# Effects of Biochar Addition on Nitrogen Leaching Loss in the Vegetable Soil

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*Abstract*—**Leaching loss from vegetable production systems was one of the mainly polluters to lake eutrophication in China, which could be attributed to poor soil nitrogen retention capacity caused by intensive cultivation. It was hypothesized that biochar addition to soils used for vegetable production could reduce leaching loss by improving soil nitrogen retention. A pot experiment was conducted with soil collected from a vegetable field in the Tailake region. Three levels of biochar (0, 1%, 5%) were added into the soil in the no nitrogen and nitrogen conditions. The soil ammonium nitrogen content was increased due to biochar addition from 5.64 mg/kg to 12.47 mg/kg and 20.28 mg/kg to 34.54 mg/kg in the no nitrogen and nitrogen conditions, respectively. Volume and nitrate concentration of leachate was significantly decreased in soils amended with biochar by 17%-58% and 6%-35%, respectively. Biochar addition could increase soil water retention capacity and residence time of nitrate nitrogen for pakchoi uptake. It was suggested that biochar could be used as a potential soil amendment to improve soil nitrogen retention and reduce nitrogen leaching for vegetable production. Therefore, the contribution of vegetable production systems to lake eutrophication could be decreased by biochar addition.**

***Index Terms*—biochar addition, leaching loss, soil nitrogen retention, eutrophication, vegetable system**

## I. Introduction

Nitrogen is an indispensable nutrient element for crop growth and is also the element stimulating the growth of algae-eutrophication in lake systems.

Data from Chinese government pollution census showed $1.60\times10^9$ kg N got lost from agricultural soils [1] inducing 58% contribution to lake eutrophication as pollution [2], [3]. Compared to conventional crops systems (such as paddy, wheat, maize), vegetable production systems have a greater potential for nitrogen leaching due to intensive cultivation and frequent irrigation [4]. Vegetable fields are usually plowed three to five times in one year after every harvest season in China [5]-[7]. Frequent cultivation destroys the soil aggregate structure that reduces soil nutrient retention capacity [8]-[10]. Nitrogen losses via leaching is the the primary nitrogen loss pathway in vegetable production system, which can reach up to 50% of nitrogen fertilizer application rate [11]-[13] and account for over 70% of the total nitrogen loss [14]. The risk of nitrogen losses through leaching is even higher in the Tailake region due to the higher annual precipitation (over 1,000 mm). Hence, enhancing soil nitrogen retention capacity is the key to reduce nitrogen leaching loss from vegetable production fields which would decrease the contribution of vegetable production systems to lake eutrophication.

Biochar is a fine-grained and porous substance, produced through modern pyrolysis processes under oxygen-free or anoxic conditions at a relatively low temperature (450 ℃ – 650 ℃) [15], from a wide range of biomass sources including woody materials and agricultural residues [16], [17]. In recent years, biochar has received much attention with regard to its ability to increase crop yield by regulating nitrogen processes [18]-[23]. Studies on the effect of biochar addition on soil nitrogen leaching found that ammonium concentration of leachate decreased and this was attributed to adsorption by biochar [19], [24], [25]. Furthermore, other studies also reported that biochar provided a fine water- retaining capacity [26]-[28]. The addition of biochar into vegetable soils could offer an alternative for addressing the problem of nitrogen loss through leaching by enhancing soil nitrogen retention capacity [18], [29]-[31].

However, nitrogen is lost mainly through leaching in the form of nitrate nitrogen [12] and the effects of biochar on nitrate nitrogen of leachate are inconsistent [23]-[25], [32], [33]. The effect of biochar addition on leachate volume has been ignored to some extent. There was a lack of attention being paid to the change of soil nitrogen retention capacity after biochar addition. Moreover, the data on biochar addition to soils used for vegetable production under intensive cultivation systems has not been well documented. Therefore, there is an urgency to study the effect of biochar addition on soil nitrogen retention capacity and to determine the effect on nitrogen leaching loss in in vegetable production fields.

