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RESEARCH ARTICLE

REGIONAL ASSESSMENT OF SOIL NITROGEN MINERALIZATION IN DIVERSE CROPLAND OF A REPRESENTATIVE INTENSIVE AGRICULTURAL AREA

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KEYWORDS

cropland, gross nitrification rate, regulatory factors, soil nitrogen mineralization, spatial variation

HIGHLIGHTS

- Soil N mineralization (N_{min}) rates varied spatially among cropland fields.
- Soil N_{min} rates increased with a decreasing elevation.
- Soil N_{min} was mainly affected by SOC, TN, and available C and N.
- N_{min} in cropland soil should be considered when evaluating regional water pollution.

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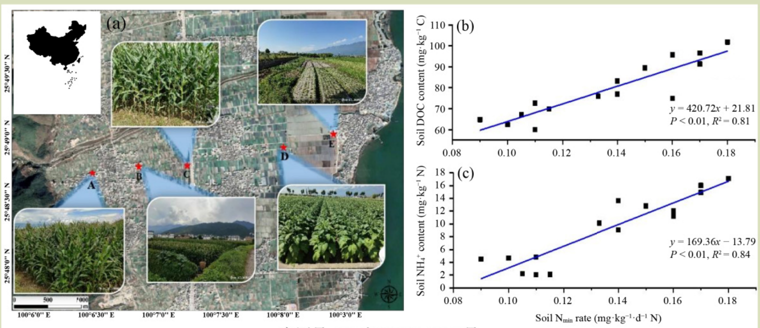
GRAPHICAL ABSTRACT



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ABSTRACT

Soil nitrogen mineralization (N_{min}) is a key process that converts organic N into mineral N that controls soil N availability to plants. However, regional assessments of soil N_{min} in cropland and its affecting factors are lacking, especially in relation to variation in elevation. In this study, a 4-week incubation experiment was implemented to measure net soil N_{min} rate, gross nitrification (Nit) rate and corresponding soil abiotic properties in five field soils (A–C, maize; D, flue-cured tobacco; and E, vegetables; with elevation decreasing from A to E) from different altitudes in a typical intensive agricultural area in Dali City, Yunnan Province, China. The results showed that soil N_{min} rate ranged from 0.10 to 0.17 $mg \cdot kg^{-1} \cdot d^{-1}$ N, with the highest value observed in field E, followed by fields D, C, B, and A, which indicated that soil N_{min} and Nit rates varied between fields, decreasing with elevation. The soil Nit rate ranged from 434.2 to 827.1 $\mu g \cdot kg^{-1} \cdot h^{-1}$ N, with the highest value determined in field D, followed by those in fields E, C, B, and A. The rates of soil N_{min} and Nit were positively correlated with several key soil parameters, including total soil N, dissolved organic carbon and dissolved inorganic N across all fields, which indicated that soil variables regulated soil N_{min} and Nit in cropland fields. In addition, a strong positive relationship was observed between soil N_{min} and Nit. These findings provide a greater understanding of the response of soil N_{min} among cropland fields related to spatial variation. It is suggested that the soil N_{min} from cropland should be considered in the evaluation of the N transformations at the regional scale.

1 INTRODUCTION

Nitrogen is an essential nutrient for crops but mineral N in soil, the only form that can be absorbed and used by crops, represents only about 1% of total soil N[1]. Although N fertilization is commonly a necessary method for supplying N to crops, N release due to excess N fertilizer in the environment through hydrological and gaseous pathways has been identified as the main obstacle to the global sustainability of food production[2,3]. In addition, soil N mineralization (N_{min}), a key process that converts organic N into mineral N during the activities of microorganisms, is normally essential for adequate N nutrition. However, a strong N_{min} may also lead to excessive amounts of nitrate (NO_3^--N) and ammonium nitrogen (NH_4^+-N) that can be lost in ground surface runoff or leach to groundwater, resulting in water pollution[4]. Although numerous reports have documented the soil N_{min} rate under different land use, such as forestry[5–7], grasslands[8] and cropland[9–11], regional assessments of soil N_{min} and its potential effects on the environment are lacking, especially for agricultural areas with intensive management.

Nitrification (Nit), another important soil N transformation linked to the soil N_{min}, contributes greatly to the regulation of the N form in soil[12]. Considerable spatial differences exist in soil N_{min} and Nit due to wide-ranging influences, N_{min} depends on organic matter composition, agricultural management practices, temperature, humidity, pH, ventilation, soil structure, soil fertility and soil microorganisms[13,14]. Soil N transformation and N_{min} are coupled processes, several studies have investigated the coupling effect between soil N_{min} and Nit among different ecosystems[15,16]. In particular, soil N_{min} can be influenced by a number of factors, such as soil pH[17], soil moisture[8], total soil N (TN)[18], total carbon (TC)[19], soil C to N ratio (C/N)[15,20], and different vegetation types[21]. Cao et al.[14] successively investigated the soil N_{min} process and its underlying mechanisms in cropland in southern China. However, a gap still existed when the effects of these factors on the soil N_{min} of different cropland differed, especially under spatial variation conditions.

In this study, we aimed to obtain a regional assessment of soil N_{min}, especially for agricultural areas with intensive management, and address the gap in how the key soil factors affect soil N_{min} of different cropland differed spatially. Also, the relationships between soil N_{min} and soil variables were examined. In addition, the potential impacts of soil N_{min} on the environment, such as water quality, were discussed.

2 MATERIALS AND METHODS

2.1 Sampling site description and soil sample collection

Soil samples were collected from representative fields (A–C, maize; D, flue-cured tobacco; E, vegetables) at different altitudes in Erhai Valley (100°06′28″ to 100°08′25″ E, 25°48′43″ to 25°49′ 02″ N) in Wanqiao Town, Dali City, Yunnan Province, China in July 2022 (Fig. 1). The sampling area has a subtropical monsoon climate with an average annual temperature of 15.1 °C and precipitation of 1065 mm. Table 1 presents detailed information on the physicochemical properties of cropland soils at different altitude levels. For soil sample collection, five topsoil (0–20 cm) samples were randomly collected in each field and mixed to prepare one composite soil sample. Then, the composite soil samples were quickly transported to the laboratory, with one part subsample used for further analysis of soil variables[22].

