Compatibility of Agricultural Management Practices and Types of Farming in the EU to enhance Climate Change Mitigation and Soil Health

Impacts of soil management on chemical soil quality

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Alicja Pecio, Alina Syp, Mariusz Fotyma,

Zuzanna Jarosz

Partner(s):

IUNG-PIB

+all contributors to the data base

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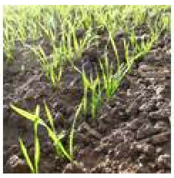

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The CATCH-C project aims at identifying and improving the farm compatibility of sustainable soil management practices for farm productivity, climate-change mitigation, and soil quality. The project is carried out by a consortium of 12 partners, led by Stichting Dienst Landbouwkundig Onderzoek (DLO), The Netherlands.

Email: hein.tenberge@wur.nl
Internet: www.catch-c.eu

Authors of this report and contact details:

Name:	Alicja Pecio	Partner acronym: IUNG-PIB
Address:	Institute of Soil Science and Plant Cultivation State Research Institute Czartoryskich 8 Street, 24-100 Puławy, Poland	
E-mail:	alicja.pecio@iung.pulawy.pl	
Name:	Alina Syp	Partner acronym: IUNG-PIB
Address:	Institute of Soil Science and Plant Cultivation State Research Institute Czartoryskich 8 Street, 24-100 Puławy, Poland	
E-mail:	asyp@iung.pulawy.pl	Partner acronym: IUNG-PIB
Name:	Mariusz Fotyma	Partner acronym: IUNG-PIB
Address:	Institute of Soil Science and Plant Cultivation State Research Institute Czartoryskich 8 Street, 24-100 Puławy, Poland	
E-mail:	fot@iung.pulawy.pl	
Name:	Zuzanna Jarosz	Partner acronym: IUNG-PIB
Address:	Institute of Soil Science and Plant Cultivation State Research Institute Czartoryskich 8 Street, 24-100 Puławy, Poland	
E-mail:	zjaroszt@iung.pulawy.pl	

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General information

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Executive summary

Chemical soil quality, from the point of view of agriculture is a synonym of soil fertility, i.e. its ability to provide crops with the nutrients. There are several measurable and commonly accepted factors of soil fertility. In this report - given the availability of data from literature and own (consortium-held) LTE's - the following indicators of chemical soil quality were analysed: pH, N total content, N total stock, C/N ratio, N min content, P and K availability. They are the most frequently used indicators in the European literature on long term experiments collected in the CATCH-C project data base.

This work reports the effects of soil management practices – under different soil and climatic conditions - on the above soil chemical quality indicators, based on the analysis of data extracted from literature on long term experiments (LTE's) in Europe, as well as from LTE's held by the Catch-C consortium partners. The following practices were analysed in this work: crop rotation, catch and cover crops (harvested), green manures (incorporated), no-tillage, no-inversion tillage, mineral fertilization, fertilization with compost, farmyard manure application, slurry application, crop residue incorporation. Only medium- and long-term effects of such practices on a set of indicators were considered important for this study, therefore only stabilized and long-term experiments (LTEs) lying in European countries were taken into consideration.

The dataset related to soil chemical quality indicators consisted of 1044 records. The data used in this work refer to 59 long term trials, nearly all of them in Europe. The indicators were analysed using their response ratio RR to a management practice. For a given treatment (management practice), this ratio was calculated as the quotient between the indicator value obtained in the treatment, and the indicator value in the reference treatment.

RR frequency distributions were tested for normality and their descriptive statistics were calculated. We tested - for each combination of practice with indicator - whether or not the corresponding mean RR differed from 1. Next, a multiple linear model (with climate, crop, soil type and duration of practice as single nominal factors without interactions) was used to evaluate if any of these 'covariate factors' affected the relative response RR to a given management practice, and by how much. For this purpose, climate, soil texture and duration of practice were divided into 4 classes ('levels') each, while 3 different depths of soil sampling were considered.

All tested practices influenced soil chemical quality indicators. Both positive and negative effects were observed. When the RRs values of seven soil chemical quality indicators were considered in an overall evaluation – based on their significance level, the number of indicators positively affected and (next) the size of the effects - , the best practices among

those tested were: farmyard manure application, no-inversion tillage, compost application, mineral fertilization, and no-tillage.

Farmyard manure (relative to mineral N or K fertilizer at equal plant available N or K) significantly increased Nt content, content of available (mineral) nitrogen, and the C/N ratio (promoting accumulation of carbon over nitrogen). Available potassium was strongly increased, too, but this refers to one case only. The response of pH to FYM was similar to that under the reference rate of mineral fertilization, but RR values slightly higher than 1 were found as the duration of FYM application increased.

No-inversion tillage compared to conventional ploughing positively influenced N total content and stock and content of available forms of K and P, all significantly.

Application of compost significantly increased soil pH, Nt content, N min content and showed a tendency (n.s.) to increase C/N ratio and K avail content.

Mineral fertilizers (relative to zero application) were effective especially in increasing available phosphorus, potassium and nitrogen, and also total N content.

No-tillage, relative to conventional ploughing, was ranked lower than the above practices because it affected (significantly) only available phosphorus and N min contents. No-tillage did not clearly enhance either of the total N indicators. There were (n.s.) tendencies for no tillage to increase Nt content and to decrease Nt stock and C/N ratio. The (positive) response of P avail in topsoil layers was clear and based on a reasonable number of data.

If we rank our indicators by the number of practices by which they are affected, the resulting ‘responsiveness ranking’ (ignoring the magnitude of the responses) is: Nt content and N min content (affected by five practices), P avail content, K avail content, C/N ratio (affected by two practices). Their responses are summarised below.

All organic fertilisers (compost, slurry and FYM) had stronger impacts on Nt content than had mineral fertilisers (the reference, at same level of ‘plant available’ nutrients). Less pronounced, but also positive, was the response of Nt content to non-inversion tillage and, then, to no-tillage. The effect of rotation will generally depend, of course, mostly on the choice of individual crops in the rotation and cannot, in our view, be generalised based on this study.

Mineral soil N, too, responded stronger to organic inputs (FYM, slurry and compost) than to fertiliser-N (the reference). Mineral fertiliser application itself (relative to zero dose) also had a clear positive effect on N min, as had the no-tillage practice.

Available P and K responded most strongly – among practices – to inputs of mineral fertilisers. Only few observations refer to organic inputs, effects of which are expected to be similar. Weaker but relevant responses of P avail and K avail were found for reduced tillage (no-tillage and non-inversion) practices: these favour the accumulation of nutrients (from inputs and residues) near the soil surface. (Note that P and K responses refer to contents – i.e. amounts per kg soil in layers sampled - and not to total stocks.) This accumulation of nutrients in the topsoil can be an advantage for early crop growth under favourable moisture conditions, but turns into a disadvantage when the topsoil dries out and renders these nutrients inaccessible for uptake. Further, available K was also promoted by FYM.

The C/N ratio was increased by the application of FYM, and by the incorporation of crop residues. Responses of pH were weak for all practices. The positive response of pH to compost application must be regarded as a side effect, and pH responses will more generally depend on the nature of the compost itself.

Specific part

1. Introduction

Chemical soil quality, from the point of view of agriculture is a synonym of soil fertility, i.e. its ability to provide crops with the nutrients. There are several measurable and commonly accepted factors of soil fertility. In this report - given the availability of data from literature and own (consortium-held) LTE's - the following indicators of chemical soil quality are analysed: pH, N total content, N total stock, C/N ratio, N min content, P and K availability. They are the most frequently used indicators in the European literature on long term experiments collected in the CATCH-C project data base.

1.1 Objectives

This work reports the effects of soil management practices – under different soil and climatic conditions - on selected soil chemical quality indicators, based on the analysis of data extracted from literature on long term experiments (LTE's) in Europe, as well as from LTE's held by the Catch-C consortium partners.

2. Materials and Methods

The practices that were analysed in this work are listed in Tab. 2-1. The effect of such practices on soil chemical quality indicators were collected from various sources: peer-reviewed scientific papers, national language scientific or technical papers, grey literature (project reports), unpublished data. However, peer-reviewed scientific journals provided most of the data. Papers were first collected in a shared on-line library and then analysed by the different task groups. An on-line shared database was then constructed to store and retrieve the data, which were entered by all project partners.

Tab. 2-1. List of practices studied in WP3

Rotation	Monoculture (reference treatment)
	Crop rotation
	No catch crops (reference treatment)
	Catch-crops (harvested)
	No green manure (reference treatment)
	Green manure (incorporated)
Tillage	Conventional tillage (reference treatment)
	No tillage
	Non-inversion/minimum tillage
Nutrient management	No fertilizer (reference treatment)
	Mineral fertilization
	Mineral fertilizer (reference treatment)
	Fertilization with compost
	Farmyard manure application
	Slurry application
Residue management: residue incorporation	Residue removal (reference treatment)
	Residue incorporation

2.1 Shared library

The on-line shared library on the Zotero free platform (www.zotero.org) was progressively filled by all partners. It contains 733 papers and allows all partners an easy and fast access to original papers describing the LTE's.

