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Management Zone-specific N Mineralization Rate Estimation in Unamended Soil

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Abstract.

An ideal and efficient N recommendation for precision fertilization should account for potential soil mineralizable N. This study aimed at estimating management zone (MZ) specific soil N mineralization rate (SNMR) of unamended soils. A total of 76 soil samples were collected from previously delineated 21 MZs distributed across 5 arable fields in Flanders, Belgium. An aerobic laboratory incubation was conducted under controlled conditions (bulk density of 1.4 g cm^{-3}, moisture content at 50% water-filled pore space, and average temperature of 22.2ºC) for a period of two months with seven sampling events. N mineralization was assessed as the net increase in soil mineral N (NH_4^+ + NO_3^-), as a function of time. Results indicated a considerable in-field variation in soil texture with the ranges of sand (4.70–58.30%), silt (27.90–83.40%) and clay content (9.06–20.50%), and total soil mineralized N (9.12–41.93 mg kg^{-1} soil) across the fields. The highest and lowest net SNMR was calculated as 0.50 and 0.0004 mg kg^{-1} soil day^{-1}, respectively. Among MZs, differences in SNMRs were significant in three fields, while remaining MZs in remaining two fields showed insignificant differences at 90% confidence interval. In turn, total 3 of 34 MZ-pairs differed significantly (padj.: 0.023 – 0.092) from one each other. The significant differences were observed in MZ pairs having high variation in particle sizes. The SNMRs frequently showed positive correlation with pH (0.20–1.00), total N (0.12–0.99), soil mineral N (0.11–1.00) and sand (0.34–0.99), whereas negative correlations were observed for silt (-0.99 to -0.17) and clay (-1.00 to -0.11) content. In conclusion, though not many MZ showed statistically significant differences in SNMR per field despite mathematical differences, still MZ-specific SNMR determination seems to be a way to forward optimizing the existing N recommendation by incorporating SNMR in the management decision. Along with other management actions, the MZ-specific SNMR determination should facilitate designing an efficient and environment friendly precision fertilization scheme.

Keywords.
Laboratory incubation; Soil nitrogen mineralization; Management zone; Precision fertilization; Soil spatial variabilities; Soil-water environment.

Introduction

Soil nitrogen (N) mineralization is a vital part of soil fertility and is crucial need for supplying directly available N for the crops through some microbial conversion of N containing soil organic matter (Harmsen and van Schreven 1955; Risch et al. 2019). However, if soil N mineralization is not considered properly in precision fertilization (PF), the produced soil mineral N (SMN) may exceed the N requirement by crops and potentially leading to N losses either by NO_3^- leaching losses or gaseous losses by denitrification. Recently a number of N recommendation system explicitly considers soil N mineralization rate (SNMR) from native soil as one of the main determinants of N fertilizer recommendations. Such N recommendations are typically given for an entire field based on one composite soil sample. However, the SNMR is expected to exhibit very large spatial and temporal variability as it is influenced by the combination of soil properties [soil pH, soil organic carbon (SOC), soil organic nitrogen (SON), soil texture and mineralogy] and highly dynamic environmental factors [moisture content (MC) and temperature] (Baitilwake et al. 2012; S. de Neve et al. 2003) that are also highly variable in time and space.

Attempts to search for the solutions, PF technology have explored this soil spatial variability to optimize N application rates, maximize yields and save the environment (Adamchuk et al. 2004). PF is capable of accounting for in-field soil and crop heterogeneities and accordingly design fertilizer rates that is assumed to be optimal for a particular zone of a field. Such a zone in the field is often known as management zone (MZ) that supposed to have a homogeneous soil fertility status (Vrindts et al. 2005). The MZ is frequently delineated based on several soil and crop attributes such as soil pH, MC, SOC, SOM, extractable N and P, soil NO_3^--N, cation exchange capacity (CEC), apparent soil electrical conductivity (ECa), texture, bulk density, porosity, crop normalized difference vegetation index (NDVI), yield records, aerial photography, farmer’s knowledge, topography and soil management practices (Hornung et al. 2006; Khosla et al. 2008; Koch et al. 2004; Munnaf et al. 2020; Nawar and Mouazen 2017). Recently Nawar et al., (2017) proposed and evaluated an innovative MZ delineation approach relaying on on-line sensing of soil pH, MC, total N (TN), SOC, P, potassium (K), calcium (Ca), magnesium (Mg), CEC crop NDVI and yield records for variable-rate N management. Most recently, this innovative MZ approach has been evaluated both for site-specific N fertilizer and manure applications (Guerrero et al. 2021a; Zhang et al. 2021). Each MZ was allocated a N fertilization rate according to the fertility status of MZ class. However, till date, there are no reports on the estimation on MZ-based variability of SNMR, and this variability is not considered when formulating N fertilizer advice in a PF context. That is how the existing MZ delineation still carries a high risk of recommending improper N doses resulting in an economic loss in production systems as well as putting the soil and water environment is under pressure.

Therefore, the main objective of this study was to estimate the MZ-specific soil N mineralization rate using unamended fresh soil. It is hypothesized that given the in-field variability of soil properties determining N mineralization, also the process of N mineralization would exhibit such spatial variability, and that accounting for this variability in site-specific management would hold great potential to increase fertilizer N use efficiency, given the crucial role of N mineralization in the N provisioning of crops. To this end (i) MZ-specific SNMR during incubations in the laboratory was measured, and (ii) the covariation of SNMR with TN, SMN, pH, and texture was evaluated. It is hypothesized that since variation of SNMR within MZs would be smaller than the variation between different MZs, coinciding with the variation of soil physical and chemical properties per MZ class, such MZ-specific SNMR would hold potential to improve the accuracy of N fertilizer recommendations in PF context.

