# Supplement of biochar and vermicompost amendments in coir and peat growing media improves N management and yields of leafy vegetables1

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ARTICLE

# Supplement of biochar and vermicompost amendments in coir and peat growing media improves N management and yields of leafy vegetables[1]

Aimé J. Messiga, Xiuming Hao, Martine Dorais, Carine S. Bineng, and Noura Ziadi

**Abstract:** A greenhouse trial assessed the effects of biochar and vermicompost as partial substitutes of conventional growing media on leafy vegetables' yields and changes of $NH_4^+$-N and $NO_3^-$-N in growing medium and leachates. Six growing media mixtures [(a) coir, (b) coir + biochar, (c) coir + vermicompost, (d) peat, (e) peat + vermicompost, (f) peat + biochar] combined with three nitrogen (N) rates [0% (0 g N·pot$^{-1}$), 50% (0.5 g N·pot$^{-1}$), and 100% (1.0 g N·pot$^{-1}$) commercial recommendation] were arranged in a split-plot design with three replicates. On average, the yield gap between 100% N and 50% N was improved when biochar and vermicompost were used as substitutes of coir (32% and 28% vs. 49%) and peat (14% and 18% vs. 27%). The concentrations of $NH_4^+$-N in the leachates for peat + biochar varied between 17.20 and 1.00 mg·L$^{-1}$. The concentrations of $NO_3^-$-N in the leachates varied between 130.0 and 1.0 mg·L$^{-1}$ for coir + vermicompost, and 60 and 1.0 mg·L$^{-1}$ for peat + vermicompost. The residual $NO_3^-$-N in peat + biochar growing media and the leachates did not match the changes observed for $NH_4^+$-N, and the much lower residual $NH_4^+$-N indicates possible $NH_4^+$-N retention by biochar and loss through volatilization in the early growth stages. Our results show that partial substitution of peat with biochar and coir with vermicompost maintained acceptable crop yield at 50% N due probably to N supply by vermicompost and decreased residual mineral N and loss by biochar in the leachates which could be beneficial for the environment.

*Key words:* ammonium, leached nitrogen, nitrate, nitrogen use efficiency.

**Résumé :** Les auteurs ont procédé à un essai en serre pour évaluer les effets du biocharbon et du vermicompost, employés comme milieux de croissance de substitution partiels, sur le rendement des légumes-feuilles et sur la conversion du N-$NH_4^+$ en N-$NO_3^-$ dans le milieu de croissance et les lixiviats. Les auteurs ont organisé six milieux de croissance en dispositif à parcelles divisées incluant trois répétitions. Les milieux étaient les suivants : (a) fibres de coco; (b) fibres de coco + biocharbon; (c) fibres de coco + vermicompost; (d) mousse de sphaigne; (e) mousse de sphaigne + vermicompost; (f) mousse de sphaigne + biocharbon. Ces traitements ont été combiné à trois taux d'application d'engrais azoté (0 % ou 0 g de N par pot, 50 % ou 0,5 g de N par pot et 100% ou 1,0 g de N par pot, ainsi qu'on le recommande dans le commerce). En règle générale, remplacer la fibre de coco par du biocharbon et du vermicompost (32 % et 28 % c. 49 %) ou de la mousse de sphaigne (14 % et 18 % c. 27 %) réduit l'écart de rendement relevé entre un apport de 100 % et de 50 % de N. La concentration de N-$NH_4^-$ dans le lixiviat du mélange mousse de sphaigne + biocharbon varie de 17,20 mg à 1,00 mg par litre. Celle de N-$NO_3^-$ dans le lixiviat varie de 130,0 mg à

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1,0 mg par litre pour le mélange fibres de coco + vermicompost et de 60 mg à 1,0 mg par litre pour le mélange mousse de sphaigne + vermicompost. La concentration résiduelle de N-$NO_3^-$ dans le mélange mousse de sphaigne + biocharbon et dans son lixiviat ne correspond pas à la variation de la concentration de N-$NH_4^-$ observée. La concentration de N-$NH_4^-$ résiduelle nettement plus faible pourrait signifier que le biocharbon retient le N-$NH_4^-$ et que la perte est due à la volatilisation, aux stades de croissance antérieurs. D'après ces résultats, les auteurs estiment qu'on pourrait remplacer en partie la mousse de sphaigne par du biocharbon et la fibre de coco par du vermicompost tout en maintenant un rendement acceptable avec un apport de 50 % de N, sans doute à cause du N fourni par le vermicompost. La diminution du N minéral résiduel et la plus faible perte de N dans le lixiviat attribuables au biocharbon pourraient s'avérer bénéfiques pour l'environnement. [Traduit par la Rédaction]

*Mots-clés :* ammonium, lixiviation de l'azote, nitrate, efficacité de l'utilisation de l'azote.

## Introduction

Organic materials mainly agricultural and municipal food wastes are becoming integral parts of highly performing growing media to support soilless production systems (Zulfiqar et al. 2019). This shift is driven by concerns over environmental impacts of nonrenewable materials such as peat used in conventional growing media (Barrett et al. 2016). Organic materials have been extensively studied, and their benefits in soil-based conventional and organic production systems are well documented (Pereira et al. 2017; Bhat et al. 2018; Huang and Gu 2019). They can be used as soil conditioners to improve soil structure, water-holding capacity (WHC), and fertility. Several studies have been conducted to understand the feasibility of using organic materials to replace conventional growing media, totally or in part, but results are still limited to an experimental level, making the assessment widely dependent on crop cultivation systems (Barrett et al. 2016; Depardieu et al. 2016; Lévesque et al. 2018).

An effective growing media is characterized by a physical structure that enables a good balance between air and water throughout the growth period (Caron and Nkongolo 1999). It also provides a suitable biological and chemical environment for plant roots. However, organic amendments used in highly performing growing media interact differently when used alone or in combination with other materials including soils and conventional growing media such as peat or coir. It is important to elucidate these interactions if highly performing growing media are to be used in soilless cultivation. One crucial concern is the lack of synchrony between the timing of nitrogen (N) mineralization of organic amendments and the N demand of plants which represent a challenge for plant N management. High residual N in growing media and excess nitrate ($NO_3^-$) in leachate can cause water pollution upon disposal, and nitrous oxide emissions can contribute to increased atmospheric greenhouse gases (Lévesque et al. 2018). A better understanding of organic materials used in soilless production is, therefore, crucial to match N supply and plant demand and reduce N losses without compromising yields.

Biochar is a charcoal-like product obtained through the thermal treatment of biomass without oxygen (Lehmann and Joseph 2009). The chemical and physical characteristics of plant-derived biochar as well as their benefits for use as soil amendments are well documented (Lehmann 2007). The benefits of biochar include reduced nutrient leaching and increased cation-exchange capacity (Pereira et al. 2017). Biochar can also reduce total $N_2O$, methane, and carbon dioxide emissions in peat-based growing media, indicating its favorable use for the development of a sustainable greenhouse production (Lévesque et al. 2018; Huang and Gu 2019). A study conducted in three microcosm experiments showed increased N use efficiency of *Malus hupehensis* under biochar-amended from 6.77% to 261.53%, indicating that biochar amendment could decrease $NO_3^-$-N leaching and $NO_3^-$-N reduction in soil, by promoting $NO_3^-$-N absorption (Cao et al. 2019). Biochar can also alter microbial activity in soils (Van Zwieten et al. 2010) and growing media (Lévesque et al. 2018), which might impact plant N use efficiency.

Vermicompost is the end product of the decomposition of organic wastes by earthworms and mesophilic microbes (Bhat et al. 2013). The transit of organic waste in the gut earthworms changes their composition, decreases organic carbon content, C/N ratio, and increases the availability of macro- and micronutrients including N and P (Atiyeh et al. 2001). In low-input agricultural systems, vermicompost is considered a good substitute of inorganic fertilizers (Bhat et al. 2018). Vermicompost has been used as a soil conditioner and source of nutrients for many horticultural crops with significant increase in growth including tomato (Atiyeh et al. 2001). Vermicompost has been used in several occurrences as a partial substitute of peat in growing media. In Germany, tomato seedlings were planted in a mixture of peat and vermicompost, and results showed that vermicompost could be an environmentally friendly substitute for peat in potting media with no detrimental effects on seedling performance and fruit quality (Zaller 2007). The addition of vermicomposts to potting media increased the growth and flowering of marigolds (Gupta et al. 2014). Gong et al. (2018) compared green waste compost and vermicompost as peat substitutes in growing media and found that the latter was better in the cultivation of geranium and calendula.

