of biochar application on plant growth and N and P leaching from soil. Biochar materials used in this study were produced from rice husks and coconut shells, which were common agriculture wastes in Asian countries.

MATERIALS AND METHODS

1. Biochar materials used

Coconut shells were collected from dumping garbage near Dong Ba Market in Hue, Vietnam in September 2011. Rice husks were provided from Nisshoku Corporation, Japan. Pyrolysis of coconut shells and rice husks was performed using a muffle furnace for 60 min at the temperature of 500 ^{o}C, with a rise rate of 10 ^{o}C min^{-1}. The yields of biochar from coconut shells were 40.5% and that from rice husks 45.9%. The yield of biochar from coconut shells was smaller than that from rice husks.

2. Pot experiments

Komatsuna was grown in Wagner's pots with 200 cm^2 area and 19 cm deep, in which 3 kg of sandy soil (Masa soil, 14 cm high) on 1.1 kg of gravel (4.9 cm high) was packed, in a greenhouse at Okayama University, Japan from 25 April to 31 May 2012. Total C and N contents in soil were both not detectable. Ammonium-N and NO_3^--N was not detected in the soil and Truog-P content in soil was 40 mg kg^{-1}. As shown in Table 1, experimental treatments include no addition of biochar and additions of rice-husk biochar or coconut-shell biochar (1500 g m^{-2} each) in triplicate. The biochar materials were mixed in the top layer (0–7 cm). Chemical compounds were applied to the top layer just before sowing of komatsuna seeds (3 in each pot) at rates of 12 g N m^{-2}, 4.4 g P m^{-2}, and 10 g K m^{-2}(indicated as ×1 hereafter), which followed cultivation guidelines in Okayama, or at the double rates(indicated as ×2 hereafter). Irrigation was 4–7 mm day^{-1}.

3. Chemical analysis

The drainage of pots was collected in a 500-mL polyethylene bottle for few hours after every irrigation event. The weight of the leachate was measured. The subsamples of the leachate were immediately subjected to pH and electrical conductivity (EC) analyses (Horiba pH/Ion Meter F-23 and Horiba Conductivity Meter, DS-14, respectively). The rest of the subsamples were kept at -20 ^{o}C until the analysis of total N, nitrate–N (NO_3-N) and ammonium–N (NH_4-N), total P, and phosphate-P (PO_4-P) by using an automated continuous flow analyzer (BL-Tec, QuAAtro2-HR).

Harvested komatsuna plants were separated into above and root parts, immediately weighed and dried at 70 ^{o}C for 1 week. Total N and P contents were determined after the Kjeldahl digestion with the automated continuous flow analyzer.

Table 1 Experimental design of the study

Treatment	Biochar*	N input g m^{-2}	P input g m^{-2}	K input g m^{-2}
No char (NPK×1)	No addition	12	4.4	10
No char (NPK×2)	No addition	24	8.8	20
Rice (NPK×1)	Rice husks	12	4.4	10
Rice (NPK×2)	Rice husks	24	8.8	20
Coconut (NPK×1)	Coconut shells	12	4.4	10
Coconut (NPK×2)	Coconut shells	24	8.8	20

* The application rate of biochar materials was at 1500 g m^{-2}.

After the harvest of komatsuna plant, soil samples were destructively collected from two layers: the top (0–7 cm) and lower layers (7–14 cm). These field-moist subsamples were extracted with 2 *M* KCl at a 1:10 solid water ratio for determination of extractable NO_3-N and NH_4-N, and with the Truog solution (1×10^{-3} *M* H_2SO_4, 3 g $(NH_4)_2SO_4$ L^{-1}) at a 1:200 ratio for Truog (available) P. Those concentrations in extracts were analyzed with the automated continuous flow analyzer.

4. Statistical analysis

A two-way analysis of variance (ANOVA) was computed to determine the effect of biochar and fertilizer using the open-source statistical package R (R Development Core Team, 2008). The statistical differences in the means of uptake and leaching loss of N and P among different treatments were detected by using Tukey's multiple-comparison test at $p = 0.05$.

RESULTS AND DISCUSSION

1. Nutrient uptake by komatsuna

Both biochar applications increased the uptake of N ($p < 0.01$, Fig. 1) and P ($p < 0.05$, Fig. 2) in leaves by komatsuna. This is probably because soil water retention was improved with the incorporation of biochar materials. For N uptake, this trend was more obvious in treatments receiving the double rates of fertilizer (Fig. 1). For P uptake, more P was absorbed by komatsuna leaves in the rice-husk treatment with the double rates of fertilizer (Rice×2, Fig. 2). In contrast, dry matter yields were not significantly different among treatments ($p > 0.05$).

2. Nutrient leaching and retention

Most of total N leached was in the form of NO_3-N. The amount of total N losses during the experiment was the greatest in the coconut-shell treatment with the double rates of fertilizer (Coconut×2, Fig. 3). After the harvest of komatsuna, NO_3-N remained in the top layer was significantly higher in this Coconut×2 treatment (0.6 g m^{-2}, $p < 0.05$) probably due to more nitrification and/or less denitrification, than in other treatments (< 0.12 g m^{-2}). Biochar from coconut shells may have

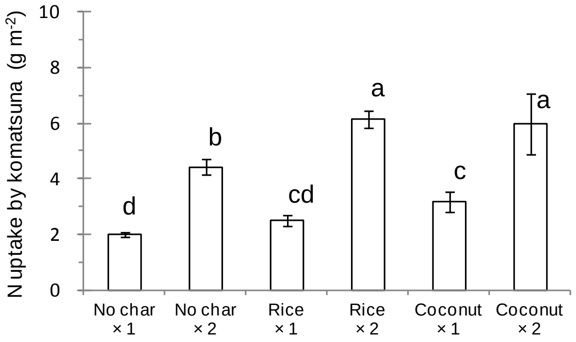

Fig. 1 Nitrogen in leaves absorbed by Komatsuna. ANOVA: Biochar at $p < 0.01$, fertilizer at $p < 0.01$, and the interactive effects at $p < 0.05$ were detected.