2.2 Design of the incubation trial

Sixty Erlenmeyer flasks (250 mL) each containing 20 g of oven-dried soil were used. Preincubation (15 °C for 5 days) of soils was done at 40% water holding capacity (WHC). The temperature of preincubation corresponded to the approximate average annual temperature of the soil sampling region. After preincubation, the moisture content of soils was adjusted to 60% WHC, and soils were then incubated for at 15 °C for 30 days. The moisture content of soils was maintained by weighing and replenishing with distilled water every 2 days. Soil samples were taken at 1, 8, 15, 22 and 30 days (i.e., nominally 0 to 4 weeks) to determine soil NH_4^+, NO_3^-, dissolved organic carbon (DOC) contents and soil pH.

2.3 Soil parameter measurements

Soil subsamples were used to determine the soil water content (SWC), soil pH, soil DOC and soil dissolved inorganic nitrogen

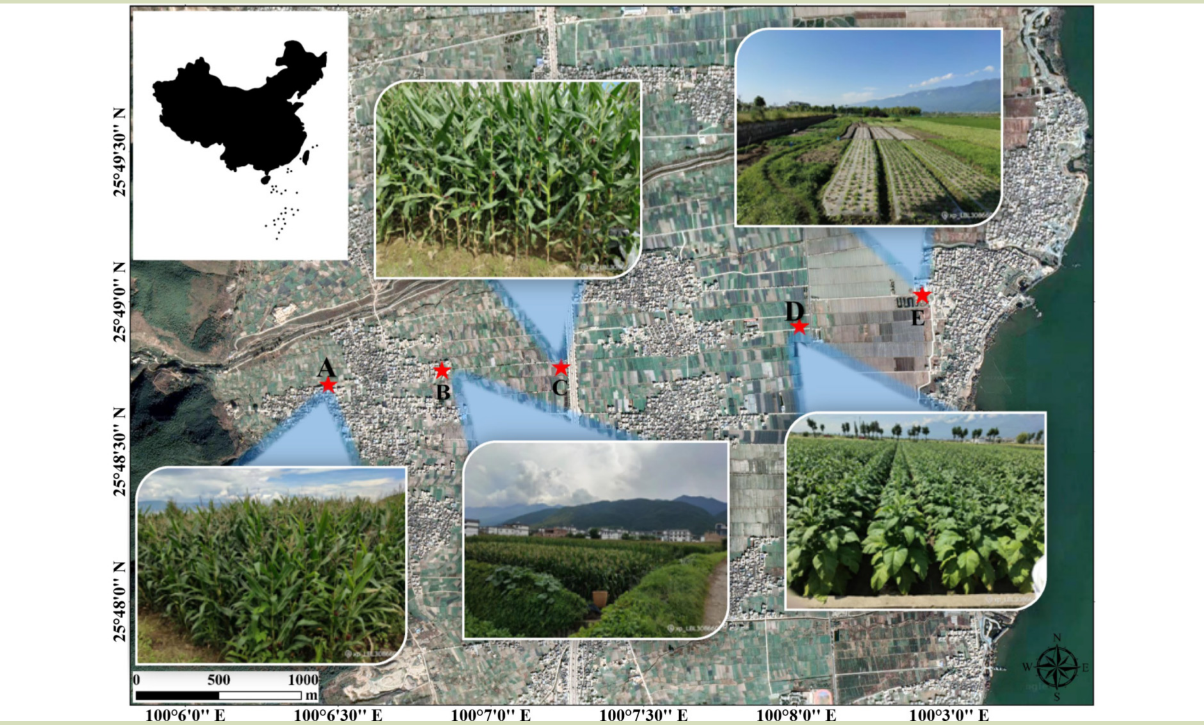

Fig. 1 Locations of sampled cropland fields; A, B, and C were maize fields, D was a flue-cured tobacco field, and E was a vegetable field (审图号: GS 京 (2023) 2266 号).

Table 1 Topsoil (0–20 cm) initial physicochemical properties of soil from five cropland fields

Field	SOC ($mg·kg^{-1}$ C)	TN ($mg·kg^{-1}$ N)	NH_4^+ ($mg·kg^{-1}$ N)	NO_3^- ($mg·kg^{-1}$ N)	DOC ($mg·kg^{-1}$ C)	Bulk density ($g·cm^{-3}$)	pH
A: maize	21.8 ± 0.94	2.33 ± 0.03	4.67 ± 0.14	15.5 ± 1.33	62.4 ± 2.40	1.02 ± 0.01	5.22
B: maize	18.4 ± 0.44	2.25 ± 0.13	2.13 ± 0.07	4.55 ± 0.23	69.8 ± 2.57	1.03 ± 0.02	6.60
C: maize	18.7 ± 0.06	1.93 ± 0.01	10.1 ± 1.09	11.0 ± 0.39	76.0 ± 0.89	1.05 ± 0.02	4.25
D: flue-cured tobacco	23.8 ± 1.28	2.99 ± 0.06	12.8 ± 0.56	22.64 ± 1.51	89.4 ± 6.54	0.98 ± 0.02	6.08
E: vegetables	21.3 ± 1.19	2.52 ± 0.05	16.0 ± 1.11	17.7 ± 2.12	96.6 ± 5.23	1.01 ± 0.02	6.42

Note: SOC, soil organic carbon; TN, total nitrogen content; NH_4^+, ammonium nitrogen content; NO_3^-, nitrate nitrogen content; and DOC, dissolved organic carbon concentration. The values are presented as mean ± standard deviation (n = 3).

(DIN, including NH_4^+ and NO_3^-). In brief, the soil subsamples were stored in an aluminum specimen box after oven drying at 105 °C for 24 h and weighed to determine the SWC. Soil organic carbon (SOC) was measured via the potassium dichromate volumetric method. Soil total organic carbon (TOC) and TN were determined using the potassium dichromate oxidation method and a C/N element analyzer (Shimadzu Corporation, Kyoto Japan), respectively. For soil DOC determination, the soil subsamples were extracted with deionized water and shaken in a mechanical shaker for 1 h at 250 revolutions per minute. Afterward, the samples were centrifuged at 8000 g for 10 min, and the supernatant was filtered through a 0.45 μm membrane and analyzed using a TOC analyzer (TOC-VWP, Shimadzu Corporation). NH_4^+-N and NO_3^--N concentrations in soil were determined using a flow-injection autoanalyzer (Tecator FIA Star 5000 Analyzer, FOSS Tecator, Höganäs, Sweden) after being extracted with 2 $mol·L^{-1}$ KCl and filtered by quantitative filter paper. In addition, soil samples were collected using cylinder rings and oven-dried to determine the soil bulk density.

2.4 Soil organic N mineralization calculation

Soil dissolved inorganic nitrogen content (DIN) is expressed by the sum of NH_4^+-N plus NO_3^--N contents.