**Table 1.** Physico-chemical properties of the growing media and amendments.

| | Units | Coir | Peat | Biochar | Vermicompost |
|---|---|---|---|---|---|
| Particle size | | | | | |
| >2000 μm | % | 10.0 (1.34)[a] | 3.0 (1.13) | 10.0 (0.71) | 17.0 (3.26) |
| 2000–1000 μm | % | 70.0 (2.26) | 60.0 (4.03) | 58.0 (0.71) | 81.0 (0.01) |
| 1000–250 μm | % | 18.0 (1.91) | 31.0 (0.64) | 24.0 (0.57) | 2.0 (0.06) |
| <250 μm | — | 2.0 (0.0) | 6.0 (0.0) | 8.0 (0.02) | 0.0 (0.0) |
| Bulk density | $kg{\cdot}m^{-3}$ | 258.00 (24.04) | 228.50 (26.16) | 349.50 (3.54) | 569.50 (20.51) |
| Conductivity | $mS{\cdot}cm^{-1}$ | 0.31 (0.01) | 0.29 (0.01) | 4.81 (0.08) | 3.49 (0.19) |
| pH | — | 6.08 (0.02) | 4.03 (0.06) | 9.56 (0.08) | 4.22 (0.06) |
| Organic matter | % | 25.35 (0.35) | 36.80 (0.42) | 33.00 (0.28) | 18.90 (0.00) |
| Dry matter | % | 31.40 (0.57) | 42.12 (2.52) | 51.30 (0.14) | 25.15 (0.07) |
| Total N | % | 0.29 (0.04) | 0.61 (0.02) | 0.57 (0.02) | 0.74 (0.00) |
| C/N ratio | — | 49.50 (7.78) | 33.50 (0.71) | 98.50 (2.12) | 14.00 (0.00) |
| $NH_4^+$-N | $mg{\cdot}kg^{-1}$ | 2.00 (0.00) | 223.00 (48.08) | 11.50 (9.19) | 19.00 (4.24) |

[a]Values in parentheses represent standard deviations of means ($n = 2$).

Biochar and vermicompost are still primarily used for field agricultural application, and the standards are not yet developed for usage in growing media (Zulfiqar et al. 2019). When mixed with conventional materials such as peat and coir, they still exhibit inherent variability among batches (Barrett et al. 2016). Research is, therefore, needed to improve our understanding of the benefits or constraints of these materials as substitutes in growing media. The objective of this study was to assess the effects of biochar (10% *v*/*v*) and vermicompost (10% *v*/*v*) as substitutes of peat (90% *v*/*v*) and coir (90% *v*/*v*) in highly performing growing media and various N rates of application on fresh yield, residual mineral N, and N losses during two cropping cycles in a greenhouse study. We hypothesized that biochar and vermicompost amendments have the potential to increase leafy vegetable yields at 50% or 100% of the commercial recommendation N.

## Materials and Methods

### Greenhouse conditions and experimental design

Greenhouse trials were conducted from 22 Dec. 2017 to 20 Feb. 2018 for Chinese cabbage (*Brassica rapa*) and 4 Mar. 2018 to 6 May 2018 for lettuce (*Lactuca sativa*) at Agassiz Research and Development Centre (49°14′N, 121°45′W) of Agriculture and Agri-Food Canada. Greenhouse temperature was maintained at 22 ± 1 °C during the day and 18 ± 0.5 °C at night. Plants were exposed to a 16 h day photoperiod (0500–2100), and natural light was supplemented with 250 μmol $PAR{\cdot}m^{-2}{\cdot}s^{-1}$ artificial light (PAR, photosynthetically active radiation; Philips Ceramalux C400S51 high-pressure sodium, P.L Lighting 400w HID) when outdoor global solar radiation was less than 300 $W{\cdot}m^{-2}$. The experimental design was a split plot with six growing media mixtures as main plots and three N rates as subplots with three replicates for a total of 54 experimental units. The growing media mixtures were prepared by mixing coir and peat with biochar or vermicompost amendments [volume based (*v*:*v*)] on a plastic tarp: (1) 100% coir, (2) 90% coir + 10% biochar, (3) 90% coir + 10% vermicompost, (4) 100% peat, (5) 90% peat + 10% vermicompost, and (6) 90% peat + 10% biochar. As such, the amount of growing medium was 4 $kg{\cdot}pot^{-1}$ fresh weight for 100% coir, 3.15 + 0.85 $kg{\cdot}pot^{-1}$ for 90% coir + 10% biochar, 3.15 + 2.30 $kg{\cdot}pot^{-1}$ for 90% coir + 10% vermicompost, 5.5 $kg{\cdot}pot^{-1}$ for 100% peat, 4.35 + 1.75 $kg{\cdot}pot^{-1}$ for 90% peat + 10% vermicompost, and 4.35 + 0.85 $kg{\cdot}pot^{-1}$ for 90% peat + 10% biochar. Total N for the conventional growing media and amendments was 0.29% for coir (CANNA COCO Natural PLANT MEDIUM, CANNA Canada Corp.), 0.61% for peat (Sungro Horticulture, Canadian Sphagnum Peat Moss Grower Grade White, OMRI Listed), 0.57% for biochar (Canadian AgriChar, OMRI Listed), and 0.74% for vermicompost (Nurturing Nature Organics Inc., OMRI Listed) (Table 1). Accordingly, the total amount of N associated with the growing medium was 11.60 g $N{\cdot}pot^{-1}$ for 100% coir, 13.97 g $N{\cdot}pot^{-1}$ for 90% coir + 10% biochar, 26.12 g $N{\cdot}pot^{-1}$ for 90% coir + 10% vermicompost, 33.6 g $N{\cdot}pot^{-1}$ for 100 peat, 31.4 g $N{\cdot}pot^{-1}$ for 90% peat + 10% biochar, and 39.5 g $N{\cdot}pot^{-1}$ for 90% peat + 10% vermicompost. Concentrations of $NH_4^+$-N for the conventional growing media and amendments were 2.00 $mg{\cdot}kg^{-1}$ for coir, 223.00 $mg{\cdot}kg^{-1}$ for peat, 11.50 $mg{\cdot}kg^{-1}$ for biochar, and 19.00 $mg{\cdot}kg^{-1}$ for vermicompost (Table 1). The rates of N applications were 0, 0.5, and 1.0 g $N{\cdot}pot^{-1}$ corresponding to 0% (0 g $N{\cdot}pot^{-1}$), 50% (0.5 g $N{\cdot}pot^{-1}$), and 100% (1 g $N{\cdot}pot^{-1}$) of the commercial fertilization recommendation (80 kg $N{\cdot}ha^{-1}$ with a plant density of 80 000 $plants{\cdot}ha^{-1}$, BC Ministry of Agriculture 2018). Nitrogen and other macro- and micronutrients were applied using a Hoagland solution through fertigation. Two Hoagland solutions: HOPO1 (Hoagland's No. 2 basal salt mixtures with N, $NH_4H_2PO_4 + Ca(NO_3)_2 + KNO_3 + Zn(NO_3)_2$, Caisson Laboratories Inc.) and HOPO3 (Hoagland's No. 2 basal salt mixtures without N, Caisson Laboratories Inc.) were used. For treatment 0% N, 10 L of solution was prepared every week by mixing one bag of HOPO3 in 10 L of distilled water. For treatment 50% N, 10 L of solution was prepared every week by mixing 0.5 bag of HOPO1 and 0.5 bag of HOPO3 in 10 L of distilled water. For treatment 100% N, 10 L of solution was prepared every week by mixing one bag of HOPO1 in 10 L of distilled water.

Pots used for the greenhouse experiment are 17 L in volume (30 cm diameter and 24 cm height) each, with four holes at the bottom for drainage. An equivalent of 15 L of each growing media mixture was weighed and transferred into pots. Pots with growing media mixtures were moistened with distilled water and allowed to drain freely to reach WHC and placed on saucers. At WHC, the weight of each pot was recorded and used to calculate the volume of water at WHC. A hole was drilled at the bottom of each saucer to which a hose was glued to collect the leachate.