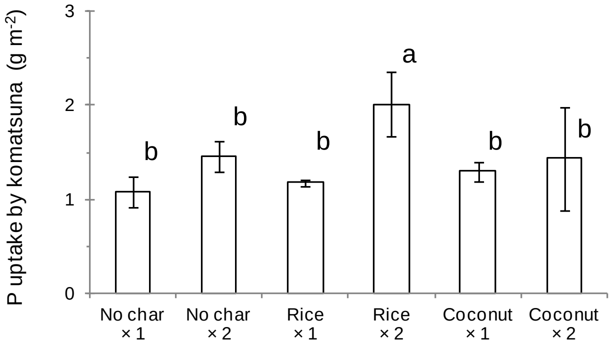

Fig. 2 Phosphorus in leaves absorbed by Komatsuna. ANOVA: Biochar at $p < 0.05$, fertilizer at $p < 0.01$, and the interactive effects at $p < 0.05$ were detected.

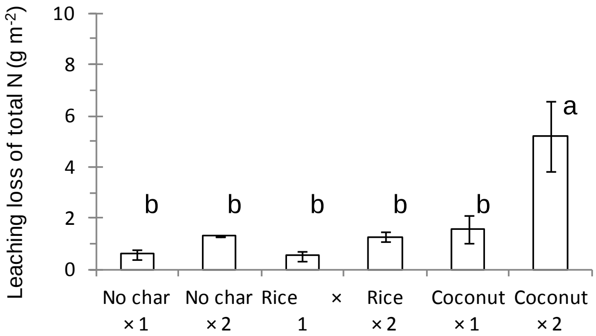

Fig. 3 Leaching loss of total nitrogen during the experiment. ANOVA: Biochar, fertilizer, and the interactive effects were detected at $p < 0.01$.

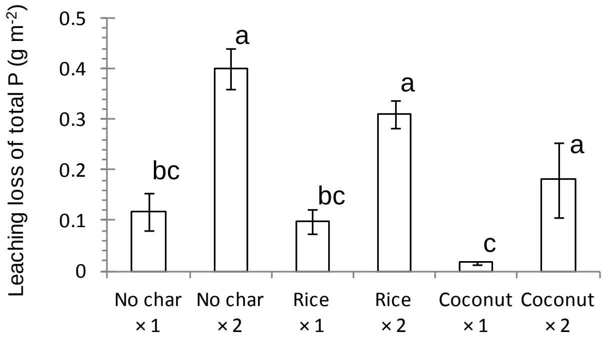

Fig. 4 Leaching loss of total phosphorus during the experiment. ANOVA: Biochar, fertilizer, and the interactive effects were detected at $p < 0.01$.

created more space of the air in soil. More NO_3-N in soil would lead to increased leaching of total N in Coconut×2. Total N concentrations reached to 154 and 92 mg L^{-1} in Coconut×1 and ×2, respectively.

Most of total P leached was in the form of PO_4-P. Biochar application significantly reduced total P ($p < 0.01$, Fig. 4). The amount of leaching losses of total P during the experiment was particularly lower in the coconut-shell treatment (Coconut×1 and ×2) than in other treatments with the double rates of fertilizer ($p < 0.05$, Fig. 3). After the harvest of komatsuna, Truog-P content in the top layer was the highest in Coconut×2 ($p < 0.05$) and the second highest in Coconut×1. Biochar from coconut shells retained more P, resulting in reduced P leaching. However, total P concentrations in leachate exceeded 0.2 and 2 mg L^{-1} even in Coconut×1 and ×2, respectively.

3. Inputs and outputs of nutrients

Inputs and outputs during the experiment is shown in Table 2. Recovery rates of N were 25–52% of each input. A large portion of N was presumably lost by denitrification (Table 2). In coconut shell treatments (Coconut×1 and ×2), the amounts of unknown N were smaller than in other treatments, which supported inferred less denitrification, which led to more N leaching in Coconut×2. The unknown fraction of N was large in this study and may have released nitrous oxide during the processes of nitrification and denitrification (Clough and Condron, 2010). We should further study the N dynamics in soil treated with biochar materials.

Recovery rates of P were 87–102% of each input (Table 2). Truog-P in the initial soil was comparable to the standard application rate of P fertilizer. More than 80% of input P remained in soil after the harvest of komatsuna. The amount of P leached accounted for 3.1% of the total P inputs in soil without biochar addition with the double rates of fertilizer (No char×2) while those did 2.3% and 1.2% in soil treated with rice-husk (Rice×2) and coconut-shell biochar materials (Coconut×2), respectively. Although the fraction of P leaching was small, total P concentrations were enough high as described above.