## II. Materials and Methods

### A. Descriptions of Soil Planting and Biochar

Soil used for the pot experiment in this study was collected from a vegetable field (31°17'N, 119°54'E) in

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Yixing City, China. This vegetable field was located in the Tailake region, with a subtropical monsoon climate, with an average annual temperature and rainfall of 15.7 ℃ and 1,177 mm, respectively. This vegetable field has been under paddy production for hundreds of years before being converted to vegetable production in the past 10 years with planted 3-4 times (seasons) and applied 900 -1300 kg N/ha in one year [9], [14], [28], [32]. The soil is a Hydragric Anthrosols evolved from lacustrine deposits, with a pH ($H_2O$) of 5.56; an organic matter (SOM) content of 18.2 g/kg; total N (TN) and phosphorus (TP) contents of 1.21 and 0.62 g/kg, respectively; and mineral N, available phosphorus and potassium contents of 64.77, 73.0 and 152.3 mg/kg, respectively.

Pakchoi (*Brassica chinensis L.*) is a type of Chinese cabbage, popular in southern China and Southeast Asia. The typical growing period for pakchoi is 20-35 days in a moderate climate (around 25 ℃). The nitrogen applied on vegetable fields for the production of pakchoi planting is nearly 200 kg/ha every season [34] in the Tailake region.

Biochar used in this study was produced from wheat straw using a biogas-energy slow pyrolysis system. The reactor was heated via a step-wise procedure under oxygen-limited conditions. The temperature was increased to 450 ℃ at a rate of 5 ℃ per minute and was then maintained for over 5 hours until no visible smoke was emitted from the gas vent. The biochar properties in this study are as follows: Total Nitrogen (TN) and Total Carbon (TC) contents were 12.5 and 503.1 g/kg, respectively; ammonium and nitrate nitrogen contents were 1.8 and 3.0 mg/kg, respectively; pH 8.9; and BET 7.4 $m^2$/g. The biochar was milled to pass through a 0.25-mm sieve prior to experimental application.

## B. Pot Experiment

The pot experiment was carried out in the greenhouse at the Jiangsu Agricultural Academy of Sciences, with the temperature maintained between 25 ℃-35 ℃ (The temperature outside ranged from 15 ℃-40 ℃ during this period.). Soil was sampled from the 0-20 cm profile depth from a vegetable field two months after the harvesting of a celery crop. The collected soil was air-dried and 2 kg was used to fill pots with the following dimensions: 28 cm in height, 15 cm in width and 10 cm in depth. One pot was considered as an individual unit for sampling, harvesting and data analysis. The vegetable pakchoi was planted for four growing seasons beginning in April 2016 until November 2016.

The experiment comprised three biochar addition levels (0, 1% w/w, 5% w/w) in the two nitrogen conditions (no nitrogen and nitrogen) (Table I).

TABLE I. THE TREATMENTS IN POT EXPERIMENT WITH 4 GROWING SEASONS

| Treatments | Rates of biochar addition (% w/w) | Rates of nitrogen fertilizer application (mg N/kg soil) |
|---|---|---|
| CK | 0 | 0 |
| 1%BC | 1 | 0 |
| 5%BC | 5 | 0 |
| CKU | 0 | 100 |
| U1%BC | 1 | 100 |

Biochar was weighted as the additional rate for each pot (20 g biochar for each pot of 1%BC and U1%BC treatments and 100 g biochar for each pot of 5%BC and U5%BC treatments). Three grams of biochar was separated, divided into three equal parts and then packed into three non-woven bags (1g/bag) which allowed water, nutrients and microbes, but not soil or biochar particles, to pass through. The rest of the biochar (17 g biochar for 1%BC and U1%BC treatments and 97 g biochar for 5%BC and U5%BC treatments) was mixed through with 2 kg air-dried soil (Fig. 1).


Figure 1. Method for biochar addition.

All of the packs were buried 3 cm below surface soil at the beginning of pot experiment. Soil and biochar were left standing for 10 days in a state of steady soil microbial activity with moisture being maintained by irrigation.

After that, 85 mg P/kg and 120 mg K/kg chemical fertilizers were applied as base fertilizers and 0.2 g (about 50-60 seeds) seeds were sown into each pot containing soil (P, K fertilizer application repeated every growing season). The germination time was calculated from planting date until more than 35 seeds had germinated (3-5 days after sowing). $^{15}$N-labeled urea with 10 atom% $^{15}$N excess was used as the nitrogen chemical fertilizer. During 1$^{st}$ – 3$^{rd}$ seasons, 100 mg N/kg was applied into the pots of CKU, U1%BC and U5%BC treatments at the 14$^{th}$ day every season but no more nitrogen fertilizer was applied to any treatment in the 4$^{th}$ season. Pakchoi was harvested on the 35$^{th}$ day, and another growing season began after pre-treatment (Fig. 2).