Cabbage and lettuce were seeded in germination trays, and two seedlings were transplanted to the prepared pots at approximately 2 wk after germination. One week later, one seedling was removed, and only one plant was allowed to grow for the rest of the experiment. Standard 5TE sensors (Decagon Devices Equipment) were inserted in each pot at approximately 10 cm depth and connected to a EM50 data logger (Decagon Devices Equipment) to monitor daily volumetric water content, temperature, and electrical conductivity. The plants were drip irrigated with two 1 $L \cdot h^{-1}$ drippers per bucket at a rate of 1 min (63 mL of water) every 4 h (0800, 1200, and 0400). Fertilizers were supplied through a drip irrigation system with two 1 $L \cdot h^{-1}$ drippers per bucket at a rate of 1 min (77 mL of solution) two times per day (1000 and 0600). In total, four drippers were placed in every pot: two drippers for the irrigation and two drippers for the fertigation. The pH of water used for irrigation and fertilizer preparation was adjusted to 6.5 using phosphoric acid 75% (Food Grade, Terralink Inc.). General properties of the peat, coco fiber, biochar, and vermicompost were analyzed using the Compost Analysis Proficiency package (A & L Canada Laboratories Inc., London, ON, Canada).

**Plant analyses**

Plants were harvested 62 d after planting for Chinese cabbage (20 Feb. 2018) and 60 d after planting for lettuce (6 May 2018) and weighed. Plant leaves were oven-dried at 60 °C for 48 h and weighed for dry matter (DM). Oven-dried leaves were ground using a ball mill fitted with a 1 mm screen before N concentrations were analyzed using a LECO CNS-1000 analyzer (LECO Corporation, St. Joseph, MI, USA). Leaf N accumulation was calculated by multiplying leaf N concentration by DM weight. Nitrogen recovery efficiency (NRE) was calculated as N accumulation in fertilized pot minus N accumulation in 0% N pot, divided by N fertilizer applied (Carranca 2012). Nitrogen use efficiency (NUE) was calculated as leaf DM weight in the fertilized pot minus leaf DM weight in the 0% N, divided by the amount of N fertilizer applied (Carranca 2012).

**Mineral nitrogen and pH analyses of growing media and leachate**

After harvest of Chinese cabbage and lettuce, five growing media cores were collected at depth 0–15 cm and composited. A subsample was used to assess growing media moisture content gravimetrically by oven-drying for 48 h at 105 °C. Growing media mineral N ($NH_4^+$-N and $NO_3^-$-N) was analyzed using KCl extraction of all moist growing media samples. Briefly, 5 g subsample of growing media was extracted with 2 $mol \cdot L^{-1}$ KCl using a 1:10 (*w*:*v*) growing media : extractant ratio. All extracts were analyzed colorimetrically for $NO_3^-$ and $NH_4^+$ using a flow injection analyzer (Tecator FIAStar 2010) as described by Maynard et al. (2007). The volume of leachates was recorded every week, and a subsample of approximately 50 mL was kept frozen until analyses of mineral N ($NH_4^+$-N and $NO_3^-$-N) using a flow injection analyzer (Tecator FIAStar 2010) as described above. The weekly mineral N loss was calculated by multiplying the concentration of mineral N ($NH_4^+$-N and $NO_3^-$-N) in the leachate by the volume of leachate. The cumulative mineral N loss was calculated by summing up the weekly mineral N losses. The partial N budget was calculated as the difference between N applied as fertilizer during the whole experiment and the sum of N uptake and cumulative mineral N loss. In this calculation, N inputs by the growing media and the amendments were not considered. We refer to partial N budget because N loss routes such as ammonia volatilization and nitrous oxide emission were not considered. In air-dried growing media samples, pH was measured in distilled water with a 1:2 soil:solution ratio (Hendershot et al. 1993).

**Statistical analysis**

Data were tested for normality using the Shapiro–Wilk's test of SAS univariate procedure, version 9.3 (SAS Institute, Inc. 2010). An analysis of variance based on the split-plot design was performed for data of fresh yield, NRE, NUE, residual $NH_4^+$-N and $NO_3^-$-N in the growing media, N uptake, N loss in the leachates and partial N budget using SAS PROC MIXED considering block as a random factor and treatments as fixed effects. Data for the concentrations of mineral N ($NH_4^+$-N and $NO_3^-$-N) in the leachate and cumulative mineral N loss were also analyzed using SAS PROC MIXED considering block as a random factor, treatments as fixed effects, and sampling dates as repeated factors. Differences among least-square means for all treatment pairs were tested using the Tukey's test and a significance level of $P = 0.05$.

## Results

**Fresh yield and NUE**

During the two production cycles, leaf yield (fresh weight) decreased with decreasing N fertilization rates,

**Table 2.** Nitrogen recovery efficiency (NRE, g N uptake·$g^{-1}$ $N_{fertilizer}$) and nitrogen use efficiency (NUE, g DM·$g^{-1}$ $N_{fertilizer}$) of Chinese cabbage and lettuce planted on high-performance growing media with various rates of nitrogen application by fertigation.

| Growing media mixtures (GM) | Chinese cabbage | | | | Lettuce | | | |
|---|---|---|---|---|---|---|---|---|
| | NRE (g N uptake·$g^{-1}$ $N_{fertilizer}$) | | NUE (g DM·$g^{-1}$ $N_{fertilizer}$) | | NRE (g N uptake·$g^{-1}$ $N_{fertilizer}$) | | NUE (g DM·$g^{-1}$ $N_{fertilizer}$) | |
| | N rates (% of commercial recommendation) | | | | | | | |
| | 50% N | 100% N | 50% N | 100% N | 50% N | 100% N | 50% N | 100% N |
| 100% coir | 0.54 | 0.54 | 36.67 | 25.40 | 0.32 | 0.40 | 14.76 | 16.08 |
| 90% coir + 10% biochar | 0.61 | 0.62 | 44.46 | 24.75 | 0.35 | 0.31 | 19.54 | 11.35 |
| 90% coir + 10% vermicompost | 0.65 | 0.47 | 40.64 | 21.50 | 0.37 | 0.32 | 17.47 | 14.32 |
| 100% peat | 0.74 | 0.51 | 33.49 | 18.77 | 0.37 | 0.33 | 18.75 | 9.96 |
| 90% peat + 10% biochar | 0.63 | 0.49 | 16.13 | 9.09 | 0.21 | 0.25 | 6.65 | 13.73 |
| 90% peat + 10% vermicompost | 0.92 | 0.93 | 32.08 | 23.95 | 0.34 | 0.34 | 11.52 | 11.26 |
| SEM | 0.095[a] | | 1.65[b] | 2.86[c] | 0.015[d] | | 1.32[e] | |
| | *P* values[f] | | | | | | | |
| N rates | 0.962 | | <0.001 | | 0.103 | | 0.392 | |
| GM | 0.011 | | <0.001 | | <0.001 | | 0.001 | |
| N rates × GM | 0.896 | | 0.496 | | 0.087 | | 0.095 | |