Materials and methods

Study area and soil sampling

Total 5 agricultural fields located in the west Flanders region, Belgium (Table 1) were selected for this study covering multiple soil types, crops, and management strategies. All those fields were previously used for PF (variable rate) applications based on delineated MZ maps (Guerrero et al. 2021a; Zhang et al. 2021) except for Kroky field. Briefly, the MZ mapping was carried out by the fusion of soil pH, SOC, P, K, Mg, Ca, Na, and MC measured with an on-line visible and near-infrared (vis-NIR) reflectance spectroscopy sensor (Mouazen 2006), NDVI retrieved from Sentinel 2 images, and previous yield records collected from yield monitoring system of combine harvesters. The integration of the above-mentioned soil and crop properties was done by means of a k-means cluster analysis, following a raster analysis to align the different layers of data at 5m by 5m cell size.

Table 1: General information on the five study fields

Sl no	Fields	Co-ordinates	Area ha	No. of MZs	Total samples	Precision Fertilization	Previous crop	Soil type	MZ reference
1	Dal	(50°44'59.5"N 5°05'45.8"E)	6	4	13	NPK	Wheat	Luvisols	(Munnaf et al. 2020)
2	Gingelomse	(50°45'07.8"N 5°05'58.8"E)	11	4	14	N	Wheat	Luvisols	(Munnaf et al. 2021)
3	Grootland	(50°47'15.8"N 5°06'53.7"E)	-	4	15	N	Wheat	Luvisols	(Guerrero et al. 2021b)
4	Kroky	(51°00'02.1"N 2°32'46.7"E)	13	5	20	NPK	Oil seed rape	Cambisols	na
5	Fabrieke	(51°01'53.7"N 2°34'19.9"E)	8	4	14	N	Wheat	Cambisols	(Zhang et al. 2021)

MZ, management zone; *N*, nitrogen; *P*, phosphorous; *K*, potassium. The soil type was extracted from the WRB classification based on the Belgian soil map (Dondeyne et al. 2014).

A total of 76 top soil samples (0–0.20 m) were collected using a hand auger of 50 mm in diameter. Each sample is a composite of 5 subsamples collected from the tips of a 'W' shape sampling pattern of 10x10m square.

Laboratory incubation

An aerobic laboratory incubation experiment was conducted following the method reported earlier (Stefaan de Neve et al. 2004; Stefaan de Neve and Hofman 2000). All types of visible fragments like roots, small stones, organic debris, and visible organisms were manually removed by hand sorting, and soil was thoroughly mixed in a glass jar. Seven replicates of each composite soil sample (271.86 g of fresh soil, which is equivalent to 232.67 g of dry soil) were inserted in polyvinyl chloride (PVC) tubes of 0.18 m height and 0.046 m inner diameter, and the soil was gently compacted to obtain a bulk density of 1.4 Mg m^{-3}. The initial soil MC of all soil samples was measured by oven drying for 24 h at 105 ℃. After the soil was brought to the desired bulk density, distilled water was then added to bring the soils to the desired water content i.e., 50% of water-filled pore space (WFPS). The tubes were covered with gas-permeable para-film to minimize water loss but still allow gas exchange. Soil filled-tubes were incubated for 56–60 days. Temperature was monitored at 4 h intervals with a digital temperature data logger (RS RPO, RS-172, Belgium). The maximum, minimum and average temperature over the whole incubation period was recorded as 28.95 ºC, 20.55 ºC and 22.21 ºC, respectively. Water content was monitored regularly during the incubation by weighing the tubes and distilled water was slowly added, when needed, to keep the MC at the desired level. Soil samples were taken destructively at the 3rd, 5th, 7th, 14th, 28th, and 56th days of incubation for the fields of Dal, Gingelomse and Grootland, and at fixed 10 days intervals for Kroky and Fabrieke fields up to 60 days. At sampling, the soil was removed from the tubes, mixed thoroughly, and a 20 g sub-sample was shaken with 1 M KCl (extraction ratio = 1:5) for 1 hr on a rotational shaker. Then the soil slurries were filtered with Whatman 589/3 filter paper, and NH_4^+-N and NO_3^--N were measured colorimetrically using a 'continuous flow auto-analyzer' (Chemlab System 4, Skalar, the Netherlands). The initial concentrations of NH_4^+-N and NO_3^--N (before the start of the incubations) were also measured.

Basic soil properties

Soil pH-KCl was measured by using pH electrometric method with air-dried, grinded and sieved soil samples with 2 mm strainer. About 100 g air-dried and sieved soil per sample was delivered to Soil Service of Belgium (Haverlee, Belgium) to analyze soil texture fractions i.e., sand (>0.05

mm), silt (0.002–0.05 mm) and clay (<0.002 mm), which were then used for textural classification according to the United State Department of Agriculture (USDA) criteria. In addition, soil TN content was analyzed with a Variomax CNS- analyzer (Elementar Analysensysteme, Germany).