Table 2 Inputs and outputs of nutrients during the experiment (g m^{-2})

	Treatment					
	No char×1	No char×2	Rice×1	Rice×2	Coconut×1	Coconut×2
N inputs						
Fertilizer	12.0	24.0	12.0	24.0	12.0	24.0
Soil (mineral N)	0.0	0.0	0.0	0.0	0.0	0.0
Biochar	0.0	0.0	0.0	0.0	0.0	0.0
Total	12.0	24.0	12.0	24.0	12.0	24.0
N outputs						
Plant uptake	2.2	4.7	2.8	6.5	3.5	6.3
Leaching	0.6	1.3	0.5	1.3	1.6	5.2
Soil (mineral N)	0.2	0.9	0.1	0.9	0.1	0.9
Total	3.0	6.8	3.4	8.7	5.1	12.4
Unkown N	9.0	17.2	8.6	15.3	6.9	11.6
P inputs						
Fertilizer	4.4	8.7	4.4	8.7	4.4	8.7
Soil (Truog-P)	6.1	6.1	6.1	6.1	6.1	6.1
Biochar	0.0	0.0	0.2	0.2	0.9	0.9
Total	10.4	14.8	10.7	15.1	11.4	15.7
P outputs						
Plant uptake	1.2	1.6	1.4	2.1	1.4	1.6
Leaching	0.1	0.4	0.1	0.3	0.0	0.2
Soil (Truog-P)	8.4	11.0	8.9	11.3	10.2	13.5
Total	9.7	12.9	10.4	13.7	11.6	15.2
Unkown P	0.7	1.9	0.3	1.4	-0.3	0.5

CONCLUSIONS AND PERSPECTIVES

We evaluated soil application effects (better soil quality and crop growth) of biochar produced from coconut shells and rice husks. Biochar from both materials improved improve N and P uptake by komatsuna while did not affect the dry matter yield of komatsuna. Biochar addition to soil increased the retention of P in soil, resulting in reduced leaching losses of total P. On the other hand, coconut-shell biochar increased total N leaching when the double amount of N of fertilizer management guidelines was applied to the soil. Less denitrification would lead to more leaching of total N in this treatment. We further study the N dyanamics in soil treated with biochar materials.

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Influence of biochar application to soil komatsuna growth and nutrient leaching

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Purpose

- In the Asia-Pacific region, agricultural wastes are increasing due to their economic growth.
- It is a promising way to produce biochar for soil amendment from agriculture wastes.
- The purpose of the study was to examine the influence of biochar application to soil plant growth and nitrogen (N) and phosphorus (P) leaching from soil.

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Materials and methods

- Plant: Komatsuna
- Period: 25 April- 31 May (in the greenhouse)
- Wagner pots (ϕ200 cm^2, 19 cm deep)
- Biochar: Rice husk, Coconut shell (at 500℃, 60 minutes)
- Sandy soil: 3.0 kg + Gravel: 1.1 kg
- Fertilizer: N: $(NH_4)_2SO_4$, P: KH_2PO_4, K: KH_2PO_4, KCl
- Irrigation:

25 and 28 April:	20 mm
1- 16 May:	12.5 mm/3 days
19- 28 May:	20 mm/3 days
30 and 31 May:	50 mm

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Experimental design

Treatments	Biochar (g/m^2)	Fertilizer (g/m^2)		
		N	P	K
1. No char (NPK × 1*)	No addition	12	4.4	10
2. No char (NPK × 2)	No addition	24	8.7	20
3. Rice (NPK × 1)	Rice-husk 1500	12	4.4	10
4. Rice (NPK × 2)	Rice-husk 1500	24	8.7	20
5. Coconut (NPK × 1)	Coconut-shell 1500	12	4.4	10
6. Coconut (NPK × 2)	Coconut-shell 1500	24	8.7	20

*According the cultivation guideline in Okayama (2001)
All treatments were prepared in triplicate.