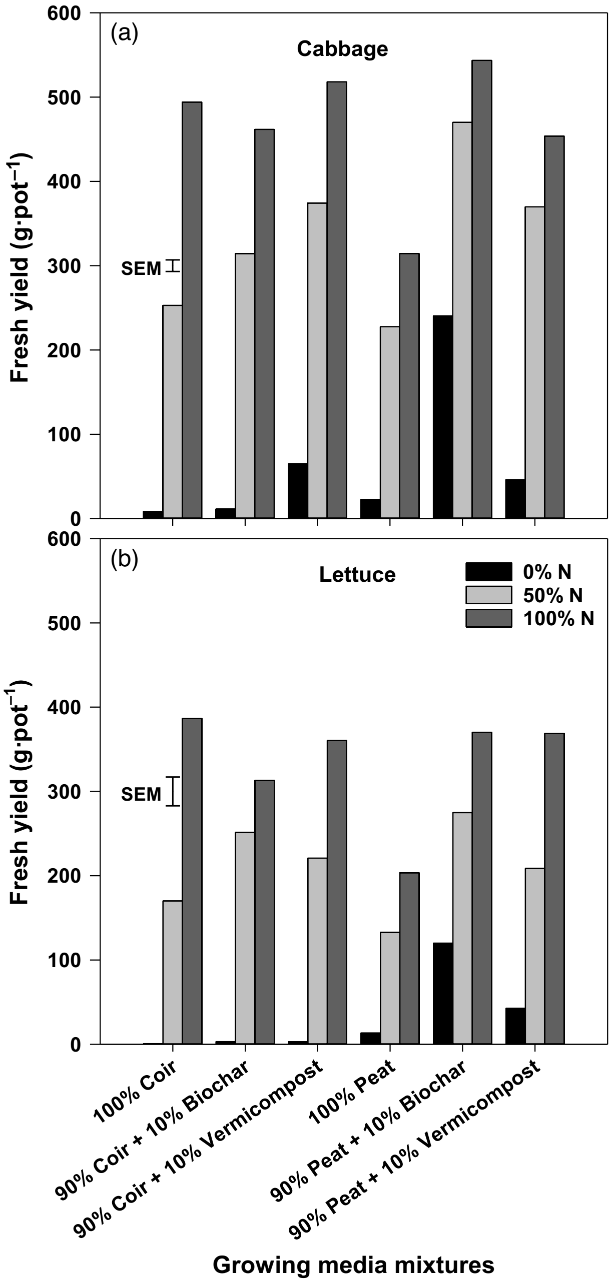
**Note:** DM, dry matter; SEM, standard error of the mean.
[a]SEM for comparing means of GM mixtures of NRE for Chinese cabbage.
[b]SEM for comparing means of N rates of NUE for Chinese cabbage.
[c]SEM for comparing means of GM mixtures of NUE for Chinese cabbage.
[d]SEM for comparing means of GM mixtures of NRE for lettuce.
[e]SEM for comparing means of GM mixtures of NUE for lettuce.
[f]Probability values.

but the extent varied with the type of growing media and the amendments (cabbage: $P < 0.001$; lettuce: $P < 0.001$; Table 2). For cabbage, fresh yield varied between 8.4 g·$pot^{-1}$ for coir and 240 g·$pot^{-1}$ for peat amended with biochar in 0% N pots; 228 g·$pot^{-1}$ for peat and 470 g·$pot^{-1}$ for peat amended with biochar in 50% N pots; and 314 g·$pot^{-1}$ for peat and 544 g·$pot^{-1}$ for peat amended with biochar in 100% N pots (Fig. 1*a*). For coir-based growing media, the reduction of N inputs by 50% decreased cabbage yield by 49% with coir alone versus 32% and 28% with coir amended with biochar and vermicompost, respectively (Fig. 1*a*). In addition, for peat-based growing media, cabbage yield decreased by 27% with peat alone versus 14% and 18% with peat amended with biochar and vermicompost, respectively (Fig. 1*a*). The yield in peat with biochar at 50% N rate was similar or slightly higher than the coir with biochar and peat with vermicompost at 100% N rate (Fig. 1*a*).

For lettuce, fresh yield varied between 0.8 g·$pot^{-1}$ for coir and 120 g·$pot^{-1}$ for peat amended with biochar in 0% N pots; 133 g·$pot^{-1}$ for peat and 275 g·$pot^{-1}$ for peat amended with biochar in 50% N pots; 203 g·$pot^{-1}$ for peat and 387 g·$pot^{-1}$ for coir in 100% N pots (Fig. 1*b*). For coir-based growing media, the reduction of N input by 50% decreased lettuce yield by 56% with coir alone versus 20% and 39% with coir amended with biochar and vermicompost, respectively (Fig. 1*b*). In addition, for peat-based growing media, lettuce yield decreased by 34% with peat alone versus 25% and 43% with peat amended with biochar and vermicompost, respectively (Fig. 1*b*).

The NRE for cabbage was different ($P = 0.011$; Table 2) among growing media, and the highest NRE was 0.93 g N·$g^{-1}$ $N_{fertilizer}$ obtained under peat amended with vermicompost, and the lowest was 0.54 g N·$g^{-1}$ $N_{fertilizer}$ obtained under coir (Table 2). The rates of N application did not affect the NRE for cabbage ($P = 0.962$). The NUE for cabbage varied with both growing media ($P < 0.001$) and rates of N application ($P < 0.001$). It decreased with increasing rates of N application. It was on average 34 g DM·$g^{-1}$ $N_{fertilizer}$ with 50% N inputs, but only 20 g DM·$g^{-1}$ $N_{fertilizer}$ with 100% N input. This difference indicates an increase of NUE for cabbage by 70% upon reduction of the commercial recommendation by 50%. Cabbage showed a trend of high NUE for coir-based growing media compared with peat-based growing media (Table 2). The NRE for lettuce was different among growing media ($P < 0.001$) and was on average 0.35 g N·$g^{-1}$ $N_{fertilizer}$ for all growing media except peat amended with biochar exhibiting a NRE of 0.23 g N·$g^{-1}$ $N_{fertilizer}$ (Table 2). The NUE for lettuce was different among growing media ($P = 0.001$; Table 2) and was on

**Fig. 1.** Fresh yield (g·pot$^{-1}$) of (*a*) Chinese cabbage and (*b*) lettuce planted on high-performing growing media mixtures with various rates of nitrogen application by fertigation [SEM, error bar represent standard error of the mean for comparing all values ($n = 54$ and df = 36)]. (0% N, 50% N, and 100% N of recommended rates).




average 12.0 g DM·g$^{-1}$ $N_{fertilizer}$ in peat-based growing media and 15.5 g DM·g$^{-1}$ $N_{fertilizer}$ in coir-based growing media (Table 2).

### Residual mineral nitrogen in the growing media

At the end of the cabbage production cycle, residual $NH_4^+$-N concentrations varied between 5.67 mg·kg$^{-1}$ for coir with 0% N input and 213.59 mg·kg$^{-1}$ for peat in the commercial recommendation (Table 3). After cabbage production, residual $NH_4^+$-N concentrations decreased with decreasing N fertilization rates, but the extent varied with the type of growing media. The magnitude of decrease in peat-based media was much larger, especially the peat with biochar (Table 3). When considering the commercial N recommendation rate and the 50% N input, residual $NH_4^+$-N concentration was on average 10.41 mg·kg$^{-1}$ among coir-based growing media, but 209.7 mg·kg$^{-1}$ for peat, 36.71 mg·kg$^{-1}$ for peat amended with biochar, and 86.76 mg·kg$^{-1}$ for peat amended with vermicompost (Table 3). Residual $NO_3^-$-N concentrations varied between less than 1.00 and 37.15 mg·kg$^{-1}$ for peat with 100% N rate (Table 3). Residual $NO_3^-$-N concentrations decreased with decreasing fertilization N rates particularly under peat-based growing media and were only detected in coir-based growing media receiving the 100% N rate. At the end of the lettuce production cycle, residual $NH_4^+$-N concentrations varied between 6.41 mg·kg$^{-1}$ for coir in 0% N input and 79.83 mg·kg$^{-1}$ for peat in the 100% N rate (Table 3). The residual $NH_4^+$-N concentrations decreased with decreasing N rates in both coir- and peat-based growing media. The residual $NH_4^+$-N concentrations in coir-based growing media were lower than in peat-based growth media (Table 3). No residual $NO_3^-$-N was detected in coir-based growing media. In the peat-based growing media, residual $NO_3^-$-N concentrations varied between less than 1.00 and 12.56 mg·kg$^{-1}$ for peat in the 50% N input (Table 3). The trends of residual $NH_4^+$-N and $NO_3^-$-N concentrations at the end of lettuce production cycle were similar to the cabbage production cycle.