Soil net organic N_{min} is determined by the difference in DIN content before and after incubation.

Soil N_{min} rate = N_{min}/t, where t is the actual incubation duration as days.

2.5 Soil nitrification rate

Soil Nit rate (μg·kg^{-1}·h^{-1} N) was measured by the barometric process separation system[23]. In brief, four undisturbed soil samples collected with cutting cylinders were used to determine the soil Nit, with the soil moisture, weight, and pH obtained previously.

2.6 Statistical analyses

The values of the soil variables were compared between the five fields by one-way analysis of variance. Linear or nonlinear regressions were performed to exhibit the functional relationships between soil N_{min} and parameters. Corresponding figures were prepared using Origin 8.5 (OriginLab Corporation, Northampton, MA, USA). All statistical analyses were performed with SPSS (SPSS19.0, SPSS Inc., Chicago, USA), with $P \leqslant 0.05$ deemed statistical significant.

3 RESULTS

3.1 Soil variables

The soil TOC and TN contents differed between the soils from the sampled fields (Fig. 2). In comparison to the soil from the maize fields, those from flue-cured tobacco and vegetable fields had higher TOC and TN contents but lower C/N. The dynamics of soil NH_4^+-N content during the incubation period varied between fields. For fields D and E, the content declined swiftly during the incubation period, whereas for the other fields, it remained at a lower and more stable level (Fig. 3(a)).

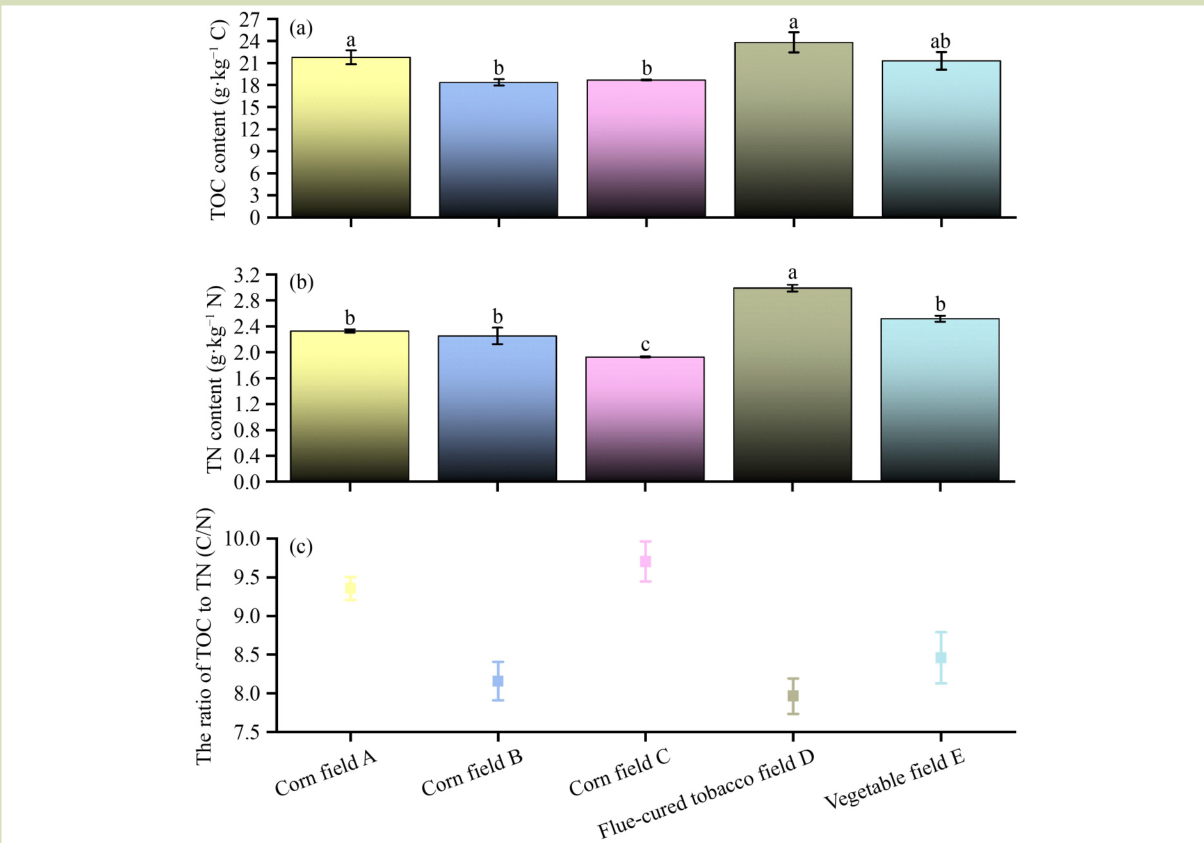

Fig. 2 Content of soil total organic carbon (TOC), total nitrogen (TN), and the ratio of TOC to TN for five cropland fields. Different lowercase letters represent significant difference (LSD, P < 0.05), while the same lowercase letters represent no significantly difference between cropland fields.