2.2 Database

The data analysis was conducted on the Catch-C online dataset which has been filled by all the project partners. While the complete dataset developed by the project is much larger, the set relevant to document soil management effects on 'chemical soil quality' indicators consisted of 1044 records. The relevant indicators are pH, N total content and stock, C:N ratio, N min content, K available content, P available content. Each of these indicators can be assessed by a range of methods which often vary between the constituent studies. For the purpose of this meta-analysis we pooled all methods, e.g., for available phosphorus, but documented the chemical analysis method per trial in the database.

The data used in this work refer to 59 long term trials. The list of LTE's is given in Tab. 2.2-1. Note that soil organic carbon (SOC, not included here) was covered by a separate study on indicators for climate change mitigation (Deliverable D3.3.4).

Tab. 2.2-1. Long term trials (n=59) used in this work and practices compared in each experiment. *Management practices columns include the names of relevant indicators: 'pH' is soil reaction pH, 'Nt'* is total *N content, 'NtS is* total *N stock, 'C/N'* is *C:N ratio, 'N* min*' is N min* content, *'K* avail*' is available K, 'P* avail*' is available P. Letters in the last four columns indicate the type of climate, soil, duration of practice and crop (according to paragraph 2.4): climate classes are N (northern), W (western), E (eastern) and S (southern); soil texture classes are C (clay), I (silt), A (sand), L (loam); sampling depth classes are: LW (Low<10 cm), MM (Medium=10-30 cm), HH (High>30 cm), duration is L (Low<5 yrs), M (Medium=5-10 yrs), H (High11-20 yrs), and V (very high>20 yrs);*

Tab. 2.2-1. Long term trials used in this work and practices compared in each trial.

	Characteristic													
Experiments	Crop rotation	Catch and cover crops (harvested)	Green manures (incorporated)	No tillage	Non-inversion tillage	Mineral fertiliser	Compost	FYM	Slurry	Residue management	Climate class	Soil txt class	Sampling depth	Duration
Acadie Canada				P avail							N	L	LW	H
As						Nt	Nt			Nt	N	L	MM	V
As Norway Rotation & FYM Expt	Nt										N	L	MM	V
As Norway Straw Expt						Nt				Nt	N	L	MM	V
Aurajoki				P avail							N	L	LW, MM, HH	L
Bernburg					P avail						W	I	LW, MM, HH	H
Boigneville		NtS		NtS	NtS						W	L	MM	V
Broadbalk					P avail	C/N	C/N				W	L	LW	V
Brody				Nt, C/N, P avail	Nt, C/N, P avail						E	L	LW, MM	M
Cologne			Nt, C/N				Nt, C/N			Nt, C/N	W	L	MM	V
Cordoba					C/N						W	L	LW	L
Coria del Río					P avail						S	L	LW, MM	M

Court-St-Etienne					C/N						W	L	LW	H
Experimental Station of Lithuanian Agriculture of University					P avail						E	L	LW, MM	L
General Toshevo				P avail	P avail						E	I	LW, MM	H
Gleadthorpe (ADAS)										Nt	W	C	LW	M
Huldenberg (Gryze)					P avail						W	C	LW, HH	L
Illinois				P avail	P avail						E	I	LW	M
IOSDV Puch										C/N	E	L	MM	H
Isaszeg						Nt					E	L	HH	L
Jaen				NtS, C/N	NtS, C/N						S	L	LW, MM	V
Jokioinen				P avail							N	A	LW, MM	L
Kerlavic		NtS			NtS,						W	L	MM	H
La Higuerela (tillage x rotation)				NtS	NtS						S	L	LW, MM	H
Lodi - POC1	pH, Nt, C/N										S	L	MM, HH	V
LTE 1 Grabów						pH, Nt	pH, Nt C/N				E	C	MM	V
LTE 3 Grabów	P avail										E	A	MM	V
LTE 7 BOPACT					pH, Nt, P avail						W	L	LW, MM	L
LTE 8 VEGTILCO					Nt, N min, K avail, P avail						W	L	LW, MM, HH	L, M
LTE 9 FARMCO								pH, Nt, K avail			W	L	MM	L, M

LTE 10_Ferti							pH, Nt N min, C/N, K avail	pH, NtC/N, N min, K avail	pH, Nt N min, C/N, K avail	pH, Nt N min, C/N, K avail	W	L	MM, HH	L
LTE 11_CROPRO	pH, Nt, C/N, K avail, P avail	pH, Nt C/N, K avail								P avail	W	L	MM	L
LTE 12 Tetto Frati						pH, Nt, C/N				pH, Nt C/N	S	C	MM	H
LTE 13 Lombriasco				Nt	Nt						S	C	HH	M, H
LTE 16 TOMEJIL_				pH, Nt N min, Kavail, P avail	C/N, P avail						S	A	LW, MM, HH	L, M, H, V
LTE 17 CONCHUELA				C/N, K avail							S	L	LW	M
LTE 18 Effects of diff. tillage trets					pH, Nt, K avail, P avail						E	L	LW, MM	L, M, H, V
LTE 19 Alpenvorland						P avail					E	L	MM	V
LTE 19 Marchfeld						P avail					E	L	MM	V
LTE 20 IOSDV						pH, Nt, N min, K `avail, P avail					E	L	MM	H, V
LTE 21 14C	Nt										E	L	MM	L, H, V
LTE 22 Compost						Nt		Nt,	Nt,		E	C	MM	H

								C/N	C/N					
LTE 26 GarteSud					C/N						W	L	LW, MM, HH	V
LTE Braunschweig						P avail					E	L	MM	V
Lukavec						C/N	C/N	C/N			E	L	MM	M
Morley (ADAS)										Nt	W	A	MM	M
Osaker						Nt				Nt	N	L	MM	H
Osaker Norway straw Expt						Nt				Nt	N	L	MM	H
Pisa 3		NtS		NtS							S	C	MM	L, H
PL-Brody				C/N, P avail	C/N, P avail						E	L	LW, MM	L, M
Rennes				P avail	P avail	C/N	C/N				W	L	M, M	M, V
Ros Klammer						Nt		Nt	Nt		E	C	MM	H
SE-Ultuna										C/N	N	L	MM	V
Suchdol							C/N	C/N			E	L	MM	M
Swojec				P avail	P avail						E	A	LW, MM	L
Thibie		NtS			NtS						W	L	MM	H
Trutnov							Nt	Nt		Nt	W	L	MM	H
Wierzchucinek							C/N	C/N			E	L	MM	H
Witter et al										C/N	N	L	LW	V

Tab. 2.2-2 shows the number of records and of LTEs regarding each of the main soil chemical quality indicators that were taken into consideration for this analysis. Enough data to justify analyses were available for the following indicators: soil reaction pH, N total content, N total stock, C/N, N min content, K available content, and available phosphorus. In contrast, insufficient data were available on CEC (cation exchange capacity), Mg and Na contents. Therefore, these indicators were ignored.

Tab. 2.2-2. Number of records in the Catch-C database reporting soil chemical quality indicators.

Indicator	Number of records	Number of LTEs
pH	132	10
N total content	265	26
N total stock	109	10
C/N ratio	133	23
N min content	76	4
K available content	103	8
P available content	234	24

2.3 Data treatment

The indicators were analysed using their relative response ratio RR to a management practice. For a given treatment (management practice), this ratio was calculated as the quotient between the indicator value obtained in the treatment, and the indicator value in the reference treatment. (For definitions of the reference treatments, see Table 2-1.). We will refer to the RR value of indicator x as RR(x).

2.4 Statistical analysis

All statistical analyses were performed with the help of the package Statgraphics Centurion v.XVI.

RR frequency distributions were tested for normality and their descriptive statistics were calculated. We tested - for each combination of practice with indicator - whether or not the corresponding mean RR differed from 1, based on the one-sample Student-t test.