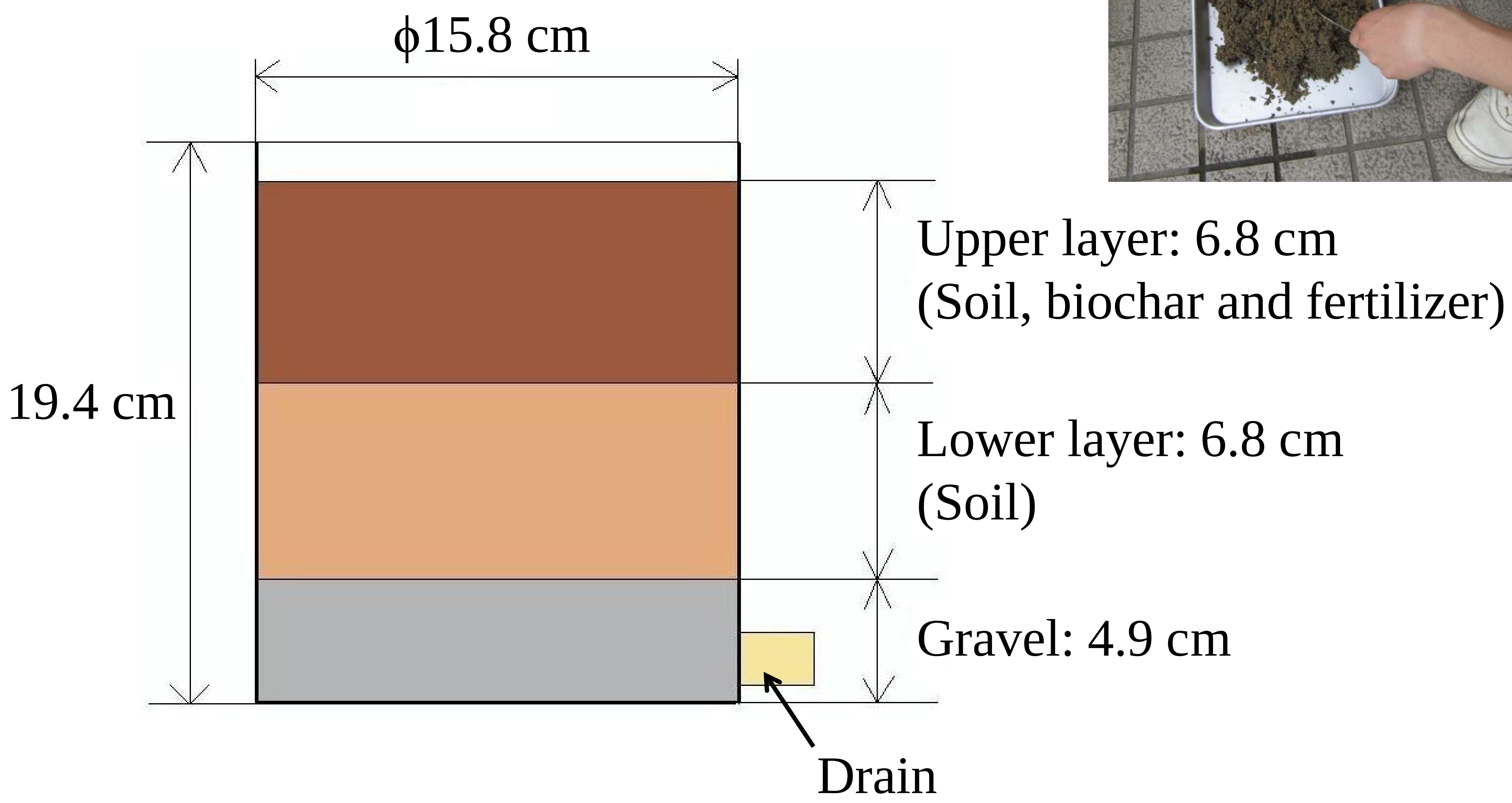
Properties of soil and biochar

Materials	pH	EC (mS/cm)	CEC ($mmol_c$/kg)
Sandy soil	8.7	0.007	–
Rice-husk	9.4	0.002	71.0
Coconut-shell	9.0	0.218	15.5

Nutrient inputs from soil and biochar (g/m^2)

NO_3-N	NH_4-N	PO_4-P	SiO_2-Si
0.0	0.0	6.0	–
0.0	0.0	0.2	0.9
0.0	0.0	0.9	0.4

Experimental pots



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Measurement

- During the experiment (with irrigation)
  N and P leaching via drainage water
- After the experiment
  Komatsuna (dry matter weight, N, P)
  Contents of mineral N and P in soil
- Statistical analysis
  ANOVA and Tukey's multiple comparison test
  (R software, Version 2.15.0)

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Results

Water balance

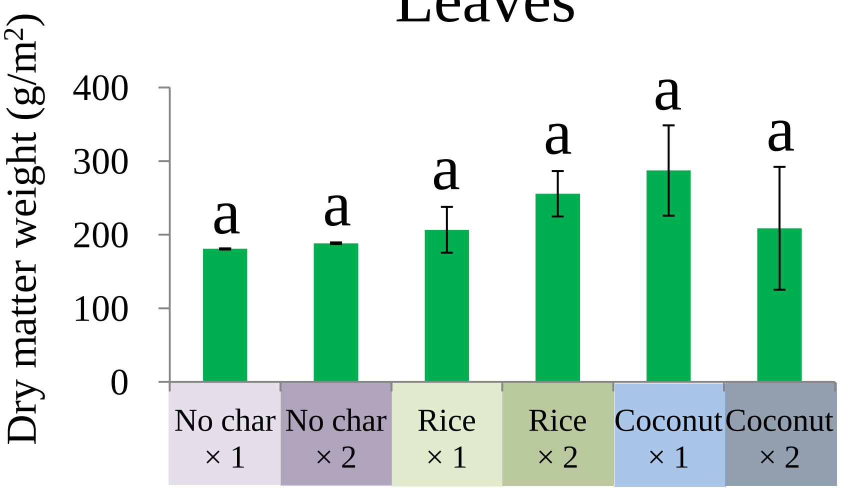
Treatments	Irrigation (mm)	Discharge (mm)	Average of soil water (mm)	Evapotranspiration (mm)
1. No char × 1	309[a]	170[ab]	23[c]	116[ab]
2. No char × 2	310[a]	181[a]	23[c]	106[b]
3. Rice × 1	310[a]	158[ab]	26[b]	126[ab]
4. Rice × 2	309[a]	161[ab]	26[b]	122[ab]
5. Coconut × 1	310[a]	142[b]	27[a]	140[a]
6. Coconut × 2	310[a]	165[ab]	29[a]	116[ab]

- Discharge: No char × 2 > Coconut × 1
- Average of soil water: Coconut > Rice > No char
- Evapotranspiration: Coconut × 2 > No char × 2

→ Biochar kept soil moisture content higher.