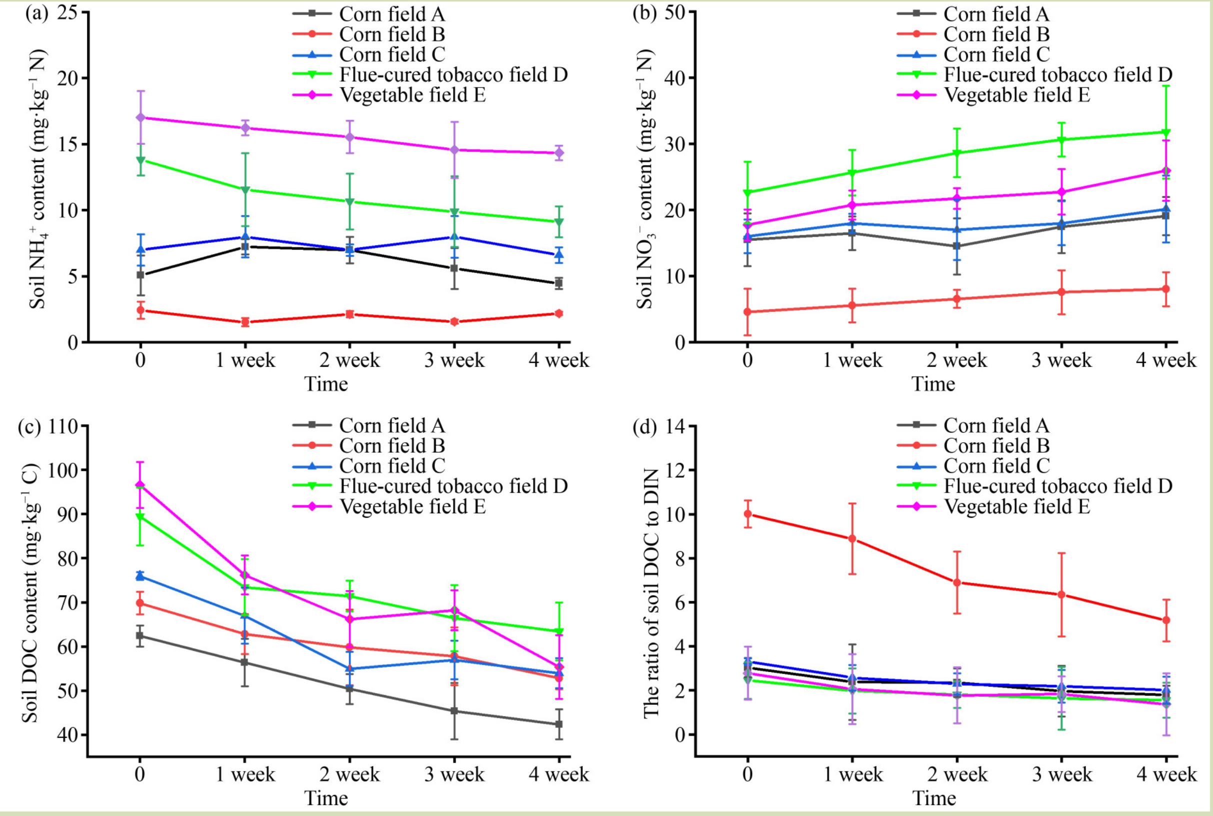

Fig. 3 Dynamics of (a) soil NH_4^+, (b) soil NO_3^-, (c) dissolved organic carbon (DOC), and (d) the ratio of DOC to dissolved inorganic nitrogen (DIN) under incubation period for five cropland fields.

In contrast, the soil NO_3^--N concentration gradually increased for all fields, particularly in fields D and E (Fig. 3(b)). Soil DOC content decreased gradually during the incubation period (Fig. 3(c)) and the ratio of DOC to DIN also decreased gradually (Fig. 3(d)), except that the decrease was more evident for field B. Soil pH was largely steady for all fields, with the highest value observed in the soil of fields B and E, followed by those of field D, A and C (Fig. 4).

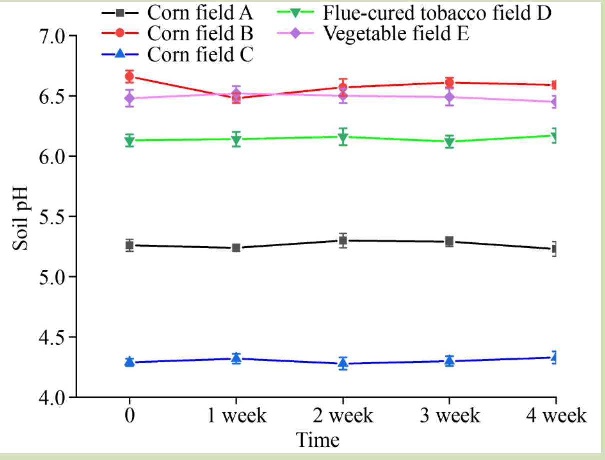

Fig. 4 Dynamics of soil pH under incubation period for five cropland fields.

3.2 Soil N_{min}

The soil N_{min} quantum and rate differed among the studied fields (Table 2). The soil N_{min} quantity and rate ranged from 2.98 to 5.52 mg·kg^{-1} N and from 0.10 to 0.17 mg·kg^{-1}·d^{-1} N, respectively. The soil annual N_{min} ranged from 74.5 to 127.1 kg·ha^{-1}·yr^{-1} N. The soil daily and annual N_{min} values were similar across the sampled fields, with the highest value in field E, followed by those in fields D, C and B. The lowest value was observed in field A.

3.3 Soil nitrification

The soil Nit rate showed different dynamics among the studied cropland (Table 3). The soil Nit rate ranged from 434.5 to

Table 2 Topsoil (0–20 cm) organic N mineralization rate during the 30 days incubation duration for five sampled fields

Field	Initial soil DIN content ($mg \cdot kg^{-1}$ N)	Final soil DIN content ($mg \cdot kg^{-1}$ N)	Net N_{min} content ($mg \cdot kg^{-1}$ N)	N_{min} rate ($mg \cdot kg^{-1} \cdot d^{-1}$ N)	Annual N_{min} content ($kg \cdot ha^{-1} \cdot y^{-1}$ N)
A: maize	20.55 ± 5.49 b	23.53 ± 2.34 b	2.98 ± 0.62 b	0.10 ± 0.02 c	74.5 ± 17.08 c
B: maize	6.97 ± 2.16 c	10.19 ± 0.77 c	3.22 ± 0.25 b	0.11 ± 0.03c	80.3 ± 27.23 c
C: maize	17.12 ± 5.73 b	21.18 ± 2.19 b	4.06 ± 2.01 b	0.14 ± 0.04 b	102.1 ± 23.60 b
D: flue-cured tobacco	36.46 ± 7.84 a	40.93 ± 4.56 a	4.47 ± 1.56 ab	0.15 ± 0.02 ab	107.6 ± 24.05 ab
E: vegetables	34.75 ± 4.34 a	40.27 ± 5.11 a	5.52 ± 0.42 a	0.17 ± 0.03 a	127.1 ± 31.53 a

Note: DIN, soil dissolved inorganic nitrogen. The values are presented as mean ± standard deviation ($n = 3$). Means followed by different lower case letters represent significantly different (LSD, $P < 0.05$) and means followed by the same lower case letters represent no significantly difference between cropland fields.

Table 3 Soil nitrification rate for five cropland fields based on barometric process separation system[23]

Field	Nitrification rate ($ug \cdot kg^{-1} \cdot h^{-1}$ N)
A: maize	470.5
B: maize	434.2
C: maize	540.1
D: flue-cured tobacco	827.1
E: vegetables	671.6

827.1 $\mu g \cdot kg^{-1} \cdot h^{-1}$ N, with the highest value determined in cropland D, followed by those in cropland E, C, and B. The lowest value was found in cropland A.