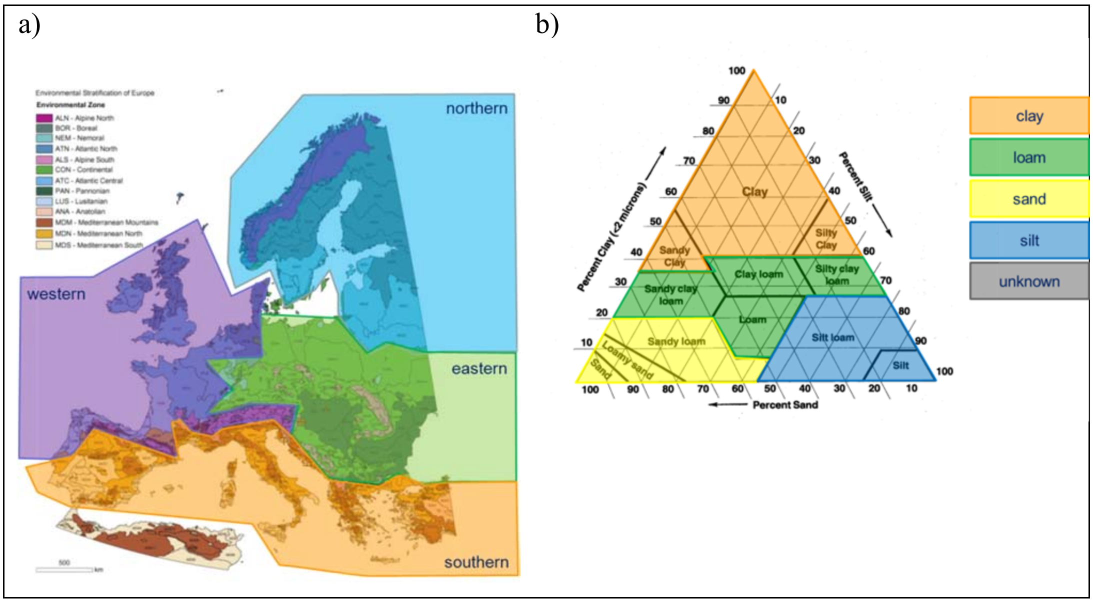
Next, we used a multiple linear model (with climate, crop, soil type and duration of practice as single nominal factors without interactions) to evaluate if any of these factors affected the relative response RR to a given management practice, and by how much.

For this purpose, climate, soil texture and duration of practice were divided into 4 classes ('levels') each, while 3 different depths of soil sampling were considered (Tab. 2.3-1). A type III Wald statistics for maximum likelihood estimate of regression was chosen. Then, a t- test was used to separate means of single factors different at $p<0.05$.

Tab. 2.3-1. Levels of the four factors considered in the linear multiple regression. Climate types were those reported by Metzger et al., 2005. (Note that the number in first column refers to each of the cells within the same line, but otherwise cells within the same line are unrelated across columns.)

Num.	Climatic zone	Soil texture	Sampling depth	Duration of practice
1	Northern Alpine North (ALN) Boreal (BOR) Nemoral (NEM)	clay (clay, silty clay)	low <10 cm	low (< 5 yrs)
2	Western Atlantic North (ATN) Atlantic South (ATS) Atlantic Central (ATC) Lusitanian (LUS)	loam (loam, clay loam, sandy clay loam, silty clay loam)	medium 10-30 cm	medium (5-10 yrs)
3	Eastern Continental (CON) Pannonian (PAN)	sand (sand, loamy sand, sandy loam)	high >30 cm	high (11-20 yrs)
4	Southern Anatolian (ANA) Mediterranean Mountains (MDM) Mediterranean North (MDN) Mediterranean South (MDS)	silt (silt, silty loam)		very high (> 20 yrs)

Fig. 2.3-1. Levels of the two factors considered in the linear multiple regression. a) Climate (acronyms as in Tab. 2.3-1), from Metzger et al., 2005, modified; b) soil texture classes.



3 Results and Discussion

3.1 Crop rotation

3.1.1 Expected results from the literature

Among annual crops, cereals generally produce the most residues while crops such as grain legumes, dry beans and root crops produce less. Thus, SOM levels tend to be lower under maize-soybean rotations compared with continuous maize (Paustian et al., 1997). Changes in SOM for six rotations including maize, sugar beet, navy bean, oats and lucerne were directly correlated to amounts of residue returned and the frequency of maize in the rotation (Zielke and Christensen, 1986). The inclusion of perennial forages (i.e. leys) in rotations increases SOM levels relative to rotations with annual crops alone. Experiments in Europe with 3 or more years of ley within annual crop rotations had up to 25% more SOM compared to rotations with only annual crops (Van Dijk, 1982; Nilsson, 1986). Such changes in SOM can be generally expected to have major impacts on other soil chemical indicators, too. In one study, crop rotation had significant impact on total nitrogen (Aziz et al. 2011). The corn–soybean-wheat-cowpea rotation was characterized by significantly higher total nitrogen content than continuous corn and corn-soybean. The values of selected soil quality properties under the given crop rotation significantly decreased with increasing soil depth. The results suggest that multiple-crop systems could be more effective for maintaining and enhancing soil quality than single-crop systems. Another study (Karlen et al. 1991) emphasized the effect of total N input (as determined by the cropping system) on soil pH. The latter was lower with continuous corn than with crop rotation because of greater N input. Generally, the different nutrient balances associated with different cropping systems should be expected to have a major impact on soil fertility indicators. This renders somewhat problematic our analysis of the effects that crop rotation has on our indicators. We include this paragraph nevertheless, to remain consistent in this report with the other task reports issued from Work Package 3.

3.1.2 Description of cases and Reference treatment

Many types of crop rotation were analyzed in the LTEs collected in Catch-C data base. The rotations differed in crops involved and the duration of the cycle. The duration varied from 2 to 6 years. The rotations with cereals, with legume crops, with tuber or root crops and with grassland were compared with monoculture as a reference treatment.

Tab. 3.1-1. Main descriptive statistics for the response RR of indicators to crop rotation.

Indicator	*Count*	*Mean*	*St. dev.*	*Min*	*Max*	*Skewness*	*Kurtosis*	*Smirnov test*	*t-test*
RR(pH)	6	0.99	0.03	0.95	1.02	0.517	0.146	0.18 ns	0.252 ns
RR(Nt)	24	1.04	0.14	0.75	1.33	-0.43	0.44	0.86 ns	0.217 ns
RR(C/N)	6	0.96	0.033	0.91	0.99	-1.05	-0.57	0.831 ns	0.046
RR(K avail)	3	0.76	0.012	0.74	0.78	-1.66			0.002
RR(P avail)	6	0.95	0.08	0.88	1.06	0.85	-1.73	0.292 ns	0.216 ns

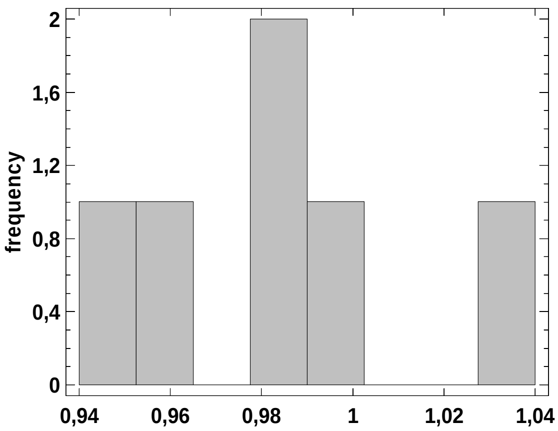
The largest number of cases, 24 in total, was available for comparisons on total N content. The following rotation types were considered: 2 with legume crops, 1 with tuber/root crops, 6 with fallow land, 3 with grasslands, 12 with 2-4 years of ley and arable land, 6 with both root and cereal crops and 2 with legume, tuber, fallow and grassland crops.

Effects of rotation on pH were studied in 6 cases: 2 with legume crops, 1 with tuber crop and 3 rotations with grassland. Effects of rotation on available P were studied in 6 cases with rotations based on maize.

Effects of rotation on C/N were studied in 2 cases with legume crops, 1 with tuber/root and 3 with grasslands.

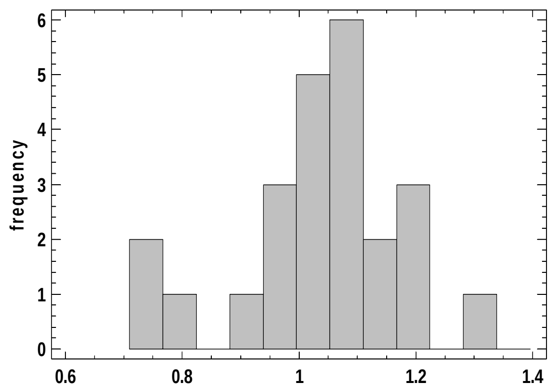
Effects of rotation on available K were studied in rotations with legume crops (2 cases) and with potato (1 case). For the reason of too small number of cases, this indicator was ignored in our analysis of soil fertility response to crop rotation.

Besides the choice (or availability) of a suitable 'reference treatment', another problematic issue when dealing with 'crop rotation' as a management option is the fact that nutrient (N, P, K) balances were hardly ever reported in the publications studied. Therefore, we had to ignore contrasts in nutrient balances as possible causes for RR values being different from 1.