Soil N mineralization rate and statistical analysis

A zero-order kinetics model was fitted to the data of N mineralization (evolution of mineral N as a function of time):

$$N_t = N_0 + k_0 t \tag{1}$$

Where, t = time (in days), N_t = amount of mineralized N at time, N_0 = initial amount of mineral N (mg N kg^{-1} soil), k_0 = zero-order N mineralization rate in mg N kg^{-1} soil day^{-1}

SNMR was calculated both for each of the sampling points separately, and for the average of the sampling points per MZ.

Soil pH, SMN, and texture were explored using descriptive statistics. One-way analysis of variance (ANOVA) coupled with Duncan's PostHoc test compared the mean SNMR across MZ classes per field. Besides, the association of SNMR with soil pH, TN, SMN, and percent sand, silt and clay contents was evaluated by analyzing the Pearson pairwise correlation matrix. To further analyze their relationships with SNMR, a multiple linear regression (MLR) was established. An on-way multivariate analysis of variance (MANOVA) was conducted over soil pH, TN, SMN, sand, silt, and clay to investigate the much influences of MZ exists on those basic soil properties. Moreover, a linear discriminant analysis (LDA) has been conducted on soil pH, TN, SMN, sand, silt and clay content to explore differences between MZ classes.

Results

Descriptive statistics of soil properties

Soil properties exhibited a small to moderate variability across the studied fields with coefficients of variation decreasing from sand content to SMN, clay, silt, TN and pH. For example, there was less variation in clay percentages: it ranged between 10-18% for Dal, Gingelomse, Grootland and Kroky fields. Fabrieke soil contained comparatively higher amount of clay content (mean = 16.26%), compared to all other four fields (mean = 10.47 to 13.13%). The range of mean textural fractions across the fields indicated a minimum sand content of 6.37%, a maximum silt content of 80.58% and 13.05% clay in Grootland. The Kroky field confined the moderate silt content (46.61%), the highest sand proportion and in turn the lowest clay percentage. Fabrieke attained the smallest proportion of silt (45.52%) and the highest percentage of clay content with a CV of 0.24. However, Grootland field has the highest and lowest variation of clay and silt content, respectively, while Gingelomse has the largest and smallest variation of silt and clay content respectively. The considerable variation in both basic soil properties and in SNMR supports our hypothesis that investigating SNMR for different MZ may be very important in optimizing N management.

Comparing within field MZ-based textural variation, one can observe a relatively higher variation in Gingelomse and Kroky than that observed for Fabrieke, Grootland and Dal. Perhaps the smallest texture variability is the one of the Grootland field. Larger variations in sand and silt contents were observed for all MZs and fields, excepts for Grootland. Grootland has larger difference in clay proportions, although Fabrieke field has higher clay percentages comparative to other fields (Fig 1). However, variation in the texture of all fields is rather limited to those of sandy loam, loam, silt loam and silt soil textures.

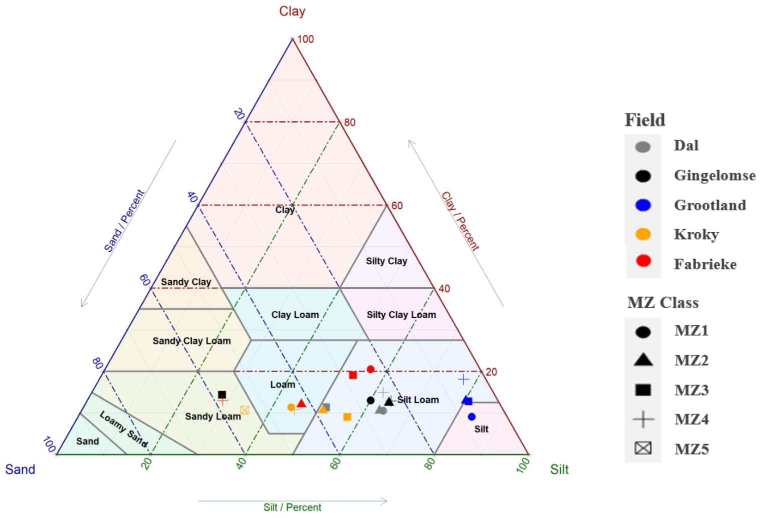


Fig 1. Management zone (MZ)- and field-specific soil texture, according to the United States department of agriculture texture classes.

Variations in soil N mineralization rate

The SNMR varied over the MZs within- and across the fields (Table 2; detailed in Appendix-A). Individual sample in Dal results in MZ1 and MZ3 showed slow mineralization trend, whereas most of the samples in MZ2 and MZ4 revealed comparatively fast mineralization. As a result, the highest average SNMR per MZ was observed in MZ2 sequentially followed by MZ1, MZ4 and MZ3. The MZ3 and MZ4 in Gingelomse had close to zero SNMR for 2 out of 3 and 2 out of 4 samples, while the MZ1 and MZ2 overall had low to moderate SNMR. As a result, MZ2 had the highest SNMR followed by MZ1, MZ4 and MZ3 in a descending order. In Grootland field, the MZ1 and MZ3 had a high SNMR, whereas most samples in MZ2 and MZ4 had comparatively low SNMR. In Kroky, the highest average SNMR was in MZ1 and MZ4 followed by MZ3, MZ5 and MZ2. In Fabrieke, the highest SNMR was estimated in MZ1 and other three MZs showed equal SNMR while their ranges varied slightly. In general, a mixed behavior in N mineralization trend was also observed in Fabrieke, where half of samples showed considerable net mineralization, and another half gave very low or no N mineralization at all.