3.4 Relationships between soil variables and soil N_{min} and nitrification

The soil N_{min} rate was correlated with several key soil parameters in all sampled fields (Table 4, Fig. 5, and Fig. 6). Table 5 shows that the soil N_{min} rate was positively correlated with soil TN, NH_4^+ and DOC. In particular, the soil N_{min} rate increased linearly with increasing soil NH_4^+ and DOC contents (Fig. 5). Significant positive correlations were observed between Nit and soil TN, DOC, NH_4^+ and NO_3^- for all sampled fields (Table 4). Similarly, the increase in Nit was associated with the increase in soil TN, DOC, NH_4^+ and NO_3^- contents (Fig. 6). In particular, the increased soil N_{min} rate was associated with the increase in soil Nit (Fig. 7).

3.5 Comparison of soil N_{min} rates between different land uses in the literature

We compared the soil N_{min} rate determined in this study with other investigations. Table 5 shows that the research on soil N_{min} has mainly focused on crops and forests over the past 30

Table 4 Relativity of between soil N mineralization and soil basic physicochemical characters of all cropland

	TOC	TN	C/N	DOC	NH_4^+	NO_3^-	pH	N_{min} content	N_{min} rate	Nit rate
TOC	1									
TN	0.86**	1								
C/N	−0.25	−0.71*	1							
DOC	0.32	0.52	−0.50	1						
NH_4^+	0.45	0.44	−0.18	0.90**	1					
NO_3^-	0.97**	0.88**	−0.33	0.51	0.62*	1				
pH	0.16	0.56*	−0.93**	0.34	0.04	0.22	1			
N_{min} content	0.39	0.58*	−0.33	0.98**	0.95**	0.54	0.18	1		
N_{min} rate	0.38	0.57*	−0.40	0.97**	0.91**	0.53	0.26	0.98**	1	
Nit rate	0.53	0.79**	−0.42	0.82**	0.80**	0.81**	0.19	0.83**	0.81**	1

Note: TOC, soil total organic carbon; TN, total nitrogen content; C/N, the ratio of TOC to TN; DOC, dissolved organic carbon concentration; NH_4^+, ammonium nitrogen content and NO_3^-, nitrate nitrogen content. *Significant correlation ($P < 0.05$) and **highly significant correlation ($P < 0.01$).

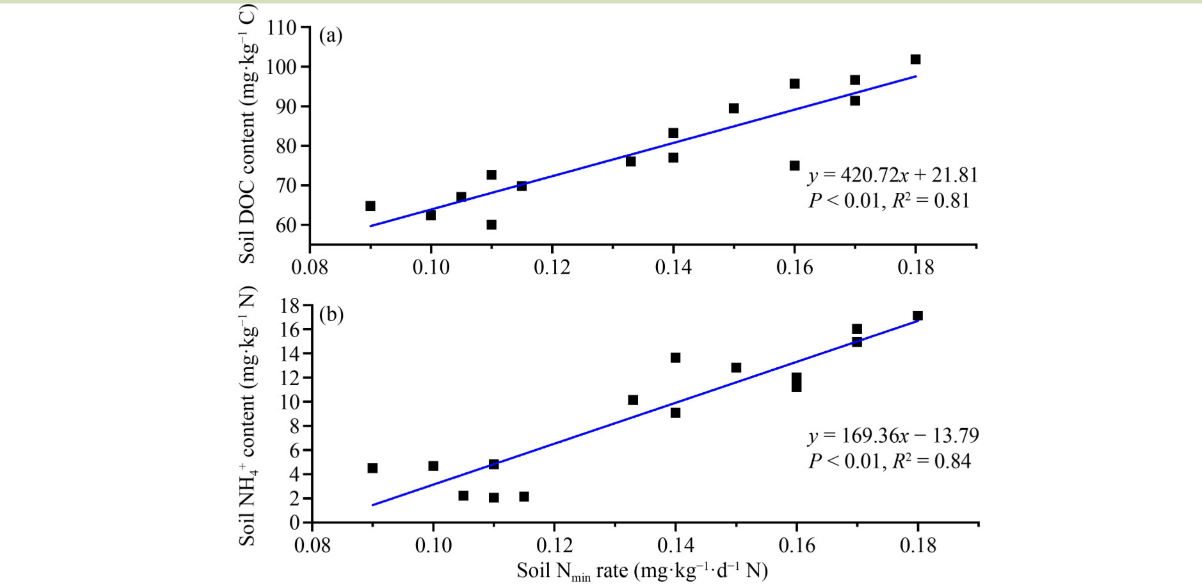

Fig. 5 Relationships between soil dissolved organic carbon (DOC) (a) and NH_4^+ (b) and N mineralization rate for five cropland fields.