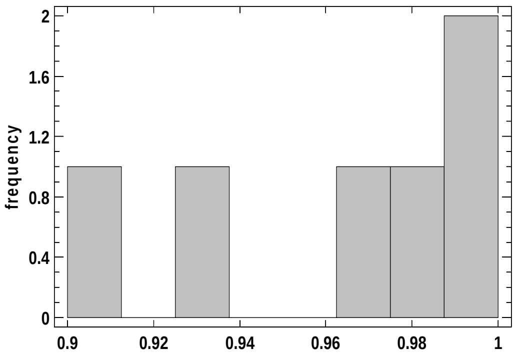
Mean = 0.986
Std. Dev = 0,027
N =6

Fig. 3.1-1. Frequency distribution for the response RR of pH to crop rotation



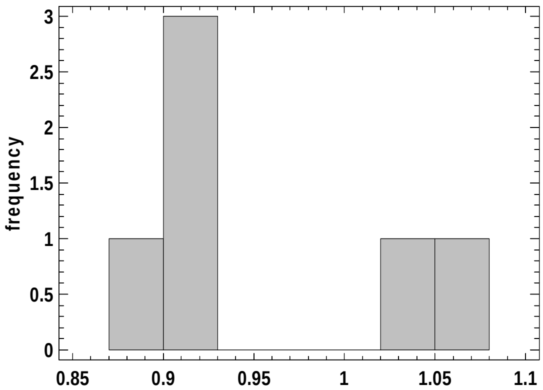
Mean = 1.036
Std. Dev = 0,140
N =24

Fig. 3.1-2. Frequency distribution for the response RR of Nt to crop rotation



Mean = 0.965
Std. Dev = 0.033
N = 6

Fig. 3.1-3. Frequency distribution for the response RR ofC/N to crop rotation.



Mean = 0.954
Std. Dev = 0.079
N = 6

Fig. 3.1-4. Frequency distribution for the response RR of P avail to crop rotation.

The distribution of RR was normal for all indicators and the means were 0.99 for RR(pH), 1.04 for RR(Nt), 0.96 for RR(C/N) and 0.95 for RR(P). Only for C/N and K avail are these means significantly different from 1. We ignore the result for NtS, as Nt (many more observations) shows RR not different from 1. Given the low number of data, the result for K avail can also be ignored.

The total ranges for RR were 0.95 to 1.02 for pH, 0. 75 to 1.33 for Nt, 0.91 to 0.99 for C/N and 0.88 to 1.06 for P avail. RR was greater than 1 in 16.7% (pH), 62.5% (Nt), 0.0% (C/N) and 33.3% (P) of the cases.

Tab. 3.1-2. Number of pH data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10															
	10-30		3		3	6		6			6	3			3	6
	>30															
	Total		3		3	6		6			6	3			3	6
Duration	<5		3			3		3			3					
	5-10															
	11-20															
	>20				3	3		3			3					
	Total		3		3	6		6			6					
Soil texture	Clay															
	Loam		3		3	6										
	Sand															
	Silt															
	Total		3		3	6										

Tab. 3.1-3. Number of Nt data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10															
	10-30	6	3	12		21		21			21	9		2	10	21
	>30				3	3		3			3				3	3
	Total	6	3	12	3	24		24			24	9		2	13	24
Duration	<5	3	3	3		9		9			9					
	5-10															
	11-20			2		2		2			2					
	>20	3		7	3	13		13			13					
	Total	6	3	12	3	24		24			24					
Soil texture	Clay															
	Loam	6	3	12	3	24										
	Sand															
	Silt															
	Total	6	3	12	3	24										

Tab. 3.1-4. Number of C/N data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10															
	10-30		3		3	6		6			6	3			3	6
	>30															
	Total		3		3	6		6			6	3			3	6
Duration	<5		3			3		3			3					
	5-10															
	11-20															
	>20				3	3		3			3					
	Total		3		3	6		6			6					
Soil texture	Clay															
	Loam		3		3	6										
	Sand															
	Silt															
	Total		3		3	6										

Tab. 3.1-5. Number of P avail data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10															
	10-30		6			6		3	3		6	3			3	6
	>30															
	Total		6			6		3	3		3	3			3	6
Duration	<5		3			3		3			3					
	5-10															
	11-20															
	>20			3		3			3		3					
	Total		3	3		6		3	3		6					
Soil texture	Clay															
	Loam		3			3										
	Sand			3		3										
	Silt															
	Total		3	3		6										

3.1.3 Influencing factors

None of the covariate factors had a significant impact on the responses RR of the respective indicators to the practice of crop rotation.

The experiments comparing soil pH between treatments with crop rotations and monoculture were conducted in both Western and Southern Europe, on loamy soils (tab. 3.1-6). Samples were taken from the 10-30 cm soil layer and the practice duration was shorter than 5 or longer than 20 years. The effect of crop rotation on pH was not significantly affected by any of the factors studied.

Tab. 3.1-6. Results of the linear multiple regression for the response RR of pH to crop rotation

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
code	n	mean		n	mean		n	mean		n	mean
Northern	-	-	clay	-	-	<10	-	-	<5	3	0.98 a
Western	3	0.98 a	loam	6	0.99	10-30	6	0.99	5-10	-	-
Eastern	-	-	sand	-	-	>30	-	-	11-20	-	-
Southern	3	0.99 a	silt	-	-	-	-	-	>20	3	0.99 a

There were not significant effects of the factors tested on RR(Nt) (tab. 3.1-7). RR(Nt) was similar in all climatic zones, in all from short-run (< 5 years) to longer-run (11-20 years) LTS and in samples taken from deeper than 10 soil layers. All samples were taken from loamy soils.

Tab. 3.1-7. Results of the linear multiple regression for the response RR of Nt to crop rotation

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		N	mean		n	mean
Northern	6	1.03 a	clay			<10			<5	9	1.11 a
Western	3	0.99 a	loam	24	1.04	10-30	21	1.03 a	5-10	2	0.94 a
Eastern	12	1.05 a	sand			>30	3	1.06 a	11-20	13	1.00 a
Southern	3	1.06 a	silt			-			>20		

None of the tested factors affected significantly the response of C/N to crop rotation (tab. 3.1-8). All data come from loamy soils, sampled at 10-30 cm depth. Climate zone (Western or Southern) nor duration of practice (<5 or >20 years) affected RR(C/N) significantly.

Tab. 3.1-8. Results of the linear multiple regression for the response RR of C/N to crop rotation

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern			clay			<10			<5	3	0.98 a
Western	3	0.98 a	loam	6	0.96	10-30	6	0.96	5-10		
Eastern			sand			>30			11-20		
Southern	3	0.95 a	silt			-			>20	3	0.95 a

The studied factors did not affect RR(P) significantly. The samples were taken in western and eastern climatic zones and from 10-30 cm layer of loamy and sandy soils. Neither did the duration of practice (<5 years or > 20 years) affect RR(P).

Tab. 3.1-9. Results of the linear multiple regression for the response RR of P avail to crop rotation

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern	-	-	clay	-	-	<10	-	-	<5	3	0.91 a
Western	3	0.91 a	loam	3	0.91 a	10-30	6	0.96	5-10	-	-
Eastern	3	1.00 a	sand	3	1.00 a	>30	-	-	11-20	-	-
Southern	-	-	silt	-	-	-	-	-	>20	3	1.00 a

3.2 Catch and cover crops (harvested) and green manures (incorporated)

3.2.1 Expected results from the literature

Leguminous catch crops can supplement N by fixing N_2 from the atmosphere. Forage legumes contain 3-4% N that can originate from both the soil and air (Evers, 2001). When legumes are incorporated into the soil their biomas rich in nitrogen contributes to increase the content of soil organic matter. The same role, though not fixing nitrogen, play non-leguminous catch crop. These crops intercept the residual nitrogen left after the harvest of the main crop. It can be expected that green manures (not harvested) will increase the content of organic nitrogen in the soil and lower the C/N.

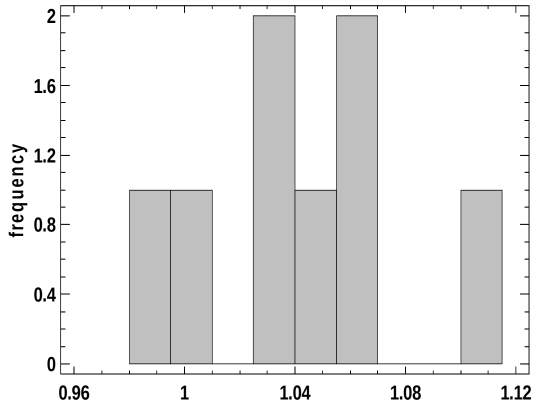
3.2.2 Description of cases and Reference treatment

Our database included only a very limited number of cases that enable to assess the effects of catch or cover crops and green manures on soil chemical indicators (tab. 3.2-1). We report the original observations here, but the statistical analysis was possible only for NtS.

Tab. 3.2-1. Main descriptive statistics for the response RR of indicators to catch and cover crops (harvested).

