

Article

Effects of Bamboo (*Phyllostachys praecox*) Cultivation on Soil Nitrogen Fractions and Mineralization

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Abstract: The mineralization of soil organic nitrogen (N) is the key process in the cycling of N in terrestrial ecosystems. Land-use change to bamboo (*Phyllostachys praecox*) cultivation that later entails organic material mulching combined with chemical fertilizer application will inevitably influence soil N mineralization (N_{\min}) and availability dynamics. However, the soil N_{\min} rates associated with various N fractions of *P. praecox* in response to land-use change and mulching are not well understood. The present study aimed to understand the effects of land-use change to *P. praecox* bamboo cultivation and organic material mulching on soil N_{\min} and availability. Soil properties and organic N fractions were measured in a *P. praecox* field planted on former paddy fields, a mulched *P. praecox* field, and a rice (*Oryza sativa* L.) field. Soil N_{\min} was determined using a batch incubation method, with mathematical models used to predict soil N_{\min} kinetics and potential. The conversion from a paddy field to *P. praecox* plantation decreased the soil pH, soil total N, and soil organic matter (SOM) content significantly ($p < 0.05$); the mulching method induced further soil acidification. The mulching treatment significantly augmented the SOM content by 7.08% compared with the no-mulching treatment ($p < 0.05$), but it decreased soil hydrolyzable N and increased the nonhydrolyzable N (NHN) content. Both the N_{\min} rate and cumulative mineralized N were lowest in the mulched bamboo field. The kinetics of N_{\min} was best described by the ‘two-pool model’ and ‘special model’. The Pearson’s correlation analysis and the Mantel test suggested soil pH was the dominant factor controlling the soil cumulative mineralized N and mineralization potential in the bamboo fields. These findings could help us better understand the N cycling and N availability under mulching conditions for shifts in land use, and provide a scientific basis for the sustainable management of bamboo plantations.

Keywords: kinetic equations; nitrogen mineralization; organic material mulching; organic nitrogen fraction; *Phyllostachys praecox*; soil acidification



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1. Introduction

Nitrogen (N) is a limiting factor for the growth and development of plants as well as a robust indicator of soil fertility [1,2]. In terrestrial ecosystems, N mainly exists in organic forms in which its availability is restricted by its chemical composition and structure [3]. Soil organic N can be divided into hydrolyzable N (THN) and nonhydrolyzable N (NHN) components via a chemical extraction method; the forms of THN include ammonium N (AN), amino acid N (AAN), amino sugar N (ASN), and unknown hydrolyzable N (UHN) [4,5]. Because of its rapid turnover and high proportion in soil N, the AAN is considered an important indicator of N cycling and the state of organic matter degradation [6,7]. Accordingly, soil N fractionation is a widely accepted method for identifying the potential bioavailability of nitrogen [8]. Although some THNs can be directly absorbed by plants or assimilated by microorganisms, most soil organic N must first be converted into nitrate N (NO_3^- -N) and ammonium N (NH_4^+ -N) by mineralization before it can be

absorbed and utilized by plants [9]. Furthermore, this mineralization process can also affect the dynamics of soil N leaching and its gaseous losses [10]. Thus, N mineralization (N_{\min}) rates can better convey changes in soil quality and ecosystem functions [11].

Soil N_{\min} is strongly influenced by various abiotic factors, such as temperature, moisture, pH, and fertility levels [12–14]. Moisture and temperature are two well-known major factors controlling N_{\min} ; moreover, Neina [15] reported that N_{\min} mainly occurs at a pH of 6.5–8. Nitrification is quite sensitive to soil pH values; generally, raising the soil pH can increase the amount of soluble soil organic matter (SOM), which provides C and N substrates for microbes, thereby increasing both microbial diversity and soil enzyme activity [16,17]. Yet, it was also reported that nitrification can occur rapidly within the pH range of 4.5–5.2 [18]. Both the amount and forms of SOM can also have substantial impacts upon N_{\min} , especially the labile C and N pools, given the positive correlation between the mineralization potential and SOM content [19]. Ros [20] concluded that N_{\min} is primarily related to the size of SOM and extractable organic matter fractions, whereas those variables corresponding to soil texture and organic matter quality are deemed less important. However earlier, Bechtold and Naiman [21] found that N_{\min} was maximal in fine-textured soil samples under long-term laboratory incubation, and went on to suggest that particle size influenced the N content and its mineralization. Thus, it is not a single factor that determines N_{\min} , but rather a variety of factors capable of exerting interactive effects upon N_{\min} dynamics. In addition to the local environment and soil factors, soil N_{\min} can vary considerably among locations due to their cultivated plant species and management practices [22]. In particular, land-use changes involving the planting of different species often entail a combination of different forms of management. In this respect, the sudden and heavy input of organic manure and fertilizers (N fertilizer) is especially relevant, as it can seriously affect the amount and the cycling of soil N.

Paddy rice production is one of the traditional land-use systems in South China due to the high population [23], but the increase of the rice yield has inhibited the price of the rice. Therefore, in the last few decades, with the goal of improving the local economy, increasingly more agricultural land in South China is undergoing conversion to *Phyllostachys praecox* bamboo plantations [24]. Since its shoots are edible by humans, *P. praecox* is a favored species, and because of its high economic returns, *P. praecox* plantations are now extensively cultivated in southern China [25]. Intensive management techniques for its cultivation there include organic material mulching, heavy fertilization, and the application of organic manure, all of which are commonly used to increase soil temperatures in winter so as to stimulate the early emergence of bamboo shoots and obtain a premium price when the market supply is low [26]. As reported by other researchers, mulching can foster soil organic matter accumulation and lead to soil acidification, as well as bamboo recession [27–29]. In general, the high content of SOM ought to increase the soil N_{\min} [30], but a low pH could reduce the potential N mineralization rate [31]. Accordingly, the soil N_{\min} potential of *P. praecox* plantations can be complicated under conditions of mulching applications, making it hard to predict, especially since it has not yet been robustly elucidated.