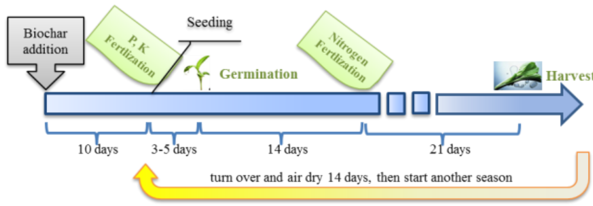



Figure 2. Process of one growing season (nitrogen fertilizer only applied in the 1$^{st}$, 2$^{nd}$ and 3$^{rd}$ growing seasons).

## C. Simulation of Leaching

Trays were placed under each pot to collect all the leachate flowing from the three pores at the base of the pots. Since there was no natural rainfall in the greenhouse, excess irrigations were implemented four times (on the 7$^{th}$, 14$^{th}$, 21$^{st}$ and 28$^{th}$ days) during every growing season. An amount of 1.05 L deionized water was added for every irrigation event (4.2 L every season) to each pot (equivalent to 25 mm precipitation per event and 100 mm precipitation in one growing season). Deionized water was added frequently in small quantities to avoid water flowing down along the inner wall. The process of irrigation was carried out over two hours.

### D. Sampling

One composite soil sample was collected from each pot by mixing four soil cores after the pakchoi harvest in each growing season. The soil samples were air dried and then divided into two subsamples. One subsample was passed through a 2-mm sieve to remove large organic debris and then stored in plastic bags at 4℃ for subsequent determination of mineral nitrogen (ammonium and nitrate nitrogen) content.

Biochar was sampled from 1%BC, 5%BC, U1%BC and U5%BC treatments by taking back the 3 buried non-woven bags after the pakchoi harvest. Three pots in each of these treatments would be used for biochar sampling every season and cannot be used for pakchoi planting for the next season. The biochar in the 3 non-woven bags was taken out and stored in plastic bags at 4℃ for subsequent determination of mineral nitrogen (ammonium and nitrate nitrogen) content.

Leachate was collected 6 hours after each excess irrigation event from the tray under each pot.

### E. Sample Analysis

The soil and leachate samples were collected from every pot with pakchoi in a specific season. Due to the decrease in replicates of biochar relative treatments (1%BC, 5%BC, U1%BC and U5%BC treatments), the number of soil and leachate samples changed with deceasing replicates. The mean value (and SD) of data from soil and leachate analysis was calculated based on all the samples collected in a specific season. However, biochar analysis was always based on the samples from the 3 replicates.

#### 1) Leachate

Leachate volumes were measured and recorded immediately after sampling from each pot. For the ammonium and nitrate analysis, every leachate sample was filtered through 0.45 lm membranes respectively and the ammonium and nitrate concentrations were determined using a continuous-flow analyzer (Skalar Corp., Netherlands). The amount of nitrogen lost via leaching was calculated with the equation (1) and (2):

$$m_{n\ (leaching\ loss)} = \rho_{n\ (leachate\ N)} \times V_{n\ (leachate)} \tag{1}$$

where, $m_{n\ (leaching\ loss)}$= amount of nitrogen loss via leaching in $n$ time (mg/pot), $\rho_{(leachate\ N)}$ =mineral nitrogen concentrations (ammonium concentration and nitrate concentration) of leachate in $n$ time (mg/L), $V_{(leachate)}$ = volume of leachate in $n$ time (L/pot) and n=1, 2, 3, 4 means the data from 1$^{st}$, 2$^{nd}$, 3$^{rd}$ and 4$^{th}$ leaching in one growing season.

$$m_{(leaching\ loss)} = \sum_{n=1}^{4} m_{n\ (leaching\ loss)} \tag{2}$$

where, $m_{(leaching\ loss)}$ = amount of nitrogen loss via leaching in one growing season (mg/pot).