Indicator	*Count*	*Mean*	*St. dev.*	*Min*	*Max*	*Skewness*	*Kurtosis*	*t-test*
RR(pH)	2	0.99	0.01	0.98	0.99	-	-	0.295 ns
RR(Nt)	2	0.98	0.02	0.96	0.99	-	-	0.330 ns
RR(C/N)	2	0.99	0.01	0.99	1.00	-	-	0.293 ns
RR(NtS)	8	1.04	0.04	0.99	1.11	0.22	0.04	0.02
RR(K avail)	2	0.81	0.07	0.77	0.86	-	-	0.155 ns

Effects of catch crops on Nt stock were studied in 4 cases: 2 cases with radish, 1 with Italian ryegrass, 1 with white mustard and effects of cover crops in 4 cases: 2 with high N supply legumes, 2 with low N supply legumes.



Mean = 1.04
Std. Dev = 0.04
N = 8

Fig. 3.2-1. Frequency distribution for the response RR of NtS to catch and cover crops (harvested).

The distribution of RR(NtS) was normal and mean equalled to 1.04 was significantly different from 1 (tab. 3.2-1, fig. 3.2-1). The total range was 0.99 to 1.11. RR(NtS) was greater than 1 in 75.0% of cases.

Tab. 3.2-2. Number of pH data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10															
	10-30		2			2		2			2	2				2
	>30															
	Total		2			2		2			2	2				2
Duration	<5		2			2		2			2					
	5-10															
	11-20															
	>20															
	Total		2			2		2			2					
Soil texture	Clay															
	Loam		2			2										
	Sand															
	Silt															
	Total		2			2										

Tab. 3.2-3. Number of Nt data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10															
	10-30		2			2		2			2	2				2
	>30															
	Total		2			2		2			2	2				2
Duration	<5		2			2		2			2					
	5-10															
	11-20															
	>20															
	Total		2			2		2			2					
Soil texture	Clay															
	Loam		2			2										
	Sand															
	Silt															
	Total		2			2										

Tab. 3.2-4. Number of NtS data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth																
	0-30		4		4	*8*		7	1		*8*	2		5	1	*8*
	>30															
	Total		*4*		*4*	*8*		*7*	*1*		*8*	*2*		*5*	*1*	*8*
Duration	<5				2	*2*		2			*2*					
	5-10															
	11-20		3		2	*5*		5			*5*					
	>20		1			*1*			1		*1*					
	Total		*4*		*4*	*8*		*7*	*1*		*8*					
Soil texture	Clay															
	Loam		3		4	*7*										
	Sand		1			*1*										
	Silt															
	Total		*4*		*4*	*8*										

Tab. 3.2-5. Number of C/N data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10															
	10-30		2			*2*		2			*2*	2				*2*
	>30															
	Total		*2*			*2*		*2*			*2*	*2*				*2*
Duration	<5		2			*2*		2			*2*					
	5-10															
	11-20															
	>20															
	Total		*2*			*2*		*2*			*2*					
Soil texture	Clay															
	Loam		2			*2*										
	Sand															
	Silt															
	Total		*2*			*2*										

Tab. 3.2-6. Number of K avail data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10															
	10-30		2			*2*		2			*2*	2				*2*
	>30															
	Total		*2*			*2*		*2*			*2*	*2*				*2*
Duration	<5		2			*2*		2			*2*					
	5-10															
	11-20															
	>20															
	Total		*2*			*2*		*2*			*2*					
Soil texture	Clay															
	Loam		2			*2*										
	Sand															
	Silt															
	Total		*2*			*2*										

3.2.3 Influencing factors

The two experiments comparing soil pH, Nt, C/N and K avail content between rotations with cover and catch crop and without them were both conducted in Western Europe, on loamy soils (tab. 3.2-6–3.2.9). Samples were taken from the 10-30 cm soil layer and the duration of the management practice was shorter than 5 years. Therefore, the influence of covariate factors on RR could not be investigated for any of the indicators.

The experiments comparing Nt stock between treatments with catch and cover crops were conducted in Western and Southern Europe, on loamy and sandy soils (tab. 3.2-7). Samples were taken from 10-30 soil layer and the practice duration and the practice duration was shorter than 5 or longer than 10 years. The effect of catch and cover crop was significantly affected only by the duration of practice. The longer time of the practice significantly increased Nt stock comparing short time.

The experiment on the effect of green manures was conducted in Western Europe, on loamy soil. Samples were taken from 10-30 cm soil layer. The management practice was applied more than 20 years.

Tab. 3.2-7. Results of the linear multiple regression for the response RR of NtS to catch and cover crops

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern			clay						<5	2	0.99 b
Western	4	1.04a	loam	7	1.04a	0-30	8	1.04	5-10		
Eastern			sand	1	1.03a	>30			11-20	5	1.06 a
Southern	4	1.04a	silt			-			>20	1	1.04ab

3.3 No tillage

3.3.1 Expected results from the literature

The long-term practice of no-tillage (NT) generally entails larger C and N stocks than conventional tillage (CT) due to better preservation of the organic matter originally present in the soil and/or less mineralization of recently added material (Oorts et al. 2007). However, the difference in organic matter (OM) stocks between the two systems depends on factors such as texture, parent material, regional climate, OM content, cultivation history, cropping system and physical properties (Doran, 1987; Balesdent et al., 2000; Collins et al., 2000). Physical protection of OM by the soil structure is often mentioned as an important contributor to the slower mineralization of OM in NT compared with CT (Balesdent et al., 2000). However, Oorts et al. (2007) showed that under NT system the N stocks, calculated for an equivalent mass of dry soil, were only 10–15% larger than under CT. In studies by other authors (Dzienia et al. 2001, Blecharczyk et al. 2007, Tarkalson et. al 2006) no-tillage system decreased soil pH in the plough layer. According to Stevenson (1994) it can be related to an increased organic matter mineralization process, which produces nutrient elements (in particular NH_3), whose oxidation may contribute to H^+ production. Hansen and Djurhuus, 1997 indicated that no-tillage reduced leaching of nitrogen by 13 kg ha^{-1}, as compared to ploughing on a coarse sandy soil. Under no-tillage system (compared to conventional), nitrogen, phosphorus, potassium and organic carbon contents increased in the surface soil layer (0-5 cm) ; at 5-20 cm depth, an increase of phosphorus and potassium and a decrease of total nitrogen and organic carbon were noticed (Dzienia et al. 2001, Hussain et al.1999, Idkowiak and Kordas, 2004, Małecka et al. 2007, Pecio and Niedźwiecki, 2008).

3.3.2 Description of cases and Reference treatment

A total of 98 cases were analysed to assess the effects of no tillage practices on soil chemical quality indicators (tab. 3.3-1). The results were evaluated in comparison to conventional tillage as a reference treatment. The descriptive statistics are given in Table 3.3-1, and the distributions are shown in figures 3.3-1–3.3-7.

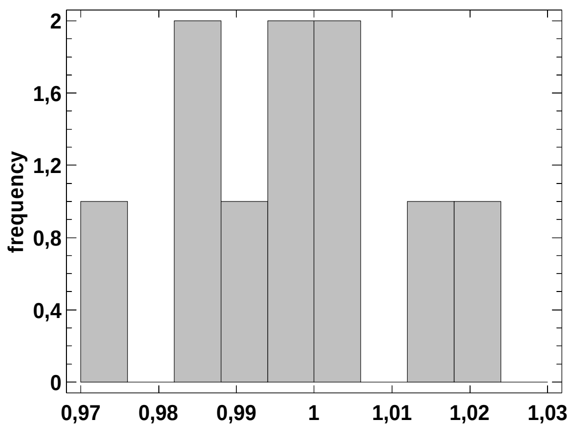
Tab. 3.3-1. Main descriptive statistics for the response RR of indicators to no-tillage.

Indicator	*Count*	*Mean*	*St dev.*	*Min*	*Max*	*Skewness*	*Kurtosis*	*Smirnov test*	*t-test*
RR(pH)	10	1.00	0.016	0.97	1.02	-0.19	0.31	0.139 ns	0.526 ns
RR(Nt)	8	1.02	0.11	0.82	1.19	-0.42	0.28	0.178 ns	0.674 ns
RR(NtS)	25	0.94	0.24	0.56	1.62	0.79	1.19	0.115 ns	0.207 ns
RR(C/N)	13	0.94	0.14	0.70	1.17	-0.24	-0.55	0.158 ns	0.145 ns
RR(N min)	7	1.15	0,24	0,98	1,63	1.62	1.99	0.294 ns	0.071
RR(K avail)	5	0.97	0.28	0.65	1.32	-0.06	-1.99	0.252 ns	0.826 ns
RR(P avail)	30	1.30	0.40	0.64	2.20	0.88	0.11	0.178 ns	0.000

RR showed a normal distribution for all indicators, and the mean RR for all indicators except P avail remained close to 1, deviations not being significant. The percentages of cases where RR was larger than 1 were 40% (pH), 62.5% (Nt), 85.7% (N min), 32% (NtS), 38.5% (C/N), 60% (K avail.) and 80% (P avail).