Mineralization of soil organic N in bamboo soils is the key process underpinning N nutrition. When land-use change is followed with organic mulching materials combined with chemical fertilizer application, this is apt to influence soil N availability. However, despite the prevalence of bamboo plantations worldwide, how the soil organic N fraction and N_{\min} rates of *P. praecox* fields have responded to land-use changes and mulching remain poorly understood. Here we hypothesized that land-use change could significantly change the soil N forms and N_{\min} of bamboo-cultivated soil. At the same time, the organic material mulching technique would further reduce soil N availability because of severe soil acidification. Therefore, the objectives of this study were: (1) to investigate the effects of bamboo plantation establishment and its organic material mulching on the soil N fraction and N_{\min} rate; (2) to evaluate the soil N availability potential by using kinetic models of N_{\min} ; (3) to explore the joint, comprehensive impacts of soil organic matter and soil pH upon N_{\min} . The empirical determination of the soil organic N fraction and N_{\min} rate

advances our understanding of the effects of mulching on N-use efficiency and N cycling in plantation settings. Moreover, it could provide a timely reference for moving closer to the sustainable production of *P. praecox* in practice.

2. Materials and Methods

2.1. Study Area

The soil samples were collected from the Lin'an District of Hangzhou City, Zhejiang Province, China (30°17'17" N, 119°32'44" E). The study area is within a subtropical monsoon climate zone, and has an annual precipitation of 1420 mm and an annual average temperature of 15.9 °C. The soil texture is medium loam and the soil type is classified as Anthrosols according to the FAO (Food and Agriculture Organization).

An area of about 4 km² was selected for this study. Due to economic and historical reasons, some of the paddy fields were converted to *P. praecox* stands in recent years and these two different land-use systems (paddy fields and *Phyllostachys praecox* plantations) were distributed randomly in this area. *P. praecox* plantations shared the same soil texture with paddy fields before the conversion of the rice fields into bamboo plantations.

2.2. Experimental Design and Organic Mulching Technique

Our study contained two *P. praecox* plantations including a mulching treatment (mulched in 2015 and 2017, PM) and a nonmulching treatment (PNM); in this area, the two *P. praecox* plantations were planted on fields no longer used for rice paddy farming since 2010. The bamboo culm density of the PM and PNM was 1.51 stems m⁻² and 1.31 stems m⁻², respectively; the mean diameter at breast height of the *P. praecox* bamboo in the PM and PNM was 4.67 cm and 3.65 cm, respectively. The still-farmed paddy field (PS) was randomly chosen as a control. Within each treatment, three plots (each 200 m²) were established for sampling. For the paddy field, the fertilization rate was 375 kg N ha⁻¹ year⁻¹ and the rice was harvested in early November of each year. For the *P. praecox* plantation without mulching, its fertilization rate was 150 kg N ha⁻¹ year⁻¹. For the *P. praecox* plantation with mulching, an organic material mulching technique was applied. In brief, this mulching involved placing 10–15 cm of rice straw (42.18% organic carbon (OC), 0.78% total N (TN)) on the soil surface, then adding 10–15 cm of rice husks (35.86% OC, 0.47% TN) to form a thick mulch. The yearly application amount of these mulching materials was equivalent to 40 Mg ha⁻¹ of rice straw and 55 Mg ha⁻¹ of rice husk. In the present study, the mulching period started in December and terminated in March of the next year. After March, the mulching materials were removed as much as possible. A high fertilization rate, comprising 1125 kg ha⁻¹ of urea and 2250 kg ha⁻¹ of complex fertilizer (N–P–K: 16–16–16), was applied every year prior to mulching.

2.3. Soil Sampling and Sample Assay

All the soil samples were collected in November 2018. The soil (0–20 cm depth) was collected from five randomly selected locations within each plot and combined to form a composite sample. These nine soil samples were air-dried, ground, and sieved for their later analysis. Soil pH was measured in 1:2.5 (*w/v*) distilled deionized water by a FE28-Standard pH meter (METTLER TOLEDO Co., Ltd., Shanghai, China); SOM was determined by the heating digestion method with 5% K₂Cr₂O₇ and H₂SO₄ [32]. Soil TN was determined by the Kjeldahl method; soil NH₄⁺-N and NO₃⁻-N were each extracted by 2 M KCL and respectively quantified by indophenol blue colorimetry and dual wavelength colorimetry [33]. The soil basic properties of the three sites are summarized in Table 1.

2.4. Incubation Experiment and Measurement of Soil Nitrogen Mineralization

An aerobic incubation method with intermittent leaching was used to determine N mineralization (N_{min}) [34]. Briefly, a layer of glass wool was first placed at the bottom of a 50-mL cylinder vial, then quartz sand (15 g) was added on top of it, and another layer of glass wool placed on that sand, above which a homogeneous mixed sample of air-dried soil

(15 g) and quartz sand (20 g) filled the cylinder vial; atop it, a layer of glass wool and quartz sand (15 g) were added to prevent the soil sample from splashing. Both the glass wool and quartz sand were pretreated with acid. The soil samples ($n = 3$) were adjusted to 60% of field water capacity [35], sealed, and incubated at 35 °C in an LRH-80 incubator (Juchuang Co., Ltd., Qingdao, China). At days 0, 7, 14, 21, 28, 42, and 56, the soil samples were leached with 100 mL of 0.01 M CaCl₂; this was done four times, followed with 20 mL of a nutrient solution devoid of N (0.002 M CaSO₄·2H₂O; 0.002 M MgSO₄; 0.005 M Ca(H₂PO₄)₂·H₂O; 0.0025 M K₂SO₄). After the leaching, the excess water was removed under 8 kPa negative pressure; all the leachate was collected for the determination of NH₄⁺-N and NO₃⁻-N.

