Soil Microbial Activity During 9 Years of Region-Typical Agricultural Practices in Northern Germany and Interactions Between Soil Unit, Tillage, Fertilisation and Crop

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1 Introduction

In accordance to current national programmes for implementing sustainable agricultural management practices, the Collaborative Research Centre 192 of the German Research Foundation at the Agricultural Faculty of the Univervsity of Kiel aimed at optimising agricultural cropping systems for food production with reference to both the economical and ecological outcomes for systems in northern Germany. In view of sustainable agricultural practices, the following systems and management practices were addressed: A reduced tillage system was compared with a conventional tillage system as avoiding the turn-around of the soil and, thus, the stratification of the natural habitats. The reduced system is considered favourable with respect to organic matter losses and nutrient retention (Alvarez *et al.*,1988; Beare 1997). Several inorganic N fertilisation levels and slurry application were compared in order to evaluate nutrient use efficiency of external inputs and organic fertilisers that enhance the nutritional status for both soil organism and plants and, thus, increase soil quality (McCarty and Meisinger 1997). In addition, strategies for fungicide application were checked ranging from no to 'full' stem base, stem and ear protection.

Since microbial properties are modified specifically according to their nature by environmental factors and local climatic factors, it is hypothesises that soil microbial biomass and C and N mineralisation capacities adjust over time to crop and tillage systems. Soil microbial activities may be modified by the rate of N fertiliser, the use of organic fertiliser and the fungicide application, which should be evaluated here for the ploughing depth of 0 cm to 30 cm. The interactions between soil units, tillage system, fertilisation practices and crops were particularly addressed.

2 Materials and methods

The experiment was carried out approximately 15 km west of Kiel in northern Germany. The field was part of the experimental farm 'Hohenschulen' of the University of Kiel and located in a moraine landscape of loamy till with gentle slopes formed during the last glacial period. Before the experiment was started, the plot of approximately 3 ha was uniformly managed with region-typical crop rotation (oilseed rape, winter wheat and winter barley) and fertilisation practices. The experiment was started in autumn 1990 and the plot was separated in 3 fields with the 3 crops. Each field was again divided in 288 parcels containing 1 crop and 2 tillage systems with 6 fertiliser and 8 fungicide treatments, all in triplicate. From field no. 3, 36 typical plots of 36 m^2 each were selected containing the two soil units 'Luvisols' and 'Anthrosols' and also conventional tillage (CT) and reduced tillage (RT), each in 18 replicates.

The mean annual temperature and precipitation were 8.5°C and approximately 750 mm respectively. The long history of agricultural land use resulted in the development of two soil units 'Haplic Luvisol',

partly eroded (Ap horizon with 2.4 % humus, 14.4 % clay), and 'Cumulic Anthrosol', partly stagnic and/or gleyic (Ap horizon with 2.8 % humus, 12.6 % clay), according to ISSS/ISRIC/FAO (1998). The Luvisols are sandy loams with clay migration, partly eroded and located mainly in upper slope position; the Anthrosols were sandy loams, have substantial amounts of humic material up to 80 cm soil depth and located in foot slope to valley position. The Luvisols can be distinguished by dryness in summer and less wet conditions during spring from the Anthrosols.

The crop rotation 'winter oilseed rape', 'winter wheat' and 'winter barley' was repeated 3 times between 1990 and 1999. At each harvest, straw was cut and remained on the field. CT operated with ploughing at approximately 30 cm soil depth, and reduced tillage RT with a rotary hoe at approximately 5 cm soil depth (each in 18 replicates). Thus, the straw was distributed over the depth of 30 cm in CT or remained mostly in the upper 5 cm in RT. All treatments received approximately 39 kg phosphorus, 100 kg to 116 kg potassium, 70 kg to 100 kg magnesium and 800 kg calcium $ha^{-1} \cdot year^{-1}$. Five N fertilisation practices were: Zero mineral N and no pig slurry application [Nil] with 8 replicates, 120 kg NH_4NO_3-N ha^{-1} divided at equal rates and applied at three plant growth stages [120N] with 8 replicates, 160 kg to 240 kg NH_4NO_3-N ha^{-1} divided at equal rates and applied at the same growth stages [240N] with 8 replicates, approximately 15 m^3 pig slurry applied in spring and autumn [+SL] with 4 replicates, and 120 kg NH_4NO_3-N ha^{-1} plus the pig slurry [120N+SL] with 8 replicates. The slurry treatment represented an additional fertilisation of approximately 615 kg organic C, 145 kg N, 70 kg P, 54 kg K, 24 kg Mg and 68 kg Ca $ha^{-1} \cdot year^{-1}$. The whole experiment with 864 parcels contained 8 fungicide treatments ranging from no application to stem base (basal part of the plant), stem and/or ear protection. When the occurrence of the fungal pathogen exceeded the respective damage threshold, approximately 1.0 kg to 1.5 kg Perchloraz, Fenpropimorph + Propiconazol and Tebunconozol or Vinclozolin + Thiophanate-methyl were applied for the stem base, stem and ear treatment respectively.