Komatsuna growth (dry matter weight)

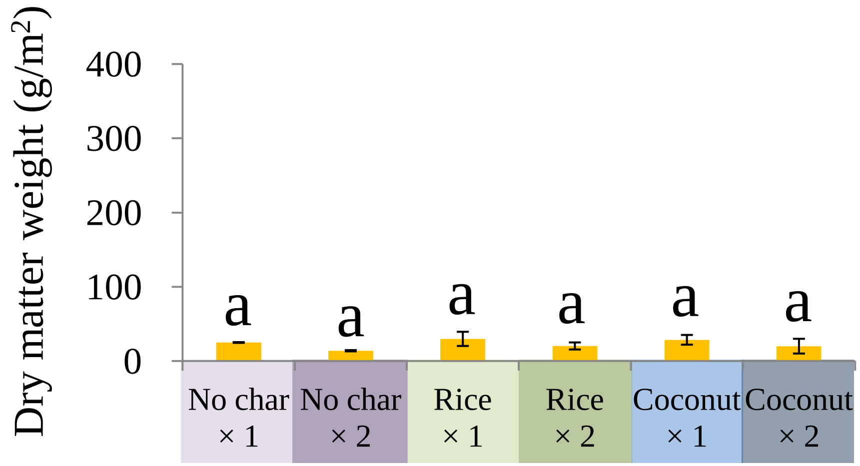
Leaves



Biochar
Fertilizer
Bio × Fer

ANOVA
* : $p < 0.05$
** : $p < 0.01$

Roots

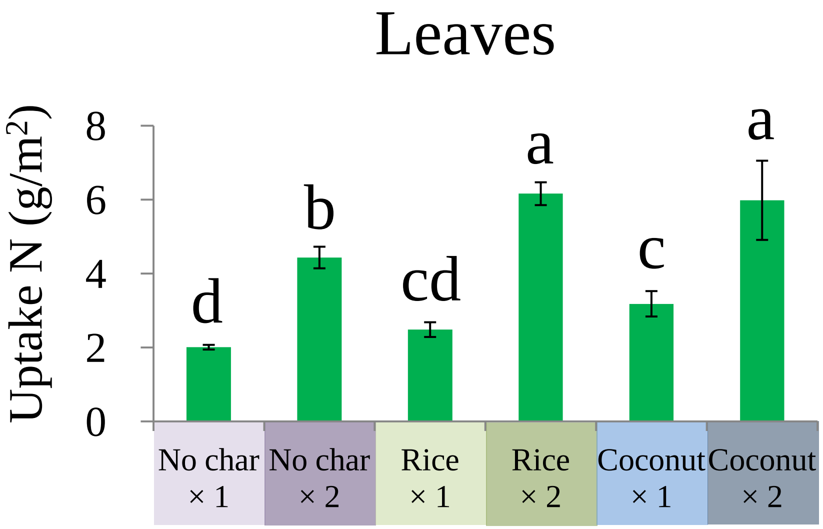


Biochar
Fertilizer **
Bio × Fer

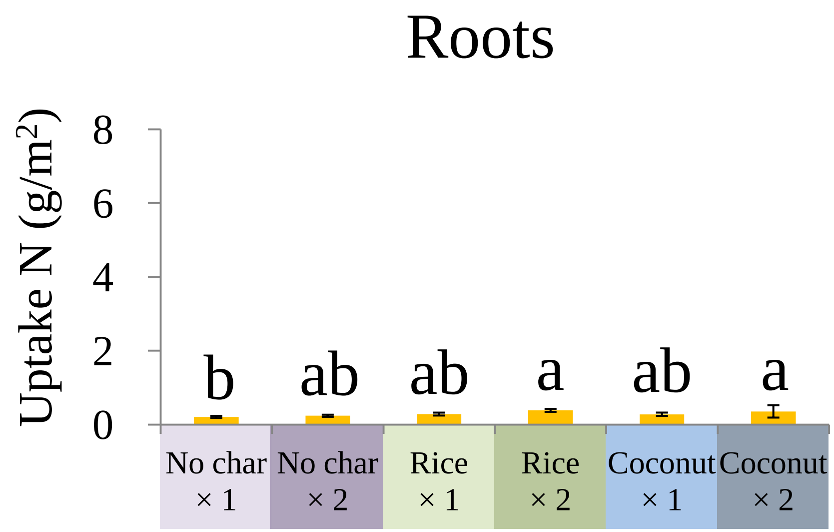
Not significantly different ($p > 0.05$)

→ Biochar did not significantly affect komatsuna growth.

N uptake by komatsuna



Biochar **
Fertilizer **
Bio × Fer *



Biochar **
Fertilizer *
Bio × Fer

Biochar increased N uptake ($p < 0.01$).

This trend was clearer in × 2 treatments.

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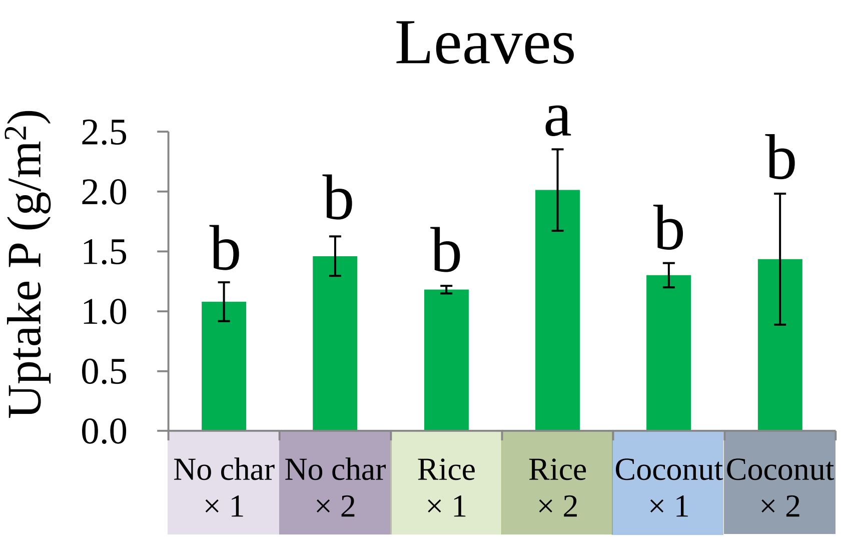
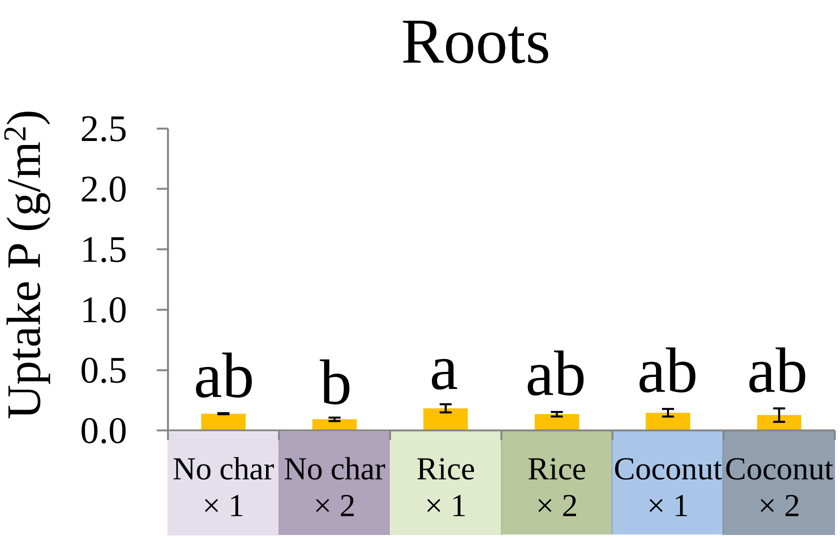
P uptake by komatsuna



