Mendoza-Carreón *et al. Soil Health* 2023;1:2
DOI: 10.20517/sh.2022.02

Soil Health

Review

Open Access

Importance and inconsistencies of the influence of soil properties on nitrogen mineralization: a systematic review

Gabriela Mendoza-Carreón[1], Juan Pedro Flores-Márgez[1], Pedro Osuna-Avila[1], Soum Sanogo[2]

[1]Department of Chemical and Biological Sciences, Universidad Autonoma de Ciudad Juarez, Juarez 32310, Mexico.
[2]Department of Plant and Environmental Sciences, New Mexico State University, Las Cruces, NM 88003, USA.

Correspondence to: Dr. Juan Pedro Flores-Margez, Department of Chemical and Biological Sciences, Universidad Autonoma de Ciudad Juarez, av. Plutarco Elias Calles 1210, Juarez 32310, Mexico. E-mail: juflores@uacj.mx

How to cite this article: Mendoza-Carreón G, Flores-Márgez JP, Osuna-Avila P, Sanogo S. Importance and inconsistencies of the influence of soil properties on nitrogen mineralization: a systematic review. *Soil Health* 2023;1:2. https://dx.doi.org/10.20517/sh.2022.02

Received: 22 Jun 2022 **First Decision:** 29 Jan 2023 **Revised:** 20 Feb 2023 **Accepted:** 22 Mar 2023 **Published:** 20 Apr 2023

Academic Editors: Manoj Shukla, Wenyou Hu **Copy Editor:** Ying Han **Production Editor:** Ying Han

Abstract

Climate and soil properties profoundly impact N mineralization (N_{min}). Hence, there is a critical need to identify how physical-chemical-biological factors involved in organic matter decomposition influence globally reported predictive models. This paper reflects research focused on those factors considered relevant and used during the construction of N_{min} models. The literature data found on factors affecting N_{min} or N availability in soils published since 1990 was downloaded to a database in Access. Using different bivariate and multivariate statistical techniques, we compiled results of 785 statistical analyses presented by authors of 90 research articles that related N_{min} and environmental factors, management strategies, and soil biological and physicochemical attributes. For organization purposes, we decided to group results according to the similarity of properties related to mineralization into environmental factors (18.6%), ecosystem/vegetation (14.52%), management (7.64%), soil physicochemical properties (34.65%), organic matter (16.05%), and microbiota (6.37%). The measurements of the response variables were 16.2% using N content in soil (as ammonium, nitrates, Organic N and Total N), and 83.88% represent N in the process of mineralization, including potentially mineralized N. As N_{min} is the dependent variable, the results included 109 independent variables, of which 47.7% presented seemingly inconsistent results, which means different effects in N_{min}. The difference in results was found to be related mostly to a difference in ecosystems or variable interactions. We conclude that acquiring a general prediction model for N_{min} or constructing a specific equation for local conditions poses a limitation to optimizing N management for crop production. A more useful strategy is to generate a prediction model for $N_{min,}$ including significative soil and weather conditions, within a

© The Author(s) 2023. **Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License (https://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, sharing, adaptation, distribution and reproduction in any medium or format, for any purpose, even commercially, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

region and ecosystem; thus, the information can support soil and crop management decisions.

Keywords: Soil properties, N availability, predicting models, organic matter decomposition, ecosystems

INTRODUCTION

Nitrogen (N) is an essential nutrient for plants and a limiting factor in primary production[1,2]. Plants obtain N from the soil in ionic forms, which are products of the decomposition of organic matter, a process driven mostly by soil microbes and is called mineralization[3]. Nitrogen mineralization (N_{min}) and its availability in soil are influenced by several factors, such as soil properties and environmental variables, used in N predicting models[4,5]. Specifically, N_{min} is influenced by temperature[6,7], mean annual precipitation[1], clay content[6,8], humidity[9], organic matter[1], pH[1,6], microbial activity[10,11], and microbial community composition[12].

Various studies have been conducted on the association of these variables with N_{min}, yielding consistent results in some studies and inconsistent results in others. For example, a positive correlation has been shown consistently between microbial activity and N_{min} across different studies[1,6,10,11]. In contrast, the correlation between clay content and N_{min} was found to be largely inconsistent, either negative[13] or positive[14], or there was no correlation between clay content and N_{min}[1]. In another example, Li *et al.* found that N_{min} was negatively correlated with pH[1], while Liu *et al.* reported that N_{min} was generally suppressed by soil acidification[6]. Even within the same study, results did not always match. For example, it has been found that the mean annual precipitation (MAP) is related to N_{min}, but this relationship is not demonstrated in wetlands[1].

The cause and frequency of these discrepancies are unclear. However, it has been inferred that the data from different ecosystems may contribute to these inconsistencies[1,6]. Other reasons for contrary results may be the differences among the methodological tools used in characterizing various variables and analyzing their relationships. An example is microbial activity measured as microbial biomass, basal respiration, enzymatic activity (hydrogenase, nitrogenase), phospholipid fatty acid concentration, microarrays, and sequencing[15].

The inconsistencies are found when determining the influence of soil and environmental factors on soil N_{min} and availability. As a result, the type and strength of their influence make developing nutrient prediction techniques difficult, resulting in the progress of soil management strategies for maintaining crop production and reducing soil degradation inefficient or ineffective. The specific reasons for the discrepancies can vary depending on the factor. In this review, we hypothesize that inconsistencies can be found in several variables, like clay content, pH, and soil temperature, among others. Also, soil management and the type of ecosystem have no clear correlation with N_{min}. Therefore, we aim to perform a systematic review of the literature on N_{min} to ascertain the influence of soil properties and environmental variables on N_{min} and identify variables with inconsistent results. To accomplish this, we aimed (1) to build a database of soil properties and environmental variables that have examined N_{min}, detailing the analysis used; (2) to identify the variables that have shown different results in their relation to or influence over N_{min}; and (3) to detect the possible source of discrepancies found in results of analysis relating different variables to N_{min}. This systematic review can guide research focused on predictive modeling of mineralized N or N availability in soils by assembling and synthesizing information about the factors driving or influencing mineralization and the outcome of the relationship analysis.

MATERIALS AND METHODS

The initial scope of the chosen topic was performed, after which a work scheme was planned considering the recommendations to construct systematic reviews found in Cochrane[16] and the work on reviews done by Koutsos *et al.* and the Collaboration for Environmental Evidence[17,18].

The article search was carried out in Spanish and English, independently by three researchers in the Jstor and ScienceDirect databases, followed by a grey literature search in Google Scholar. The search string strategy for databases using the Boolean operators was: (factor OR "soil properties") and "soil nitrogen mineralization"; and in Spanish (factor OR "propiedades del suelo") and "mineralización de nitrógeno".

During the compilation of research articles, a database was filled independently by the searchers using ACCESS. The publishing information was obtained for each scientific article considered relevant to the review based on the title and abstract. The metadata of this database consisted of titles, authors, journals, and other publishing information, as well as abstracts. The three independent databases obtained were merged, and the duplicates were eliminated. The remaining articles were screened based on the eligibility criteria and the focus of this review by experts. Three consistency of inclusion checks were performed. The first check was from the independent databases of the searchers, using the titles of 10% of articles of each database to determine the inclusion of articles that focus on relating soil properties and environmental variables to N mineralization. The second check was conducted after the merge and duplicate elimination using the abstracts of 5% of the articles. The last check was performed after screening and critical appraisal by the experts by determining the percentage of articles that only one, only two, only three or the four evaluators consider relevant to be included in the review.

Criteria for selecting studies

Determination of articles to be included in the study during expert appraisal was performed considering the following criteria.

Inclusion criterion

Articles aiming to determine, relate or predict N_{min} or availability in soils, using soil chemical, physical or biological properties, and environmental factors as the independent variables to relate to nitrogen.

Exclusion criterion

Articles without specifications of the methods used to determine the variables (specific variables and units) and their relationship (type of data analysis) are excluded. For instance, when a simple comparison of the variables is made without relating them. We decided to exclude publications before 1990 to limit the search and maintain consistency in the methodologies used to measure mainly soil N. Since the objective was to include relational or cause-effect analyses, the date cutoff also eliminated a lot of mainly descriptive or comparative studies more common before 1990.

Data collection and analyses

The studies approved after the criteria filter were exhaustingly revised to extract the data necessary for the review, which were stored in a database designed in ACCESS for this review. The database included general information about each study (source, citation, and reference) and article registry from the first database. The information extracted from each article included sample size, ecosystem studied, conditions of the experiment (natural, field incubation, greenhouse, and laboratory), independent variable, dependent variable, statistical analysis to determine the significance of variable relationships, as well as *P*-value or significance determined.

We summarized the studies for each independent variable from the second database and determined the least studied variables. We also obtained the number of relationships analyzed in the included articles, the variables studied, and the proportion of studies where a significant relationship was found. As a result, the consistency in the results for the influence of each factor and the proportion for each different outcome was determined. A summary of the process to follow for the realization of the proposed systematic review is shown in Figure 1.

RESULTS AND DISCUSSION

Literature search on N mineralization

The literature search in Jstor and Science Direct resulted in 94 and 856 English publications, respectively, and no Spanish publications. An internet search in Google Scholar resulted in 8,500 English and 258 Spanish publications. After eliminating duplicates and combing through titles for relevance, we obtained abstracts of 749 studies, of which 129 were passed to the inclusion and exclusion criteria screening. A total of 90 studies were considered for this review, from which we extracted 788 relational results from various statistical analyses, including analysis of variance, linear and non-linear regression, correlation, multiple regression, principal component analysis (PCA), path analysis, and structural equation models. In all these, the objective was to test the influence of different factors on N_{min} or availability.