Soil was sampled from 0 cm to 15 cm and 15 cm to 30 cm soil depth from 2 replicated plots per treatment. Twenty-six samplings were done between 1991 and 1999 (Elsner 1994; Bode 1998; Frahm 2000). Field-moist soil was sieved to pass a 5-mm screen (visible pieces of crop residues and roots were removed) and stored at a moist condition at 4 °C. Soil was stored at –21 °C when analyses could not be done within one month and later gently melt in the fridge. The average bulk density was 1.29 and 1.41 $Mg \cdot m^{-3}$ for the ploughed soil and 1.12 $Mg \cdot m^{-3}$ and 1.61 $Mg \cdot m^{-3}$ for the soil below reduced tillage for the respective depths (Frey 1998).

Substrate-induced respiration 'SIR' (Anderson and Domsch 1978) and basal respiration 'BAS' (Anderson 1988) were determined in the laboratory as microbial biomass estimate and current C mineralisation capacity respectively. Before determining SIR and BAS, soil was preconditioned for at least 3 days at approximately 22 °C in the laboratory. Both were measured on the basis of the O_2 uptake using a Sapromat. Microbial biomass was calculated using the conversion factor 29 mg C corresponding to 1 mg O_2 h^{-1}, which is equivalent to 40.04 mg C for 1 ml CO_2 h^{-1} (Anderson and Domsch 1978) and basal respiration was assumed a respiratory quotient of 1. Soil moisture content corresponded to approximately 40 % to 70 % WHC. The β-glucosidase activity, GLU (an 'extracellular' enzyme), and the arginine ammonification, ARG ('intracellular' since being related to active organisms) were analysed as referring to C and N cycling respectively. Here, these microbial capabilities were checked as indicators of the current C polymer degradation capacities and N mineralisation (Dilly 1997) respectively although the estimates may not be critical with reference *in situ* conditions (May and Recous 1994). In these enzymatic assays, the phenol released from salicine and NH_4^+ released after arginine addition was estimated after 3 hours at 37 and 30 °C respectively (Hoffmann and Dedeken 1965; Alef and Kleiner 1986).

The microbial metabolic quotient qCO_2 was calculated by dividing basal respiration by SIR-derived microbial C. Furthermore, ratios between (i) BAS and ARG, (ii) SIR and ARG and (iii) GLU and ARG were calculated as gentle indicators for soil C-to-N degradation capacity since BAS refers to the current C mineralisation potential based on endogenous soil C compounds, SIR to the current C mineralisation potential when available C is not restricting microbial metabolism, GLU to the enzymatic C polymer degradation potential and ARG to the current N mineralisation in the presence of N substrate.

ANOVA on Ranks and Two Way ANOVA were performed to estimate parameters controlling soil microbiological characteristics. It is imprtant to acknoledge that normality test and equal variance test failed that limit the use of Multiple ANOVA. Spearman rank correlations were used to evaluate the interrelationships between microbiological characteristics when normality test failed and constant variance test has been passed ($P < 0.05$).

3 Results and discussion

3.1 Soil microbial biomass and activities in the luvisols and anthrosols during 9 years

The pooled data of Elsner (1994) Bode (1998) and Frahm (2000) gave that soil microbial biomass content and microbial activities decreased continuously in comparison to the initial values (Dilly *et al.* 2002). The slurry application retarded the decline, compared to either no or mineral N fertilisation. In comparison to no and mineral N fertilisation, slurry application increased microbial biomass content. Both slurry and mineral N application stimulated soil microbial activities in the long-term. Soil under oilseed rape showed highest microbial activities and soil under wheat and barley greater microbial biomass. The comparison of conventional and reduced tillage showed that microbial biomass and activities was highest from 0 to 15 cm under reduced tillage. However, no prominent differences in microbiological characteristics when considering 0 to 30 cm soil depth. Evident effects with reference to the plant protection strategy were not detectable, but environmental conditions in Anthrosols improved microbial activity in comparison to those in the Luvisols. Some effects of microbial adjustment could only be assured when analysing the whole experiment of 9 years and here the interaction between SOIL UNIT, TILLAGE,FERTILISATION AND CROPwere addressed more in detail.