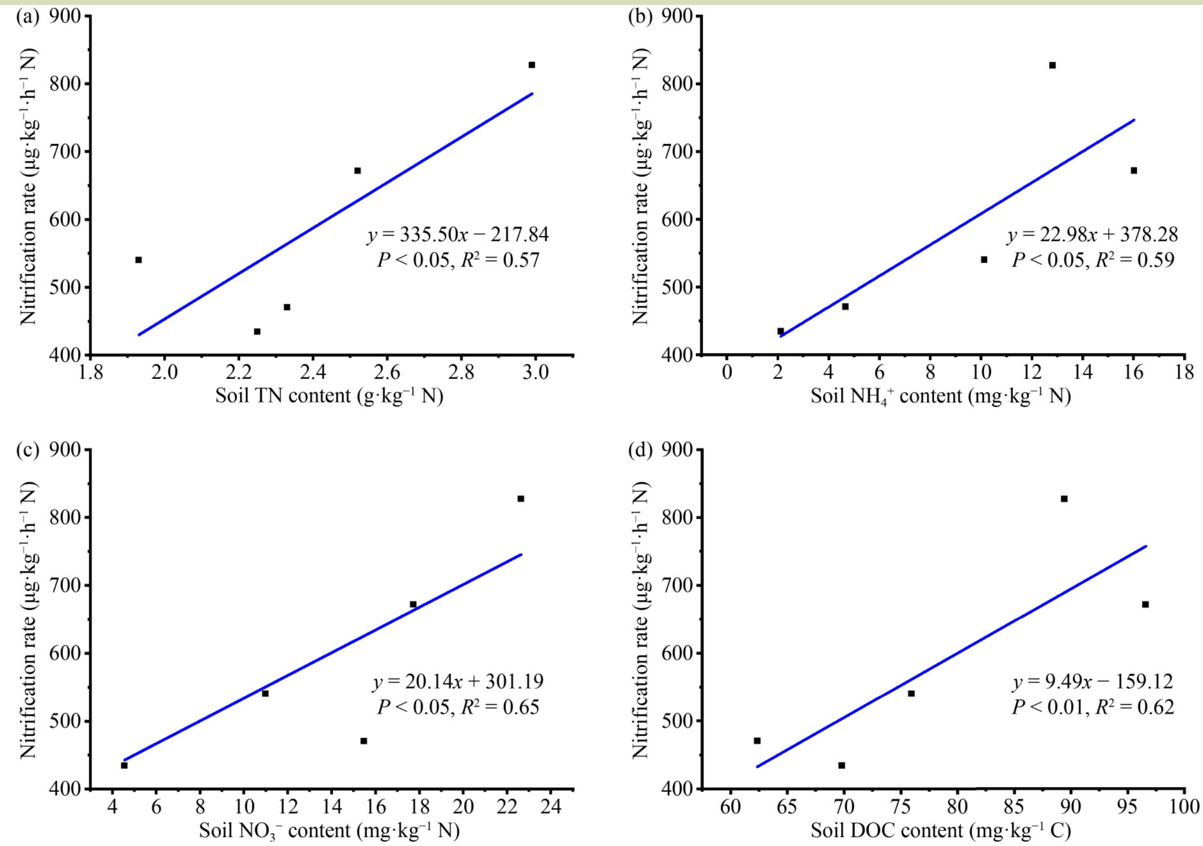

Fig. 6 Relationships between nitrification rate and soil total nitrogen (a), NH_4^+ (b), NO_3^- (c), and dissolved organic carbon (DOC) (d) for five cropland fields.

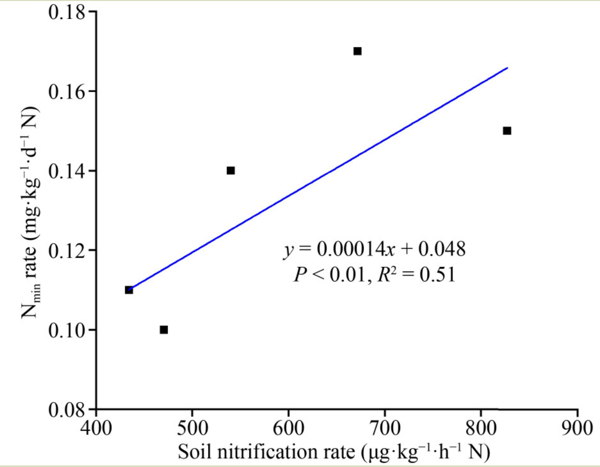

Fig. 7 Relationships between soil nitrification and N mineralization rate for five cropland fields.

years. The soil average N_{min} rate varied from 0.04 to 1.10 $mg \cdot kg^{-1} \cdot d^{-1}$ N for forests, and these values were comparable to those in cropping soils (0.03–1.15 $mg \cdot kg^{-1} \cdot d^{-1}$ N). In this study, the soil N_{min} rate varied from 0.10 to 0.17 $mg \cdot kg^{-1} \cdot d^{-1}$ N across all sampled fields, with an average N_{min} rate of 0.13 $mg \cdot kg^{-1} \cdot d^{-1}$ N, which is below the ranges in the literature.

4 DISCUSSION

4.1 Spatial differences in soil N_{min} of cropland

Land-use changes can modify soil N_{min} processes, but the magnitude and direction of this depends on environmental conditions, soil variables and management practices[31]. However, the response mechanism of soil N_{min}, one of the key biochemical nutrient cycle processes, to changes in elevation for different contexts remains unclear. Liu et al.[4] reported that the potential of soil N_{min} among diverse agricultural ecosystems decreases considerably with increasing latitude and altitude. In the present study, the soil N_{min} quantum and rate were of similar orders across the different fields sampled, with the highest value in field E, followed by those in fields D, C and B. The lowest value was found in field A. In addition, field C had higher soil N_{min} rate than maize fields A and B. These results suggest that the soil N_{min} rate varied spatial among the sample fields and increased with the decrease in elevation. Rustad et al.[32] demonstrated that soil N_{min} is significantly negatively correlated with latitude. In a field experiment, Gutiérrez-Girón et al.[33] observed that labile SOC gradually decreased with increasing altitude, and soil N_{min} was less at high-altitude sites owing to the decreased substrate availability, which agrees with our findings. Also, Zhang et al.[21] reported that an increase in C/N ratios caused an increase in soil organic

Table 5 Comparison among daily soil N mineralization rate under different land uses

Source	Country	Land uses	Method	N_{min} rate ($mg \cdot kg^{-1} \cdot d^{-1}$ N)	N_{min} average rate ($mg \cdot kg^{-1} \cdot d^{-1}$ N)
[5]	England	Forest	*In situ* incubation	0.08–0.25	0.15
[6]	America	Forest	*In situ* incubation	0.08–1.20	0.64
[7]	China	Forest	Laboratory incubation	−1.89–0.81	0.18
[8]	China	Grassland	Laboratory incubation	1.19–1.49	–
[9]	Canada	Cropland	*In situ* incubation	–	0.75
[10]	German	Cropland	*In situ* incubation	0.04–0.30	0.17
[11]	China	Cropland	Laboratory incubation	0.81–1.51	1.15
[12]	Canada	Forest	Laboratory incubation	0.02–0.53	0.04
[24]	Venezuela	Forest	*In situ* incubation	–	0.40
[25]	Greece	Cropland	Laboratory incubation	0.10–0.65	0.40
[26]	America	Forest	N balance	–	1.10
[27]	Australia	Forest	*In situ* and laboratory incubation	−0.08–1.87	0.49
[28]	America	Cropland	*In situ* incubation	0.27–0.41	0.34
[29]	Venezuela	Cropland	Laboratory incubation	0.02–0.03	0.03
[30]	Denmark	Cropland	*In situ* incubation	0.30–0.70	0.30
This study	China	Cropland	Laboratory incubation	0.10–0.17	0.13

matter (SOM) in alpine meadows with elevated altitude, which resulted in a low N_{min} rate. Thus, our results showed that the soil C/N decreased among sampled fields with decreased elevation.