Table 2. Summary statistics of soil nitrogen mineralization rate (SNMR) across fields and management zones (MZs)

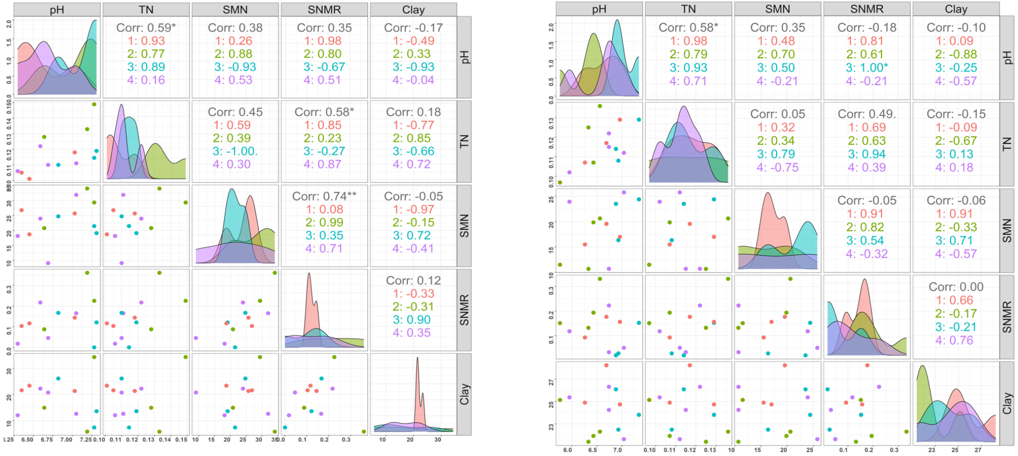
Fields	MZs	Statistics of SMNR [mg kg^{-1} soil day^{-1}]				
		Min	Max	Mean	SD	CV
Dal		0.0004	0.36	0.14	0.09	0.68
	MZ1	0.10	0.14	0.12	0.02	0.14
	MZ2	0.09	0.36	0.22	0.11	0.50
	MZ3	0.0004	0.17	0.10	0.07	0.73
	MZ4	0.02	0.22	0.11	0.08	0.74
Gingelomse		0.02	0.33	0.13	0.08	0.63
	MZ1	0.09	0.18	0.14	0.04	0.25
	MZ2	0.13	0.33	0.20	0.08	0.39
	MZ3	0.02	0.15	0.07	0.06	0.91
	MZ4	0.03	0.22	0.11	0.07	0.71
Grootland		0.08	0.50	0.26	0.13	0.48
	MZ1	0.23	0.50	0.36	0.11	0.30
	MZ2	0.09	0.32	0.24	0.10	0.44
	MZ3	0.16	0.43	0.28	0.11	0.40
	MZ4	0.08	0.24	0.15	0.06	0.37
Kroky		0.07	0.42	0.22	0.09	0.40
	MZ1	0.21	0.32	0.26	0.04	0.16
	MZ2	0.07	0.18	0.13	0.04	0.34
	MZ3	0.19	0.37	0.24	0.06	0.27
	MZ4	0.14	0.34	0.26	0.09	0.34
	MZ5	0.09	0.42	0.20	0.13	0.63
Fabrieke		0.04	0.15	0.11	0.03	0.32
	MZ1	0.09	0.15	0.12	0.02	0.17
	MZ2	0.05	0.13	0.10	0.04	0.35
	MZ3	0.04	0.15	0.10	0.05	0.47
	MZ4	0.07	0.12	0.10	0.02	0.22

SD, standard deviation; *CV*, coefficient of variance, *Min*; minimum; *Max*; maximum.

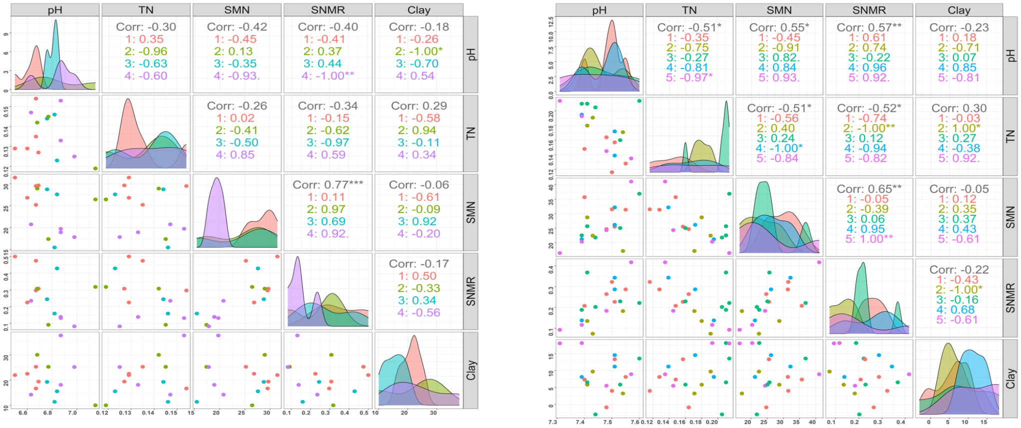
ANOVA along with Duncan's PostHoc test for mean comparison of SNMR per MZ class did not show statistically significant differences of SNMR among the MZs in Dal, Gingelomse and Kroky fields despite the differences mentioned above (Table 2; Appendix-B). Only one MZ pair in Grootland (MZ1 and MZ4) showed significant difference (padj. = 0.023) at 90% significance level. Other MZ pairs across fields did not show significant differences but near to significantly different SNMRs were observed between MZ2 and MZ3 in Gingelomse (padj. = 0.061) and MZ1 and MZ2 in Kroky (padj. = 0.092).