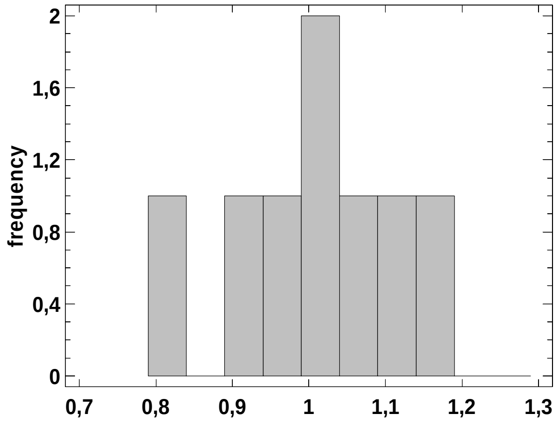
So overall, no-tillage had no significant impact (relative to conventional tillage) on any of our indicators, except on available phosphate (Pavail). Here, no-tillage resulted in a mean increase by 30%. This is largely attributed to the accumulation of fertilizer-P and manure-P in the topsoil, in absence of mechanical soil mixing. Apparently, earthworm activity is insufficient to redistribute P to the extent possible with farm implements. Near surface accumulation of P can be relevant for early crop growth provided that moisture and temperature support root activity; but under dry conditions shallow P may be inaccessible and then this stratification should be considered a disadvantage. Also, water-soluble P was shown to be more prone to loss via surface runoff under no-tillage or reduced tillage. (Rasmussen 1999).

Some increase (though n.s.) in Nmin was observed under no-tillage. This may be related to the decay of crop residues, although we do not see this reflected in elevated Nt under no-tillage. We do not regard this slight increase in N min as very relevant, even if it had been significant.



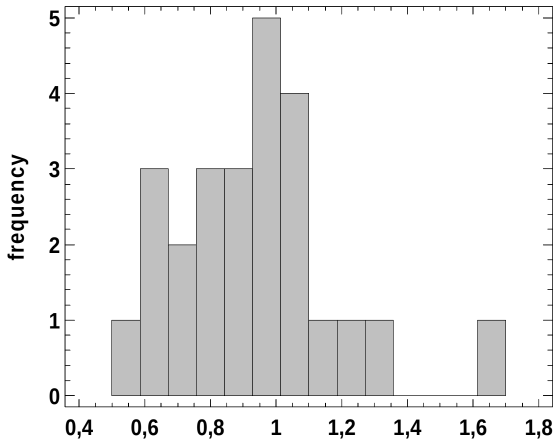
Mean = 0.998
Std. Dev = 0.133
N = 10

Fig. 3.3-1. Frequency distribution for the response RR of pH to no-tillage



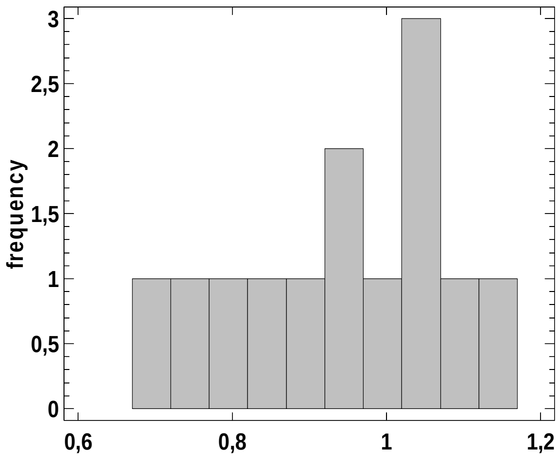
Mean = 1,018
Std. Dev = 0,114
N = 8

Fig. 3.3-2. Frequency distribution for the responseRR of Nt to no-tillage



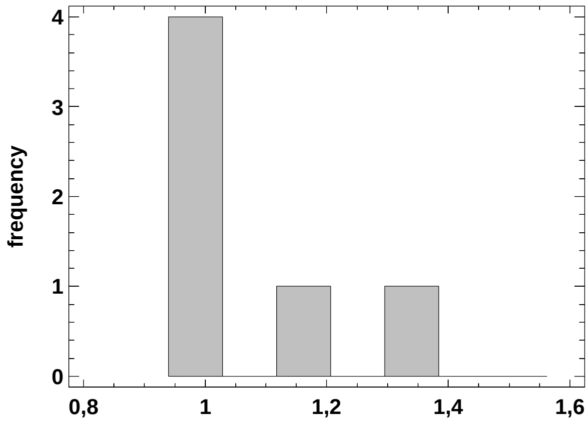
Mean = 0.938
Std. Dev = 0.241
N = 25

Fig. 3.3-3. Frequency distribution for the response RR of NtS to no-tillage



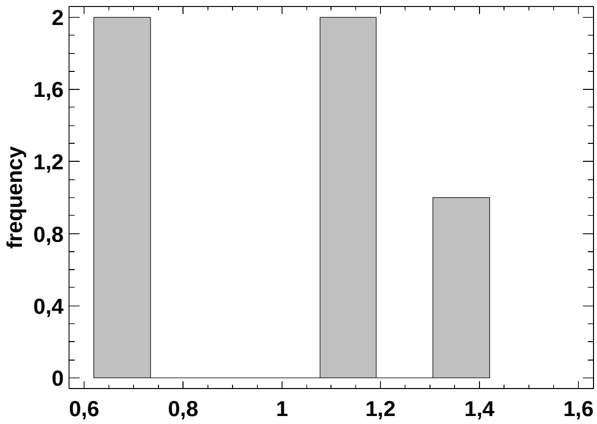
Mean = 0.942
Std. Dev = 0.135
N = 13

Fig. 3.3-4. Frequency distribution for the response RR of C/N to no-tillage



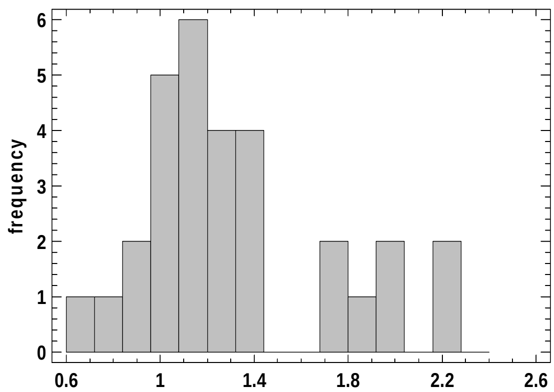
Mean = 1.154
Std. Dev = 0.240
N = 7

Fig. 3.3-5. Frequency distribution for the response RR of N min to no-tillage



Mean = 0.970
Std. Dev = 0.282
N = 5

Fig. 3.3-6. Frequency distribution for the response RR of K avail to no-tillage



Mean = 1.305
Std. Dev = 0.400
N = 30

Fig. 3.3-7. Frequency distribution for the response RR of P avail to no-tillage

Tab. 3.3-2. Number of pH data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10				4	*4*			4		*4*				4	*4*
	10-30				4	*4*			4		*4*			4		*4*
	>30				2	*2*			2		*2*			2		*2*
	Total				*10*	*10*			*10*		*10*			*6*	*4*	*10*
Duration	<5															
	5-10															
	11-20				6	*6*			6		*6*					
	>20				4	*4*			4		*4*					
	Total				*10*	*10*			*10*		*10*					
Soil texture	Clay															
	Loam															
	Sand				10	*10*										
	Silt															
	Total				*10*	*10*										

Tab. 3.3-3. Number of Nt data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10			1		*1*	1				*1*		1			*1*
	10-30			1	2	*3*		2	1		*3*		1	2		*3*
	>30				4	*4*	1		3		*4*				4	*4*
	Total			*2*	*6*	*8*	*2*	*2*	*4*		*8*		*2*	*2*	*4*	*8*
Duration	<5															
	5-10			2		*2*	2				*2*					
	11-20				2	*2*		2			*2*					
	>20				4	*4*			4		*4*					
	Total			*2*	*6*	*8*	*2*	*2*	*4*		*8*					
Soil texture	Clay			2		*2*										
	Loam				2	*2*										
	Sand				4	*4*										
	Silt															
	Total			*2*	*6*	*8*										

Tab. 3.3-4. Number of NtS data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10		5		1	*6*	2	4			*6*	1		5		*6*
	10-30				19	*19*		19			*19*			5	14	*19*
	>30															
	Total		*5*		*20*	*25*	*2*	*23*			*25*	*1*		*10*	*14*	*25*
Duration	<5		1			*1*	1				*1*					
	5-10															
	11-20		4		6	*10*	1	9			*10*					
	>20				14	*14*		14			*14*					
	Total		*5*		*20*	*25*	*2*	*23*			*25*					
Soil texture	Clay		2			*2*										
	Loam		3		20	*23*										
	Sand															
	Silt															
	Total		*5*		*20*	*25*										

