Nitrogen dynamics in deep ploughed soils of North Germany

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Abstract
On average 45 years after the deep ploughing operation, deep ploughed soils contained 24±5% more total N compared to conventionally ploughed reference soils. However, the mean N stock in the new topsoils was still 8% lower compared to the reference soils. This indicates a long-term N accumulation potential lasting more than 4-5 decades. The potential N mineralization and nitrification capacities of loamy deep ploughed soils were higher compared to sandy deep ploughed soils. All sites showed very low N mineralization potentials and nitrification capacities in the buried Ap material compared to surface Ap horizons.

Key Words: Deep ploughing, long-term N accumulation, N mineralization potential, nitrification capacity

Introduction

Deep ploughing in Germany has been promoted until the 1960s as a measure of breaking hardpans of sandy Podzols, improving soil structure and increasing infiltration in loess-derived Luvisols, thus improving crop growing conditions. The main characteristics of deep ploughed soils are dilution of soil organic matter (SOM) in the "new" Ap horizon and coexistence of slanted Ap and B horizon stripes in the subsoil. Until now there is not a single study available that describes possible N stock changes in these soils following deep ploughing. Moreover, there is currently no knowledge about the mineralization and nitrification behavior of buried vs. non-buried Ap material of deep ploughed and reference soils. The specific objectives of this study are to investigate the influence of deep ploughing on i) N stock changes in the whole soil profile, ii) net N mineralization potential and iii) nitrification capacity of buried Ap horizon material vs. surface Ap horizons of deep ploughed soils and their reference soils.

Methods

Study area and sampling locations

We investigated 10 locations in Lower Saxony, north-western Germany on that ploughing operations using a deep plough were conducted between 1965 and 1978. Half of the plots were deep ploughed to a depth of 55 to 99 cm and the other half were tilled conventionally with a mouldboard plough (range of depth between locations: 25-38 cm), serving as a reference or control subplot. Since the onset of deep ploughing both the deep ploughed plots and their references were treated equally by the same management practices. Characteristics of the sampling locations are shown in Table 1.

Table 1. Characteristics of the sampling locations

Location	Short form	Parent material	Soil type*	Texture	pH** ($CaCl_2$)	Total N** (%)	Deep ploughing depth in cm (year)
Ahlhorn	AH	Pleistocene sand	Spodic Cambisol	Sand	5.6	0.16	90 (1968)
Banteln	BT	Loess	Haplic Luvisol	Silty loam	6.5	0.12	85 (1965)
Drüber	DB	„	„ „	“ “	6.8	0.12	87 (1966)
Essemühle	EM	Pleistocene sand	Dystric Cambisol	Sand	4.6	0.09	75 (1968)
Eickenrode	ER	„ „	Gleyic Cambisol	“	5.8	0.13	65 (1968)
Elze	EZ	„ „	Dystric Cambisol	“	5.4	0.09	55 (1968)
Hemmelsberg	HB	„ „	Haplic Podzol	“	5.4	0.18	80 (1978)
Halchter	HT	Loess	Haplic Luvisol	Silty loam	6.3	0.10	70 (1966)
Salzgitter	SZ	„	„ „	“ “	6.8	0.15	90 (1966)
Warberg	WB	„	Stagnic Luvisol	“ “	5.6	0.09	65 (1966)

*According to WRB (IUSS Working Group, 2007); **pH and total N in Ap horizons of the reference soils

Soil sampling and sample preparation

In 2013 and 2014, we took soil samples from these sites. At each location, a subplot of 20 x 40 m in size was sampled from deep ploughed and the directly adjacent reference plots to a depth of 150 cm, by digging a pit perpendicular to the deep ploughing direction. The sampling depth increments included the current Ap horizon and the deep ploughed buried topsoil stripes divided into upper and lower half, and soil below the deep ploughed horizon to 100 cm depth. We took disturbed samples from the above increments for chemical analyses and for conducting laboratory experiments. Undisturbed samples were taken in triplicate with sampling cores (100 cm^3) from each increment for soil bulk density analysis. In order to account for the spatial variability, 20 core samples were collected on the deep ploughed plot and 15 on the reference plot, each at five randomly distributed positions within the plots using a soil auger (60 mm inner diameter) from 0 to 100 cm depth. The depth increments were consistent with the ones from the pit sampling. The samples were kept cool (~4°C) during transport and storage until sample preparation. An aliquot of the disturbed samples from the profile was sieved to <2.00 mm, homogenized thoroughly and dried at 65°C in an oven.An aliquot was used for texture analysis. Another aliquot of each sieved sample was ground in a planetary ball mill for total C and N analyses. A fresh aliquot from surface Ap horizon and buried Ap material from selected locations was used for the laboratory incubation experiments on N mineralization and on nitrification. Before the onset of the experiments, the soil was passed through a 4.00 mm sieve. The dried samples from the soil cores were weighed in order to determine soil bulk density which is needed for conversion of N contents to N amounts on an area basis (kg N ha^{-1}).