Correlation of SNMR with pH, TN, SMN and clay content

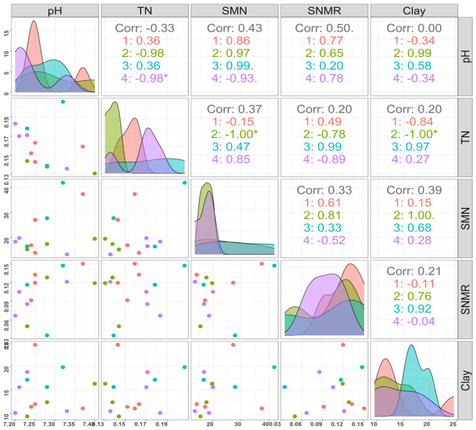
Fig 2 illustrates the Pearson's correlation among the basic soil properties including SNMR both at the field- and MZ scale (upper part), together with respective density distribution (diagonal) and scatter plots (lower part).



Dal Gingelomse



Grootland Kroky



Fabrieke

Fig 2. Field and management zone (MZ) wise correlation matrix of soil nitrogen mineralization rate (SNMR) with soil pH, total nitrogen (TN), soil mineral nitrogen (SMN), and clay for five fields.

At field scale, the SNMR showed positive correlation with soil pH in Dal, Kroky and Fabrieke fields, while the correlations were negative in Gingelomse and Grootland. The SMN were significantly positively correlated with SNMRs for all fields except for Gingelomse. The TN and SNMR were moderately positively correlated in Dal and Gingelomse and poorly in Fabrieke, whereas they were negatively correlated in Kroky and Grootland. SNMR was negatively and positively but poorly correlated with clay content in all fields except for Gingelomse, where no correlation was found. At MZ scale, there was a poor to strong positive correlation (0.20–1.00) between soil pH and SNMR in 16 out of 21 MZs, and a poor to strong negative correlation (-1.00 to -0.21) in the other 5 MZs. The SMN in the 15 MZs revealed strong to weak positive correlation (0.11–1.00) with SNMRs, when 3 MZs had weak but negative correlation (-0.52 to -0.32), and 3 MZs showed no correlation (-0.05 to 0.08). Besides, total of 11 MZs had poor to strong positive correlation between TN and SNMRs (0.12–0.99), whereas 10 MZs observed a strong to poor negative relation (-1.0 to -0.15). SNMR was poorly to strongly negatively correlated (-1.00 to -0.11) to clay content in 11 MZs, whereas in 9 MZs SNMR was poorly to strongly positively correlated (0.34 to 0.92) to clay content, and it was not correlated to clay content in 1 MZs (-0.04). In further exploration the degree of association of SNMR with all the basic soil properties, an MLR showed moderate correlation with an R2 = 0.63 (p=0.04; degree of freedom=13), while the regression coefficients of TN (p=0.0031) and interaction between TN and sand (p=0.0035) showed significant contributions.

Discussion

It is obvious that the overall SMN was small in most fields. This could be well explained by the nature of the current incubation experiment that used the fresh soil samples where no organic amendment was added. Moreover, crop residues as well as all other visible living organisms (i.e., earth worm) were removed, because the intension was to simulate a very natural incubation that should not be biased by other influencing agents, and to confirm a fair comparison among the fields. Earlier studies indeed reported that the addition of organic amendment significantly enhanced the potential soil N mineralization (González-Prieto et al. 1992).

The causal and driving forces of SNMR can further be supported by the Pearson's correlation, although the correlations indicated a mixed nature and hence difficult to explain the influences of individual soil properties on SNMR. In broad sense, pH and TN frequently showed positive correlations (Fig 2), that were in good agreement with the earlier studies. Sahrawat (1982) reported from a 4 weeks-period of incubation study that soils with pH lower than 5.0 did not nitrify in aerobic incubation, soil with pH of 5.6 produced NO_3^--N of 5 mg kg^{-1} soil, and a rapid release of NO_3^--N (98–123 mg kg^{-1} soil) occurred in the soil with a pH higher than 6.0. Their findings were explained by the strong positive correlation between NO_3^--N and soil pH (r = 0.86).

Similar to the current finding, some previous studies (Jegajeevagan et al. 2013; Miller et al. 2019; Wade et al. 2016) reported good positive correlations between TN and SNMR (r = 0.65, 0.59 and 0.57 respectively). Soil TN is a good predictor of N mineralization (Dessureault-Rompré et al. 2015). However, a couple of studies found weak positive correlation of SNMR with TN. For instance, Wade et al. (2016) found that the Pearson correlation coefficient between TN and mineralized N from a laboratory incubation conducted for different lengths of time did not exceed 0.57.