Nitrogen has been widely studied because of its importance as a limiting nutrient for plant growth, ecosystem services, and crop productivity. Therefore, there is a consistency in the measurements of this nutrient. These measurements are generally based on determining ammonium and nitrates by colorimetry and using the Kjeldahl method. Other methods, like the measurement of the ^{15}N isotope, have also been used[19]. From these measurements, 16.12% of the analysis included here represents N as the content in soils (as Ammonium, Nitrates, Inorganic Nitrogen, Organic Nitrogen, and Total Nitrogen), and 83.88% represents N in the process of mineralization, including Potentially Mineralized Nitrogen (N_0)[8], N ammonification (N_{amm} or R_{amm}), nitrification (N_{nit} or R_{nit})[20] of which the most represented (67.39%) is N mineralization (N_{min}), which is sometimes measured as Net N_{min}[21], or Gross N_{min}[19,22], and in different rate units (e.g., mgN $m^{-2}d^{-1}$, mgN Kg^{-1}, mgN $m^{-2}d^{-1}$, mgN g^{-1}, %N mineralized, and μgN g^{-1} $month^{-1}$).

The papers included in this review were from 28 countries spanning five continents [Table 1]. Besides, two of the papers were global[1,6], including locations from all continents, and four papers did not specify the country the soil samples originated from since they worked under lab or greenhouse conditions. The continent best represented was Europe, with 20.5% of the countries included, followed by America, Asia, Oceania, and Africa (19.4, 15.2, 14.29, and 5.6%, respectively).

In America and Asia, the countries represented are distributed in temperate, subtropical, and tropical climate zones. On the other hand, Europe and Oceania only include temperate zones, and the three African countries are in the subtropical and equatorial zones.

Factors relevant to N mineralization

Multiple factors have been studied to understand how they influence N_{min}. A total of 785 records were grouped into environmental factors (18.6%), ecosystem/vegetation (14.52%), management (7.64%), soil physical and chemical properties (34.65%), organic matter (16.05%), and soil microbiota (6.37%). In addition, there were two independent variables in 17 records, which were not considered in these groups unless they were in combination with another factor, in which case they were with that factors' group. These variables included laboratory incubation time and sites that represented random plots to have enough samples.

Table 1. Countries where soil samples of studies originated. Number of papers from each country in parenthesis

Continent	Countries/Regions
America	Canada (4), United States (17), Mexico (1), Costa Rica (4), Bolivia (1), Brazil (1), Argentina (2)
Europe	Austria (1), Belgium (1), Spain (3), Cyprus (1), Germany (1), Netherlands (6), Scotland (4), Switzerland (1), Turkey (2)
Africa	Tunisia (1), Kenya (1), Egypt (1)
Asia	China (24), Mongolia (4), Taiwan (1), Tibet (1), Japan (1), India (1), Iran (1)
Oceania	Australia (2), New Zealand (1)

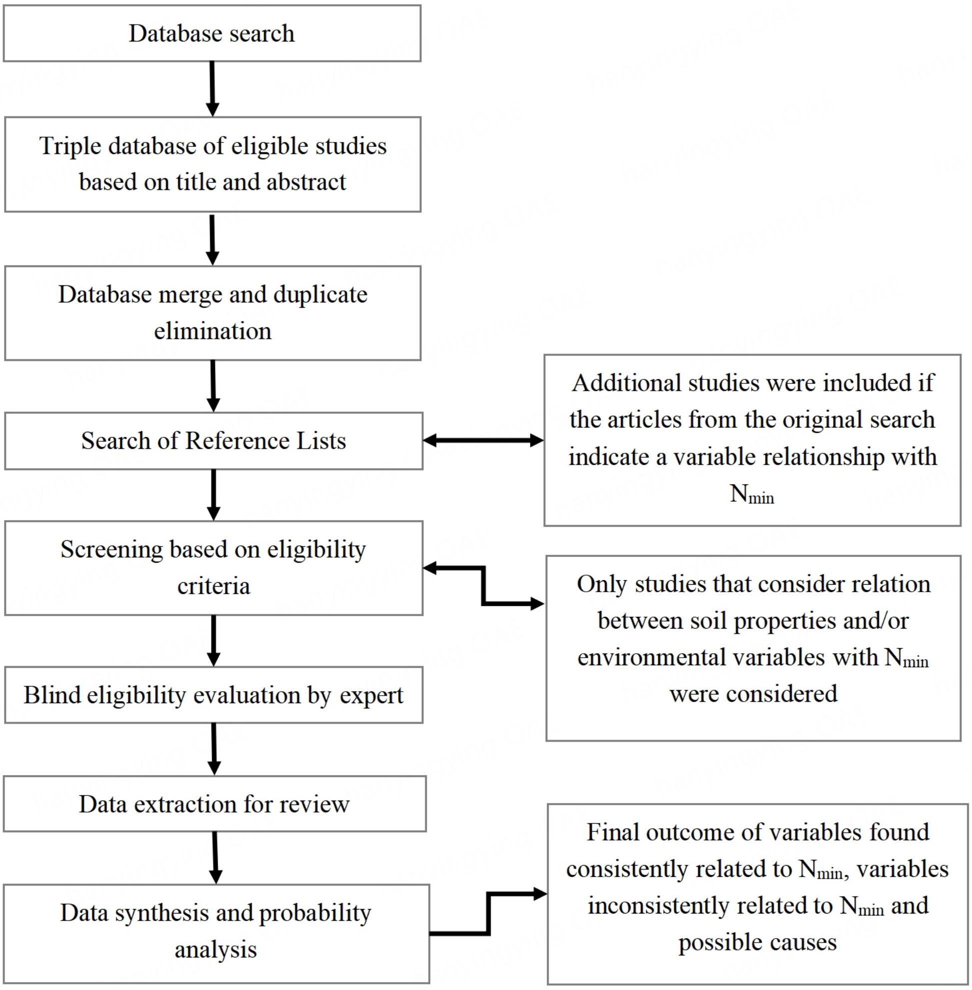

Figure 1. Study design summary.

Environmental factors

A total of 33 papers included environmental factors as explanatory variables to N availability or mineralization. Most of the environmental factors can be divided into topographic or climate variables. We found 36 records of topographic variables that include four instances in which topography was a factor with levels having different topographic characteristics[23,24] or several topographic variables meshed into one[25]. There was a significant effect of topography on N_{min}, Total N (TN), and Available N (AN). Altitude has a significant effect on N_{min}[6,26]. However, the elevation was reported as not significant to TN[25,27] and AN[25], indicating an influence on the process of mineralization but not on the N pool. Slope position was found significant to TN[28] and N_{min}, even interacting with texture[29]. Aspect and the Topographic Wetness Index significantly affected both TN and AN[25,27]. Slope length and horizontal curvature showed no influence on N[25,27]. The slope, stream power index, and Vertical curvature were inversely proportional ($P < 0.05$) to AN but not significant to TN[25,27], showing an influence on mineralized N but not on N contained in organic matter. The topographic variables are important to N because they measure the shape of the terrain, which influences the type of vegetation found, indicate whether the soil can accumulate or remain in place for enough time to impact nutrient accumulation, and even if texture (also impacted by topography) has the qualities to maintain the microbiome and nutrients. Annual Potential Evapotranspiration was the only climatic independent variable not found relevant to No or N_{min}[30]. We only considered one study each for tides[31], snow density[32], environmental CO_2[33], disturbance as burning and cutting[33], and disturbance simulation as sieving[14]; for all, there was a significant influence on N_{min} (CO_2 on N_o), while drying the soil had no significant effect on N_{min}[14]. Erosion was studied by Wang *et al.* by comparing erosional to depositional soil, but they found that it only affected N_{min} and N_{nit}, but not N_{amm}[34]. Ma *et al.* found that wind disturbance significantly diminished N_{min} and had an interactive effect with vegetation, indicating that the vegetation can change how the wind damages the soil processes[35].

The most common environmental variable is temperature. This environmental variable has been considered as the Mean Annual Temperature (MAT)[6] and soil temperature[36], or it has been manipulated in controlled environments to determine the effects of freezing[37] or warming[20] to study changes caused by extreme weather conditions and climate change. We considered 35 records with temperature as the independent variable, and only 37.14% were found significant. Dessureault-Rompré *et al.* found that MAT is inversely proportional to N_{min} and N_o, which coincides with the results reported by Urakawa *et al.* when MAT was related to Net N_{min}[30,19]. On the other hand, MAT has shown no significance to Gross N_{min}[19], the same as the results reported by Liu *et al.* and Li *et al.*[6,1]. For all cases that considered a wide arrange of climates in their study[1,6], if not latitudes in all cases (in Canada[30] and in Japan[19]), the location cannot be the source of the inconsistency. When the temperature was considered a freeze-thaw cycle[37], it was found significant, elevating N_{min} in the first cycle but diminishing it after the third. The influence was found to be inconsistent at different depths. When the climatic temperature was included in the experiment, it was shown to be insignificant[38]. On the contrary, Owen *et al.* found it to have a positive correlation with Net N_{min} in the *Tsuga-Yushania* forest but not in the *Miscanthus-Yushania* grassland (and opposite results for Net N_{nit}), indicating that the microclimate created by the vegetation can change the relevance of the climatic variables to N_{min}[39]. When the temperature was measured in the soil, Wang *et al.* did not find it significant in natural or plantation forests[36]. However, Hou *et al.* found it to be significant when measured both during the thawing and freezing periods. They reported a quadratic relation during the freezing period and an exponential relation during the thawing period[40]. When the temperature was considered as treatment in laboratory incubations, Song *et al.* reported that the higher the temperature, the higher would be the N_{min}, N_{nit} and N_{amm} ($P < 0.001$)[20], which coincided with the results found when tested at higher temperatures (20 °C and 25 °C) for N_{min}[41]. While the temperature was found to be significant to Inorganic N in soil, it was not the case for Organic N and N losses[42] when comparing 15 °C and 30 °C, indicating an influence of temperature on the mineralization of N, but not the organic matter or the loss of N by other processes.