Table 1. Basic chemical properties of soils at the paddy field, *P.* plantation without mulching and *P.* plantation with mulching sites.

Site Treatment	pH	SOM g kg ⁻¹	TN g kg ⁻¹	NO ₃ ⁻ -N mg kg ⁻¹	NH ₄ ⁺ -N mg kg ⁻¹	C/N Ratio
PS	6.54 ± 0.18 a	43.26 ± 3.47 a	2.59 ± 0.11 a	6.18 ± 1.78 c	8.67 ± 0.51 c	9.69 ± 0.78 ab
PNM	4.75 ± 0.11 b	34.16 ± 0.54 c	2.08 ± 0.04 b	23.85 ± 1.56 b	12.72 ± 1.26 b	9.53 ± 0.15 b
PM	4.00 ± 0.04 c	36.58 ± 0.52 b	2.08 ± 0.12 b	43.32 ± 3.37 a	20.22 ± 1.11 a	10.20 ± 0.15 a

PS, paddy soil; PNM, *Phyllostachys praecox* plantation without mulching; PM, *P. praecox* plantation with mulching. SOM, soil organic matter; TN, soil total nitrogen; NH₄⁺-N, ammonium N; NO₃⁻-N, nitrate N. Different lower-case letters indicate significant differences among the treatments.

2.5. Soil Organic Nitrogen Fractionation

Forms of soil organic N were identified from the hydrolysate prepared by refluxing the soil with 6 M HCl in a 120 °C oil bath, for 12 h [36]. The different soil organic N fractionations were measured according to Wang et al. [37]. Total hydrolyzable N (THN) was determined by steam distillation with 10 M NaOH after the Kjeldahl digestion of the acid hydrolysate. Nonhydrolyzable N (NHN) was calculated as follows:

$$\text{NHN} = \text{Total N} - \text{THN} \quad (1)$$

Hydrolyzable ammonium N (AN) was measured by steam distillation with 3.5% (*w/v*) MgO. Amino sugar N (ASN) was calculated as the difference between the AN value and that obtained from steam distillation of the hydrolysate with a phosphate–borate buffer at pH = 11.2. Amino acid N (AAN) was also determined by steam distillation. This was with an aliquot of the hydrolysate with a phosphate–borate buffer and 5 M NaOH, after heating the 0.5 M NaOH at 100 °C to decompose the hexosamines and remove NH₃-N; with ninhydrin powder added to convert the amino-N to NH₃-N. The amount of unknown hydrolyzable N (UHN) was calculated as follows:

$$\text{UHN} = \text{THN} - (\text{AN} + \text{ASN} + \text{AAN}) \quad (2)$$

2.6. Models of Nitrogen Mineralization Kinetics

Four models may be used to fit N_{min} kinetics according to Li et al. [38]. There is the effective accumulated temperature model:

$$Y = k((T - T_0)D)^n \quad (3)$$

where, Y is the cumulative amount of N mineralized (mg N kg⁻¹), T_0 is set to 15 °C [39], T is the incubation temperature, D is the incubation time in days, while k and n are the mineralization constants.

The single first-order exponential model ('one-pool model') has this form:

$$N_t = N_0(1 - e^{-k_0t}) \quad (4)$$

where, N_t is the cumulative amount of N mineralized over time t (mg N kg^{-1}), N_0 denotes the potentially mineralizable N, while k_0 is the first-order rate coefficient [34].

The double first-order exponential model ('two-pool model') has this form:

$$N_t = N_a(1 - e^{-k_a t}) + N_r(1 - e^{-k_r t}) \quad (5)$$

where, N_a and k_a represent the N potential and the first-order rate coefficient of the readily available fraction, respectively; the N_r and k_r are the corresponding N potential and the first-order rate coefficient of the resistant matter fraction, respectively [40].

Finally, the mixed first- and zero-order model ('special model') has this form:

$$N_t = N_{a0}(1 - e^{-k_{a0} t}) + C_r t \quad (6)$$

where, C_r is the constant decomposition rate of the resistant matter fraction, while both N_{a0} and k_{a0} terms are the same as those defined for the two-pool model just above [41].

2.7. Data Analysis

The data were calculated and plotted using Origin 2019 software (OriginLab, Northampton, MA, USA). Each response variable was subjected to a one-way ANOVA (analysis of variance) using IBM SPSS Statistics 20.0 (SPSS Inc., Chicago, IL, USA); differences between the three site treatments were evaluated by Duncan's multiple range test at a significance level of 0.05. Before the statistical analysis, the obtained data was validated and fitted for normal distribution. Using nonlinear regression, the mineralization parameters were estimated from the cumulative amounts of extracted NH_4^+ and NO_3^- over the incubation time, this was done separately for all four models. The linear correlation between two variables was determined by Pearson's r coefficient. A 999-permutation Mantel test was used to test the relationships among soil properties and soil cumulative mineralized N, and performed using the "Vegan" packages in R v 4.0.2 (R Foundation for Statistical Computing, Vienna, Austria).