4.2 Key factors affecting soil N_{min} of cropping soils

Understanding how environmental factors influence N_{min} is essential for the provision of sustainable ecosystem services, especially in a resource-constrained ecosystem[34]. Previous reports have suggested that rates of soil N transformations (such as N_{min}) are affected by numerous factors[13]. Studies have detected significant differences in soil N_{min} and Nit among different ecosystems[15,16], which can be influenced by pH[17], soil moisture[8], soil TN[18], TC[19], soil C/N[16,20] and different vegetation types[21]. Vervaet et al.[13] reported that the soil N_{min} rate, along with soil texture, is related to organic matter quality, TN content, and C/N. In addition, Springob et al.[35] reported that the higher the soil C/N, the lower the nitrogen release rate. Colman and Schimel[36] demonstrated that SOM quality can explain a relatively large proportion of the variation in N_{min}. Similarly, our results showed that the soil N_{min} was correlated with soil TN, DOC and NH_4^+ (Table 5). Likewise, the increased Nit rate was associated with increases in soil TN, DOC, NH_4^+ and NO_3^- contents (Fig. 6). In general, soil TOC, TN, DOC, NH_4^+ and NO_3^- contents increased with decreased elevation, and soil N_{min} and Nit rates increased with the increased amounts of these soil variables. Our results emphasize the important effects of soil parameters on soil N_{min} under spatial variation conditions with changes in elevation. Greater amounts of available C and N suitable for microbial processes accelerated SOM decomposition and mineralization. Similarly, soil DOC and DIN are readily available substrates for microbes[22], which consequently affects the soil N transformations.

4.3 Potential effects of soil N_{min} on water quality

Soil N mineralized from SOM during the crop-growing season must be assessed to determine its contribution to crop yield variability and to evaluate the need for variable-rate N fertilization[37,38]. In addition, a strong N_{min} may lead to excessive amounts of soil NO_3^--N and NH_4^+-N in surface runoff or leaching to ground water, which results in water eutrophication[4]. Here, we suggested the regional assessment of soil N_{min} of an agricultural area and explored the potential effects of soil N_{min} on water environment quality based on the annual soil N_{min} content, which ranged from 74.5 to 127.1 $kg\cdot ha^{-1}\cdot yr^{-1}$ N, determined in different fields in the present study. The present study showed a good positive relationship between soil N_{min} and Nit (Fig. 7), which indicates that soil NH_4^+-N derived from organic N_{min} can be oxidized into NO_3^--N by the microbial Nit process. Therefore, a strong N_{min} may facilitate the conversion of high amounts of NH_4^+-N to NO_3^--N, which can be carried in surface runoff or leach to groundwater, and consequently threaten the water quality. In summary, our results suggest that more attention should be given to soil N_{min} quantum and rate in cropping contexts across significant geographical and temporal variability.

5 CONCLUSIONS

In this study, we measured the soil net N_{min} rate, gross Nit rate, and the corresponding soil abiotic properties of different cropland soils in a representative agriculturally intensive area. We conducted a regional assessment of soil N_{min} in an agricultural area with intensive management and explored the effects of key soil factors on the soil N_{min} of different cropland fields in relation to spatial variation. We observed that the rates of soil N_{min} and Nit were spatially variable across the fields sampled. In general, the soil N_{min} rate and Nit decreased with elevation and were correlated with several key soil parameters, such as soil TN and available C and N for all cropland. Our findings indicate that soil N_{min} from croplands should be considered in the evaluation of non-point source pollution at a regional scale.

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Compliance with ethics guidelines

Peng Xu, Minghua Zhou, Bo Zhu, and Klaus Butterbach-Bahl declare that they have no conflicts of interest or financial conflicts to disclose. This article does not contain any studies with human or animal subjects performed by any of the authors.