### Concentrations of mineral nitrogen in the leachates

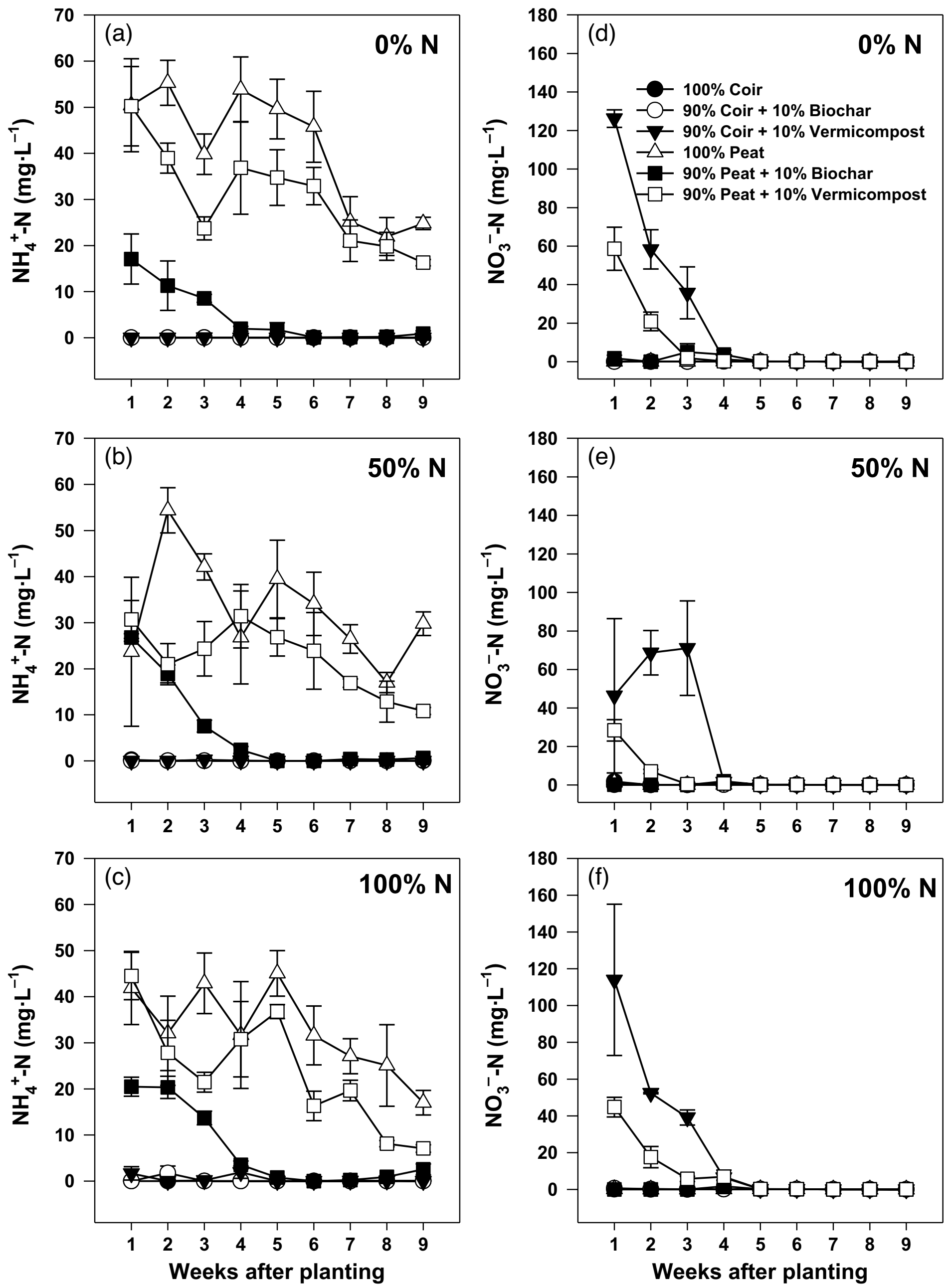
Throughout the cabbage production cycle, the concentration of $NH_4^+$-N in the leachates for peat and peat amended with vermicompost decreased from 50.4 mg·L$^{-1}$ 1 wk after planting to 24.8 mg·L$^{-1}$ after harvest (Figs. 2*a*–2*c*). In contrast, the concentration of $NH_4^+$-N in the leachates for peat amended with biochar decreased from 17.20 mg·L$^{-1}$ 1 wk after planting to less than 1.00 mg·L$^{-1}$ 4 wk after planting and remained constant thereafter. The concentration of $NH_4^+$-N in the leachates for coir-based growing media was less than 1.00 mg·L$^{-1}$ throughout the cabbage production cycle. The concentration of $NO_3^-$-N in the leachates decreased from 130.00 mg·L$^{-1}$ 1 wk after planting to less than 1.00 mg·L$^{-1}$ 4 wk after planting and remained constant thereafter for coir amended with vermicompost, and from 60 mg·L$^{-1}$ 1 wk after planting to less than 1.00 mg·L$^{-1}$ 3 wk after planting and remained constant thereafter for peat amended with vermicompost (Figs. 2*d*–2*f*). These trends were similar among the fertilization N rates. Throughout the lettuce production cycle, the concentration of $NH_4^+$-N in the leachates decreased from 40.00 mg·L$^{-1}$ 1 wk after planting to 25.00 mg·L$^{-1}$ after harvest for peat, and 18.00 mg·L$^{-1}$ 1 wk after planting to 10.00 mg·L$^{-1}$ after harvest for peat amended with

**Table 3.** Residual ammonium nitrogen and residual nitrate nitrogen in high-performance growing media mixtures with various rates of nitrogen application by fertigation after 62 d of Chinese cabbage and 60 d of lettuce production.

| Growing media mixtures (GM) | Chinese cabbage | | | | | | Lettuce | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Residual $NH_4^+$-N ($mg \cdot kg^{-1}$) | | | Residual $NO_3^-$-N ($mg \cdot kg^{-1}$) | | | Residual $NH_4^+$-N ($mg \cdot kg^{-1}$) | | | Residual $NO_3^-$-N ($mg \cdot kg^{-1}$) | | |
| | N rates (% of recommendation) | | | | | | | | | | | |
| | 0% N | 50% N | 100% N | 0% N | 50% N | 100% N | 0% N | 50% N | 100% N | 0% N | 50% N | 100% N |
| 100% coir | 5.67 | 9.53 | 12.12 | 0.00 | 0.00 | 0.00 | 6.41 | 7.50 | 12.30 | 0.00 | 0.00 | 0.00 |
| 90% coir + 10% biochar | 7.41 | 8.67 | 13.78 | 0.00 | 0.00 | 6.94 | 8.72 | 12.11 | 21.60 | 0.00 | 0.00 | 0.00 |
| 90% coir + 10% vermicompost | 6.28 | 8.12 | 10.26 | 0.00 | 0.00 | 6.84 | 10.80 | 24.27 | 20.20 | 0.00 | 0.00 | 0.00 |
| 100% peat | 88.67 | 205.87 | 213.59 | 7.88 | 17.00 | 37.15 | 30.13 | 46.99 | 79.83 | 0.00 | 12.56 | 0.62 |
| 90% peat + 10% biochar | 27.96 | 32.34 | 41.08 | 0.36 | 5.18 | 24.61 | 25.51 | 37.95 | 46.58 | 0.00 | 3.66 | 0.80 |
| 90% peat + 10% vermicompost | 62.59 | 81.27 | 92.25 | 5.65 | 6.15 | 11.67 | 27.94 | 43.74 | 57.45 | 0.00 | 0.00 | 0.00 |
| SEM | | 12.20[a] | | 2.53[b] | | 3.58[c] | 3.04[d] | | 4.30[e] | | 0.374[f] | |
| | *P* values[g] | | | | | | | | | | | |
| N rates | | <0.001 | | | 0.004 | | | 0.011 | | | 0.016 | |
| GM | | <0.001 | | | 0.003 | | | <0.001 | | | <0.001 | |
| N rate × GM | | <0.001 | | | 0.512 | | | 0.968 | | | 0.004 | |

**Note:** SEM, standard error of the mean.
[a]SEM for comparing all means of residual $NH_4^+$-N.
[b]SEM for comparing means of N rates of residual $NO_3^-$-N under cabbage.
[c]SEM for comparing means of GM of residual $NO_3^-$-N under cabbage.
[d]SEM for comparing means of N rates of residual $NH_4^+$-N under lettuce,
[e]SEM for comparing means of GM of residual $NH_4^+$-N under lettuce.
[f]SEM for comparing all means residual $NO_3^-$-N under lettuce.
[g]Probability values.