3.2 Interactions between soil unit and tillage practices

Fig.1 shows that microbial characteristics were controlled by soil unit rather than by the tillage system. Basal respiration, arginine ammonification and ß-glucosidase were higher in the Anthrosol than in the Luvisol. In contrast, microbial biomass content was not modified by either soil unit or tillage system. Furthermore, the qCO_2, the SIR/ARG and GLU/ARG ratios did not differ significantly between the treatments indicating that microbial biomass and activities related to soil mass were mostly modified similarly in the two soil units (Fig.2). Only, the BAS/ARG ratio was reduced under reduced tillage indicating that the current mineralisation with reference to the ammonification is reduced in this system when an available C and N resource is present.

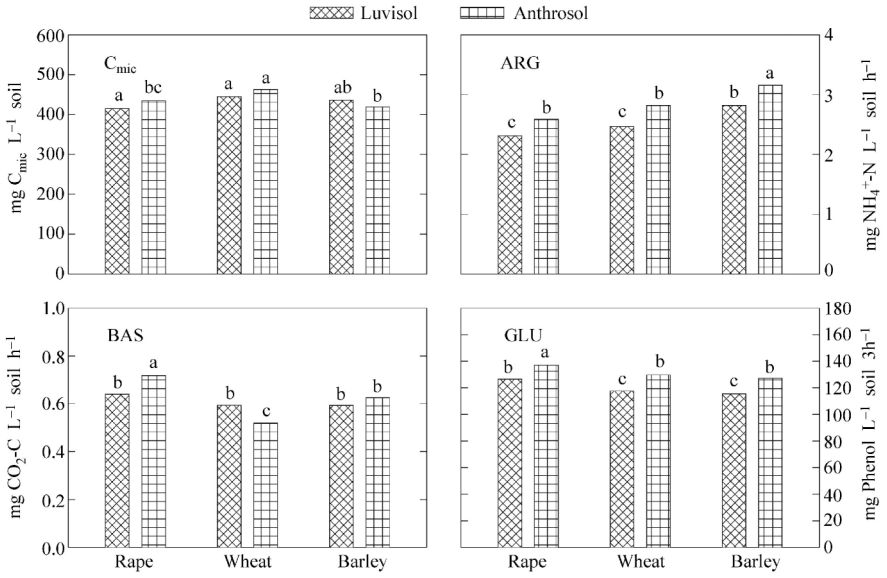

Fig. 1 Microbial biomass (C_{mic}), arginine ammonification (ARG), basal respiration (BAS) and ß-gluco-sidase activity (GLU) with reference to soil unit and tillage system (conventional CT and reduced RT) in agri-cultural systems at 'Hohenschulen' in northern Germany; different letters indicate significant different values.

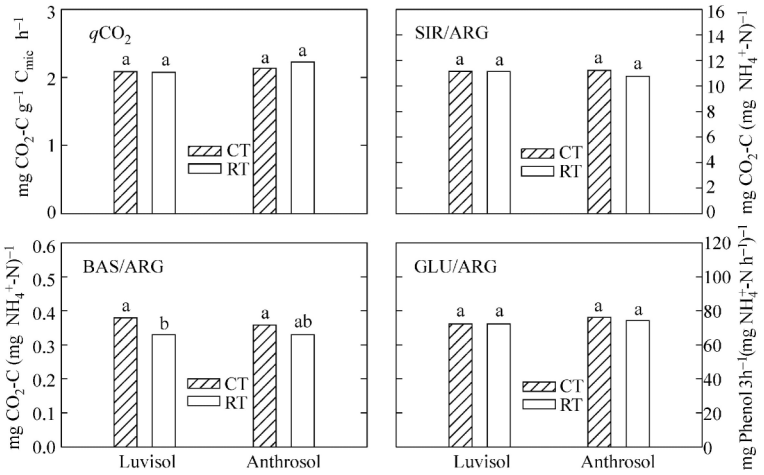

Fig. 2 Ratios between microbial biomass (C_{mic}), arginine ammonification (ARG), basal respiration (BAS) and ß-glucosidase activity (GLU) with reference to soil unit and conventional and reduced tillage system (CT, RT) in agricultural systems at 'Hohenschulen' in northern Germany; different letters indicate significant different values.