#### 2) Soil and biochar

Mineral nitrogen in the soil or mineral nitrogen retained by biochar was extracted using a 2 M KCl solution at a ratio of sample and solution=1:10, followed by shaking for 1 hour on the reciprocating shaker, and then filtering the extract. The extract was analyzed using an auto analyser (Traacs 800, Bran & Luebbe, Hamburg) to determine the mineral nitrogen content in soils and the mineral nitrogen retained by biochar.

The amount of the mineral nitrogen retained by biochar per kilogram soil was calculated using the following Equations (3), (4) and (5):

$$w_{(AN\ on\ BC)} = w_{(BC\ AN)} \times r \tag{3}$$

where, $w_{(AN\ on\ BC)}$=ammonium nitrogen retained by biochar per kilogram soil (mg/kg), $w_{(BC\ AN)}$ = ammonium nitrogen content per kilogram biochar (mg/kg), $r$ =biochar additional rate (1% w/w and 5%w/w in this study)

$$w_{(NN\ on\ BC)} = w_{(BC\ NN)} \times r \tag{4}$$

where, $w_{(NN\ on\ BC)}$=nitrate nitrogen retained by biochar per kilogram soil (mg/kg), $w_{(BC\ NN)}$ = nitrate nitrogen content per kilogram biochar(mg/kg)

$$w_{(MN\ on\ BC)} = w_{(AN\ on\ BC)} + w_{(NN\ on\ BC)} \tag{5}$$

where, $w_{(MN\ on\ BC)}$=mineral nitrogen retained by biochar per kilogram soil (mg/kg)

The percentages of the mineral nitrogen retained by biochar to the mineral nitrogen in soil were calculated with the Equation (6), (7) and (8):

$$P_{A(BC\ to\ soil)} = w_{(AN\ on\ BC)}/w_{(AN\ in\ S)} \tag{6}$$

where, $P_{A(BC\ to\ soil)}$ =the percentages of ammonium nitrogen from biochar, $w_{(AN\ in\ S)}$ =the ammonium nitrogen content in soil

$$P_{N(BC\ to\ soil)} = w_{(NN\ on\ BC)}/w_{(NN\ in\ S)} \tag{7}$$

where, $P_{N(BC\ to\ soil)}$ =the percentages of nitrate nitrogen from biochar, $w_{(NN\ in\ S)}$ =the nitrate nitrogen content in soil

$$P_{M(BC\ to\ soil)} = w_{(MN\ on\ BC)}/w_{(MN\ in\ S)} \tag{8}$$

where, $P_{M(BC\ to\ soil)}$ =the percentages of mineral nitrogen from biochar, $w_{(MN\ in\ S)}$ =the mineral nitrogen content in soil.

#### 3) Statistical analyses

The mean and standard differences (presented in figures), of three replications were used to ascertain soil mineral nitrogen contents and the amount of nitrogen loss. Significant differences were tested using the standard Analysis of Variance (ANOVA) by Duncan's multiple-range test at the 5% level (SPSS ver. 16.0 for Windows, SPSS Inc., USA).

## III. Result

### A. Nitrogen Leaching Loss

Leachate volumes were affected by the biochar addition but not with the nitrogen conditions. Similar values of leachate volume was observed between CK and CKU treatments, 1%BC and U1%BC treatments, 5%BC and U5%BC treatments, respectively. Biochar significantly reduced leachate volumes, and the reduction was higher at the 5% biochar addition rate. On average, 1% biochar addition (1%BC and U1%BC treatments) reduced leachate volume by 17%-48% and 5% biochar addition (5%BC and U5%BC treatments) reduced by 28%-58% compared to no biochar treatments (CK and CKU treatments) (Fig. 3).

In the no nitrogen condition, biochar addition increased ammonium nitrogen contents in the 2nd and 3rd growing seasons (Fig. 4a) and its effect on nitrate nitrogen was different (Fig. 4c) during the four growing seasons. However ammonium nitrogen in leachate was reduced by 9%-51% in response to 1% biochar addition and 10%-68% in response to 5% biochar addition (Fig. 4b), and nitrate nitrogen was reduced by 7%-33% in response to 1% biochar addition and 6%-35% in response to 5% biochar addition (Fig. 4d) in the nitrogen condition. Furthermore, the effect of biochar on ammonium and nitrate concentrations leachate was more pronounced in the 4th season than those in the first three seasons.