Soil analyses

Soil pH was measured in 0.01 M $CaCl_2$ using a glass electrode. Soil texture was determined using the sedimentation method. Total C and N were analyzed with an elemental analyser via dry combustion (TruMac CN LECO, St. Joseph, MI, USA).

Soil incubation experiment on N mineralization

An aerobic long-term soil incubation experiment on N mineralization was conducted with soils from six of the ten sampling locations using a modified procedure of that introduced by Stanford and Smith (1972). In contrast to their method, our experiment was performed with field-moist soil to prevent alterations of the sample prior to incubation. The sieved soil samples (20 g) were mixed with the same amount of quartz sand (>0.6 mm) and put into 100 mL leaching tubes embedded in two layers of quartz sand. The mineral N initially present in the soil was removed by leaching the samples before incubation. The mixture of soil and sand was equilibrated at a soil water content corresponding to 60% of the water holding capacity after leaching with 20 mL of an N-free nutrient solution. Triplicate samples were incubated at 35°C. The samples were leached with 100 mL 0.01 M $CaCl_2$ solution at 3, 7, 14, 21, 35, 56, 91, 119, 149 and 177 days after the onset of the incubation. Nitrate and ammonium in the leachate were measured with an auto-flow analyzer (Skalar, Breda, The Netherlands). A first-order single exponential model was used to describe the N mineralization potential (Stanford and Smith, 1972; Benbi and Richter, 2002).

Nitrification experiment

A laboratory experiment on net nitrification was carried out with soil samples from three of the ten locations. Before the onset of the experiment, a soil water content corresponding to about 60% of the water holding capacity was adjusted in the sieved soil samples using pressure plates. 20 g of soil was filled into 250 mL Erlenmeyer flasks (in triplicate) and ammonium sulphate (100 µg $NH4^+$-N g^{-1} soil) was added. In a parallel approach, samples were incubated without fertilizer application (zero N treatment). The samples of both approaches were incubated at 25°C. For extraction (extraction days: 0, 1, 3, 5 and 7) 100 mL 2 M KCl was used and the samples were put on a shaking device for one hour and shaken. Nitrate and ammonium in the filtered extract were measured with an auto-flow analyzer (Skalar, Breda, The Netherlands).

Results

Long-term N stock change

Deep ploughing resulted in a mean N accumulation of 1.8±0.4 Mg ha^{-1} (0-100 cm), corresponding to a mean increase by 23% (Figure 1). This is equal to a mean N accumulation of 41 kg N ha^{-1} $year^{-1}$. Only two locations (HB and DB) showed slightly negative N balances.