3.3 Interactions between soil unit and crop

Less obvious were crop-related differences in the two soil units (Fig.3 and Fig.4). Wheat and barley cultivation favours microbial growth and rape cultivation gave higher microbial activities. This trend was, however, only significant when the total data set is used (Dilly *et al.*, 2002).

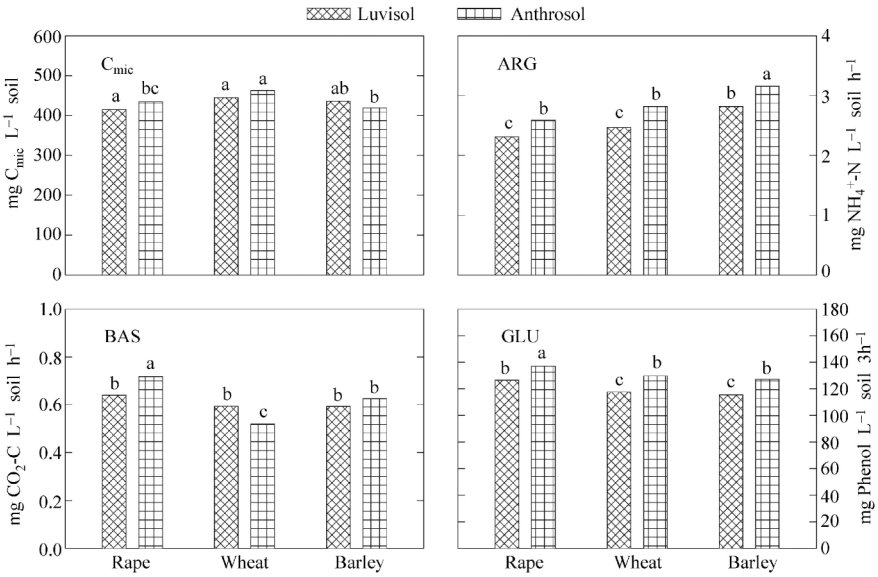

Fig. 3 Microbial biomass (C_{mic}), arginine ammonification (ARG), basal respiration (BAS) and ß-glucosidase activity (GLU) with reference to soil unit and crop in agricultural systems at 'Hohenschulen' in northern Germany; different letters indicate significant different values.

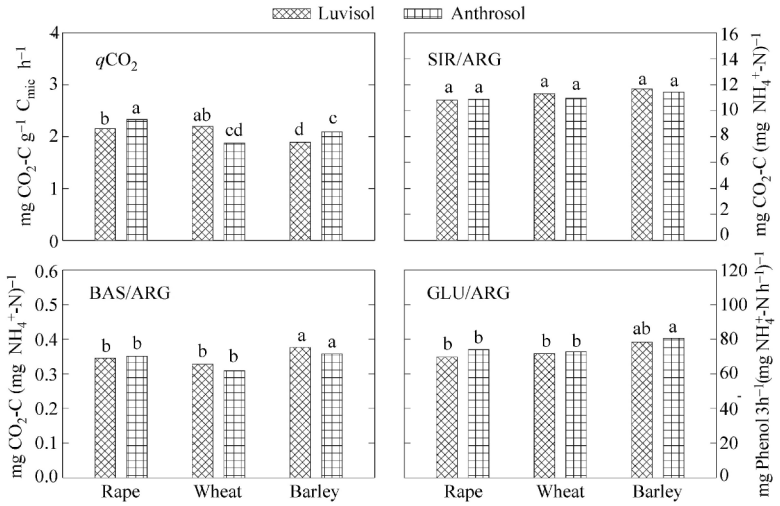

Fig. 4 Ratios between microbial biomass (C_{mic}), arginine ammonification (ARG), basal respiration (BAS) and ß-glucosidase activity (GLU) with reference to soil unit and crop in agricultural systems at 'Hohenschulen' in northern Germany; different letters indicate significant different values.

3.4 Interactions between soil unit or tillage and fertilisation

With reference to soil unit and fertilisation, higher level of microbial activities were again determined in the Anthrosols (data not shown). The microbial quotients, however, did not differ significantly with the exception of 240N for SIR/ARG ratio und +SL for GLU/ARG ratio.