Current findings about positive relation of SNMR with sand in MLR could be supported by the results of several previous studies (Anderson et al. 1981). For an example, Ros et al. (2011) reported a faster N mineralization in sandy soil (0.61 mg kg^{-1} soil day^{-1}) comparative to clay soil (0.26 mg kg^{-1} soil day^{-1}). The positive correlation between sand and SNMR suggested that the coarse fraction of soil contained less N resistant to microbial attack and the better aeration also might favor microbial activities and hence the N mineralization (González-Prieto et al. 1992). N mineralization was often found to be negatively correlated with clay and silt content because of high degree of stabilization, large capacity to bind organic matter with mineral particles and biomass preservation (Côté et al. 2000; Hassink 1997). Fabrieke soil contained comparatively higher amount of clay than the other four fields, that could be the possible reason for the significantly lower SNMR for Fabrieke among the other fields. The MZ basis SNMR analysis from Grootland soil also revealed the inverse correlation with MZ basis clay particle analysis for this specific field. The sequence of clay percentage in descending order (MZ4<MZ2<MZ3<MZ1) justified the sequence of SNMRs analysis in ascending order (MZ1<MZ3<MZ2<MZ4), which is exactly similar but inverse. Although, clay content inversely drives N mineralization process, the opposite evidences were also documented i.e., high SNMRs in high clayey soil (Braos et al., 2020). Jegajeevagan et al. (2013) reported positive correlation between SNMR and silt plus clay content.

While field wise statistical results indicated no significant variation of SNMR among the MZ classes in Dal and Fabrieke, but in Grootland, variations in Gingelomse and Kroky were of significant difference (at 90% significant level) in a few MZ pairs. A significantly higher net SNMR was measured in the Grootland soil for MZ1 (0.5 mg kg^{-1} soil day^{-1}), compared with the MZ4 (0.08 mg kg^{-1} soil day^{-1}) with a p-value of 0.023. The bigger differences in Grootland's SNMR range than other fields resulted in a significantly different SNMR for these specific zones. Such a significant variation between MZ1 and MZ4 most probably ascribed to their difference in clay content. Similar justification is also applied for the significant difference between MZ1 and MZ2 in Kroky field while the significant difference between MZ2 and MZ3 in Gingelomse could be attributed to their large difference in silt content.

The MANOVA results of basic soil properties (excluding SNMR) showed insignificant differences (p = 0.193 to 0.731) among the MZs in each field despite indicating large influences of MZs on all basic properties (ET2 = 0.30 to 0.52). Nevertheless, linear discriminators could not differentiate many MZs but 4 MZs in Gingelomse and one MZ (e.g., MZ2) in Dal from its other MZs (Fig 3). This finding iterates the necessity of SNMR inclusion in MZ delineation since soil pH, TN, SNM, sand, silt and clay content jointly could not differentiate MZ significantly (as per MANOVA) while SNMR alone can differentiate 3 of 34 MZ pairs significantly (as per ANOVA).

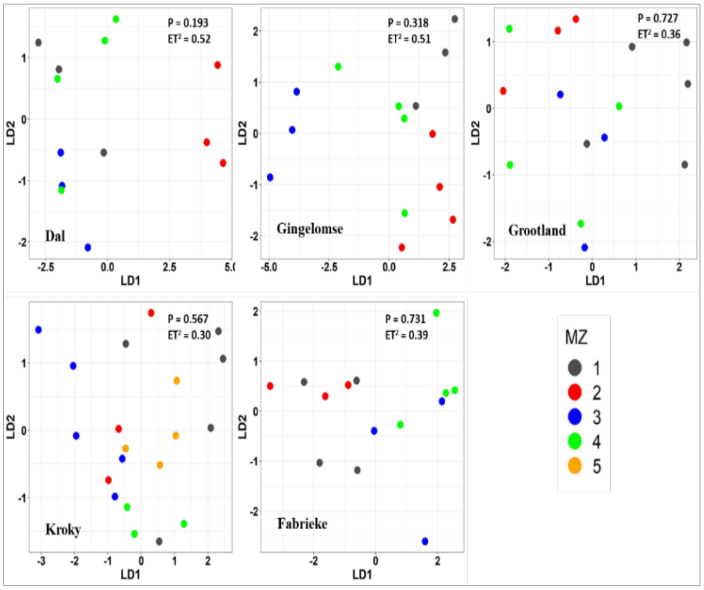


Fig 3. Linear discriminant analysis of management zones (MZs) based of soil pH, total nitrogen (TN), soil mineral nitrogen (SMN), and clay content. ET^2, a measure of effect size, LD, linear discriminator.

Based on the above discussion, it can be assumed that the MZ delineation including soil clay content could be able to represent an indirect influence of soil N mineralization. However, clay inclusion should not replace the SNMR inclusion in MZ delineation as the SNMR varies due to the many other factors related to soil as well as environmental conditions. On the other side, N recommendation based on SMN and/or TN estimated immediately before starting a cropping season can also carry a risk of N leaching and/or accumulation in the soil for over or under application. Therefore, considering clay or/and TN as the only proxy in MZ delineation may not be an ideal decision, while an integration of SNMR with sand, clay, pH, TN, MC, and SOM seems to be the promising MZ proxies. By this means, PF can enhance N use efficiency in one side and save or minimize potential environmental pollution in the other side.

Conclusion

The laboratory-based incubation experiment was conducted to estimate the SNMR per MZ in five agricultural fields located in west Flanders region, Belgium. Small to moderate variations in soil pH, TN, clay, sand, and silt content mainly drove the soil mineralization in unamended soil. Their roles in SNMR were supported by the correlation results i.e., clay and silt content frequently obtained negative correlations while pH, TN, and sand content showed positive correlations with SNMR. Therefore, SNMR varied across the fields ranging over 0.0004 to 0.5 mg kg^{-1} soil day^{-1}. Not all but in 3 of 34 MZ pairs, the SNMR varied significantly one from another at 90% confidence intervals, despite mathematical differences of SNMR among all MZs. Insignificant instances might be attributed to the potential errors in experimental set-up to some extent, but most importantly the degree of MZ delineation accuracy as well as the number of MZ classes selected per field. The MZ delineation did not include soil particles content, whereas the clay content obtained strong but negative correlation with SNMR. That is why the significantly different SNMR was observed in the fields those observed the highest clay and sand proportions. Besides, not much difference in soil texture was observed among MZ classes per field suggesting (sandy loam, loam, silt loam and silt) that a low number of actual MZ presents in the studied fields.