3. Results

3.1. Basic Soil Properties of Bamboo Plantations

As Table 1 shows, the pH of the surface layer soil (0–20 cm) in the PS was decreased significantly after initial conversion to the *P. praecox* bamboo plantation ($p < 0.05$), and the mulching significantly decreased the pH of PNM by 15.79% ($p < 0.05$). Similarly, the SOM content decreased significantly after conversion from paddy field to bamboo plantation ($p < 0.05$), but the mulching significantly increased the SOM content of PNM by 7.08% ($p < 0.05$). The TN content ranged from 2.08 to 2.59 g kg^{-1} among all three treatment sites, being significantly higher in the PS than the two established bamboo plantations ($p < 0.05$). Although the NO_3^- -N and NH_4^+ -N contents were increased after mulching, the highest content of NO_3^- -N and NH_4^+ -N was observed in the PM, not the PNM treatment. In addition, NH_4^+ -N accounted for the majority of mineralized N at PS, while the mineralized N was dominated by NO_3^- -N at the two *P. praecox* plantations. The C/N ratio ranged from 9.53 to 10.20 among the three treatments.

3.2. Soil Organic Nitrogen Fractions

The soil THN of PS, PNM, and PM site treatments accounted for 74.90%, 75.72%, and 75.11% of the TN content, respectively. The THN content ranged from 1564 to 1940 mg kg^{-1} (Figure 1), and it was significantly higher in the PS than *P. praecox* soils ($p < 0.05$). With mulching applied, the soil THN content decreased whereas the soil NHN content increased, but no significant difference was detected between PNM and PM ($p > 0.05$). The AAN content ranged from 532.1 to 819.6 mg kg^{-1} among the three site treatments. With conversion of the paddy field to a *P. praecox* bamboo plantation, the soil's AAN content and proportion decreased significantly ($p < 0.05$), but then slightly increased with mulching applied (Figure 2B); however,

the proportion of THN consisting of AAN was similar between PNM and PM (Figure 2A). After establishing the *P. praecox* plantations, their AN and ASN proportions of THN had both increased significantly ($p < 0.05$), but the AN and ASN contents did not differ significantly between the bamboo plantations. For the UHN content, its ranking was PS > PNM > PM. Across the site treatments, the content of the organic N fractions had this general ranking: AAN (532–820 mg kg⁻¹) > AN (434–480 mg kg⁻¹) ≈ UHN (457–498 mg kg⁻¹) > ASN (147–171 mg kg⁻¹).

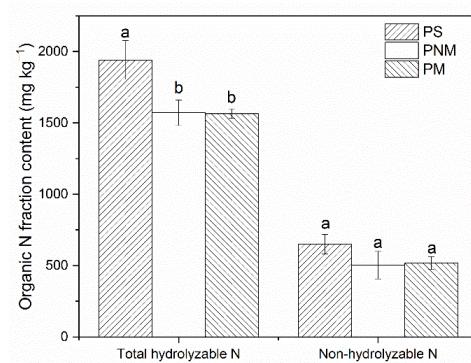


Figure 1. The content of total hydrolyzable N and nonhydrolyzable N in soils for the paddy field, *P.* plantation without mulching and *P.* plantation with mulching sites. PS, rice paddy soil; PNM, *Phyllostachys praecox* plantation without mulching; PM, *P. praecox* plantation with mulching. Bars are the mean \pm standard error ($n = 3$). Different lower-case letters indicate significant differences according to Duncan's test at the 0.05 level.

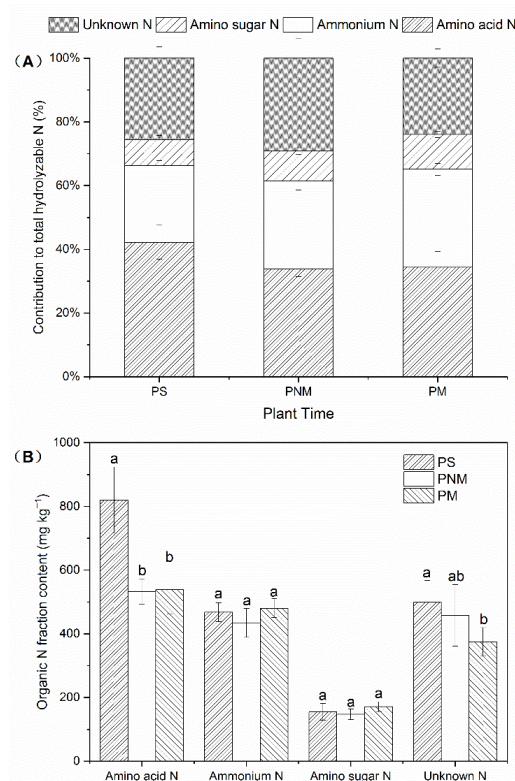


Figure 2. The proportion (A) and content (B) of different organic nitrogen fractions for the paddy field, *P.* plantation without mulching and *P.* plantation with mulching sites. PS, rice paddy soil; PNM, *Phyllostachys praecox* plantation without mulching; PM, *P. praecox* plantation with mulching. Bars are the mean \pm standard error ($n = 3$). Different lower-case letters indicate significant differences according to Duncan's test at the 0.05 level.

3.3. Soil Nitrogen Mineralization

As Figure 3 shows, the total amount of N mineralized during the 56-day incubation varied significantly among the different treatments ($p < 0.05$), being greatest in PS at 191.1 mg kg^{-1} , while the mineralized N of PNM and PM amounted to 128.8 and 95.48 mg kg^{-1} , respectively. Similarly, the soil N_{min} rate decreased significantly after converting the paddy field to a *P. praecox* bamboo plantation ($p < 0.05$), being significantly reduced by mulching as well ($p < 0.05$). Furthermore, the process of N_{min} mainly happened during the first 2 weeks and declined with time, and by day 21 of the incubation period a higher mineralization rate characterized the PNM. Across all treatments, the mineralized N of the first 2 weeks (N_{14}) ranged from 52.51 to 138.0 mg kg^{-1} and the ratio of N_{14} to N_t (total mineralized N) during the incubation period fell by 49.76% – 72.25% (Table 2). The cumulative mineralized N was mainly dominated by $\text{NH}_4^+\text{-N}$, in that it accounted for 85.47% , 72.78% , and 75.87% of the total mineralized N in PS, PNM, and PM, respectively.