The temperature was also considered a climatic index as growing degree days (GDD). The index of crop growth is defined as the number of degrees Celsius that the mean temperature is above five by the Environment Canada website. GDD was found to be negatively correlated with both N_{min} and N_o[30]. Precipitation was considered in four papers with 13 recorded analyses. MAP was found to be positively correlated with N_{min}[36]. Li *et al.* found the same in analyses of global data and data from forests, grasslands, and croplands, but not in wetlands where water is already abundant, and input from rain is not reflected on

N_{min}[1]. Contrary to this, Liu *et al.* did not find a correlation between N_{min} and MAP[6]. Although both papers were done by collecting peer-reviewed articles with sampling points from all around the world, the distinction can be because, in the work of Liu *et al.*, N_{min} was determined after laboratory incubation experiments, assuming that water availability was controlled[6]. Urakawa *et al.* also measured Gross and Net N_{min} after laboratory incubations and found no correlation to MAP[19]. Also related to water availability, a study on flooding comparing wetland types found differences in inorganic N, nitrates, N_{min} and N_{nit}, but no differences in Ammonium or N_{amm}[43]. In addition, it was found that while the aridity index was positively correlated with N_o, it did not correlate with N_{min}[30]. Latitude and seasons were also considered environmental factors, and while latitude was found to be negatively correlated with N_{min} in one study[6], another work found it positively correlated only as Net N_{min} but not correlated as Gross N_{min}[19]. The first study[6] considered sampling points worldwide, but the latter only concerned positive latitudes (Japan). Of the 29 records with seasons or months of the year as explicative variables, 27 were found significant. The only insignificant results were from the interaction of season and flooding[43], where the season on its own was significant but not interacting with flooding. In a study with five monthly measurements from the end of April to October, where a five-factor repeated measures ANOVA, Yao *et al.* found differences between the months in nitrates, ammonium and mineral N, but not in Net N_{nit}, Net N_{amm}, and Net N_{min}, probably because of samples in different vegetation types, soil texture, slope positions and depth in the soil[29].

Ecosystem/vegetation

Factors related to vegetation or ecosystem were found in 40 papers. A total of 114 records were found for relational analysis with N dynamics or availability as the response variable and 11 independent variables, of which seven had inconsistent results. These variables can be divided into descriptive variables (chemical composition) and the presence or variability of plants (including a community or ecosystem). Biomass of vegetation was not found to be correlated with N_{min}[36], TN, or inorganic N[44], and neither was N fixation[44]. However, the toughness of the vegetation was found to be negatively correlated ($P < 0.05$) to N_{min}[45]. The saturated water absorption ratio of the moss biocrust on the soil was found to be positively correlated with inorganic N ($r = 0.659$) but not with TN[44]. The C content of the moss biocrust was found to be positively correlated with inorganic N ($r = 0.612$) but not with TN[44]. The same results were observed for the N content ($r = 0.584$ for inorganic N and insignificant for TN), indicating that the composition of the biocrust will affect N readily available in the soil but not the N in organic matter. Orwin *et al.* found that the N content of grass leaves was positively correlated with N_{min} ($P < 0.05$)[45]. On the other hand, Kooijman *et al.* found that the correlation depends on the grass species, where they reported a positive correlation of N_{min} with N content of shoots of *Ammophila arenaria* ($r = 0.91$) and *Calamagristis epigeos* ($r = 0.59$), but not in case of *Elytrigia atherica* ($r = 0.45$)[46].

Several works have studied differences in mineralized N for the presence and absence of plants. The absence of plants can occur naturally through constant removal by animals[31] or anthropogenically when canopy forest gaps are created in vegetation years before[47] or when existing vegetation is purposefully removed for study purposes[10]. Studies found a higher N_{min} in the presence of plants. However, when considering a vegetation gap gradient, the results showed less mineralization in the transition zones than below the canopy and at the center of the gap[47]. When considering roots, Norton *et al.* found higher mineralization levels near the roots than in cases where there were no roots ($P < 0.05$)[48]. Conversely, Song *et al.* found that root additions did not affect the soil N_{min} and N_{amm} rates. However, Song *et al.* experiment was performed under different temperatures and depths of soils in a laboratory incubation experiment, and the results were inconsistent under different treatments[20]. These results show an interaction of climate and vegetation as explanatory variables to mineralization.

When considering vegetation cover, Knops *et al.* found that the cover of C3 grass, C4 grass, and forbs demonstrate a positive correlation with TN[49]. On the hand, the cover of Cryptograms negatively correlated with TN. Li *et al.* used a cover vegetation index from satellite images and found that vegetation coverage positively correlated with TN and available N[25]. However, the study found no significant relationship when using a randomized block analysis with two years as the blocks and four levels of canopy clearcutting as the treatments. The study found high N_{min} in the cleared areas during the first year after cutting due to the initial abundance of organic matter. However, in the following year, the N_{min} was much lower in the areas with little or no canopy compared to the cut areas, likely due to the absence of a source of organic matter[50]. Several studies have measured N_{min} levels in specific plant species from forests[51,52] and a semiarid woodland[53]. The studies revealed that the N_{min} levels vary between different plant species. Ewel also found differences in N_{min} under different trees in the plantation ($P = 0.025$) in the absence of an interactive effect of the species and their rotation ($P = 0.196$), indicating that the species is the determining factor[54].

De Boer and Kester found no differences between species in a forest when comparing the underground species[55]. Similar to the results of Van Der Krift and Berendse, who studied N_{min} levels across 14 monocultures of species of grasses and dicots, De Boer and Kester observed that grouping these species based on fertility[56] revealed significant differences ($P < 0.001$). This observation suggests that the traits of different species can be a determining factor for N_{min}. Yao *et al.*, in their study of N_{min} levels among species of shrubs in an arenosol soil, found that at a soil depth of 0-10 cm, there were significant differences in N_{min} among species ($P = 0.012$), but those differences were not maintained at a depth of 10-20 cm. Their study determined that some species of shrub (*Salix psammophila* C.) did not contribute to N_{min} as there were no differences to bare soil[57]. Barrios *et al.* compared N_{min} in different crops under aerobic and anaerobic conditions and found significant differences between the crops in both aerobic ($P = 0.033$) and anaerobic ($P = 0.013$) conditions[58]. Most studies on vegetation communities or ecosystems found significant differences (67.86%) between ecosystems[59,60], plant communities[61,62,63,64] or land use[27,61,65]. Johnson and Wedin observed differences ($P < 0.001$) when comparing a grassland and a forest. In addition, they observed a transition in N_{min} levels between a grassland and a forest, indicating an increased N_{min} level towards the forest[66]. Significant differences in N_{min} levels between communities were not observed only in one study when comparing abandoned agricultural soil, pastures, and woodlots that had not been used for 90 to 120 years[52]. However, even in this case, the N_{min} level was always different except for one month of the year (August of the year before), while significant differences were observed in the rest of the samplings ($P = 0.017$). Fisk *et al.* didn't find a difference between an old and a secondary forest on Net N_{min} or Gross N_{min}[67]. A study on bamboo invasion in an evergreen broadleaf forest found that the invasion reduced N_{nit} and N_{min} significantly ($P < 0.05$), while N_{amm} remained intact[68]. In a comparative study of a pine forest, a spruce-fir forest, and an Erman's birch forest[35], no significant differences ($P = 0.053$) were found. However, an interactive effect with soil depth ($P = 0.01$) was observed. The noted study was focused on wind disturbance, and the soil depth interaction can explain the lack of difference between forests instead of the different communities. These results are similar to a study comparing savanna woodland, pasture, and a *Eucalyptus* plantation[69], where no significant difference was observed between ecosystems ($P = 0.160$). However, an interaction with soil depth ($P < 0.001$) was found when the response variable was N_0. Another study comparing a tropical semideciduous forest, a secondary forest, a coastal dune crest, and coastal dune slack[70] found significant differences only in Net N_{amm} ($P = 0.007$). In contrast, Net N_{nit} ($P = 0.079$) or Net N_{min} ($P =0.069$) demonstrated no difference. When analyzing the interaction with the months tested, they found no ecosystem and time interaction for N_{amm} ($P = 0.292$). However, they observed the interaction for N_{nit} ($P = 0.001$), indicating that the seasons can affect each ecosystem differently. This observation suggests the need to consider the diversity of vegetation in each ecosystem and their properties in demonstrating significant differences. Zhao and Li found significant differences in Net N_{min} for 2012 and 2013, as well as in gross N_{min} ($P < 0.05$) when comparing a meadow and a shrub. They also found a significant interaction of the aspect vegetation with the months collected ($P < 0.01$) in 2013, while an interaction was not found in 2012. This observation suggests that seasonal changes and other specific climatic changes can affect the mineralization of N[71]. Wang *et al.* found differences between ecosystems when comparing grasslands to the forest and natural forests with plantation forests[36]. They also found significant positive correlations between N_{min} and the Shannon-Wiener diversity index for trees ($r = 0.71$), herbs ($r = 0.52$), and Margalef's tree diversity index ($r = 0.72$), indicating that a place with a greater diversity of plants will have a higher N_{min}.