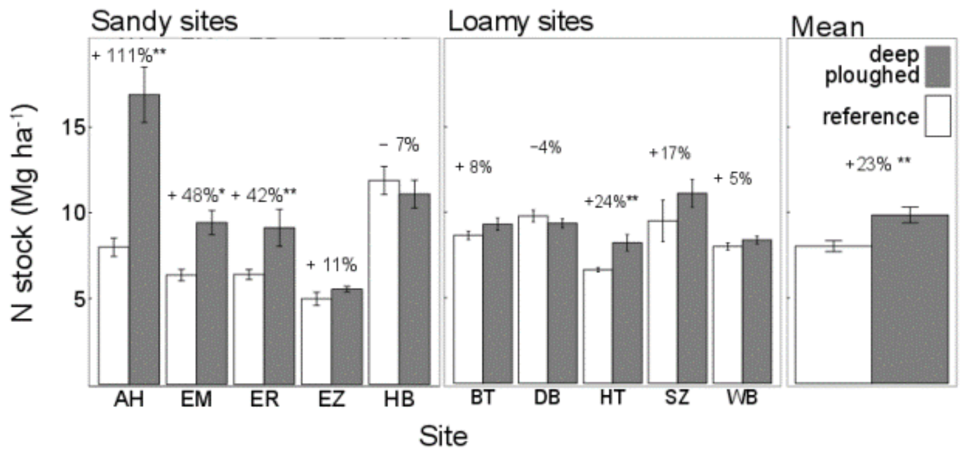

Figure 1. N stock changes after 45 years (mean) in deep ploughed vs. reference soils.

N mineralization potential

For the incubation experiment on N mineralization,six (AH, BT, ER, EM, HB, SZ) out of ten experimental soils were used but cumulative N mineralization courses (measured and estimated data) of only BT and HB soils are presented (Figure 2).

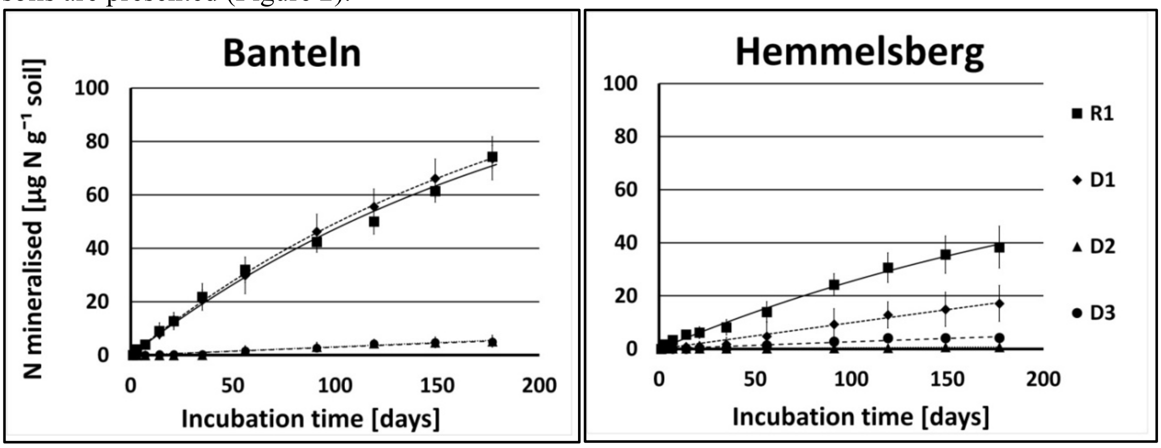

Figure 2.Courses of N mineralization in soil samples from Banteln and Hemmelsberg. The measured and the estimated values are given with dots and curves, respectively.R1: Ap of reference soil, D1: Ap of deep ploughed soil, D2 and D3: upper and lower parts of the buried Ap

Cumulative N mineralization of the reference Ap and the Ap of the deep ploughed soil was much higher in the loamy soil (BT) compared to the sandy soil (HB). This pattern was true also for the other loamy and sandy soils, respectively. At both locations (BT and HB), the buried Ap (upper and lower part) shows only a minimal N mineralization potential compared to the surface Ap horizons (reference soil and deep ploughed soil). While in the loamy soil (BT) the N mineralization courses of the reference Ap and the newly formed Ap of the deep ploughed soil are almost identical, there is a high discrepancy of these courses in the sandy soil (HB), with significantly lower N mineralization potential in the surface Ap of the deep ploughed soil. This may be mainly due to the fact that the Ap of the deep ploughed plot of HB was low in total N content. Hemmelsberg is the location with the shortest phase after deep ploughing and the expected SOM equilibrium up to now is not attained. Table 2 presents the amounts of N mineralized until day 177 of all six investigated sites on an area basis (kg N ha^{-1}). The data are on the basis of the individual depths of Ap (R1 and D1), the share of buried Ap stripes in the subsoils (D2 and D3), and the soil bulk densities of the respective increments. The data on an area basis as well show lower cumulative N mineralization in some of the Ap horizons of deep ploughed soils (particularly Ap in D1 of AH and HB) vs. the reference soils, suggesting that they still have not achieved their maximum N mineralization potentials. There is an extremely high discrepancy in cumulative N mineralization between Ap of R1 and D1 on the one hand and D2 and D3 on the other hand (Table 2).This can be drawn back not only to lower soil and total N mass of the Ap stripes in relation to the plough horizons of R1 and D1,but also to less available C and reduced microbial biomass and activity in the subsoil environment (Alcántara et al., 2016).There is no distinct pattern in higher or lower N mineralization potential in upper (D1) and lower parts (D2) of the buried Ap.