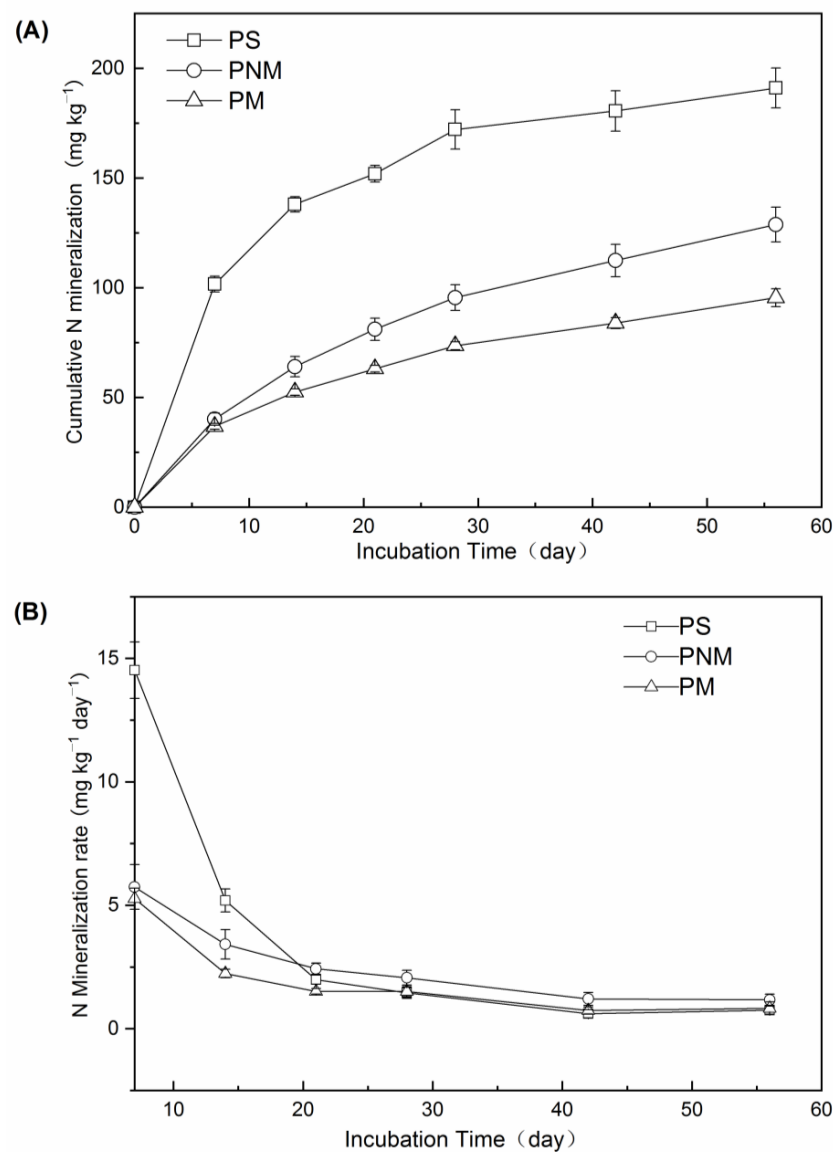


Figure 3. The cumulative nitrogen mineralization (A) and mineralization rate (B) for the paddy field, *P.* plantation without mulching and *P.* plantation with mulching sites. PS, rice paddy soil; PNM, *Phyllostachys praecox* plantation without mulching; PM, *P. praecox* plantation with mulching. Bars are the mean \pm standard error ($n = 3$).

Table 2. The N mineralization for the paddy field, *P.* plantation without mulching and *P.* plantation with mulching sites.

Treatment	NH ₄ ⁺ -N mg kg ⁻¹	14 Days NO ₃ ⁻ -N mg kg ⁻¹	N ₁₄ mg kg ⁻¹	NH ₄ ⁺ -N mg kg ⁻¹	56 Days NO ₃ ⁻ -N mg kg ⁻¹	N _t mg kg ⁻¹	N ₁₄ N _t ⁻¹ %	N ₁₄ TN ⁻¹ %	N _t TN ⁻¹ %
PS	117.03 ± 3.20 a	21.00 ± 2.18 a	138.04 ± 3.51 a	163.30 ± 7.09 a	27.76 ± 2.24 ab	191.06 ± 9.10 a	72.25	5.33	7.38
PNM	43.79 ± 0.84 b	20.30 ± 5.04 a	64.09 ± 4.65 b	93.73 ± 1.97 b	35.06 ± 8.19 a	128.79 ± 7.89 b	49.76	3.08	6.19
PM	38.90 ± 0.97 b	13.61 ± 1.64 b	52.51 ± 1.48 b	72.44 ± 1.97 c	23.04 ± 2.61 b	95.48 ± 4.10 c	55.00	2.52	4.59

N₁₄, the cumulative nitrogen mineralization at the 14th day of incubation; N_t, the cumulative nitrogen mineralization at the end of the incubation period. Different lower-case letters indicate significant differences among the treatments.