**Fig. 2.** Concentrations of (*a*–*c*) ammonium ($NH_4^+$-N) and (*d*–*f*) nitrate ($NO_3^-$-N) nitrogen in the leachates collected from high-performance growing media mixtures with various rates of nitrogen application by fertigation after 62 d of Chinese cabbage production. Error bars represent the standard deviations of the mean (*n* = 4). (0% N, 50% N, and 100% N of recommended rates).



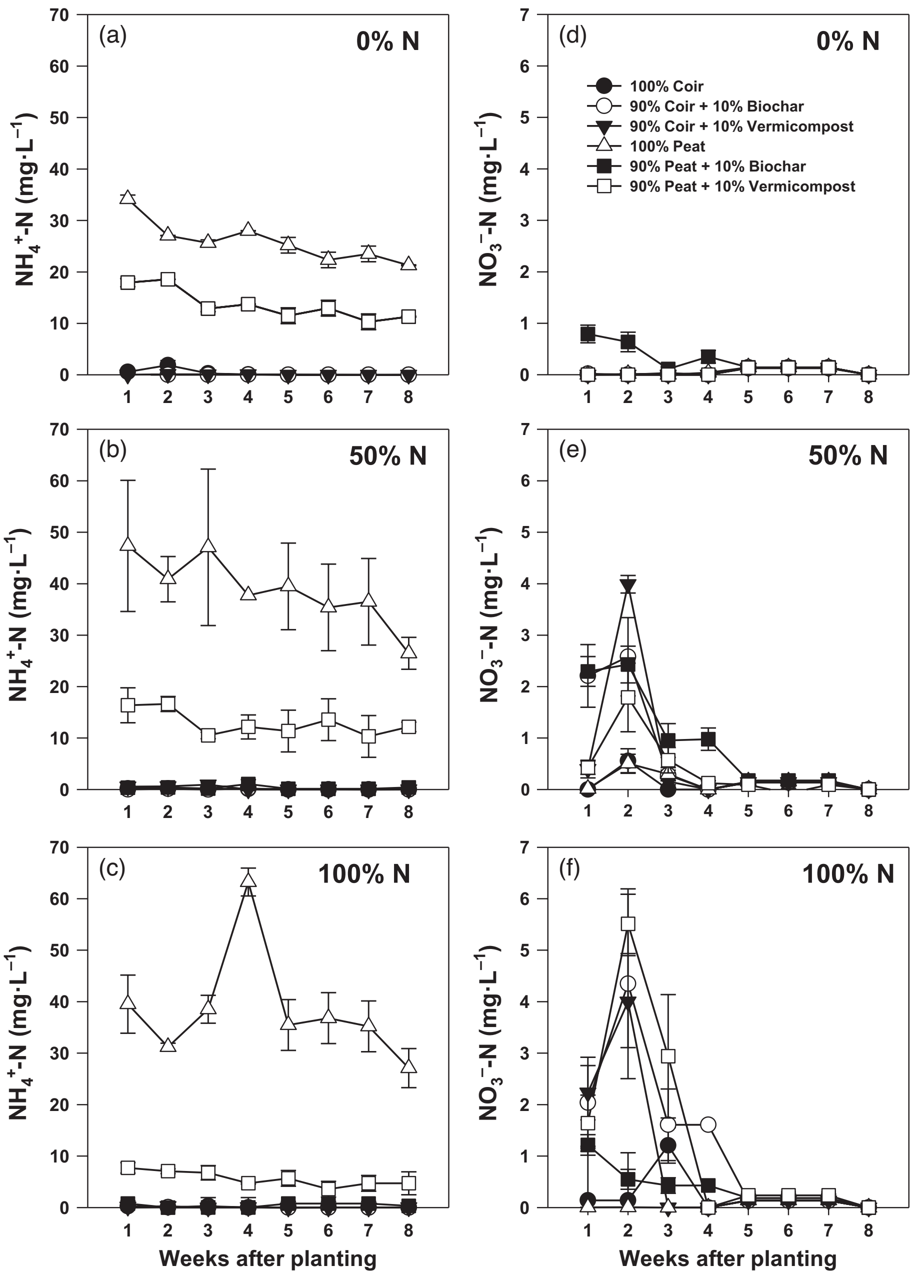

vermicompost (Figs. 3*a*–3*c*). The concentration of $NO_3^-$-N in the leachates varied between less than 1.00 and 5.5 $mg \cdot L^{-1}$ only during the first half period of the production cycle (Figs. 3*d*–3*f*).

### Cumulative mineral nitrogen loss and partial nitrogen budget

The cumulative mineral N ($NH_4^+$-N and $NO_3^-$-N) loss with leachates at the end of the cabbage production cycle varied between less than 0.01 and 0.08 g $N \cdot pot^{-1}$ and was in the order peat = peat amended with vermicompost >coir amended with vermicompost > peat amended with biochar > coir = coir amended with biochar (Figs. 4*a*–4*c*). Therefore, adding biochar-reduced mineral N loss in cabbage production. At the end of the lettuce production cycle, the cumulative mineral N loss with leachates varied between 0.01 and 0.06 $g \cdot pot^{-1}$ and was in the order peat > peat amended with vermicompost > coir amended with vermicompost = peat amended with biochar = coir = coir amended with biochar (Figs. 4*d*–4*f*). The growing media amended with biochar also had the lowest N loss.

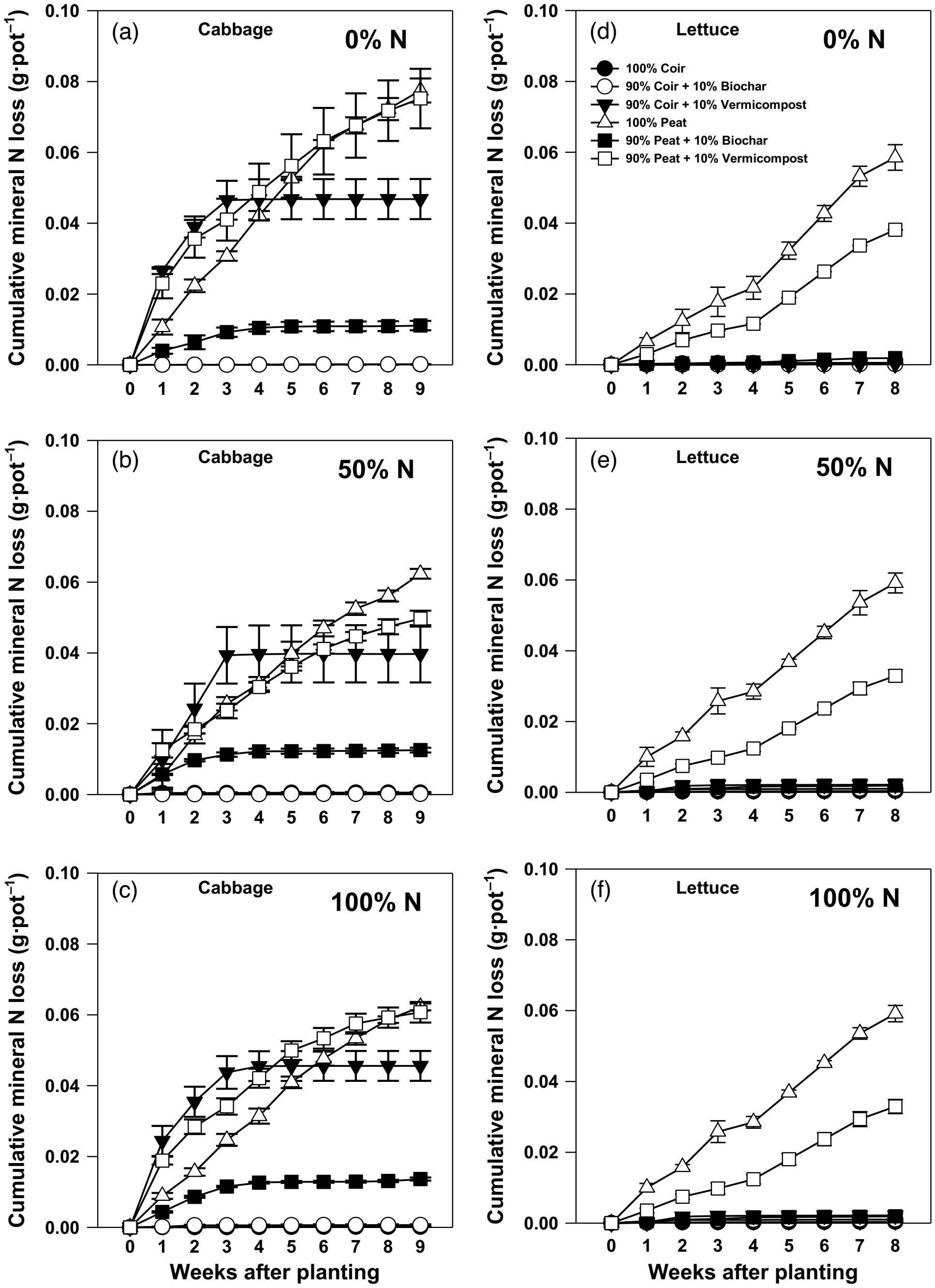
The N uptake per pot in cabbage production varied with N rates and the type and mixtures of growing