Simultarly, few modifications can be explained by interactions between tillage and fertilisation (data not shown). Variation could be determined for microbial biomass in 120N+SL. In NIL, BAS/ARG ratio was higher for RT. In +SL, GLU/ARG ratio is higher in CT suggesting that polymer degradation is stimulated by slurry application in CT.

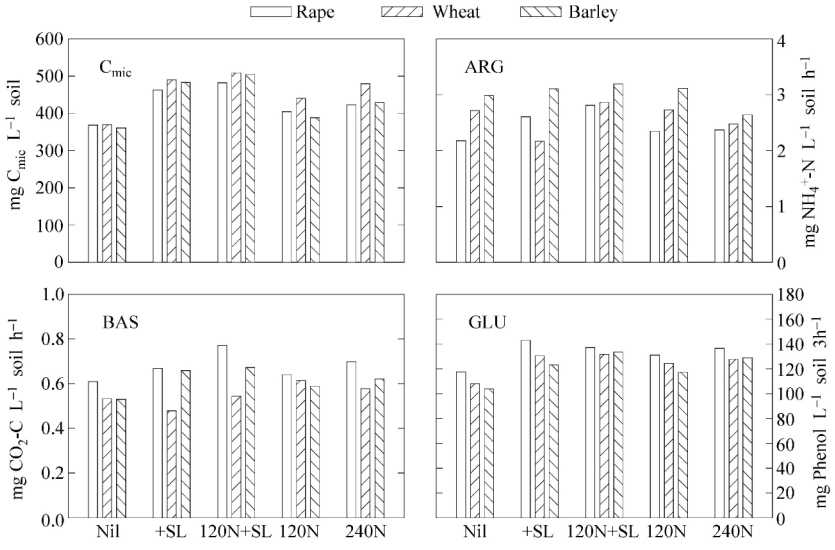

Fig. 5 Microbial biomass (C_{mic}), arginine ammonification (ARG), basal respiration (BAS) and ß-glucosidase activity (GLU) with reference to soil unit and crop in agricultural systems at 'Hohenschulen' in northern Germany.

3.5 Interactions between crop and fertilisation

Most prominent were the interactions between crop and fertilisation on soil microbiological characteristics (Fig.5, Fig.6). Microbial biomass was affected by mineral fertilisation at 120N und 240N in the 3 crops and basal respiration by 120N, +SL, and 240N. Arginine ammonification and ß-glucosidase activity were modified in NIL, 120N and +SL. Also the microbial quotients were modifed. While the qCO_2 was affected by organic matter and high mineral N application in +SL, 120N+SL and 240N, the BAS/ARG ratio was affected in NIL, and the SIR/BAS and GLU/ARG ratio in 120N and, thus, at lower input levels.

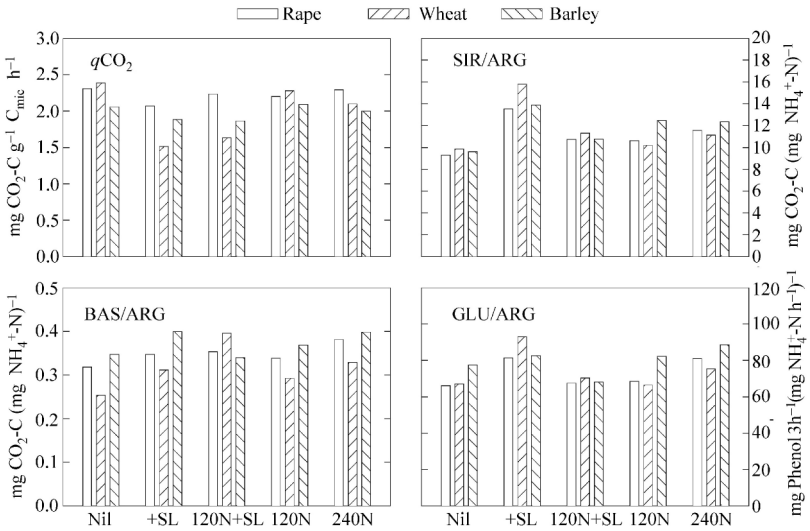

Fig. 6 Ratios between microbial biomass (C_{mic}), arginine ammonification (ARG), basal respiration (BAS) and ß-glucosidase activity (GLU) with reference to soil unit and crop in agricultural systems at 'Hohenschulen' in northern Germany.