To sum up, there were not much significant differences in SNMRs between the MZ classes, and this is particularly true for the low clay content fields. However, this should not neglect the importance of SNMR estimation per MZ for an environment friendly N advice for PF application. Although, the current SNMR may not be used directly as a measure of potential mineral N in the real field conditions, but a proxy indicator of in-soil mineral N. Worth noting that, the soil properties and environmental conditions vary across the fields from MZ to MZ, and cannot be controlled in the actual field conditions, which would affect the amounts of N mineralized at a particular MZ. Hence, a proper care should be considered to design the PF schedule with incorporation of SNMR to reserve the economic values and protect the soil-water environment.

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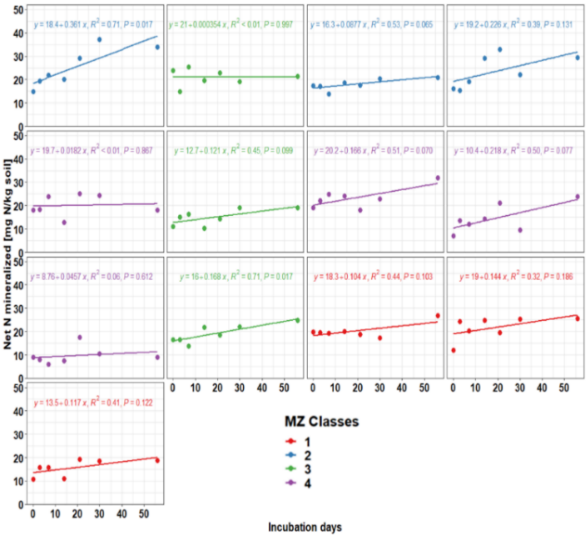
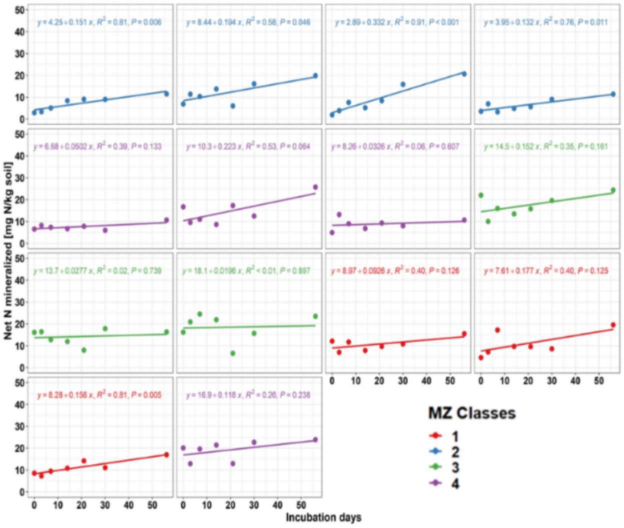
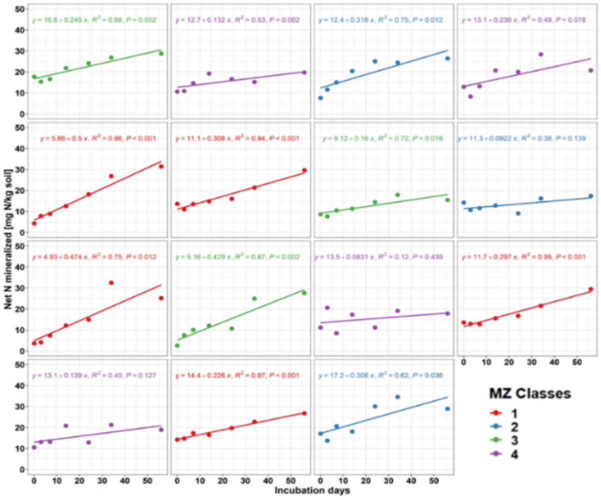
Appendix-A