Table 2.Results of cumulative N mineralization (in kg ha^{-1}) of the six investigated sites. R1: Ap of reference soil, D1: Ap of deep ploughed soil, D2 and D3: upper and lower parts of the buried Ap

Site	R1	D1	D2	D3
AH	112.9	41.9	23.8	12.7
BT	356.0	376.8	16.9	16.6
EM	219.9	171.5	13.6	27.5
ER	174.8	161.9	22.3	19.4
HB	250.5	97.3	2.5	14.3
SZ	532.1	635.4	56.4	37.0

Nitrification capacity

For the experiment on nitrification 3 (BT, EM, HB) of the 10 experimental soils were considered. The nitrification capacity (measured data) from site HB are presented here (Figure 3). The values shown (Figure 3) represent the contents of NH_4^+ and NO_3^- derived from the applied N fertilizer, i.e., NH_4^+ and NO_3^- contents from the parallel approach without fertilizer application (soil-born N) were subtracted from the total NH_4^+ and NO_3^- contents (soil-born plus fertilizer mineral N; not shown here). Mineral N determined directly after N application on day 0 thus corresponded largely to the amount of $NH4^+$-N applied as ammonium sulphate (100 µg N g^{-1} soil). After 7 days almost 50% of the NH_4^+ was nitrified in the Ap of the reference soil (R1) while the nitrification activity in the surface Ap of the deep ploughed soil (D1) was weaker with only 30 % NH_4^+being nitrified. There was almost no nitrification in the buried Ap horizon material (D2+3). A similar nitrification pattern could also be observed for the soils of the locations BT and EM.

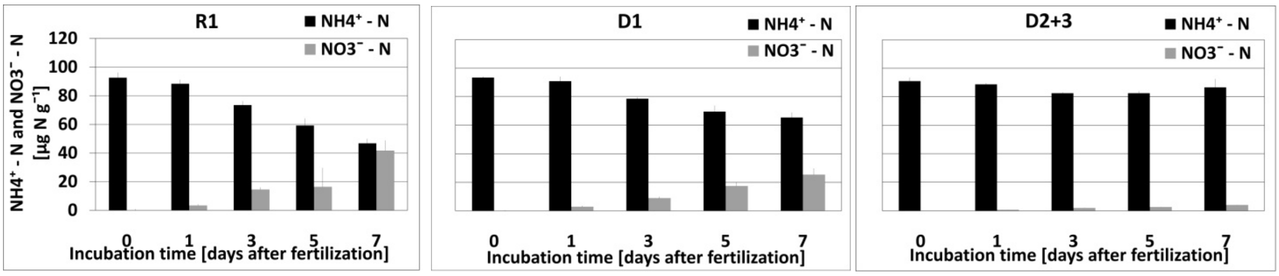

Figure 3.Results from the nitrification experiment with fertilization of the sampling site Hemmelsberg. R1: Ap of reference soil, D1: Ap of deep ploughed soil, D2 and D3: mixture of upper and lower parts of the buried Ap

Conclusions

Deep ploughing offers a significant potential for long-term N (and C) accumulation through i) burial of high amounts of SOM associated with long-term N preservation, and ii) N (and C) immobilization in newly formed SOM in the new Ap horizon. The expected SOM equilibrium may be attained over a period of more than 4-5 decades. Nitrogen mineralization and nitrification patterns in buried Ap material of deep ploughed soils vary substantially from those of the surface Ap horizons of both deep ploughed and reference soils. The very low N mineralization potentials and nitrification capacities in the buried Ap material may be drawn back to less available C as energy source, lower microbial biomass and activity, and N immobilization in stable SOM fractions.

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