Management

Soil management modifies several soil properties that influence the process of mineralization. The eight management variables found in our results come from 27 papers with 60 records, of which three were found with inconsistent results. The management factors could be divided into two categories: management regarding the vegetation on the soil (e.g., afforestation, clearfelling), and management regarding the soil (e.g., tillage, amendments). The most studied management variable (60% of the records) in this paper is amendments since nutrient availability is the first limiting factor to crop productivity, followed by water availability. The amendments found in this recompilation were urea[33], chemical fertilizers for nitrogen[10,48,72,73], chemical fertilizers for phosphorous and potassium[28,72,74], biochar[37] alone or with straw[40], broiler litter[75], liming[76], green manure[77], kelp[78], bioinput[79], manure[73,79], and digestates[80]. Results show a significant change due to the use of amendments in 80.5% of cases. Fu *et al.* tested biochar in a laboratory experiment and did not find a significant effect[37]. They evaluated biochar under different moisture levels and at different soil layers and found no interactive effect of the factors. On the contrary, Hou *et al.* found that biochar demonstrates a higher level of mineralization compared to the control group, but lower than the use of a straw[40]. Both studies used the straw to produce the biochar at temperatures over 500 °C. The first study used biochar with a pH of 8.5 with 1.28% (± 0.13) N, while the second study used biochar with a higher pH (9.68) with N content (1.57%) as the main differences between the biochar samples used. Chen *et al.* found that N enrichment increases N_{min} ($P < 0.05$), and the effect was maintained regardless of the plant presence (no interactive effect with the presence/absence of plants)[10]. Norton and Firestone found no significant effect on the ammonification rate when using an ammonium N addition[48]. Hassink also found no effect on N_{min} when measuring the percent N mineralized per day[13]. Miranda *et al.* found that using the commercial fertilizer had no effect on ammonium in soil when comparing a commercial organic fertilizer and manure[79]. However, the commercial fertilizer increased nitrates (and inorganic N as a consequence). They found that manure increased nitrates and ammonium, while the use of commercial fertilizer and manure demonstrated an interactive effect on nitrates and ammonium. However, such an interaction was not observed on inorganic N[79].

Only one study considered crop rotation[54] and found it to impact N_{min} significantly. When comparing cultivated versus uncultivated soils, the former had a higher N_{min} ($P < 0.001$). In addition, there was an interaction with the usage of different plant residues ($P < 0.01$) in the soil as a source of organic matter[81]. Afforestation of shrubs was implemented to curb desertification, which was found to raise N_{min} and N_{nit}[82] throughout the afforestation. A study on clearfelling shows that burning and cutting down a forest increases N_{min} initially due to the organic matter input into the soil, especially in burnt forests. However, the increase in N_{min} level decreases below those in the undisturbed forest within two years [83], probably due to the absence of a yearly newfound organic matter source. Another form of vegetation clearing is grazing, which has been studied with different animals. The intensity of grazing by livestock was compared using various treatments, including no grazing, moderate grazing, and heavy grazing. Shariff *et al.* found that there was no difference between no grazing and heavy grazing, but moderate grazing considerably increased the N_{min} level ($P < 0.05$)[84]. On the contrary, Biondini *et al.* found differences only in July, and the not grazed treatment presented significantly higher Net N_{min} than moderate and heavy grazing ($P < 0.05$)[85]. The ungrazed and moderately grazed treatments demonstrated higher N_{min} levels than the heavily grazing treatment when the entire growing season is considered[85]. Hassink compared grazing by cows versus a mowing treatment on a specific sandy soil ($P < 0.05$) and concluded that the former resulted in higher N_{min}. However, the results were not repeatable on the other sandy or loamy soils measured ($P > 0.05$)[13]. Frank and Groffman found that grazing by wild ungulates increased N_{min} levels in Yellowstone Park ($P < 0.05$)[64]. A study concerning vole presence indicated that grazing affected N_{min} levels only in one of the sites studied[86]. This site had different dominant forbs and graminoids than the others and demonstrated a higher mineralized N level when exposed to vole presence ($P = 0.045$). Grazing by geese in a salt marshland diminished ($P < 0.01$) the Net N_{min}[31]. A soil management practice studied is tillage. It was found that tillage increases N_{min}[76]. The strip-tillage promoted a more readily mineralizable pool of N[75] when comparing conventional and strip tillage. The more evident effects observed were the interaction with amendments. The N_{min} level was significantly higher with strip-tillage when combined with broiler amendments than when no amendments were used [75]. Interactive effects were also observed when combining tilling and liming amendment applications [76]. A management variable considered was the age of an established vegetation community. Three studies found that the older the community, the higher the nitrogen pool (NT) in abandoned cropland[49] and a tea plantation[87]. Moreover, higher N_{min}[13] levels in a grassland indicate that any changes in soil use will negatively affect N_{min} or availability.

Soil physical and chemical properties

A total of 27 physicochemical properties related to N mineralization or availability were found in 272 analyses recorded across 50 papers. Twelve of these independent variables had inconsistent results. Soil types and parent materials were considered in this category because they represent differences in the combination of physicochemical properties. All studies that compared soil types found differences in TN and AN[25,27,28]. Several studies found that parent material can affect N availability or mineralization, but not all studies demonstrated this effect. AN was found to be affected by parent material[25]. However, when TN was used as the dependent variable, Zhang *et al.* found differences when comparing alluvial, thick and thin shale, and sandstone[28]. On the other hand, in studies that included alluvial deposits and different types of purple shale, there were no significant differences in TN between the different parent materials[25,27]. Nevertheless, TN includes N contained in organic matter and finding differences can depend on the capacity of the soil to retain organic matter. Hence, when the parent material does not represent significant differences in texture or porosity, it is possible to misinterpret the differences between the materials. For example, a study comparing the N_{min} levels of Gypsum, Marl, and Serpentine found that the latter had higher N_{min} than the other two soil types, but only after 42 days of incubation[88]. On the contrary, a study on the soil derived from Serpentine (the one with the highest sand content) comparing silicate and limestone parent materials indicated no differences in gross N_{min}[59]. Moreover, soils that were tested for cambisol and luvisol were characterized as having a finer texture, which the same study found to be correlated with N_{min}.

We found seven soil physical properties that have been studied concerning N availability and mineralization. The only ones without inconsistent results were included in only one research paper, including drainage[74], aggregate size[87], and field capacity[44] and were found to be positively related to N_{min}, TN, and inorganic N, respectively.

The other variables studied were bulk density, depth, porosity, and texture (as one or all the particle sizes). There were some inconsistencies in the results of each property. Bulk density was used as an explanatory variable for N availability and mineralization in nine papers and was found to be negatively related to the dependent variable in 52% of the 25 analyses. For soils originating from natural environments, plantations, crops, restoration areas and using amendments, the bulk density was found to be negatively correlated with

N_{min}[63], N_0[8,70], inorganic N[44,89], and Total N[44]. However, two studies found no significant correlation between the variables[62,71], one carried out on forests and plantations and the other on grassland, shrubbery, and plantation soils. Breland and Hansen compared the impact of two levels of manure and green manure compaction on the control of growing grass. They found a significant difference only when using green manure, indicating that the density of the soil influences mineralization only under certain circumstances related to organic matter[90]. Yang *et al.* correlated N_{min} with bulk density monthly from May to September on 10 cm of topsoil[21]. They found a significant correlation only from July to September, indicating an influence of temporal factors[21]. The study was performed *in situ*. Since N_{min} has similar patterns to precipitation, it is possible that in May and June, there was not enough variation in N_{min}, or it was too low to detect a correlation with bulk density. N has been compared at various depths of the soil, and it was found to be highest in topsoil than in layers underneath.

Soil texture was studied as percentages of clay, silt, and sand to relate them to N, and the results were contradictory. N_{min} was found to be different when two types of soil with different textures were compared[29]. The sand percentage had a negative correlation with N_{min} and N_0[30], and the clay percentage demonstrated a positive correlation with N_{min}[30] and N_0[30,91]. Silt + Clay percentage was not found to be correlated with N_{min}[13]. Three studies used each particle size as an independent variable in the correlations. Martínez *et al.* found them all significantly correlated with N_0[8]. However, only two studies found the clay to be correlated with N_0[92] and N_{min}[59]. Clay was correlated with Organic Nitrogen, inorganic N, and N losses but was only significantly related to Organic N[42]. Porosity was correlated with Inorganic N[89] and was found to be positively correlated in both amended and unamended soils with high r values (0.99 and 0.98, respectively). When correlated with the porosity of different size pores (macropores, coarse mesopores, fine mesopores and micropores), no correlation was found between inorganic N and porosity in amended and unamended soils. The correlation was found only to macropores and micropores ($r = 0.95$ and $r = 0.99$, respectively). These results indicate that density matters to mineralization more in relation to the effective porosity of the soil, given by the distribution of particle sizes and compaction.