Biochar *
Fertilizer **
Bio×Fer *



Biochar
Fertilizer **
Bio×Fer

Biochar increased P uptake in leaves ($p < 0.05$).

This trend was clearer in Rice×2.

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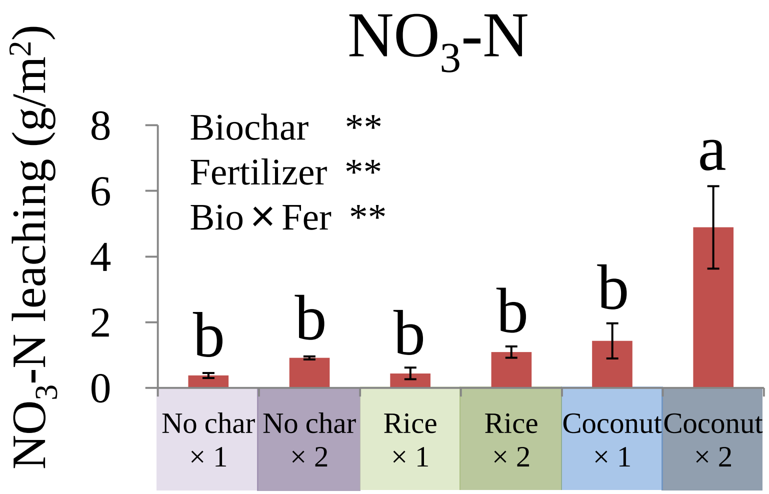
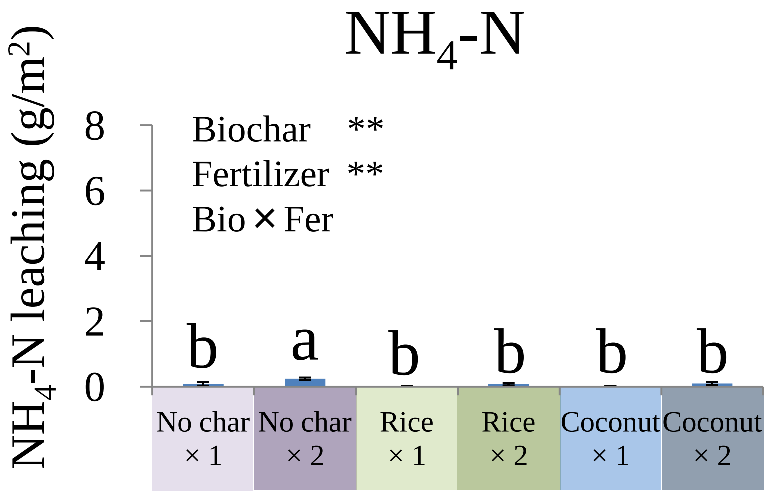
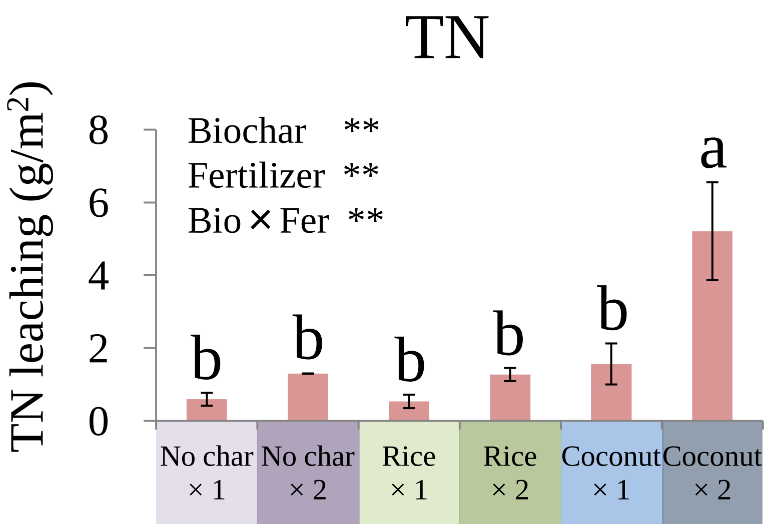
N leaching







Coconut-shell biochar increased N leaching ($p < 0.01$).