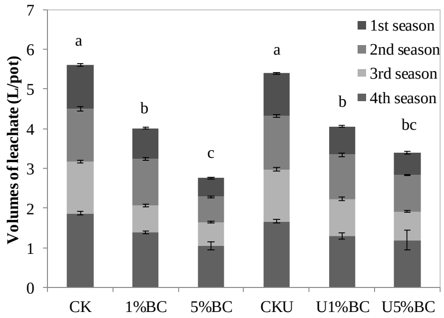
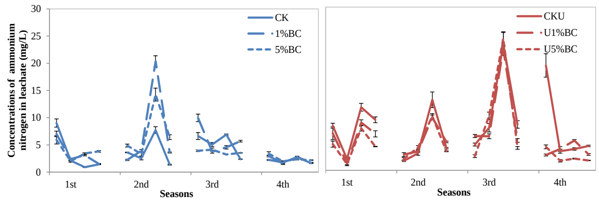
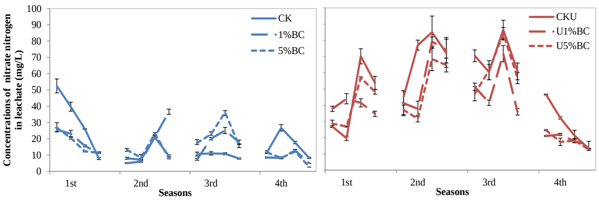



Figure 3. Volume of leachate in four growing seasons. Bars represent the SD of the means (n=3). Duncan's multiple-range test was used to determine the difference of the sum of leachate volume from four seasons. The same letters are not significantly different ($p<0.05$).



(a) Ammonium nitrogen concentration of leachate in the no nitrogen condition

(b) Ammonium nitrogen concentration of leachate in the nitrogen condition



(c) Nirate nitrogen concentration of leachate in the no nitrogen condition

(d) Nitrate nitrogen concentration of leachate in the nitrogen condition

Figure 4. Dynamics of mineral nitrogen concentrations in leachate. Bars represent the SD of the means (n=3).

Typically, nitrogen leaching loss in the nitrogen condition was 2.6-3.1 times higher than that in the no nitrogen condition (Fig. 5). The addition of biochar also reduced nitrogen loss via leaching by 37% and 55% in the 1%BC and 5%BC treatments compared to CK treatment. While U1%BC reduced 42% and U5%BC reduced 52% nitrogen loss via leaching compared to CKU treatment.

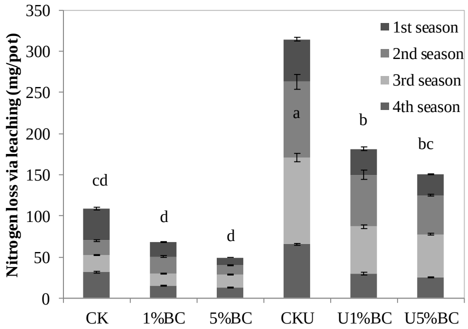
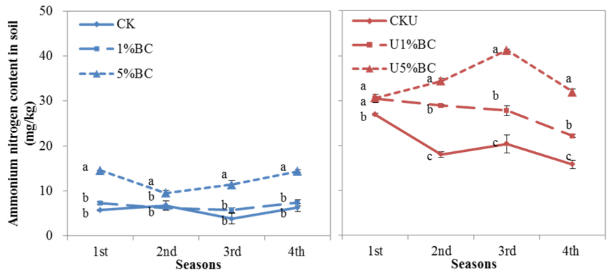



Figure 5. Mineral nitrogen loss from leaching. Bars represent the SD of the means (n=3). Duncan's multiple-range test was used to determine the difference of the sum of leachate volume from four seasons. The same letters are not significantly different ($p<0.05$).

## B. *Mineral Nitrogen Contents in Soils*

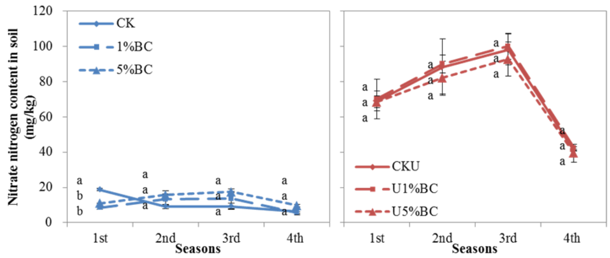
In the no nitrogen condition, biochar addition with 5% (5%BC treatment) significantly increased ammonium nitrogen content by 121% compared to no biochar treatment (CK treatment).