REFERENCES

1. Das A K, Boral L, Tripathi R S, Pandey H N. Nitrogen mineralization and microbial biomass-N in subtropical humid forest of Meghalaya, India. *Soil Biology & Biochemistry*, 1997, **29**(9–10): 1609–1612
2. Erisman J W, Sutton M A, Galloway J, Klimont Z, Winiwarter W. How a century of ammonia synthesis changed the world? *Nature Geoscience*, 2008, **1**(10): 636–639
3. Vitousek P M, Naylor R, Crews T, David M B, Drinkwater L E, Holland E, Johnes P J, Katzenberger J, Martinelli L A, Matson P A, Nziguheba G, Ojima D, Palm C A, Robertson G P, Sanchez P A, Townsend A R, Zhang F S. Nutrient imbalances in agricultural development. *Science*, 2009, **324**(5934): 1519–1520
4. Liu Y, He N P, Wen X F, Yu G R, Gao Y, Jia Y L. Patterns and regulating mechanisms of soil nitrogen mineralization and temperature sensitivity in Chinese terrestrial ecosystems. *Agriculture, Ecosystems & Environment*, 2016, **215**: 40–46
5. Evans C A, Miller E K, Friedland A J. Nitrogen mineralization associated with birch and fir under different soil moisture regimes. *Canadian Journal of Forest Research*, 1998, **28**(12): 1890–1898
6. Bonito G M. Factors regulating nitrogen mineralization rates of an oak pine and northern hardwood forest along an elevation gradient. Dissertation for the Master's Degree. Athens: *University of Georgia*, 2001
7. Wang J Y, He L Y, Xu X F, Ren C J, Wang J, Guo Y X, Zhao F Z. Linkage between microbial functional genes and net N mineralization in forest soils along an elevational gradient. *European Journal of Soil Science*, 2022, **73**(4): e13276
8. Wang C H, Wan S Q, Xing X R, Zhang L, Han X G. Temperature and soil moisture interactively affected soil net N mineralization in temperate grassland in Northern China. *Soil Biology & Biochemistry*, 2006, **38**(5): 1101–1110
9. Ma B L, Dwyer L M, Gregorich E G. Soil nitrogen amendment effects on seasonal nitrogen mineralization and nitrogen cycling in maize production. *Agronomy Journal*, 1999, **91**(6): 1003–1009
10. Heumann S, Böttcher J. Temperature functions of the rate coefficients of net N mineralization in sandy arable soils Part II. Evaluation via field mineralization measurements. *Journal of Plant Nutrition and Soil Science*, 2004, **167**(4): 390–396
11. Hou R J, Li T X, Fu Q, Liu D, Li M, Zhou Z Q, Li Q L, Zhao H, Yu P F, Yan J W. The effect on soil nitrogen mineralization resulting from biochar and straw regulation in seasonally frozen agricultural ecosystem. *Journal of Cleaner Production*, 2020, **255**: 120302
12. Carlyle J C, Nambiar E K S, Bligh M W. The use of laboratory measurements to predict nitrogen mineralization and nitrification in *Pinus radiate* plantations after harvesting. *Canadian Journal of Forest Research*, 1998, **28**(8): 1213–1221
13. Vervaet H, Massart B, Boeckx P, Van Cleemput O, Hofman G. Use of principal component analysis to assess factors controlling net N mineralization in deciduous and coniferous forest soils. *Biology and Fertility of Soils*, 2002, **36**(2): 93–101
14. Cao W, Hong H, Yue S, Ding Y, Zhang Y. Nutrient loss from an agricultural catchment and landscape modeling in southeast China. *Bulletin of Environmental Contamination and Toxicology*, 2003, **71**(4): 761–767
15. Booth M S, Stark J M, Rastetter E. Controls on nitrogen cycling terrestrial ecosystems: a synthetic analysis of literature data. *Ecological Monographs*, 2005, **75**(2): 139–157
16. Baldos A P, Corre M D, Veldkamp E. Response of N cycling to nutrient inputs in forest soils across a 1000–3000 m elevation gradient in the Ecuadorian Andes. *Ecology*, 2015, **96**(3): 749–761
17. Li D J, Yang Y, Chen H, Xiao K C, Song T Q, Wang K L. Soil gross nitrogen transformation in typical karst and nonkarst forests, Southwest China. *Journal of Geophysical Research. Biogeosciences*, 2017, **122**(11): 2831–2840
18. Dai S Y, Wang J, Cheng Y, Zhang J B, Cai Z C. Effects of long-term fertilization on soil gross N transformation rates and their implications. *Journal of Integrative Agriculture*, 2017, **16**(12): 2863–2870
19. Wang J, Cheng Y, Jiang Y J, Sun B, Fan J B, Zhang J B, Müller C, Cai Z C. Effects of 14 years of repeated pig manure application on gross nitrogen transformation in an upland red soil in China. *Plant and Soil*, 2017, **415**(1–2): 161–173
20. Bengtson G, Bengtson P, Månsson K F. Gross nitrogen mineralization-, immobilization-, and nitrification rates as a function of soil C/N ratio and microbial activity. *Soil Biology & Biochemistry*, 2003, **35**(1): 143–154
21. Zhang S H, Chen D D, Sun D S, Wang X T, Smith J L, Du G Z. Impacts of altitude and position on the rates of soil nitrogen mineralization and nitrification in alpine meadows on the eastern Qinghai-Tibetan Plateau, China. *Biology and Fertility of Soils*, 2012, **48**(4): 393–400
22. Xu P, Jiang M D, Khan I, Zhao J S, Yang T W, Tu J M, Hu R G. Available nitrogen and ammonia-oxidizing archaea in soil regulated N_2O emissions regardless of rice planting under a double rice cropping-fallow system. *Agriculture, Ecosystems & Environment*, 2022, **340**: 108166
23. Ingwersen J, Butterbach-Bahl K, Gasche R, Richter O, Papen H. Barometric process separation: new method for quantifying nitrification, denitrification, and nitrous oxide sources in Soils. *Soil Science Society of America Journal*, 1999, **63**(1): 117–128
24. Montagnini F, Buschbachier R. Nitrification rates in two undisturbed tropical rain forests and three slash and burn sites of the Venezuelan Amazon. *Biotropica*, 1989, **21**(1): 9–14
25. Sierra J. Temperature and soil moisture dependence of N mineralization in intact soil cores. *Soil Biology & Biochemistry*, 1997, **29**(9–10): 1557–1563
26. Knoepp J D, Swank W T. Rates of nitrogen mineralization

across an elevation and vegetation gradient in the southern Appalachians. *Plant and Soil*, 1998, **204**(2): 235–241
27. Trindade H, Coutinho J, Jarvis S, Moreira N. Nitrogen mineralization in sandy loam soils under an intensive double-cropping forage system with dairy-cattle slurry applications. *European Journal of Agronomy*, 2001, **15**(4): 281–293
28. Eghball B, Wienhold B J, Gilley J E, Eigenberg R A. Mineralization of manure nutrients. *Journal of Soil and Water Conservation*, 2002, **57**(6): 470–473
29. Sierra J. Nitrogen mineralization and nitrification in a tropical soil: effects of fluctuating temperature conditions. *Soil Biology & Biochemistry*, 2002, **34**(9): 1219–1226
30. Kristensen H L, Debosz K, McCarty G W. Short-term effects of tillage on mineralization of nitrogen and carbon in soil. *Soil Biology & Biochemistry*, 2003, **35**(7): 979–986
31. Yang L, Zhang F, Gao Q, Mao R, Liu X. Impact of land-use types on soil nitrogen net mineralization in the sandstorm and water source area of Beijing, China. *Catena*, 2010, **82**(1): 15–22
32. Rustad L, Campbell J, Marion G, Norby R, Mitchell M, Hartley A, Cornelissen J, Gurevitch J. GTCE-NEWS. A meta-analysis of the response of soil respiration, net nitrogen mineralization, and aboveground plant growth to experimental ecosystem warming. *Oecologia*, 2001, **126**(4): 543–562
33. Gutiérrez-Girón A, Díaz-Pinés E, Rubio A, Gavilán R G. Both altitude and vegetation affect temperature sensitivity of soil organic matter decomposition in Mediterranean high mountain soils. *Geoderma*, 2015, **237–238**: 1–8
34. Urakawa R, Ohte N, Shibata H, Isobe K, Tateno R, Oda T, Hishi T, Fukushima K, Inagaki Y, Hirai K, Oyanagi N, Nakata M, Toda H, Kenta T, Kuroiwa M, Watanabe T, Fukuzawa K, Tokuchi N, Ugawa S, Enoki T, Nakanishi A, Saigusa N, Yamao Y, Kotani A. Factors contributing to soil nitrogen mineralization and nitrification rates of forest soils in the Japanese archipelago. *Forest Ecology and Management*, 2016, **361**: 382–396
35. Springob G, Kirchmann H. Bulk soil C to N ration as a simple measure of net N mineralization from stabilized soil organic matter in sandy arable soils. *Soil Biology & Biochemistry*, 2003, **35**(4): 629–632
36. Colman B P, Schimel J P. Drivers of microbial respiration and net N mineralization at the continental scale. *Soil Biology & Biochemistry*, 2013, **60**: 65–76
37. Katsvario T W, Cox W J, Van Es H M. Spatial growth, and nitrogen uptake variability of corn at two nitrogen levels. *Agronomy Journal*, 2003, **95**(4): 1000–1011
38. Shahandeh H, Wright A L, Hons F M, Lascano R J. Spatial and temporal variation of soil nitrogen parameters related to soil texture and corn Yield. *Agronomy Journal*, 2005, **97**(3): 772–782