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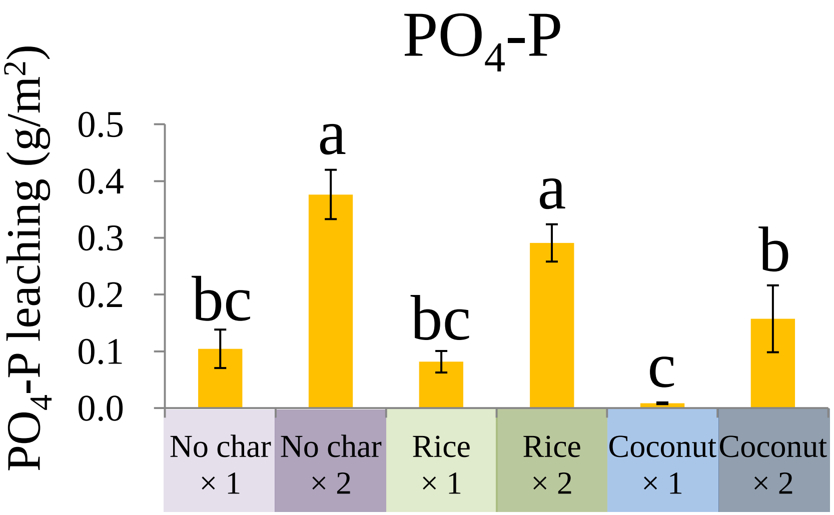
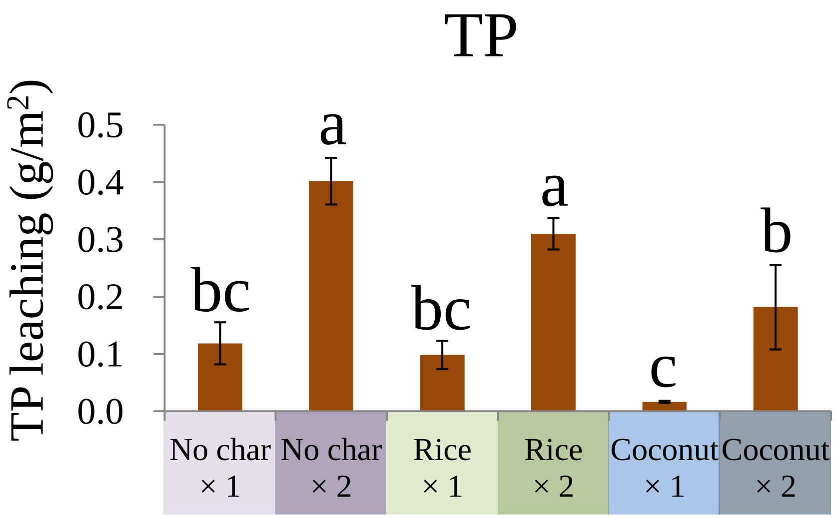
P leaching



Biochar **
Fertilizer **
Bio × Fer *



Biochar **
Fertilizer **
Bio × Fer **

Biochar reduced P leaching ($p < 0.01$).

This trend was clearer in Coconut treatments.

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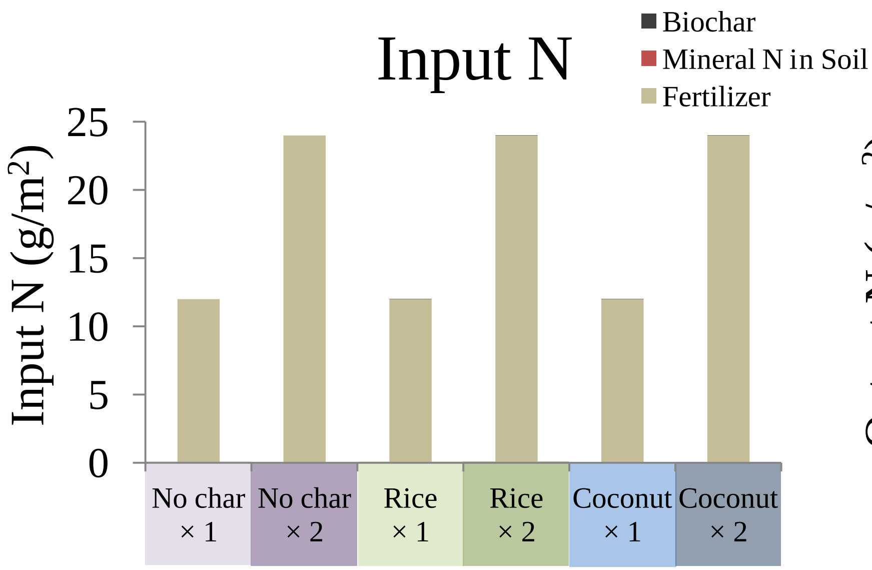
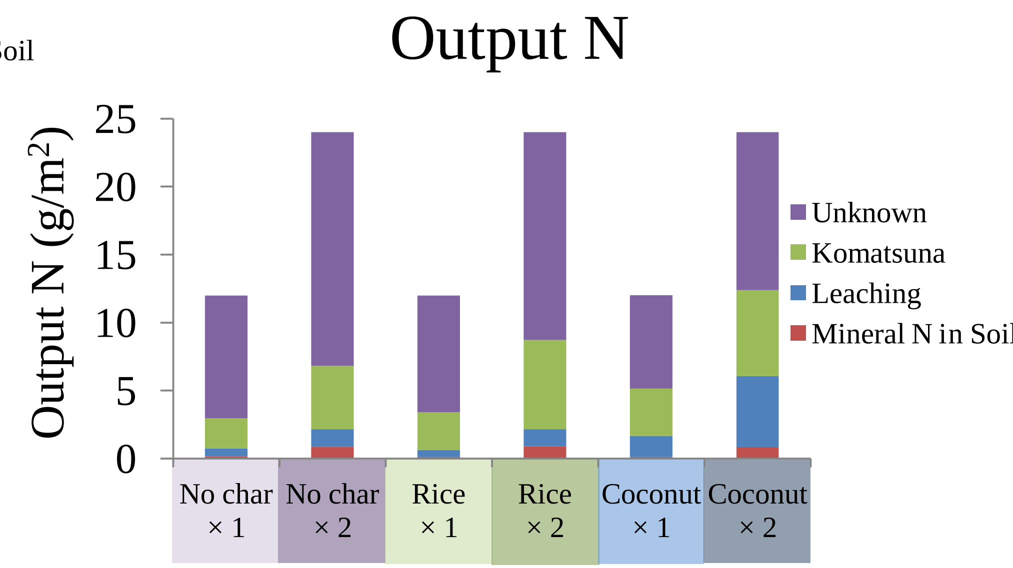
N Input and Output