The ammonium nitrogen contents in the soil during growing seasons were on average 5.64 mg/kg, 6.61 mg/kg, 12.47 mg/kg for CK, 1%BC and 5%BC treatments, respectively (Fig. 6a). The ammonium nitrogen content showed slight changes over four continuous growing seasons. The nitrate nitrogen content in the soil were on average 10.88 mg/kg, 10.25 mg/kg, 13.49 mg/kg for CK, 1%BC and 5%BC treatments, respectively (Fig. 6c). No significant differences were observed in nitrate nitrogen content of treatments in the no nitrogen condition.




(a) Ammonium nitrogen content in the no nitrogen condition

(b) Ammonium nitrogen content in the nitrogen condition




(c) Nitrate nitrogen content in the no nitrogen condition

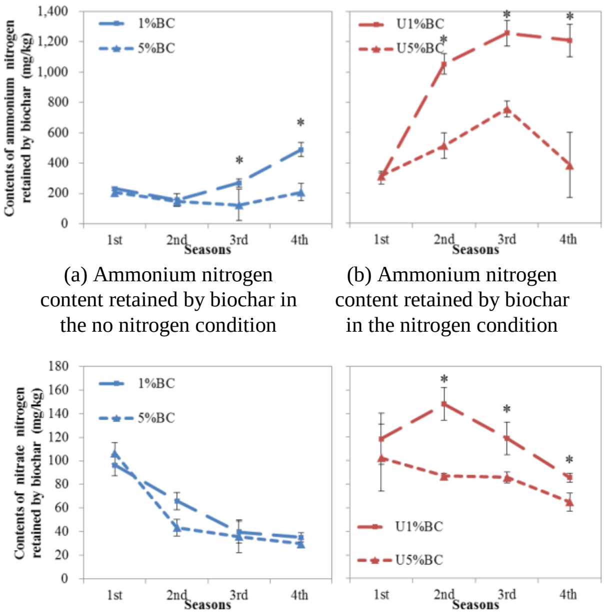
(d) Nitrate nitrogen content in the nitrogen condition

Figure 6. Mineral nitrogen content in soils during four growing seasons. Bars represent the SD of the means (n=3). SD in the same letters in one season are not significantly different, determined by Duncan's multiple-range test ($p<0.05$).

Nitrogen fertilizer application increased both ammonium nitrogen and nitrate nitrogen content in the soil (Fig. 6b, Fig. 6d). Similar to the trend in the no nitrogen condition, biochar addition significantly promoted ammonium nitrogen content in soil in the nitrogen condition. The ammonium nitrogen content of U5%BC treatment was at a higher level than that of 1%BC treatment from the 2nd growing season. Ammonium nitrogen contents in the soil during the growing season were on average 20.28 mg/kg, 27.34 mg/kg, 34.54 mg/kg for CKU, U1%BC and U5%BC treatments, respectively (Fig. 6b). The differences of nitrate nitrogen in soil of CKU, U1%BC and U5%BC treatments were not significant during the 4 growing seasons, but showed similar trends. Nitrate nitrogen content of treatments with nitrogen fertilizer all sharply decreased in the 4th growing season (Fig. 6d). Nitrate nitrogen content in the soil during the growing season were on average 74.10 mg/kg, 275.77 mg/kg, 70.79 mg/kg for CKU, U1%BC and U5%BC treatments, respectively.

### C. *Mineral Nitrogen Retained by Biochar*

The quantities of ammonium nitrogen retained by biochar attained maximum values in the 4$^{th}$ season and 3$^{rd}$ season under the no nitrogen and nitrogen conditions, respectively (Fig. 7a & b) and the quantities of nitrate nitrogen reached the maximum values in the 1$^{st}$ season and 2$^{nd}$ season under the no nitrogen and nitrogen conditions, respectively (Fig. 7c & d).




(a) Ammonium nitrogen content retained by biochar in the no nitrogen condition

(b) Ammonium nitrogen content retained by biochar in the nitrogen condition

(c) Nitrate nitrogen content retained by biochar in the no nitrogen condition

(d) Nitrate nitrogen content retained by biochar in the nitrogen condition

Figure 7. Contents of mineral nitrogen retained by biochar during four growing seasons. Plots represent the SD of the means (n=3).