3.4. Model Fitting of N Mineralization Kinetics

As seen in Figure 4, the effective accumulated temperature, one-pool, two-pool, and special models, all provided a very good fit to the data according to their R² (R²-values: 0.989–1.000), and their estimated model parameters are listed in Table 3. In the effective accumulated temperature model, the *k* value (i.e., the mineralization capacity) of the paddy field significantly exceeded that of either *P. praecox* plantation, which matched the trend in the variation of cumulative N_{min}. In the one-pool model, the N₀ value surpassed its N_t (Table 2) in the PNM and PM, but not in the PS treatment, and the trend in the variation of N₀ (i.e., potentially mineralizable N) was on par with N_t among all the treatments; the *k*₀ values ranged from 0.044 to 0.1 d⁻¹. In the two-pool model, the value of N_a (i.e., N potential of the readily available fraction) was significantly higher than that of N_r (i.e., N potential of the resistant matter fraction). In the special model, the N_{a0} values ranged almost threefold, from 50.44 to 146.1 mg kg⁻¹, and their pattern resembled that found for N_a in the two-pool model; indeed, the special model gave a similarly good fit to empirical data as the two-pool model.

3.5. Relationship between N Mineralization Kinetics Parameters with Soil Properties

The obtained correlation coefficients between the N_{min} kinetics parameters and SOM, soil TN, NH₄⁺-N, NO₃⁻-N, and organic N fractions are shown in Table 4. Significant correlations emerged between the cumulative mineralized N and most of the indicators assessed. In particular, the N₀, N_a, and N_{a0} were correlated with many indicators, while relatively few indicators were significantly correlated with the mineralization potential parameters N_r and C_r, and the rate constants (*k*₀, *k*_a, *k*_r, *k*_{a0}). Soil pH, SOM, TN, THN, and AAN were each significantly and positively correlated with N_t and the mineralization potential, whereas they were poorly correlated with the mineralization potential parameters N_r and C_r of the resistant matter fraction. Both NH₄⁺-N and NO₃⁻-N had significant negative correlations with N_t and the mineralization potential; by contrast, ASN, AN, and NHN had relatively little influence on the soil N_{min} parameter.

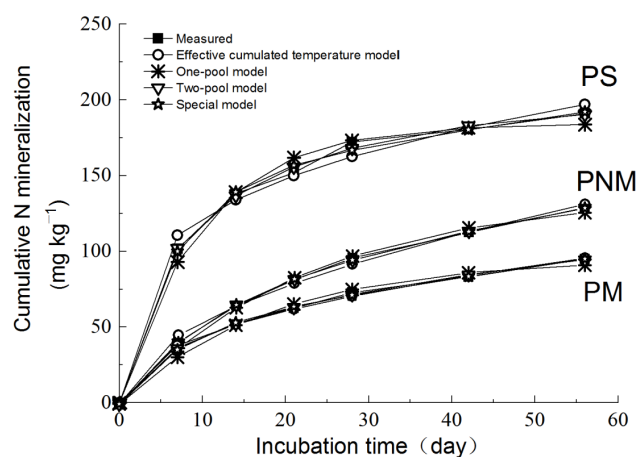


Figure 4. The cumulative nitrogen mineralization for the paddy field, *P.* plantation without mulching and *P.* plantation with mulching sites. PS, rice paddy soil; PNM, *Phyllostachys praecox* plantation without mulching; PM, *P. praecox* plantation with mulching. Bars are the mean ± standard error (*n* = 3).

Table 3. Estimated parameters of four different models and their goodness-of-fit (R^2) obtained from nonlinear regressions.

Model Name	Parameter	Unit	PS	PNM	PM
Effective cumulated temperature model	R^2		0.991	0.996	0.998
	k		28.01	3.468	4.421
	n		0.278	0.517	0.439
One-pool model	R^2		0.991	0.996	0.989
	N_0	mg kg ⁻¹	184.4	137.5	95.76
	k_0	d ⁻¹	0.100	0.044	0.056
Two-pool model	R^2		0.999	1.000	0.999
	$N_a + N_r$	mg kg ⁻¹	197.7	255.3	124.3
	N_a	mg kg ⁻¹	79.97	61.01	31.05
	k_a	d ⁻¹	0.265	0.095	0.213
	k_r	d ⁻¹	0.049	0.008	0.021
Special model	R^2		0.998	1.000	0.999
	N_{a0}	mg kg ⁻¹	146.1	72.94	50.44
	k_{a0}	d ⁻¹	0.148	0.085	0.131
	C_r	mg kg ⁻¹ d ⁻¹	0.821	1.006	0.808

PS, rice paddy soil; PNM, *Phyllostachys praecox* plantation without mulching; PM, *P. praecox* plantation with mulching.

Table 4. Pearson correlations between the mineral-N, parameters in the fitted models, and soil properties.

Soil Properties	N_f	k	n	N_0	k_0	N_a	k_a	N_r	k_r	N_{a0}	k_{a0}	C_r
SOM	0.713 **	0.757 **	-0.764 **	0.603 **	0.765 **	0.485 *	0.658 **		0.770 **	0.685 **	0.639 **	
TN	0.798 **	0.863 **	-0.843 **	0.729 **	0.858 **	0.625 **	0.658 **		0.847 **	0.810 **	0.629 **	-0.409 *
NH ₄ ⁺ -N	-0.722 **	0.637 **	0.463 *	-0.798 **	-0.539 **	-0.753 **	-0.144		-0.475 *	-0.725 **		
NO ₃ ⁻ -N	-0.677 **	-0.671 **	0.541 **	-0.755 **	-0.597 **	-0.680 **	-0.288		-0.553 **	-0.716 **		
pH	0.906 **	0.946 **	-0.819 **	0.968 **	0.884 **	0.912 **	0.446 *		0.823 **	0.984 **		
AAN	0.744 **	0.832 **	-0.806 **	0.714 **	0.825 **	0.624 **	0.609 **		0.810 **	0.789 **	0.578 **	-0.407 *
ASN						-0.467 *		-0.436 *				
AN							0.458 *	0.568 **			0.477 *	-0.413 *
UHN	0.440 *	0.475 *		0.609 **		0.617 **				0.561 **		
NHN	0.449 *											
THN	0.718 **	0.860 **	-0.827 **	0.747 **	0.849 **	0.653 **	0.619 **		0.831 **	0.819 **	0.587 **	0.393