Recovery rate (%)

No char × 1	25
No char × 2	29
Rice × 1	28
Rice × 2	36
Coconut × 1	43
Coconut × 2	52

- Input: Fertilizer
- Output: More than half was unknown.
  Leaching was higher in Coconut × 2.

→ Denitrification

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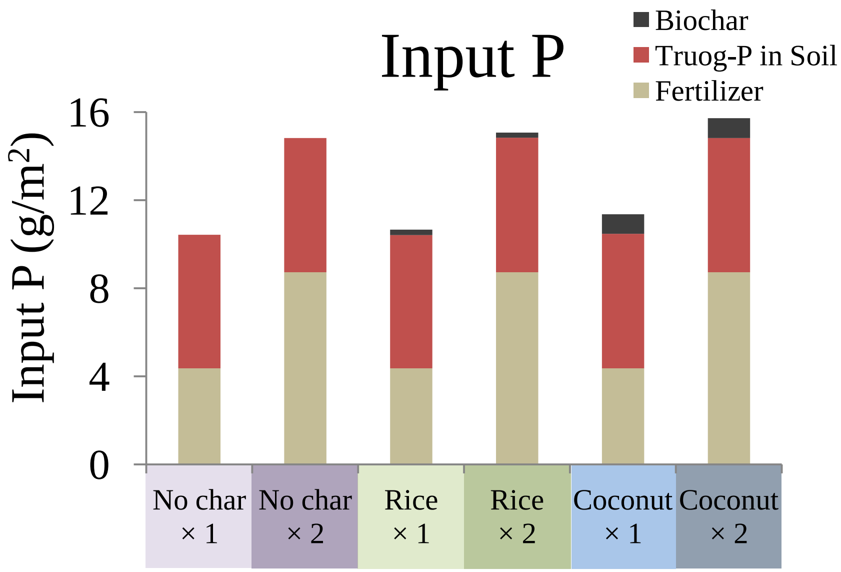
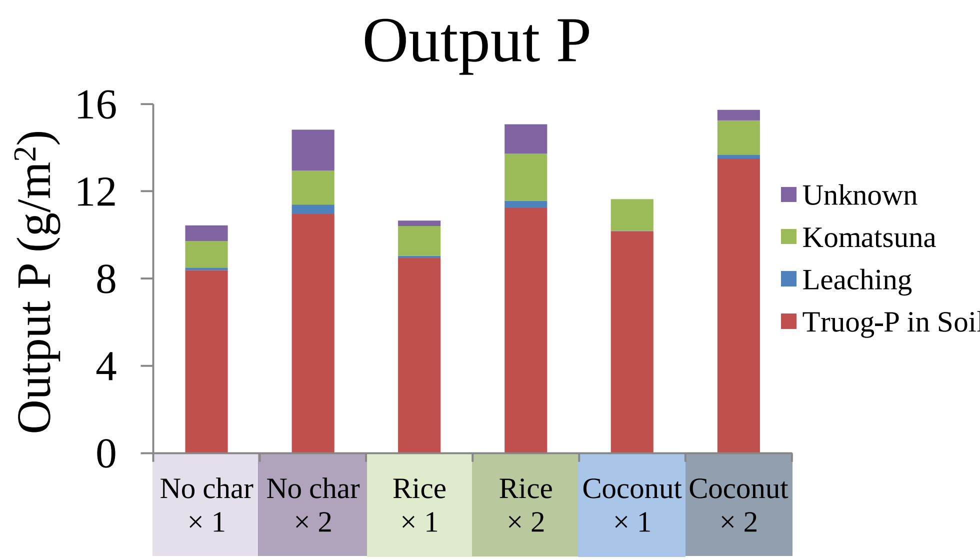
P Input and Output





Recovery rate (%)

No char × 1	93
No char × 2	87
Rice × 1	98
Rice × 2	91
Coconut × 1	102
Coconut × 2	97

- Input: Fertilizer and soil mineral P
- Output: Truog-P in soil
- Recovery rate was more than 90%.

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Conclusion

We examined the effect of biochar application to soil on plant growth and nutrient leaching.

Results showed:

1. Biochar kept soil moisture content higher.
2. Coconut-shell biochar reduced P leaching.
3. Coconut-shell biochar might reduce denitrification in soil, which led to increased N leaching.
4. N dynamics in soil should be further studied.