4 Conclusions

Over the 9-year experimental period with static agricultural management practices in particular with reference to fertilisation treatments, the basal respiration, which was considered to evaluate the current C mineralisation capacity, was not modified. In contrast, soil microbial biomass content, intracellular N mineralisation and extracellular C polymer degradation capacities declined which concurred with the decline of organic C and the increase in pH value. The trends may be attributed to slightly modified agricultural management practices, e.g. more diverse practices and increased liming, and to environmental changes. The current management with plant residues remaining on the field seemed not to stabilise the initial C_{org} and microbial levels.

Wheat and barley were found to favour microbial biomass, and oilseed rape to stimulate microbial activities. Reduced tillage promoted microbial activities close to the soil surface but did not significantly modify the microbiological characteristics and, thus, elemental cycling for 0 to 30 cm soil depth. Specific nutritional and environmental factors existing in Anthrosols stimulated soil microorganisms in comparison to those in Luvisols and finally the fungicide application system only slightly modified soil microbiological characteristics. Some significant effects on interactions between SOIL UNIT, TILLAGE, FERTILISATION AND CROP were found for all except tillage.

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References

Alef K & Kleiner D (1986) Arginine ammonification, a simple method to estimate microbial activity potentials in soils. Soil Biology and Biochemistry 18: 233-235

Alvares CR, Alvarez R, Grigera MS & Lavado RS (1998) Associations between organic matter fractions and the active soil microbial biomass. Soil Biology and Biochemistry 30: 767-773

Anderson JPE & Domsch K-H (1978) A physiological method for the quantitative measurement of microbial biomass in soils. Soil Biology and Biochemistry 10: 215-221

Anderson T-H (1988) Determination of eco-physiological constants for the characterization of soil microbial comunities. PhD Thesis Essex U. K.

Beare MH (1997) Fungal and bacterial pathways of organic matter decomposition and nitrogen mineralisation in arable soils. In: Brussard L & Ferrera-Cerrato R (Eds) Soil ecology in sustainable agricultural systems (pp. 37-70). Lewis Publishers, Boca Raton

Bode M (1998) Einflüsse verschiedener Bewirtschaftungsmaßnahmen auf Bodenorganismen typischer Ackerböden einer norddeutschen Jungmoränenlandschaft. Schriftenreihe Institut für Pflanzenernährung und Bodenkunde der Universität Kiel 41: 1-161

Dilly O (1997) Ammonification of amino acids in field, grassland and forest soils. In: Insam H & Rangger A (Eds) Microbial communities. Functional versus structural approaches (pp 248-260). Springer, Berlin

Dilly O, Blume H-P, Munch JC (2002) Soil microbial activities in Luvisols and Anthrosols during 9 years of region-typical tillage and fertilisation practices in northern Germany. Biogeochemistry (submitted)

Elsner D-C (1994) Einflüsse von Bodenbearbeitung und Düngung auf die Mikroorganismen und ihre Leistungen typischer Ackerböden einer norddeutschen Moränenlandschaft. Schriftenreihe Institut für Pflanzenernährung und Bodenkunde der Universität Kiel 27: 1-103

Frahm A (2000) Das Edaphon in Oberböden einer norddeutschen Jungmoränenlandschaft unter dem Einfluß verschiedener Bewirtschaftungsmaßnahmen. Schriftenreihe Institut für Pflanzenernährung und Bodenkunde der Universität Kiel 55: 1-107

Frey D (1998) Eignung des Systems Horsch als reduzierte Bodenbearbeitung zur Förderung der Bodenfruchtbarkeit auf Böden des Östlichen Hügellandes in Schleswig-Holstein. Schriftenreihe Institut für Pflanzenernährung und Bodenkunde der Universität Kiel 43: 1-165

Hoffmann G & Dedeken M (1965) Eine Methode zur colorimetrischen Bestimmung der ß-Glucosidase-Aktivität in Böden. Zeitschrift für Pflanzenernährung, Düngung und Bodenkunde 108: 193-198

ISSS/ISRIC/FAO (1998) World reference base for soil resources. World Soil Resources, Report 84. FAO, Rome

McCarty GW & Meisinger JJ (1997) Effects of N fertilizer treatments on biologically active N pools in soils under plow and no tillage. Biology and Fertility of Soils 24: 406-412.