Tab. 3.3-5. Number of C/N data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10			6	2	8		8			8	4	4			8
	10-30				5	5		5			5				5	5
	>30															
	Total			6	7	13		13			13	4	4		5	13
Duration	<5			4		4		4			4					
	5-10			2	2	4		4			4					
	11-20															
	>20				5	5		5			5					
	Total			6	7	13		13			13					
Soil texture	Clay															
	Loam			6	7	13										
	Sand															
	Silt															
	Total			6	7	13										

Tab. 3.3-6. Number of N min data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10															
	10-30				3	3			3		3				3	3
	>30				4	4			4		4				4	4
	Total				7	7			7		7				7	7
Duration	<5															
	5-10															
	11-20															
	>20				7	7			7		7					
	Total				7	7			7		7					
Soil texture	Clay															
	Loam															
	Sand				7	7										
	Silt															
	Total				7	7										

Tab. 3.3-7. Number of K avail data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10				5	5		2	3		5	1	3	1		5
	10-30															
	>30															
	Total				5	5		2	3		5	1	3	1		5
Duration	<5				1	1		1			1					
	5-10				3	3			3		3					
	11-20				1	1		1			1					
	>20															
	Total				5	5		2	3		5					
Soil texture	Clay															
	Loam				2	2										
	Sand				3	3										
	Silt															
	Total				5	5										

Tab. 3.3-8. Number of P avail data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10	7		7	5	*19*		6	10	3	*19*	9	5	4	1	*19*
	10-30	3		6	1	*10*		4	5	1	*10*	4	3	2	1	*10*
	>30	1				*1*		1			*1*	1				*1*
	Total	*11*		*13*	*6*	*30*		*11*	15	4	*30*	*14*	*8*	*6*	*2*	*30*
Duration	<5	9		2	3	*14*		3	11		*14*					
	5-10			8		*8*		6		2	*8*					
	11-20	2		2	2	*6*		2	2	2	*6*					
	>20			1	1	*2*			2		*2*					
	Total	*11*		*13*	*6*	*30*		*11*	15	4	*30*					
Soil texture	Clay															
	Loam	5		6		*11*										
	Sand	6		1	6	*13*										
	Silt			6		6										
	Total	*11*		*13*	*6*	*30*										

3.3.3 Influencing factors

We analysed the effects of climate, soil texture, sampling depth and duration of practice on the responses of our indicators to no-tillage. The results are given in Tables 3.3-9 to 3.3-15. Significant effects were found for sampling depth on RR(pH), for duration of practice on RR(NtS), for texture on RR(K avail), and for all factors (climate, texture, depth and duration) on RR(P avail). These effects are discussed below, but most of them seem irrelevant or accidental.

The effect of depth on RR(pH) (Table 3.3-9), is very small and can be ignored. The effect of duration on RR(NtS) (Table 3.3-11) is inconsistent in that the intermediate duration shows RR>1 while the shorter and longer durations both show RR<1. The soil texture effect on RR(K avail) (Table 3.3-14) suggests that no-tillage decreases K avail on loam soils, whereas it would increase K avail on sand. We can suggest no plausible mechanism for this contrast. For RR(P avail) (Table 3.3-15), values differed between climate zones, with highest RR found for no-tillage in the Southern zone, intermediate RR in Northern zone, and lowest (near 1) in the Eastern climate zone. The effect of no-tillage on P avail was more pronounced in sandy soils than in loam soils, and there is a reasonable number of data to support this contrast. However, we cannot explain it. The response of P avail to no-tillage was stronger in the 0-10 cm layer than in the 10-30 cm interval. This is consistent with our understanding that – as stated before - the stratification arises from the lack of turbation combined with fertilizer inputs at the surface. We suggest that the extreme value for RR(P avail) at sampling depth >30 cm (RR=2.2) be ignored, as it applies to one case only.

Tab. 3.3-9. Results of the linear multiple regression for the response RR of pH to no-tillage

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern	-	-	clay	-	-	<10	4	0.99 b	<5	-	-
Western	-	-	loam	-	-	10-30	4	0.99 b	5-10	-	-
Eastern	-	-	sand	10	1.00	>30	2	1.02 a	11-20	6	0.99 a
Southern	10	1.00	silt	-	-	-	-	-	>20	4	1.00 a

Tab. 3.3-10. Results of the linear multiple regression for the response RR of Nt content to no-tillage

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern	-	-	clay	2	1.02 a	<10	1	1.19 a	<5	-	-
Western	-	-	loam	2	1.00 a	10-30	3	0.98 a	5-10	2	1.00 a
Eastern	2	1.00 a	sand	4	1.02 a	>30	4	1.00 a	11-20	2	1.02 a
Southern	6	1.02 a	silt	-	-	-	-	-	>20	4	1.02 a

Tab. 3.3-11. Results of the linear multiple regression for the response RR of NtS to no-tillage

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern	-	-	clay	2	1.06 a	<10	6	0.89 a	<5	1	0.96 ab
Western	5	0.99 a	loam	23	0.93 a	10-30	19	0.95 a	5-10	-	-
Eastern	-	-	sand	-	-	>30	-	-	11-20	10	1.12 a
Southern	20	0.93 a	silt	-	-	-	-	-	>20	14	0.81 b

Tab. 3.3-12. Results of the linear multiple regression for the response RR of C/N ratio to no-tillage

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern	-	-	clay	-	-	<10	8	0.95 a	<5	4	1.02 a
Western	-	-	loam	13	0.94	10-30	5	0.92 a	5-10	4	0.91 a
Eastern	6	1.01 a	sand	-	-	>30	-	-	11-20	-	-
Southern	7	0.89 a	silt	-	-	-	-	-	>20	5	0.91 a

Tab. 3.3-13. Results of the linear multiple regression for the response RR of (Nmin) to no-tillage

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern	-	-	clay	-	-	<10	-	-	<5	-	-
Western	-	-	loam	-	-	10-30	3	1.11 a	5-10	-	-
Eastern	-	-	sand	7	1.15	>30	4	1.19 a	11-20	-	-
Southern	7	1.15	silt	-	-	-	-	-	>20	7	1.15

Tab. 3.3-14. Results of the linear multiple regression for the response RR of K avail to no-tillage

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern	-	-	clay	-	-	<10	5	0.97	<5	1	1.09 a
Western	-	-	loam	2	0.68 b	10-30	-	-	5-10	3	0.82 a
Eastern	-	-	sand	3	1.16 a	>30	-	-	11-20	1	1.32 a
Southern	5	0.97	silt	-	-	-	-	-	>20		

Tab. 3.3-15. Results of the linear multiple regression for the response RR of P avail to no-tillage

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern	11	1.36 b	clay	-	-	<10	19	1.34 b	<5	14	1.45 a
Western	-	-	loam	11	1.15 b	10-30	10	1.15 b	5-10	8	0.93 b
Eastern	13	1.05 c	sand	15	1.50 a	>30	1	2.20 a	11-20	6	1.39 a
Southern	6	1.75 a	silt	4	0.99 b	-	-	-	>20	2	1.59 a

3.4 Non-inversion tillage

3.4.1 Expected results from the literature

By changing the soil tillage system from a ploughing system to a ploughless system with shallow cultivation, nearly all chemical properties of the soil may be affected. The success of no-inversion tillage depends on the soil type and the climatic conditions. In the Scandinavian countries of Denmark, Finland, Norway and Sweden the best results seem to be obtained on the heaviest clay soils, which is the most difficult soils to prepare with conventional soil tillage methods (Rasmussen, 1999). Under no-inversion tillage, nutrients and organic matter accumulated near the soil surface, and in the long run soil pH decreased. Also the leaching of nitrogen seemed to decrease with less intensive cultivation, and spring cultivation gave less leaching than autumn cultivation. (Hansen and Djurhuus, 1997). Stubble cultivation in spring without ploughing compared to stubble cultivation in autumn followed by ploughing on a sandy loam soil gave nitrogen losses of 35 and 76 kg ha^{-1}, respectively. Under Polish conditions of continental climate, non-inversion tillage systems also decreased soil pH in comparison to conventional tillage (Małecka et al. 2007). In the surface horizon (0-5 cm) higher contents were found of organic matter, total N and K available (Dzienia et. al., 2001, Hussain et al., 1999).

3.4.2 Description of cases and Reference treatment

The analysis considered practices of tillage to different, shallow soil depths (around 10 or 15 cm), without inverting the soil. The machinery used was much differentiated between studied experiments. However, disc harrow, stubble cultivator, rotary driller were used the most often. In 5 cases, an Actisol cultivator to 25-30 cm soil depth was used. Conventional (mouldboard) ploughing to 25-30 depth with soil inversion was used as a reference treatment.

Tab. 3.4-1. Main descriptive statistics for the response RR of indicators to non-inversion tillage.