SOM, soil organic matter; TN, soil total nitrogen; NH₄⁺-N, ammonium N; NO₃⁻-N, nitrate N; THN, hydrolyzable N; AN, ammonium N; AAN, amino acid N; ASN, amino sugar N; UHN, unknown hydrolyzable N; NHN, nonhydrolyzable N. The * and ** denote significance at $p < 0.05$ and $p < 0.01$, respectively. The blanks in the form indicate there is no significant correlation between the two parameters.

As revealed by the Mantel test (Table 5), the soil pH value, SOM, soil AAN content, TN, NH₄⁺-N, and NO₃⁻-N content exerted a significant impact on soil cumulative mineralized N, wherein TN ($r = 0.9839$, $p = 0.001$), NH₄⁺-N ($r = 0.9720$, $p = 0.001$), and the pH value ($r = 0.9549$, $p = 0.001$) were the primary drivers.

Table 5. Significance tests of the relationship between soil properties and soil cumulative mineralized N based on the Mantel test.

	r	p
SOM	0.5219	0.011
TN	0.9839	0.001
NH ₄ ⁺ -N	0.9720	0.001
NO ₃ ⁻ -N	0.8338	0.002
pH	0.9549	0.001
AN	-0.1961	0.889
AAN	0.6123	0.004
ASN	0.0055	0.392
UHN	0.1737	0.140
NHN	0.2506	0.061

SOM, soil organic matter; TN, soil total nitrogen; NH₄⁺-N, ammonium N; NO₃⁻-N, nitrate N; AN, ammonium N; AAN, amino acid N; ASN, amino sugar N; UHN, unknown hydrolyzable N; NHN, nonhydrolyzable N.

4. Discussion

It is well known that land-use changes as well as forest management practices can greatly alter the properties of soil [11,42]. Our results suggest the conversion from paddy field to *P. praecox* bamboo plantation could decrease soil pH considerably, which is consistent with findings reported by Holubík et al. [43]. In addition, the mulching practice further induced soil acidification, likely due to the heavy application of chemical fertilizer and phenolic acids excreted from the decomposition of organic materials in the mulch [28]. It is widely accepted now that land-use change can markedly change SOM content in soils [44]. Our results showed that mulching can increase the SOM in a bamboo plantation, an outcome largely driven by the direct input from organic materials [45]. Nevertheless, the mulched bamboo plantation showed less SOM than the paddy field. This result could be explained in two ways. First, the soil organic carbon (SOC) of bamboo stands with mulching mostly exists in unstable forms that are not conducive to preservation [46,47]. Second, the waterlogging condition in a paddy field generally promotes the preservation and fixation of SOC [48]. The decline of TN in soils of the bamboo without mulching mainly arose from the reduction in fertilization and rapid growth of *P. praecox*. We found that NH_4^+ -N made up most of the mineralized N present in rice paddy soil, which could have resulted from waterlogging that inhibited bacterial nitrification activities, thereby preventing NH_3 volatilization and NO_3^- -N denitrification losses. This would have created an environment suitable for soil organic N_{min} , enabling the accumulation of NH_4^+ -N [49]. In stark contrast, the higher proportion of NO_3^- -N present in both *P. praecox* plantations might be linked to their high N fertilization input and better ventilation [50,51].

Adding organic material can change soil environmental conditions and increase the N inputs into soil [52], for which the N forms and fractions are important factors affecting the overall N availability in soils [53]. In this context, the THN is often classified as labile soil organic N while the NHN is considered as stable organic N [54]; our study revealed the sensitivity of labile fractions of soil to land-use change (from a paddy field to a bamboo plantation). The AAN accounted for 25.64%–31.66% of the TN among different site treatments, a result consistent with Stevenson [55], who found AAN comprised approximately 20%–30% of the soil TN. Free amino acids can be absorbed by plants and assimilated directly by soil microorganisms [56,57], so mulching had a negligible impact on the AAN content. However, AN and ASN are more labile than the other two fractions of hydrolyzable soil N, and both play vital roles in the mineralization process [58,59]. Mulching led to a marked improvement in the AN and ASN contents, but still, the stable fractions accumulated to a higher level than did the labile N fraction in the mulched bamboo plantation (Figure 1). A plausible reason for why that happened, is that the mineralization rate of NHN was too low, which would have driven an accumulation in soil. Furthermore, the low soil pH of *P. praecox* likely augmented the soil exchangeable aluminum (Al) and organic complexed Al, which would have contributed to the accumulation of stable organic N [60]. In general, increasing the soil organic N content will necessarily influence aspects of soil N cycling to some extent, namely the mineralization rate [61]. However, due to the higher accumulation of NHN, the effects of mulching on N_{min} could be rather complicated.