**Fig. 3.** Concentrations of (*a*–*c*) ammonium ($NH_4^+$-N) and (*d*–*f*) nitrate ($NO_3^-$-N) nitrogen in the leachates collected from high-performance growing media mixtures with various rates of nitrogen application by fertigation after 60 d of lettuce production. Error bars represent the standard deviations of the mean (*n* = 4). (0% N, 50% N, and 100% N of recommended rates).




media (Table 4). The N uptake increased with the increasing rate of N application. The growing media (both peat-based and coir-based) with biochar had the highest N uptake rate at all three N rates. The leached N per plot also varied both with N rates and the type of growing media (Table 4). The coir with vermicompost and peat only had higher leached N per plot (Table 4). The partial N budget for cabbage varied between −0.334 g N·pot$^{-1}$ for peat amended with biochar and −0.017 g N·pot$^{-1}$ for coir alone in the 0% N pots (Table 4). The partial N budget varied between −0.473 g·pot$^{-1}$ for peat amended with biochar and 0.026 g N·pot$^{-1}$ for peat alone in the 50% N pots. The partial N budget varied between −0.146 g·pot$^{-1}$ for peat amended with biochar and 0.387 g·pot$^{-1}$ for peat alone in the 100% N pots. The N uptake of lettuce per plot increased with the increasing rate of N application (Table 5). However, the leached N per plot only varied with the type and mixture of the growing media not with N rates (Table 5). Coir with vermicompost and 100% peat had higher leached N per plot in all three N rates (Table 5). The partial N budget for lettuce was significantly different among growing media and decreased with decreasing N rates (Table 5). The highest partial N budget for lettuce was 0.439 g·pot$^{-1}$ obtained under peat

**Fig. 4.** Cumulative mineral nitrogen (N) loss with leachates collected from high-performance growing media mixtures with various rates of nitrogen application by fertigation after 62 d of Chinese cabbage (*a–c*) and 60 d of lettuce (*d–f*) production. Error bars represent the standard deviations of the mean ($n = 4$). (0% N, 50% N, and 100% N of recommended rates).




amended with biochar at 100% commercially recommended N rate, and the lowest was −0.160 g·pot$^{-1}$ obtained under peat at 0% N input (Table 5).

## Discussion

### Fresh yield and nitrogen efficiency

Our results confirmed the positive effects of biochar and vermicompost on plant growth observed in previous investigations (Pereira et al. 2017; Cao et al. 2019). In our study, cabbage fresh yields under growing media amended with biochar and vermicompost at 50% N application rate indicate that the two amendments influenced N uptake. The yield reduction of cabbage and lettuce at 50% N application rate was smaller under amended growing media in comparison to conventional growing media (Fig. 1). Cao et al. (2019) also observed the positive effects of biochar combined with reduced N fertilizer rates on the biomass of *M. hupehensis*. Van Zwieten et al. (2010) in a glasshouse study using soil collected from a commercial vegetable

**Table 4.** Partial nitrogen budget of Chinese cabbage production on different growing media mixtures with various rates of nitrogen application through fertigation.

| Growing media mixtures (GM) | Fertilizer N (as % of recommended rate) | N uptake ($g \cdot pot^{-1}$) | Leachate ($g \cdot pot^{-1}$) | Partial N budget ($g \cdot pot^{-1}$) |
|---|---|---|---|---|
| 100% coir | 0 | 0.017 | 0.000 | −0.017 |
| 90% coir + 10% biochar | 0 | 0.024 | 0.000 | −0.024 |
| 90% coir + 10% vermicompost | 0 | 0.090 | 0.047 | −0.137 |
| 100% peat | 0 | 0.044 | 0.077 | −0.121 |
| 90% peat + 10% biochar | 0 | 0.323 | 0.011 | −0.334 |
| 90% peat + 10% vermicompost | 0 | 0.077 | 0.075 | −0.152 |
| 100% coir | 50 | 0.574 | 0.001 | −0.075 |
| 90% coir + 10% biochar | 50 | 0.658 | 0.000 | −0.158 |
| 90% coir + 10% vermicompost | 50 | 0.834 | 0.040 | −0.374 |
| 100% peat | 50 | 0.412 | 0.062 | 0.026 |
| 90% peat + 10% biochar | 50 | 0.960 | 0.013 | −0.473 |
| 90% peat + 10% vermicompost | 50 | 0.807 | 0.050 | −0.357 |
| 100% coir | 100 | 1.054 | 0.000 | −0.054 |
| 90% coir + 10% biochar | 100 | 1.043 | 0.001 | −0.044 |
| 90% coir + 10% vermicompost | 100 | 1.088 | 0.046 | −0.134 |
| 100% peat | 100 | 0.551 | 0.062 | 0.387 |
| 90% peat + 10% biochar | 100 | 1.132 | 0.014 | −0.146 |
| 90% peat + 10% vermicompost | 100 | 1.046 | 0.061 | −0.107 |
| SEM | | 0.053[a] | 0.002[b]; 0.003[c] | 0.053[d] |
| | | *P* values[e] | | |
| N rates | | <0.001 | 0.013 | 0.084 |
| GM | | <0.001 | <0.001 | <0.001 |
| N rate × GM | | <0.001 | 0.171 | 0.001 |

**Note:** SEM, standard error of the mean.
[a]SEM for comparing all means of N uptake.
[b]SEM for comparing means of N rates of mineral N loss.
[c]SEM for comparing means of GM of mineral N loss.
[d]SEM for comparing all means of N budget.
[e]Probability values.

farm in Australia observed synergistic effects of biochar and N fertilization when application rates were lower than commercial recommendations in wheat and radish productivity. Some studies have also shown that under reduced N conditions, the beneficial effects of biochar and vermicompost on physical and chemical properties of the plant rhizosphere are enhanced (Van Zwieten et al. 2010). High NUE observed at 50% N inputs across all amended growing media during cabbage production cycle is in line with this assumption (Table 2). At commercial recommendation rate, cabbage and lettuce fresh yields were similar across coir-based growing media indicating a lesser effect of N derived from biochar and vermicompost, which could be explained by the low total N and $NH_4^+$-N content as well as high C/N ratio of coir which may enable the response of cabbage and lettuce fresh yield to N fertilizer (Figs. 1*a* and 4*b*). Overall, cabbage and lettuce fresh yields were lower under 100% peat compared with peat-amended biochar and vermicompost, indicating the benefits of the two amendments.