Moisture is considered in the physicochemical attributes of soil in this review. The results show a variety of techniques in which soil moisture has been studied concerning N mineralization and availability. Moisture as water content and water holding capacity was found to be positively correlated with N_0 in a laboratory incubation experiment of agricultural and grassland soils[91]. Water content was also found to be positively correlated with N_0 by Campos *et al.*[70]. When studied in the context of TN and inorganic N, a positive correlation to moisture was found [44]. Franzluebbers *et al.* conducted a non-linear regression of N_{min} (as a percentage of mineralized N) as a function of moisture for soils under constant moisture and dry-wet cycle management[93]. They found higher N_{min} levels under constant moisture[93]. A study found a significant logarithmic correlation of N_{min} with moisture during the freezing period of the soil and a significant quadratic correlation during the thawing period[40]. Fu *et al.* included moisture content (%) as a factor in a multi-way ANOVA and found significant differences between the moisture treatments (15%, 20%, and 25%)[37]. Contrary to these studies, others found no correlation between moisture and N_{min}[39,55,62]. Considering the variety of relations found in the previously mentioned studies, the lack of a correlation can be due to the lack of variability in the moisture content that prevents establishing a trend or the specific type of relation. Breland and Hansen compared two levels of water content and found no significant differences in N_{min} between them[90]. In a multifactor ANOVA comparing two levels of water content (12% and 18%), inorganic N was found to be significantly different, while organic N and N losses demonstrated no significant difference[42]. Inorganic N is closely related to microbial activity, which requires the presence of water. When comparing 60% and 100% moisture intensity in a three-way ANOVA, there were no significant differences in N_{min}. However, when comparing the number of dry-wet cycles in the same study, there were differences among treatments[94], indicating the higher importance of the drying cycle than the quantity of water. A multiple linear regression study was conducted to correlate water content and N_{min} in different months of the year (May to September) and at two soil depths (0-10 cm and 10-20 cm). The moisture was found to be significant only in September at a 10-20 cm depth[21]. When the correlation was done on three different dates at alpine grasslands of two different mounts, a negative correlation was found significant in the September-October period but only in one of the mounts[26]. The same study found a significant negative correlation when the soils were incubated *in situ*. These results indicate temporality significance in the importance of water to N_{min}.

One of the most studied attributes of soils with N_{min} is pH. Several studies found no correlation between pH to N_{min}[19,30,55,62] or N_0[30,92]. When there was a significant correlation, the results varied. The negative correlations of pH with N_{min}[6,36,63] and N_0[8,70,91] were the most common. Yang *et al.* correlated N_{min} with pH in ten analyses performed under different months and soil depths[21]. They found a significant positive correlation only in July at a 10-20 cm depth, and the rest were insignificant[21]. Finding a significant correlation between pH and N_{min} may depend on the variability of the data and the range of pH values. Soils that are too acidic or too alkaline can diminish microbial activity. The optimum soil pH can be in the middle range, resulting in a non-linear relationship. This premise has been confirmed in one study that revealed a significant quadratic correlation[46].

Electric conductivity, as a measure of soluble salts in soils, was found to be positively correlated with N_0 in a lab incubation study[70]. However, no correlation was found in a field study[92]. Cation exchange capacity was found to be correlated with N_0[70] but not with gross N_{min}[59]. Phosphorus addition was not found significant to N_{min}[22]. When phosphorus was correlated with N_0, one study found the correlation significant and negative[8], while another found no significance[91]. To find correlations, the attributes need enough variability to allow one variable to change depending on the variation of another variable, which is not always the case. We found chemical attributes that were studied in relation to N_{min} only in one of the publications included in this study. Oxygen in the environment was used in three-level treatments, and ANOVA analyses show that there were greater N_{min} and N_{nit} when there was more oxygen in the environment. However, there were no significant differences in treatments for N_{amm}[87], showing that nitrates have a more significant influence than ammonium in establishing the pattern that N_{min} follows. Base saturation[59] and calcium[19] were found to be positively correlated with N_{min}. The N:P ratio was found to be positively correlated with N_0[91]. On the other hand, the C:P ratio was found to be negatively correlated with N_0[91], as was the carbonate content[92]. In addition, hydraulic conductivity[70] was negatively correlated with N_0. Different dilutions of soil extracts that contained allelopathic compounds from previous plantations in the soil have been tested[95]. It was found that N_{min} and N_{nit} were lower at higher allelopathic compound content. Salinity has been tested separately as Chlorine (Cl^-) and Sodium (Na^+) content and related to Net and Gross N_{min}, but no significant correlation was found.

Organic matter

A total of 126 analyses related to soil organic matter variables were divided into 21 distinct variables from 18 papers. These variables were measured as organic matter content in the soil and different characteristics from the organic matter fraction of the soil or the litter. The organic matter has been measured as the litter on the soil, fractions of the organic matter, and chemical properties of the organic matter. In the measurements of litter, carbon content[44,68] and biomass[36,44,68] have not been found significant to N availability or mineralization, while litter decomposition (r = -0.85)[46], litter lignin content in soil (r = -0.833) and in crop (r = -0.861)[96], and litter C:N (r = -0.58)[68] ratio have been found negatively correlated with N_{min}. The C:N content was also negatively correlated with N_{nit} (r = -0.66)[68]. The N content in the litter was only found to be significantly correlated with N_{amm} ($r = 0.60$) but not to N_{nit}, N_{min}[68], TN or inorganic N[44] when using Pearson's correlation, while in a PCA was found significant to N_{min}[48]. Raiesi found differences in the N_{min} when comparing plant residues as the litter source ($P < 0.001$)[81] and when separating the parts of the plant used as litter. Only the foliage litter was found to be significantly correlated with N_{min} ($r = 0.55$), but not the plants' branches, stems, or roots[36]. The litter turnover rate was found to correlate with N_{amm} ($r = 0.65$, $P < 0.05$) and N_{min} ($r = 0.59$, $P < 0.05$) but not with N_{nit} ($r = 0.49$)[68]. The annual litter production was found to be positively correlated with N_{min}[36,68] but not significant to N_{amm} and N_{nit}[68].

De Neve and Hofman found that the water-soluble fraction in soil and crops is positively correlated ($r = 0.746$ and $r = 0.861$, respectively) with N_{min}[96] based on measurements made only on the organic matter of the soil. The dry weight of the soil organic matter (SOM) fraction was found to correlate with aerobic N_{min} only in the separated density < 1.13 g/cm^3 of the SOM[58] but not to higher density SOM or under anaerobic conditions. The C:N ratio in lignin of SOM was found to be negatively correlated with N_{min} in soil ($r = -0.833$) and crop ($r = -0.882$)[96], and in the SOM fraction, C:N was significant to N_{min} only under aerobic conditions with SOM densities under 1.7 g/cm^3[58]. Nitrogen in SOM has been measured in several studies. The moist extractable organic N was found to be positively correlated with N_0 ($r = 0.81$)[91] in corn and grasslands, and N from the heavy fraction of organic matter was positively correlated with N_{min} ($r = 0.854$) in paddy soils[97]. Zhang *et al.* found no significant correlation between Gross N_{min} and dissolved organic N ($r = 0.372$)[59]. Martínez *et al.* found a significant correlation of N_0 with Nitrogen in fine organic matter particles ($r = 0.83$)[8] but not with Nitrogen in coarse organic matter particles ($r = 0.17$), indicating that the size, which is related to ease of degradation, is important to N availability. Another study found N_0 to be positively correlated ($r^2 = 0.011$, $P < 0.05$) with N in organic matter particles but not N_{min} ($r^2 = 0.05$)[30]. Barrios *et al.* found that N_{min} is correlated with N concentration in SOM but only under aerobic conditions[58], which can happen under suboxic conditions since the mineral N liberated can be reused by the microbiota to maintain their metabolism in anaerobic conditions[59]. Measurements of C within organic matter had contradictory results. N_{min} was found to be positively correlated with heavy fraction C[1] and particulate organic matter C[30]. N_0 demonstrated a positive correlation to moist extractable organic C[91] and particulate organic matter C[30], while Zhang *et al.* found no correlation of gross N_{min} to dissolved organic C[59]. Moreover, Barrios *et al.* found no significance in the relation of N_{min} to C concentration in SOM unless it was with SOM densities less than 1.13 g/cm^3 under aerobic conditions[58]. When using water-soluble organic C as the explicative variable, Urakawa *et al.* found a significant correlation to Net N_{min} ($r = 0.34$) but not gross N_{min} ($r = 0.15$)[19]. N_0 was found to correlate with the fine-particle organic matter C ($r = 0.64$) but not with coarse-particle organic matter C ($r = 0.33$)[8].

Measurements of organic matter in the soils determined that Gross N_{min} was not correlated with free amino acids in the soil[59]. N_0 was positively correlated with soluble carbs ($r = 0.71$) and total carbs ($r = 0.72$) in soils[8], while N_{min} is negatively correlated with lignin in soil ($r^2 = 0.7$) as lignin is hard to decompose. Morecroft *et al.* found that the significance of the relation of N_{min} to loss of ignition was dependent on the site and date of sampling[26]. Since N is released from organic matter into inorganic molecules in the soil through the process of mineralization, it is assumed that there is a correlation between organic matter and N_{min}, and there are several ways to measure organic matter, but the most common approach is by measuring soil organic carbon (SOC). Our research yielded 33 records from 19 research papers, of which 60.6% showed a significant correlation between the variables. The most common results found a positive correlation with SOC with N_{min}[6,30,35,63,97] or N_0[8,30,33,70,91] as the dependent variable, while Zhang *et al.* found a significant negative correlation between SOC and N_{min} ($r = -0.555$). They inferred the negative correlation due to enhancement in relative C limitations since compounds containing C and N are utilized by a larger fraction, or organic N is not retained but mineralized[59]. Some studies found no correlation between SOC and N_{min}[36,51,62], which can be related to the negative correlations found between N_{min} and C:N ratio in the organic matter[6,96]. No correlation with N_0[8] indicated that the chemical composition of the organic matter affects N_{min}. This was confirmed by Mehnaz *et al.*, who found significant differences in N_{min} when SOC came from different sources (glucose, oxalic acid, and phenol as the SOC sources)[22]. Hu *et al.* found a significant correlation of SOC with TN ($r = 0.887$) but not with inorganic N ($r = 0.401$), again confirming a separation of what is available in organic matter and whether N is mineralized or not[44]. A study found that the relationship between N_{min} and SOC may depend on the time of year during which it is measured. They found a significant correlation between these variables in August and September but not in May, June, or July[21]. Their results coincide with the findings of Hou *et al.*, who found an interactive effect of the organic matter and the time of the year on the N_{min} rate[40]. Five studies included analyses correlating soil organic N with N_{min} or availability, finding them to be positively correlated[8,19,30,92,96], but only found a discrepancy. They related mineralizable N in the soil and crop residues to be used as amendments to soil organic N. However, while it was found to be positively correlated with the crop residues ($r = 0.591$), there was no significant correlation when testing the soil without the crop residues.