Ammonium nitrogen retained by biochar maintained 200 mg/kg in the no nitrogen condition (Fig. 7a), while the ammonium content could be up to 600 mg/kg in the U5%BC treatment and 1200 mg/kg in the U1%BC treatment. This decreased to 300 mg/kg in the 4$^{th}$ growing season (Fig. 7b). Nitrate nitrogen retained by biochar showed a decreasing trend during four growing seasons (expect for the U1%BC treatment) (Fig. 7c & d). Nitrate nitrogen retained by biochar was around 40 mg/kg and 80 mg/kg in the no nitrogen and nitrogen conditions, respectively. The significances between two addition rates were found in the ammonium and nitrate content in the 2$^{nd}$, 3$^{rd}$ and 4$^{th}$ seasons in the nitrogen condition (Fig. 7b & d) and merely in the ammonium content in the 3$^{rd}$ and 4$^{th}$ seasons in the no nitrogen condition (Fig. 7a).

TABLE II. THE PERCENTAGES OF MINERAL NITROGEN RETAINED BY BIOCHAR TO MINERAL NITROGEN IN THE SOIL IN THE FORMS OF AMMONIUM, NITRATE AND MINERAL

| | Ammonium nitrogen | Nitrate nitrogen | Mineral nitrogen |
|---|---|---|---|
| 1%BC | 42.67%ab | 6.38%b | 21.25%b |
| 5%BC | 68.97%a | 22.06%a | 44.13%a |
| U1%BC | 33.77%b | 1.63%b | 9.94%c |
| U5%BC | 72.34%a | 6.40%b | 27.81%b |

Data value was represented by mean ±SD (n = 4, data from four seasons) and SD was represented across the columns. SD with the same letters are not significantly different, determined by Duncan's multiple-range test (p<0.05).

The percentages represent how much mineral nitrogen was retained by biochar in the soils (Table II). Generally, the percentages of ammonium, nitrate and mineral nitrogen were all higher in the no nitrogen condition than those in the nitrogen condition. Biochar retained 21.25%-44.13% of the mineral nitrogen in the soil in the no nitrogen condition and 9.97%-27.18 in the nitrogen condition. Furthermore, the percentages increased with the biochar addition rates. The treatment with a 5% biochar addition (44.13%) had a significantly higher percentage than that of other treatments (p<0.05); this was the lowest percentage represented in the 1%BC treatment (9.97%). On average, the percentages of ammonium ranged from 33.77% to 72.34% of ammonium nitrogen, which consisted of 1.63% to 22.06% of nitrate nitrogen. The percentages of ammonium nitrogen of 5%BC and U5%BC treatments were around 70%, which was on average 38% for 1%BC and U1%BC treatments.

## IV. DISCUSSION

Our results show that biochar addition improved soil nitrogen retention capacity and significantly reduced nitrogen leaching loss (Fig. 6 & Fig. 7). Nitrogen retention of soil and biochar

It was found that the biochar added with different rates show quite difference in the mineral nitrogen retentions (Fig. 7). The total amount of mineral nitrogen retained by biochar in soil was increased by the increased biochar addition rate (Table II) but the amount of mineral nitrogen retained by one unit biochar was lower in the treatments with higher biochar addition rate (Fig. 7). It was implied that the part of mineral nitrogen, which could be retained by biochar in soil, was limited and less than the maximum of biochar nitrogen retention.

Additionally, adsorption conditions were different in the two nitrogen conditions (no nitrogen and nitrogen condition). In the no nitrogen condition, the content of ammonium nitrogen retained by biochar was 13-42 times higher than that in the soil (Fig. 7a). There was no significant decrease in the content of ammonium nitrogen retained by biochar, and also in the soil in the no nitrogen condition after planting pakchoi for four seasons. This indicates that (1) this part of ammonium nitrogen (200-400 mg N/kg biochar) was bonded relatively strongly and (2) soil nitrogen mineralization replenished ammonium nitrogen supply. In the nitrogen condition, there was 14-33 times the content of ammonium nitrogen retained by biochar than that in the soil (Fig. 7b). The ammonium nitrogen retained by biochar reached up to 1000 mg/kg after the 1st growing season, but the content did not grow as much with further nitrogen fertilizer applications. It suggests that the available adsorption sites on biochar were being quickly saturated [35]. Contrary to the stable retention in the no-nitrogen soil, a sharp decrease (from 1200 mg/kg to 300 mg/kg) was observed when fertilization was stopped in the 4th season. It implies that there was more than one mechanism for biochar retention of ammonium nitrogen. Studies reveal that biochar's surface is full of different functional groups which could attract positive ions [36]. The large surface [37] with proper pore diameter [26] could also supply space for ammonium ions and intermolecular forces could assist biochar bonding of ammonium ions [38]. In this study, it is difficult to specify the contribution of each individual mechanism to the ammonium nitrogen retained on biochar. However, these functions had different strengths for ammonium retention, contributing some ammonium nitrogen that was steadily retained by biochar, even in an environment of low content, but the other would release when pakchoi completing for that.