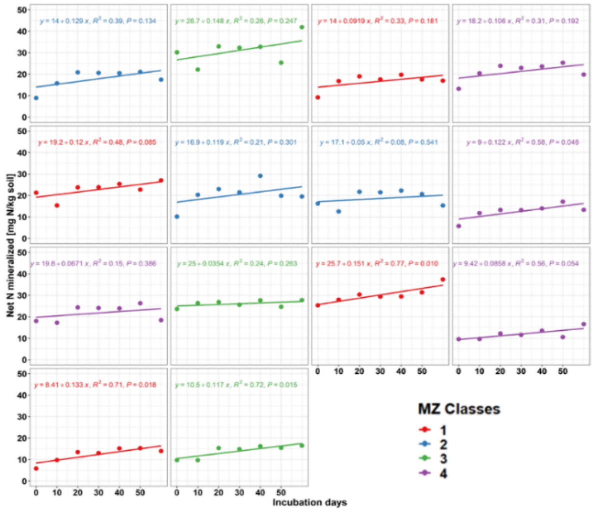
(a) Dal Field



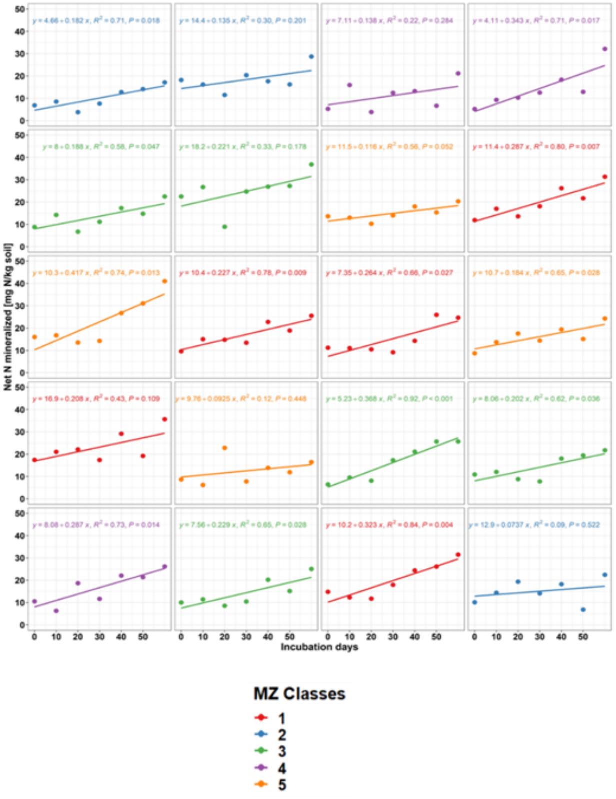
(b) Gingelomse Field



(c) Grootland Field



(d) Fabrieke Field



(e) Kroky Field

Fig 4. Soil N mineralization data across the fields

Appendix-B

Table 3. Analysis of variance soil N mineralization rate across management zones.

Fields	**ANOVA**						**Duncan’s PostHoc Test**			
	Sources	DF	SS	MS	F_{value}	p_{value}	Source	MD	CI	$p_{adj.}$
Dal	MZ	3	0.031	0.010	1.173	0.373	MZ 3-2	-0.129	-0.315 to 0.058	0.153
	Residuals	9	0.080	0.009			MZ 4-2	-0.113	-0.284 to 0.057	0.168
							MZ 1-2	-0.103	-0.278 to 0.071	0.213
							MZ 4-3	0.015	-0.148 to 0.179	0.835
							MZ 1-3	0.025	-0.157 to 0.207	0.762
							MZ 1-4	0.009	-0.154 to 0.173	0.895
Gingelomse	MZ	3	0.036	0.012	1.923	0.190	MZ 4-2	-0.096	-0.226 to 0.033	0.129
	Residuals	10	0.062	0.006			**MZ 3-2**	**-0.136**	**-0.279 to 0.008**	**0.061**
							MZ 1-2	-0.060	-0.194 to 0.073	0.339
							MZ 3-4	-0.039	-0.173 to 0.094	0.526
							MZ 1-4	0.036	-0.098 to 0.169	0.562
							MZ 1-3	0.075	-0.074 to 0.225	0.288
Grootland	MZ	3	0.104	0.034	2.713	0.096	MZ 4-3	-0.130	-0.329 to 0.068	0.177
	Residuals	11	0.140	0.013			MZ 2-3	-0.038	-0.241 to 0.165	0.686
							MZ 1-3	0.083	-0.098 to 0.264	0.335
							MZ 2-4	0.092	-0.098 to 0.281	0.308
							MZ 1-4	**0.213**	**0.035 to 0.392**	**0.023**
							MZ 1-2	0.121	-0.068 to 0.311	0.188
Krokey	MZ	4	0.039	0.009	1.211	0.347	MZ 4-2	0.126	-0.045 to 0.296	0.139
	Residuals	15	0.124	0.008			MZ 3-2	0.112	-0.037 to 0.259	0.131
							MZ 5-2	0.072	-0.076 to 0.219	0.316
							MZ 1-2	**0.131**	**-0.024 to 0.287**	**0.092**
							MZ 3-4	-0.014	-0.156 to 0.127	0.835
							MZ 5-4	-0.054	-0.209 to 0.101	0.476
							MZ 1-4	0.006	-0.136 to 0.147	0.932
							MZ 5-3	-0.039	-0.169 to 0.090	0.527
							MZ 1-3	0.019	-0.109 to 0.148	0.748
							MZ 1-5	0.059	-0.081 to 0.199	0.384
Fabrieke	MZ	3	0.002	0.001	0.477	0.705	MZ 3-2	0.001	-0.067 to 0.069	0.986
	Residuals	10	0.014	0.001			MZ 1-2	0.025	-0.042 to 0.091	0.431
							MZ 4-2	-0.004	-0.068 to 0.059	0.883
							MZ 1-3	0.024	-0.039 to 0.088	0.421
							MZ 4-3	-0.005	-0.071 to 0.062	0.873
							MZ 4-1	-0.029	-0.092 to 0.034	0.332

ANOVA, analysis of variance; *DF*, degrees of freedom; *SS*, sum of square; *MS*, mean square; *MD*, mean differences; *CI*, confidence interval; *MZ*, management zone

Significant codes: “***” 0.001 “**” 0.01 “*” 0.05 “**.**” 0.1 “ ” 1 and significant values are highlighted in bold.