Soil microbiota

Independent variables describing soil microbiota as explicative variables to N_{min} or availability were obtained from 17 papers, with a total of 50 records using 14 different variables related to microbial activity, abundance, or specific information with chemical or community composition. Of the 14 variables, only microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), and the presence of Nitrifier Bacteria were found with inconsistent results, while the rest demonstrated consistent results. MBN is the most common variable describing microbiota (28% of recorded microbiota data), followed by MBC (22%). All except four of the relational data found MBN to be positively correlated with N_{min}[6,51,76,98]. Li *et al.* found that the correlation was significant in the global data, and when separated, they confirmed the correlation for every ecosystem except wetlands ($P = 0.13$)[1]. A study conducted in a headwater catchment of the Taizi River in China, a place with a temperate monsoon climate, reported no significant correlation between N_{min} and MBN[36]. Conversely, a study conducted in a subtropical monsoon climate showed that MBN was positively correlated with inorganic N but not with total N[44]. Similarly, Zhang *et al.* found no significant correlation between N_{min} and MBN or MBC[59]. It is important to mention that this was the only study that did not find a significant correlation with MBC in a laboratory study that included different water content treatments that have a 90% water-holding capacity (WHC) level and a low oxygen level (1%). Also, it has been reported that microbial growth reaches its maximum at 33% WHC [60]. A higher WHC level changes the microcosms to a suboxic regime, resulting in a decline in potential enzyme activities and slowing metabolic activity and microbial growth. However, N mineralization persists and increases due to a decrease in N immobilization, resulting in a separation between MBN and N_{min}. Such a separation can most likely happen in any place where the soil gets saturated with water, like watersheds, wetlands, paddies or over-irrigated croplands. When using MBC as an explanatory variable, only one study found it unrelated to N mineralization[59]. The rest found it to be positively correlated ($P < 0.05$) with N_{min}[1,6,36,76], TN, and inorganic N[44].

Microbial abundance measured as active biomass[93] or as phospholipid fatty acids abundance[10] was found to be positively correlated with N_{min} ($r = 0.991$ and $r^2 = 0.43$, respectively). The density of ammonifier bacteria was correlated with N_{min}[53], whereas no correlation was found when using the density of nitrifier bacteria. Another study related the abundance of nitrifying bacteria to Organic N, Inorganic N, and N losses[42]. However, only found it significantly related to inorganic N ($P = 0.0084$), showing a relation to mineralization but not to the availability of organic matter or leaching.

With respect to microbial activity, respiration was found to be positively correlated with N_0[99], and urease activity was correlated with the N_{min} rate with an exponential relationship[40]. But, when several enzymes were condensed into one variable and analyzed by a path analysis[76] or a structural equation model[98], a negative correlation was found with N_{min}. Several studies have used specific information about the microbiota to relate it to N cycling. Zhang found no relation between the presence of fungi (pathogenic, non-pathogenic, or mixed) and N_{min} or N_{nit} rates[95]. But, when Vazquez *et al.* included a Fungi: Bacteria ratio in the path analysis, they found it negatively correlated with Net N_{min} (r = -0.16), indicating that bacteria have a higher mineralization power than fungi[76]. When using the C:N ratio in the microbiota as an independent variable, two studies found a negative correlation with N_{min}[6,59]. One study compared treatments with a chitinolytic fungus, a chitinolytic bacterium, and two nitrifying bacteria in different combinations. The results ($P < 0.05$) indicate that not only does the presence of certain organisms promote mineralization, but the combination of the organisms can affect mineralization due to the interactions within the microbial community, including inhibitions and competition.

CONCLUSION

Our wide exploration of state of the art for N_{min} process showed that soil and environmental factors evaluated under different circumstances resulted in inconsistencies in the amount of N mineralized. The major factors that have a tremendous and variable effect on N_{min} are identified. These factors include soil microbial biomass, organic matter, C:N ratio, aeration/O_2-CO_2, cation and anion exchange, soluble salts content, pH, moisture, temperature, textural composition, soil management focused on organic residues, plant roots effect, type of vegetation, and special conditions such as snow density, soil erosion, topography, and climate characteristics on a particular ecosystem.

The topographic and climatic *environmental factors* provide the base environment where mineralization processes occur. It is advisable to consider the experimental condition (field, lab, or greenhouse) to determine if their influence is accurately reflected in the results and that microclimates can differ from an area's general climate. The details of the *ecosystem* and *vegetation* explain the source of the organic matter, its diversity, and the nutrient proportions that compose it. Hence, it is essential to consider the combined effects of climate due to its significant impact, as shown by some of the results. The composition of the plant and proportions of tough and soft tissues are better predictors for mineralization than species diversity since they are directly correlated with organic matter lability. *Management* can affect all aspects of soil, from climate (irrigation) and ecosystem (crop species) to soil properties (density, pH) and organic matter (with weeding and amendments), and indirectly the microbiota. As a result, different management techniques will affect mineralization differently. Soil *physicochemical properties* create the microclimate in which the process of mineralization occurs. It also affects mineralization indirectly, as it influences the principal participants in the process, the *organic matter* that contains the nutrients and the *microorganisms* that liberate them through their metabolism. The classification we used grouped similar factors and separated them from the outside of the process, ranging from the general outside climate to the direct participants essential in mineralization, such as the organic matter and microorganisms.

For this reason, we have concluded that both research goal scenarios, the development of a general prediction model for the N_{min} process and the development of a specific equation for local conditions, have a limitation for use in crop production. Therefore, we deemed that generating a prediction model for N_{min} that can support decisions for soil and crop management in the face of global climate change would be helpful. This model must cover significative independent variables and a range of conditions for a productive region, uncultivated forest, or grassland.

Research prospects

Considering the findings in the present paper, future N_{min} modeling studies could include a comparison of models under the circumstances that create differences in the results of correlational relationships among variables, like comparing models for different ecosystems. Such an approach will improve our understanding of the nuances of soil processes and incorporate soil management strategies into production and conservation efforts.

DECLARATIONS

Acknowledgments

This review was developed during doctoral program at the Universidad Autónoma de Ciudad Juárez (UACJ) by Gabriela Mendoza, while receiving a CONACyT scholarship. The support from the other authors is from their participation advising as Professors at the Universidad Autónoma de Ciudad Juárez, Mexico, and the New Mexico State University, USA. Additional support for database research was received from Vianey Castillo and Nayeli Contreras, students from UACJ, who did their thesis research on fungi and bacterial activity on N mineralization in biosolid treated agricultural soils.

Authors' contributions

Made substantial contributions to conception and design of the study and performed data analysis and interpretation: Mendoza-Carreón G, Flores-Márgez JP, Osuna-Avila P, Sanogo S

Performed data acquisition, as well as provided administrative, technical, and material support: Mendoza-Carreón G and Flores-Márgez JP

Availability of data and materials

Not applicable.

Financial support and sponsorship

None.

Conflicts of interest

All authors declared that there are no conflicts of interest.

Ethical approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Copyright

© The Author(s) 2023.

REFERENCES

1. Li Z, Tian D, Wang B, et al. Microbes drive global soil nitrogen mineralization and availability. *Glob Chang Biol* 2019;25:1078-88. DOI PubMed
2. Mia S, Singh B, Dijkstra FA. Aged biochar affects gross nitrogen mineralization and recovery: a ^{15}N study in two contrasting soils. *GCB Bioenergy* 2017;9:1196-206. DOI
3. Brady NC, Weil RR. The nature and properties of soils. 15th ed. USA: Pearson; 2016. p. 740. Available from: https://www.researchgate.net/publication/301200878_The_Nature_and_Properties_of_Soils_15th_edition [Last accessed on 7 Apr 2023].
4. Vereecken H, Schnepf A, Hopmans J, et al. Modeling soil processes: review, key challenges, and new perspectives. *Vadose Zone J* 2016;15:vzj2015.09.0131. DOI
5. Schimel JP, Bennett J. Nitrogen mineralization: challenges of a changing paradigm. *Ecology* 2004;85:591-602. DOI