**Mineral nitrogen in the growing media and leachates**

Nitrogen management is a key component for the sustainability of greenhouse and other soilless cultivation systems (Zulfiqar et al. 2019). Residual mineral N concentrations in the growing media and the leachates produced should be maintained at low levels to minimize the footprint on the environment. This is particularly important for open cultivation systems where N and other nutrients present in the leachates cannot be re-used by the growing plants (Hultberg et al. 2013). In our study, residual $NH_4^+$-N concentrations in the growing media and leachates were low in coir-based growing media (Figs. 2*a*–2*c* and 3*a*–3*c*), which reflected a better match between fertilizer N inputs and plant N needs (BC vegetable production guide 2018). High concentrations of $NO_3^-$-N measured in leachates collected from coir amended with vermicompost particularly during the first 3 wk of cabbage production phase could originate from the amendment (Figs. 2*c*–2*e*). High concentrations of $NO_3^-$-N in the leachates were also extended to peat mixed with vermicompost, indicating that

**Table 5.** Partial nitrogen budget of lettuce production on different growing media mixtures with various rates of nitrogen application through fertigation (0% N, 50% N, and 100% N).

| Growing media mixtures | Fertilizer N (as % of recommended rate) | Plant N uptake ($g \cdot pot^{-1}$) | Leachate ($g \cdot pot^{-1}$) | Partial N budget ($g \cdot pot^{-1}$) |
|---|---|---|---|---|
| 100% coir | 0 | 0.003 | 0.001 | −0.004 |
| 90% coir + 10% biochar | 0 | 0.007 | 0.000 | −0.007 |
| 90% coir + 10% vermicompost | 0 | 0.007 | 0.000 | −0.007 |
| 100% peat | 0 | 0.102 | 0.059 | −0.160 |
| 90% peat + 10% biochar | 0 | 0.069 | 0.002 | −0.071 |
| 90% peat + 10% vermicompost | 0 | 0.086 | 0.038 | −0.124 |
| 100% coir | 50 | 0.322 | 0.000 | 0.178 |
| 90% coir + 10% biochar | 50 | 0.353 | 0.001 | 0.146 |
| 90% coir + 10% vermicompost | 50 | 0.381 | 0.002 | 0.117 |
| 100% peat | 50 | 0.450 | 0.059 | −0.012 |
| 90% peat + 10% biochar | 50 | 0.283 | 0.002 | 0.215 |
| 90% peat + 10% vermicompost | 50 | 0.426 | 0.033 | 0.041 |
| 100% coir | 100 | 0.806 | 0.003 | 0.190 |
| 90% coir + 10% biochar | 100 | 0.622 | 0.002 | 0.376 |
| 90% coir + 10% vermicompost | 100 | 0.646 | 0.001 | 0.353 |
| 100% peat | 100 | 0.764 | 0.058 | 0.178 |
| 90% peat + 10% biochar | 100 | 0.560 | 0.002 | 0.439 |
| 90% peat + 10% vermicompost | 100 | 0.765 | 0.034 | 0.201 |
| SEM | | 0.022[a]; 0.031[b] | 0.001[c] | 0.022[d]; 0.031[e] |
| | | | *P* values[f] | |
| N rates | | <0.001 | 0.899 | <0.001 |
| Growing media (GM) | | 0.024 | <0.001 | 0.001 |
| N rate × GM | | <0.360 | 0.333 | 0.364 |

**Note:** SEM, standard error of the mean.
[a]SEM for comparing means of N rates of N uptake.
[b]SEM for comparing means of GM of mineral N loss.
[c]SEM for comparing means of GM of mineral N loss.
[d]SEM for comparing means of N rates of N budget.
[e]SEM for comparing means of GM of N budget.
[f]Probability values.

vermicompost was the main source of $NO_3^-$-N found in the leachates. Vermicompost used in this study was characterized by high total N content and $NH_4^+$-N concentrations but low C/N ratio which could trigger nitrification (Table 1). High nitrification rates, and therefore release of high amount of $NO_3^-$-N in the plant rhizosphere, at early growth stages when the root system is not yet well developed pose a problem of synchrony between the timing of N supply and the demand of N by plants. Lv et al. (2018) in a 80 d incubation experiment using vermicompost from different origins showed that $NH_4^+$-N concentrations decreased with time concomitantly with $NO_3^-$-N accumulation indicating the occurrence of nitrification. High concentrations of nitrate in vermicompost were also reported in other studies (Lv et al. 2014). High levels of $NO_3^-$-N in the leachates can contribute to groundwater pollution which is recognized a serious threat for the health of local communities in most greenhouse vegetable production areas (Lin et al. 2012). Strategies to reduce the concentration of $NO_3^-$-N in the leachate or the re-use of N present in the leachate during the early growth stages are needed if coir and vermicompost growing media mixture is to be recommended (Hultberg et al. 2013). This could be achieved by delaying N fertilizer application until the root system is well established or by re-using N present in the leachate back to the plants through a recirculation system. Cabbage and lettuce fresh yields under coir and peat amended with vermicompost at 0% N input were significantly higher than coir or peat alone indicating that part of the $NO_3^-$-N released by vermicompost early in the growing season was used by the young seedlings to support their growth (Figs. 1*a* and 1*b*). The limited growth observed later in the growing season which resulted in low final yields was probably due to a lack or shortage of $NO_3^-$-N supply by vermicompost indicating a short lasting effect.

An interesting aspect of our study is the behavior exhibited by growing media amended with biochar. Two growing media, peat alone and peat amended with vermicompost, had high residual $NH_4^+$-N and high concentrations of $NH_4^+$-N in the leachates, and the extent was not affected by N fertilization rates (Figs. 2 and 3). This is an indication that peat was the main source of $NH_4^+$-N released in the rhizosphere. In contrast, the concentrations of residual $NH_4^+$-N in the growing media and the leachates were significantly reduced with biochar, and that of $NO_3^-$-N was also very low (Figs. 2 and 3). It is possible that the limited residual $NH_4^+$-N in peat amended with biochar was due to loss of N through ammonia volatilization. Biochar with high pH (Table 1) might introduce some alkalinity in the growing media mixture (Sommer and Hutchings 2001). The pH of growing media mixtures at the end of the two cycles of production was 3.86 for peat alone and 6.15 for peat amended with biochar (Supplementary Fig. S1[2]). The addition of biochar in peat-based growing media has the advantage to produce substantial fresh yields of cabbage and lettuce while maintaining residual mineral N and leachate N at low levels which could be explained by favorable pH. It is also possible that (1) $NH_4^+$-N released by peat in the rhizosphere early in the growing season was fixed by biochar and thus contributed to decreased concentration in the leachates and (2) $NH_4^+$-N fixed onto biochar was used later in the growing season by growing plants when their root system was well developed. A comparison of fresh yields under peat amended with biochar and peat alone shows that cabbage fresh yield under peat amended with biochar at 0% N was (1) similar to peat alone at 50% N, (2) reduced by only 23% compared with peat alone at the commercial recommendation rate, and (3) similar observations could be made for lettuce fresh yield. We observed throughout the experiment that the growth of cabbage and lettuce under peat amended with biochar at 0% N was delayed for about 3 wk after planting relative to the other N treatments. It is possible that under peat alone at 0% N, high $NH_4^+$-N in the rhizosphere early in the growing season did not contribute to the growth of young seedlings. A study using *Arabidopsis thaliana* demonstrated that when $NH_4^+$-N is the sole source of N, plant growth is suppressed due to $NH_4^+$ toxicity (Hachiya et al. 2012). Ammonia volatilization that may have occurred under peat amended with biochar probably alleviated the $NH_4^+$ toxicity that would have otherwise affected the young seedlings. There is a wide range of biochar and vermicompost available for use in container substrates depending on feedstock origin, production processes including pyrolysis and vermicomposting and mixing percentages with conventional growing medium. It is crucial to deepen our understanding of how these factors affect the growth of leafy vegetables, quality of biochar- and vermicompost-based high-performing growing medium and nutrient use efficiency and nutrient losses to the environment. Future studies focussing on mixtures with promising results are, therefore, needed to assess the stability of the effects obtained under controlled settings in production environments.

## Conclusion

Cabbage and lettuce fresh yields were reduced at 50% N application rates compared with the commercial recommendations, but the extent was limited under amended growing media compared with conventional growing media alone. Two growing media mixtures in particular, (1) 90% peat + 10% biochar and (2) 90% coir + 10% vermicompost, maintained expected yield at 50% N application relative to the commercial recommendation. Biochar retained $NH_4^+$-N released by peat early in the growing season, and this N was used by plants later in the season when the root system was well developed. This is highlighted by N uptakes greater than fertilizer N inputs at both commercial recommended rates and at 50% N applications particularly for cabbage. Additionally, the affinity of biochar to $NH_4^+$-N decreased the concentration of residual mineral N in the growing media as well as in the leachates, which could be beneficial for the environment. Vermicompost mixed with coir was also beneficial at maintaining acceptable fresh yield upon reduction of fertilizer N input by 50% due probably to N mineralization and nitrification.

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