Retention of mineral nitrogen by biochar has been widely reported. However, most referred findings were based on column leaching experiments [24], [32], [33], [36], [39] or solution adsorptive experiments [35]. In this study, some biochar was re-collected from soil to test the mineral nitrogen content directly. It was interesting to find the enrichment of biochar on both ammonium and nitrate nitrogen resulting in 9.94%-44.13% of mineral nitrogen in soil actually retained by biochar (Table II). However, the content of ammonium and nitrate nitrogen retained by biochar (from U1%BC and U5%BC, Fig. 7) decreased in the 4th season (no nitrogen fertilizer applied in that season). It might indicate that mineral nitrogen retained by biochar still displayed bio-availability. Previous studies also revealed the potential use of biochar as a fertilizer with some of adsorbed nutrient recovery [26], [40]. To some extent, the recovery of mineral nitrogen content from biochar (nitrate nitrogen in the no nitrogen condition and both ammonium and nitrate nitrogen in the 4th season) could be regarded as the response of biochar to the demands of vegetables or crops growing when the soil nitrogen supplement is low. The dynamic of mineral nitrogen content between soil and biochar reflected the continual transfer between soil-biochar environment and other nitrogen reservoirs. Compared to the decrease of nitrate nitrogen content in the soil, the change of nitrates retained by biochar was more significant. It was speculated that pakchoi might be inclined to assimilate nitrates from biochar. Further work is still needed to study the details of nitrogen source preference.

### A. *Effect of Biochar Addition on Nitrogen Leaching Loss*

Unexpectedly, biochar addition increased the average ammonium concentrations of leachate in the no nitrogen condition but decreased nitrate concentrations in both nitrogen conditions. The adsorption may partly explain the decrease in nitrate concentration of leachate in previous studies [33]. However, the nitrate retained directly by biochar was slight (Table II) and easily lost (Fig. 7d) implying directly retaining did not possibly reduce the nitrate concentration of leachate by 21% in the nitrogen condition. It was believed that biochar addition increased the residence time of nitrate nitrogen in the root zone of plants and provided a greater opportunity for plant assimilation and thus decreased the nitrate loss via leaching [27]. In this study, the decline of leachate volumes due to biochar plays an important role in decreasing nitrogen leaching loss (Fig. 3 & Fig. 5). Biochar is known to be highly porous with a good water retention capacity [26]-[28]. A great reduction in leachate volumes was observed and the effect of biochar on decreasing leachate volumes was more pronounced at higher biochar application rate (Fig. 3).

## V. Conclusion

Biochar increased soil mineral nitrogen content by enhancing nitrogen retention in soils. In addition, nitrogen leaching loss was significantly reduced due to biochar addition by decreasing leachate volumes and nitrate concentrations in the leachate. The mitigation of leachate was mainly attributed to the enhanced water retention capacity, nitrate adsorption and increased residence time of nitrate nitrogen for assimilation by pakchoi. It can be concluded that biochar addition could enhance soil nitrogen retention, reduce nitrogen leaching losses and thus may decrease the contribution of vegetable production systems to lake eutrophication.

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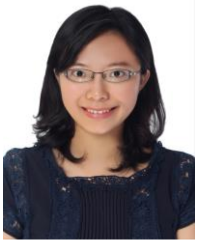

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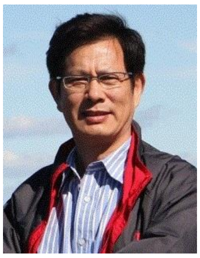

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