6. Liu Y, Wang C, He N, et al. A global synthesis of the rate and temperature sensitivity of soil nitrogen mineralization: latitudinal patterns and mechanisms. *Glob Chang Biol* 2017;23:455-64. DOI PubMed
7. Guntiñas ME, Leirós MC, Trasar-Cepeda C, Gil-Sotres F. Effects of moisture and temperature on net soil nitrogen mineralization: a laboratory study. *Eur J Soil Biol* 2012;48:73-80. DOI
8. Martínez JM, Galantini JA, Duval ME. Contribution of nitrogen mineralization indices, labile organic matter and soil properties in predicting nitrogen mineralization. *J Soil Sci Plant Nutr* 2018;18. DOI
9. Paul KI, Polglase PJ, O'connell AM, Carlyle JC, Smethurst PJ, Khanna PK. Defining the relation between soil water content and net nitrogen mineralization: Soil water modifier for mineralization of nitrogen. *Eur J Soil Sci* 2003;54:39-48. DOI
10. Chen D, Xing W, Lan Z, Salee, M, Wu Y, et al. Direct and indirect effects of nitrogen enrichment on soil organisms and carbon and nitrogen mineralization in a semi-arid grassland. *Funct Ecol* 2019;33:175-187. DOI
11. Guo Z, Han J, Li J, Xu Y, Wang X. Effects of long-term fertilization on soil organic carbon mineralization and microbial community structure. *PLoS One* 2019;14:e0211163. DOI PubMed PMC
12. Rousk J, Brookes PC, Bååth E. Contrasting soil pH effects on fungal and bacterial growth suggest functional redundancy in carbon mineralization. *Appl Environ Microbiol* 2009;75:1589-96. DOI PubMed PMC
13. Hassink J. Effects of soil texture and grassland management on soil organic C and N and rates of C and N mineralization. *Soil Boil Biochem* 1994;26:1221-31. DOI
14. Franzluebbers A. Potential C and N mineralization and microbial biomass from intact and increasingly disturbed soils of varying texture. *Soil Boil Biochem* 1999;31:1083-90. DOI
15. Schloter M, Nannipieri P, Sørensen SJ, van Elsas JD. Microbial indicators for soil quality. *Biol Fertil Soils* 2018;54:1-10. DOI
16. Cumpston M, Chandler J. Planning a cochrane review. Available from: https://training.cochrane.org/handbook/current/chapter-ii [Last accessed on 7 Apr 2023].
17. Koutsos TM, Menexes GC, Dordas CA. An efficient framework for conducting systematic literature reviews in agricultural sciences. *Sci Total Environ* 2019;682:106-17. DOI PubMed
18. Collaboration for Environmental Evidence. Guidelines and standards for evidence synthesis in environmental management. Version 5.0 (AS Pullin, GK Frampton, B Livoreil, G Petrokofsky, Eds). Available from: http://www.environmentalevidence.org/information-for-authors [Last accessed on 7 Apr 2023].
19. Urakawa R, Ohte N, Shibata H, et al. Factors contributing to soil nitrogen mineralization and nitrification rates of forest soils in the Japanese archipelago. *For Ecol Manag* 2016;361:382-96. DOI
20. Song Y, Song C, Hou A, et al. Effects of temperature and root additions on soil carbon and nitrogen mineralization in a predominantly permafrost peatland. *CATENA* 2018;165:381-9. DOI
21. Yang X, Han Y, Li B, Yan H, Yang W. Spatiotemporal heterogeneity of soil nitrogen mineralization in a Picea stand and its relation to soil physicochemical factors. *Acta Ecologica Sinica* 2015;35:20-7. DOI
22. Mehnaz KR, Corneo PE, Keitel C, Dijkstra FA. Carbon and phosphorus addition effects on microbial carbon use efficiency, soil organic matter priming, gross nitrogen mineralization and nitrous oxide emission from soil. *Soil Boil Biochem* 2019;134:175-86. DOI
23. Walley F, Van Kessel C, Pennock D. Landscape-scale variability of N mineralization in forest soils. *Soil Boil Biochem* 1996;28:383-91. DOI
24. Raghubanshi A. Effect of topography on selected soil properties and nitrogen mineralization in a dry tropical forest. *Soil Boil Biochem* 1992;24:145-50. DOI
25. Li Q, Luo Y, Wang C, et al. Spatiotemporal variations and factors affecting soil nitrogen in the purple hilly area of southwest China during the 1980s and the 2010s. *Sci Total Environ* 2016;547:173-81. DOI PubMed
26. Morecroft MD, Marrs RH, Woodward FI. Altitudinal and seasonal trends in soil nitrogen mineralization rate in the scottish highlands. *J Ecology* 1992;80:49. DOI
27. Gao X, Xiao Y, Deng L, et al. Spatial variability of soil total nitrogen, phosphorus and potassium in Renshou County of Sichuan Basin, China. *J Integr Agric* 2019;18:279-89. DOI
28. Zhang S, Xia C, Li T, et al. Spatial variability of soil nitrogen in a hilly valley: multiscale patterns and affecting factors. *Sci Total Environ* 2016;563-564:10-8. DOI PubMed
29. Yao Y, Shao M, Fu X, Wang X, Wei X. Effect of grassland afforestation on soil N mineralization and its response to soil texture and slope position. *Agric Ecosyst Environ* 2019;276:64-72. DOI
30. Dessureault-rompré J, Zebarth BJ, Burton DL, et al. Relationships among mineralizable soil nitrogen, soil properties, and climatic indices. *Soil Sci Soc Am J* 2010;74:1218-27. DOI
31. Wilson DJ, Jefferies RL. Nitrogen mineralization, plant growth and goose herbivory in an arctic coastal ecosystem. *J Ecology* 1996;84:841. DOI
32. Rixen C, Freppaz M, Stoeckli V, Huovinen C, Huovinen K, Wipf S. Altered snow density and chemistry change soil nitrogen mineralization and plant growth. *Arct Antarct Alp Res* 2008;40:568-75. DOI
33. Wu Q, Zhang C, Liang X, Zhu C, Wang T, Zhang J. Elevated CO^2 improved soil nitrogen mineralization capacity of rice paddy. *Sci Total Environ* 2020;710:136438. DOI PubMed
34. Wang X, Cammeraat EL, Kalbitz K. Erosional effects on distribution and bioavailability of soil nitrogen fractions in Belgian Loess Belt. *Geoderma* 2020;365:114231. DOI
35. Ma F, Jia X, Zhou W, et al. Soil nitrogen mineralization in a wind-disturbed area on Changbai Mountain after 30 years of vegetation

restoration. *Acta Ecologica Sinica* 2017;37:265-71. DOI

36. Wang Q, Li F, Rong X, Fan Z. Plant-soil properties associated with nitrogen mineralization: effect of conversion of natural secondary forests to larch plantations in a headwater catchment in northeast China. *Forests* 2018;9:386. DOI
37. Fu Q, Yan J, Li H, et al. Effects of biochar amendment on nitrogen mineralization in black soil with different moisture contents under freeze-thaw cycles. *Geoderma* 2019;353:459-67. DOI
38. Zhao H, Zhang X, Xu S, Zhao X, Xie Z, Wang Q. Effect of freezing on soil nitrogen mineralization under different plant communities in a semi-arid area during a non-growing season. *Appl Soil Ecol* 2010;45:187-92. DOI
39. Owen JS, Wang MK, Sun HL, King HB, Wang CH, Chuang CF. Comparison of soil nitrogen mineralization and nitrification in a mixed grassland and forested ecosystem in central Taiwan. *Plant Soil* ;251:167-74. DOI
40. Hou R, Li T, Fu Q, et al. The effect on soil nitrogen mineralization resulting from biochar and straw regulation in seasonally frozen agricultural ecosystem. *J Clean Prod* 2020;255:120302. DOI
41. Tian Q, Wang X, Wang D, et al. Decoupled linkage between soil carbon and nitrogen mineralization among soil depths in a subtropical mixed forest. *Soil Boil Biochem* 2017;109:135-44. DOI
42. Benitez C, Bellido E, Gonzalez J, Medina M. Influence of pedological and climatic factors on nitrogen mineralization in soils treated with pig slurry compost. *Bioresour Technol* 1998;63:147-51. DOI
43. Jia J, Bai J, Gao H, et al. *In situ* soil net nitrogen mineralization in coastal salt marshes (Suaeda salsa) with different flooding periods in a Chinese estuary. *Ecol Indic* 2017;73:559-65. DOI
44. Hu P, Zhang W, Xiao L, et al. Moss-dominated biological soil crusts modulate soil nitrogen following vegetation restoration in a subtropical karst region. *Geoderma* 2019;352:70-9. DOI
45. Orwin KH, Buckland SM, Johnson D, et al. Linkages of plant traits to soil properties and the functioning of temperate grassland: links of plant traits to soil properties. *J Ecology* 2010;98:1074-83. DOI
46. Kooijman AM, Besse M. The higher availability of N and P in lime-poor than in lime-rich coastal dunes in the Netherlands. *J Ecology* 2002;90:394-403. DOI
47. Bauhus J. C and N mineralization in an acid forest soil along a gap-stand gradient. *Soil Boil Biochem* 1996;28:923-32. DOI
48. Norton JM, Firestone MK. N dynamics in the rhizosphere of Pinus ponderosa seedlings. *Soil Boil Biochem* 1996;28:351-62. DOI
49. Knops JM, Tilman D. Dynamics of soil nitrogen and carbon accumulation for 61 years after agricultural abandonment. *Ecology* 2000;81:88-98. DOI
50. Kim C, Sharik TL, Jurgensen MF. Canopy cover effects on soil nitrogen mineralization in northern red oak (Quercus rubra) stands in northern Lower Michigan. *For Ecol Manag* 1995;76:21-8. DOI
51. Satti P, Mazzarino MJ, Gobbi M, Funes F, Roselli L, Fernandez H. Soil N dynamics in relation to leaf litter quality and soil fertility in north-western Patagonian forests. *J Ecol* 2003;91:173-81. DOI
52. Compton JE, Boone RD. Long-term impacts of agriculture on soil carbon and nitrogen in New England forests. *Ecology* 2000;81:2314-30. DOI
53. Mazzarino MJ, Oliva L, Abril A, Acosta M. Factors affecting nitrogen dynamics in a semiarid woodland (Dry Chaco, Argentina). *Plant Soil* 1991;138:85-98. DOI
54. Ewel JJ. Species and rotation frequency influence soil nitrogen in simplified tropical plant communities. *Ecol Appl* 2006;16:490-502. DOI
55. De Boer W, Kester R. Variability of nitrification potentials in patches of undergrowth vegetation in primary Scots pine stands. *For Ecol Manag* 1996;86:97-103. DOI
56. Der Krift TAJ, Berendse F. The effect of plant species on soil nitrogen mineralization. *J Ecol* 2001;89:555-61. DOI PubMed PMC
57. Yao Y, Zhao Z, Wei X, Shao M. Effects of shrub species on soil nitrogen mineralization in the desert-loess transition zone. *CATENA* 2019;173:330-8. DOI
58. Barrios E, Buresh R, Sprent J. Nitrogen mineralization in density fractions of soil organic matter from maize and legume cropping systems. *Soil Biol Biochem* 1996;28:1459-65. DOI
59. Zhang S, Zheng Q, Noll L, Hu Y, Wanek W. Environmental effects on soil microbial nitrogen use efficiency are controlled by allocation of organic nitrogen to microbial growth and regulate gross N mineralization. *Soil Biol Biochem* 2019;135:304-15. DOI PubMed PMC
60. Reiners WA, Bouwman AF, Parsons WFJ, Keller M. Tropical rain forest conversion to pasture: changes in vegetation and soil properties. *Ecol Appl* 1994;4:363-77. DOI
61. Man J, Tang B, Xing W, Wang Y, Zhao X, Bai Y. Root litter diversity and functional identity regulate soil carbon and nitrogen cycling in a typical steppe. *Soil Biol Biochem* 2020;141:107688. DOI
62. Arslan H, Güleryüz G, Kırmızı S. Nitrogen mineralisation in the soil of indigenous oak and pine plantation forests in a Mediterranean environment. *Eur J Soil Biol* 2010;46:11-7. DOI
63. Yan E, Wang X, Huang J, Li G, Zhou W. Decline of soil nitrogen mineralization and nitrification during forest conversion of evergreen broad-leaved forest to plantations in the subtropical area of Eastern China. *Biogeochemistry* 2008;89:239-51. DOI
64. Frank DA, Groffman PM. Ungulate *vs.* landscape control of soil C and N processes in grasslands of Yellowstone National Park. *Ecology* 1998;79:2229-41. DOI
65. Ross D, Tate K, Feltham C. Microbial biomass, and C and N mineralization, in litter and mineral soil of adjacent montane ecosystems in a southern beech (Nothofagus) forest and a tussock grassland. *Soil Biol Biochem* 1996;28:1613-20. DOI