Soil organic N is ammonified by soil microbes into NH_4^+ -N, followed by its nitrification. The ensuing NO_3^- -N is more mobile than labile organic N forms such as AAN, which can easily diffuse into the rhizosphere and is available for plant uptake [62,63]. Accordingly, soil N_{min} is the main index of the N supply capacity of soil. Nonetheless, the application of organic materials in excessive amounts onto soil could strongly affect its N cycling dynamics [64,65]. In our study, the paddy field had a significantly higher mineralization rate and mineralized amount than did the two bamboo plantations. Perhaps this was because the paddy field had a more suitable pH—since the optimum soil pH for ammonification reportedly ranges from about pH 6.0 to 8.0 [66], and the highest TN content was also observed in the paddy field, according to the Mantel test, so TN, NH_4^+ -N and pH were the key factors influencing the soil cumulative mineralized N (Table 5). The lowest ratio of N_t/TN was observed in the PM (Table 2), which indicated the organic

material mulching diminished the capacity for soil mineralization, for which N_t and pH were evidently positively correlated (Table 4). Moreover, soil pH plays a key role in modulating the relative abundance and diversity of belowground bacterial communities [67]. Chen et al. [68] reported that soil bacterial diversity and soil urease activity decreased after multiple times of mulching of a *P. praecox* plantation, and they went on to predict a lower functional diversity of soil bacterial microbiomes related to the cycling of amino acids and carbohydrates after long-term mulching. Therefore, we believe mulching slightly increased the labile soil organic N, but because the diversity of soil microorganisms was reduced, the stable organic N pool increased, resulting in the low N_{min} of *P. praecox* plantations (Figure 3). Our study highlights that soil N_{min} is restricted by soil pH. Under low pH conditions, the enhancement from fertilization and organic matter fails to increase the soil N_{min} capacity and this could reduce the N-use efficiency.

It is widely accepted that N_{min} reactions generally follow first-order kinetics [69]. According to the k value (the mineralization capacity, Table 3), the effective cumulated temperature model yielded a sound prediction for the paddy field, but neither the k nor n value can be used to directly calculate the potential of N_{min} [38]. Although both k and n values did show good correlations with soil properties and organic N fractions, the effective cumulated temperature model seemed ill suited for the *P. praecox* plantation. In the fitted one-pool model, the value for the mineralization potential N_0 was significantly correlated with the soil properties and THN, which may convey the maximal potential of soil N_{min} . Yet the N_0 value was about 96.33% of the experimental data (N_t), and over time the N_0 value should surpass the observed mineral N. Our results agree with Li et al. [70], who suggested the one-pool model was not suitable for predicting the mineralization potential of rice paddy soil. In earlier work, Serna and Pomares [71] developed the parameter $N_0 \times k_0$ to convey the soil N supply capacity; here, the $N_0 \times k_0$ values of PS, PNM, and PM respectively were 18.48, 6.01, 5.34, and 5.55 $\text{mg kg}^{-1} \text{d}^{-1}$, hence, these can better indicate the N supply capacity of the different site treatments. Based on their goodness-of-fit (R^2 values) the two-pool and special models outperformed the other two models. Crucially, the two-pool model and special model each divide the soil mineralizable organic N into two realistic parts: the readily available N pools and resistant-matter (i.e., slowly decomposing) N pools [72]. In the two-pool model the mineralization capacity and rate of the two types of N pools are different, and, unlike the two-pool model, in the special model the mineralization amount of slowly decomposing N pools is linearly correlated with the incubation time. Based on our results for the fitted two-pool model, the size of readily available N pools across the three site treatments was significantly lower than that of their slowly decomposing N pools, which suggested the latter had a greater impact on the total mineralization potential. However, N_r featured the worst correlations with soil properties and organic N fractions. Our results support the recent findings of Zhang et al. [73], who argued the special model's N_{a0} parameter could be used as an index to evaluate the soil N supply capacity. Both k_{a0} and C_r were also weakly correlated with soil properties and organic N fractions in the special model. To sum up, all four models gave respectable fits to the data, but the kinetics of N_{min} were described more accurately by the two-pool model or special model.

Confirming our hypothesis, the conversion from paddy field to *P. praecox* bamboo plantation can lead to soil acidification and reductions in soil nutrients, the THN and NHN contents, and soil N mineralization as well. The practice of mulching further lowered the soil pH and raised the NHN content, which inhibited both the rate and capacity of soil N_{min} . Hence, a suitable pH seems to be crucial for sustaining the long-term soil N supply in bamboo plantations and bamboo management.

In this study, we are aware of the limitation between the laboratory incubation for N mineralization and an in situ incubation for N_{min} . Furthermore, the risk of N leaching is substantial given the heavy on-site fertilization, low soil TN and high soil NO_3^- -N content under the mulched *P. praecox* bamboo plantation. This aspect deserves further attention,

and we recommend that future in situ research investigate soil N transformations under mulching conditions to mitigate that potential environmental risk.

5. Conclusions

Our results indicated the conversion from rice paddy field to *P. praecox* plantation could significantly decrease the soil's pH value, as well as its TN and SOM content. Land-use change significantly decreased the THN and NHN, and later mulching reduced the THN yet increased the NHN content. The cumulative mineralized N and N_{\min} rate ranked as follows: PS > PNM > PM. Further, N_{\min} mainly occurred within the initial 2 weeks of incubation and then declined over time. The mineralized N was dominated primarily by NH_4^+ -N rather than NO_3^- -N. Although all four kinetics models could be fitted well to the experimental data of N_{\min} , the two-pool and special models best described its kinetics. Our works revealed that soil pH value, SOM, TN, THN, and AAN were all significantly positively correlated with the cumulative mineralized N and mineralization potential, but vice versa for NH_4^+ -N and NO_3^- -N. Besides, the Mantel test suggested that TN, NH_4^+ -N, and the pH value were the primary drivers of cumulative mineralized N. Taken together, we may infer that soil pH exerted the greatest impact on soil N_{\min} in the mulched bamboo plantation. These findings could foster a better understanding of N cycling and N availability under land-use change and mulching conditions, and contribute to developing a scientific basis for the sustainable management of *P. praecox* plantations not only in China but perhaps elsewhere, too.

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