66. Johnson NC, Wedin DA. Soil carbon, nutrients, and mycorrhizae during conversion of dry tropical forest to grassland. *Ecol Appl* 1997;7:171-82. DOI
67. Fisk MC, Zak DR, Crow TR. Nitrogen storage and cycling in old - and second - growth northern hardwood forests. *Ecology* 2002;83:73-87. DOI
68. Song Q, Ouyang M, Yang Q, et al. Degradation of litter quality and decline of soil nitrogen mineralization after moso bamboo (Phyllostachys pubscens) expansion to neighboring broadleaved forest in subtropical China. *Plant Soil* 2016;404:113-24. DOI
69. López-Poma R, Pivello VR, de Brito GS, Bautista S. Impact of the conversion of Brazilian woodland savanna (cerradão) to pasture and *Eucalyptus* plantations on soil nitrogen mineralization. *Sci Total Environ* 2020;704:135397. DOI PubMed
70. Campos CA, Suárez MG, Laborde J. Analyzing vegetation cover-induced organic matter mineralization dynamics in sandy soils from tropical dry coastal ecosystems. *CATENA* 2020;185:104264. DOI
71. Zhao N, Li XG. Effects of aspect-vegetation complex on soil nitrogen mineralization and microbial activity on the Tibetan Plateau. *CATENA* 2017;155:1-9. DOI
72. Hartley SE, Mitchell RJ. Manipulation of nutrients and grazing levels on heather moorland: changes in Calluna dominance and consequences for community composition. *J Ecology* 2005;93:990-1004. DOI
73. Ma BL, Dwyer LM, Gregorich EG. Soil Nitrogen amendment effects on seasonal nitrogen mineralization and nitrogen cycling in maize production. *Agron J* 1999;91:1003-9. DOI
74. Wells E, Williams B. Effects of drainage, tilling and PK-fertilization on bulk density, total N, P, K, Ca and Fe and net N-mineralization in two peatland forestry sites in Newfoundland, Canada. *For Ecol Manag* 1996;84:97-108. DOI
75. Kingery W, Wood C, Williams J. Tillage and amendment effects on soil carbon and nitrogen mineralization and phosphorus release. *Soil Tillage Res* 1996;37:239-50. DOI
76. Vazquez E, Benito M, Espejo R, Teutscherova N. Effects of no-tillage and liming amendment combination on soil carbon and nitrogen mineralization. *Eur J Soil Biol* 2019;93:103090. DOI
77. Christodoulou E, Agapiou A, Anastopoulos I, Omirou M, Ioannides IM. The effects of different soil nutrient management schemes in nitrogen cycling. *J Environ Manage* 2019;243:168-76. DOI PubMed
78. Haslam SFI, Hopkins DW. Physical and biological effects of kelp (seaweed) added to soil. *Appl Soil Ecol* 1996;3:257-261. DOI
79. Miranda R, Lascano M, Caballero A, Bosque H. Influencia de la dosis de estiércol ovino y bioinsumo en la mineralización del nitrógeno (in Spanish); 2014, p. 92-8. Available from: http://www.scielo.org.bo/pdf/riiarn/v1n1/v1n1_a12.pdf [Last accessed on 7 Apr 2023].
80. Alburquerque JA, de la Fuente C, Bernal MP. Chemical properties of anaerobic digestates affecting C and N dynamics in amended soils. *Agric Ecosyst Environ* 2012;160:15-22. DOI
81. Raiesi F. Carbon and N mineralization as affected by soil cultivation and crop residue in a calcareous wetland ecosystem in Central Iran. *Agric Ecosyst Environ* 2006;112:13-20. DOI
82. Li X, Yang H, Shi W, Li Y, Guo Q. Afforestation with xerophytic shrubs accelerates soil net nitrogen nitrification and mineralization in the Tengger Desert, Northern China. *CATENA* 2018;169:11-20. DOI
83. Weston CJ, Attiwill PM. Clearfelling and burning effects on nitrogen mineralization and leaching in soils of old-age *Eucalyptus* regnans forests. *For Ecol Manag* 1996;89:13-24. DOI
84. Shariff AR, Biondini ME, Grygiel CE. Grazing intensity effects on litter decomposition and soil nitrogen mineralization. *J Range Manage* 1994;47:444. DOI
85. Biondini ME, Patton BD, Nyren PE. Grazing intensity and ecosystem processes in a northern mixed□grass prairie, USA. *Ecol Appl* 1998;8:469-79. DOI
86. Sirotnak JM, Huntly NJ. Direct and indirect effects of herbivores on nitrogen dynamics: voles in riparian areas. *Ecology* 2000;81:78-87. DOI
87. Wang S, He X, Ye S. Soil aggregation and aggregate-associated carbon, nitrogen, and phosphorus under different aged tea (Camellia sinensis L.) plantations in hilly region of southern Guangxi, China. *Scientia Horticulturae* 2020;262:109007. DOI
88. Aka Sagliker H, Cenkseven S, Kizildag N, et al. Is parent material an important factor in soil carbon and nitrogen mineralization? *Eur J Soil Biol* 2018;89:45-50. DOI
89. Pengthamkeerati P, Motavalli P, Kremer R, Anderson S. Soil compaction and poultry litter effects on factors affecting nitrogen availability in a claypan soil. *Soil Tillage Res* 2006;91:109-19. DOI
90. Breland TA, Hansen S. Nitrogen mineralization and microbial biomass as affected by soil compaction. *Soil Biol Biochem* 1996;28:655-63. DOI
91. Ros GH, Hanegraaf MC, Hoffland E, van Riemsdijk WH. Predicting soil N mineralization: relevance of organic matter fractions and soil properties. *Soil Biol Biochem* 2011;43:1714-22. DOI
92. Dridi I, Gueddari M. Field and laboratory study of nitrogen mineralization dynamics in four Tunisian soils. *J Afr Earth Sci* 2019;154:101-10. DOI
93. Franzluebbers K, Weaver R, Juo A, Franzluebbers A. Carbon and nitrogen mineralization from cowpea plants part decomposing in moist and in repeatedly dried and wetted soil. *Soil Biol Biochem* 1994;26:1379-87. DOI
94. Lu T, Wang Y, Zhu H, Wei X, Shao M. Drying-wetting cycles consistently increase net nitrogen mineralization in 25 agricultural soils across intensity and number of drying-wetting cycles. *Sci Total Environ* 2020;710:135574. DOI PubMed
95. Zhang Q. Effects of soil extracts from repeated plantation woodland of Chinese-fir on microbial activities and soil nitrogen

mineralization dynamics. *Plant Soil* 1997;191:205-12. DOI

96. Neve S, Hofman G. Modelling N mineralization of vegetable crop residues during laboratory incubations. *Soil Biol Biochem* 1996;28:1451-7. DOI
97. Li H, Han Y, Cai Z. Nitrogen mineralization in paddy soils of the Taihu Region of China under anaerobic conditions: dynamics and model fitting. *Geoderma* 2003;115:161-175. DOI
98. Yang X, Li G, Jia X, Zhao X, Lin Q. Net nitrogen mineralization delay due to microbial regulation following the addition of granular organic fertilizer. *Geoderma* 2020;359:113994. DOI
99. Smith J, Halvorson J, Boltonjr H. Spatial relationships of soil microbial biomass and C and N mineralization in a semi-arid shrub-steppe ecosystem. *Soil Biol Biochem* 1994;26:1151-9. DOI