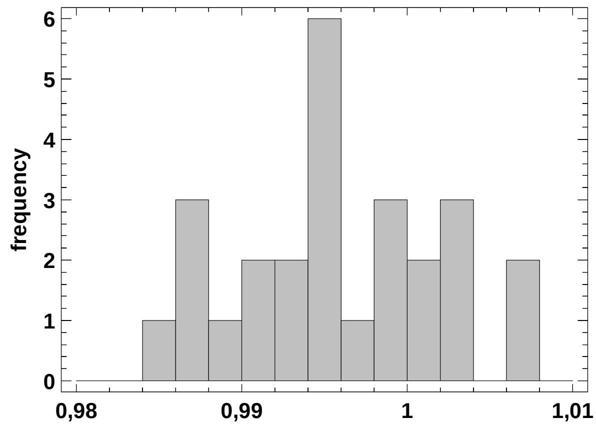
Indicator	*Count*	*Mean*	*St. dev.*	*Min*	*Max*	*Skewness*	*Kurtosis*	*Smirnov test*	*t-test*
RR(PH)	26	1.00	0.01	0.99	1.01	-0.02	-0.85	0.124 ns	0.998 ns
RR(Nt)	29	1.07	0.08	0.90	1.22	0.14	-0.38	0.106 ns	0.000
RR(NtS)	41	1.11	0.31	0.58	1.80	0.56	-0.62	0.176 ns	0.024
RR(C/N)	31	0.97	0.09	0.83	1.21	0.08	0.07	0.145 ns	0.126 ns
RR(N min)	1	0.87		0.87	0.87	-	-	-	-
RR(K avail)	26	1.46	0.30	1.04	2.21	0.73	0.07	0.116 ns	0.000
RR(P avail)	71	1.10	0.29	0.27	1.79	0.44	0.94	0.129 ns	0.005

For this management practice (non-inversion tillage) there is a considerable number of observations available to assess the responses of pH, Nt, NtS, C/N, K avail, and P avail (tab.

3.4-1). For all these indicators, RR showed a normal distribution (Figs 3.4-1–3.4-6). The indicator Nmin is ignored here, for lack of data. Responses were significant for Nt, NtS, K avail and P avail.

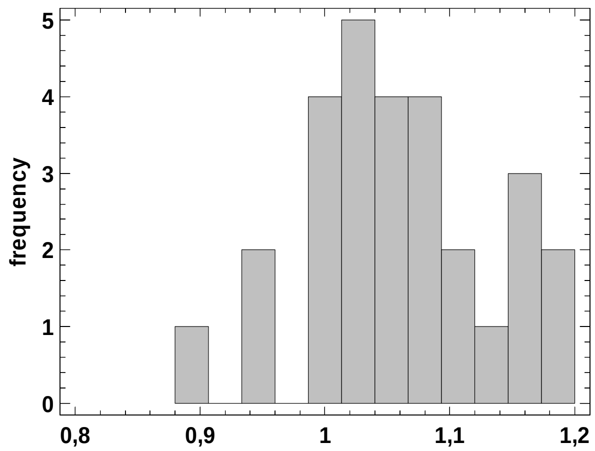
The most striking response to tillage is found here for K avail. The RR(Kavail) values ranged from 1.04 to 2.21, with a mean at 1.46. To lesser extent, also Nt, NtS and Pavail were affected by non-inversion tillage.

The percentages of cases where RR was larger than 1 were 26.9% (pH), 75.9% (Nt) 56.1% (NtS), 41.9% (C/N), 96.1% (K avail) and 47.9 % (Pavail).



Mean = 0.996
Std. Dev = 0.006
N = 26

Fig. 3.4-1. Frequency distribution for the response RR of pH to non-inversion tillage



Mean = 1.066
Std. Dev = 0.079
N = 29

Fig. 3.4-2. Frequency distribution for the response RR of Nt to non-inversion tillage

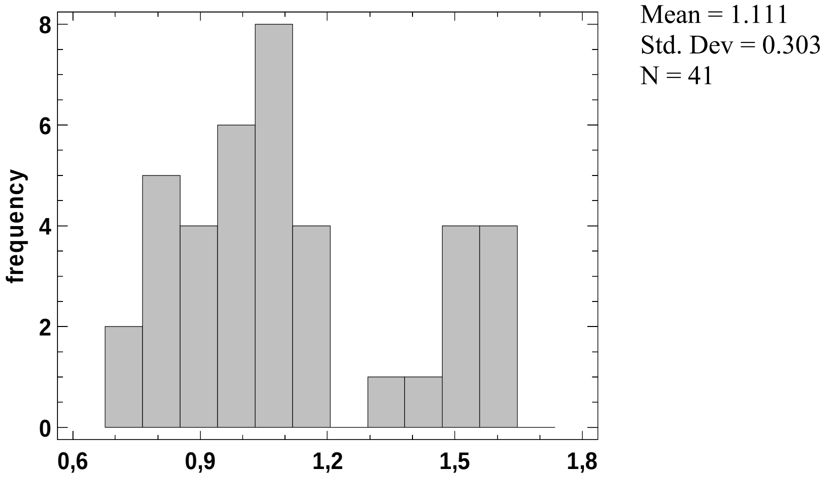


Fig. 3.4-3. Frequency distribution for the response RR of NtS to non-inversion tillage

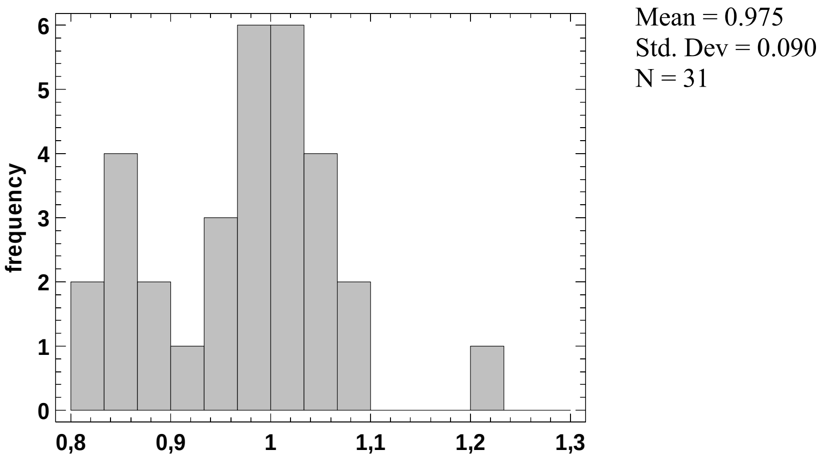


Fig. 3.4-4. Frequency distribution for the response RR of C/N to non-inversion tillage

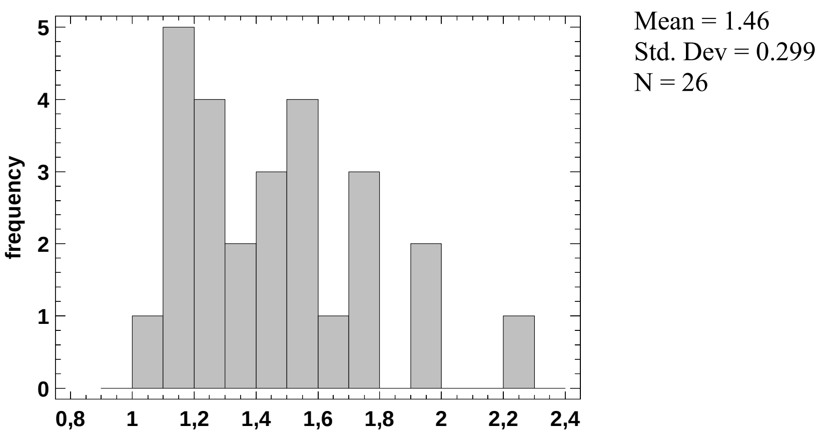
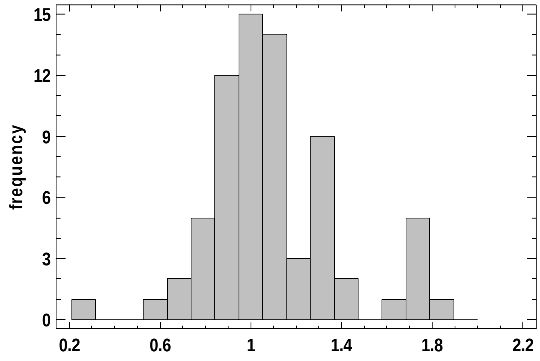


Fig. 3.4-5. Frequency distribution for the response RR of K avail to non-inversion tillage



Mean = 1.098
Std. Dev = 0.286
N = 71

Fig. 3.4-6. Frequency distribution for the response RR of P avail to non-inversion tillage

Tab. 3.4-2. Number of pH data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	To	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10		1	22		*23*		23			*23*	1	20	2		*23*
	10-30		1	2		*3*		3			*3*	3				*3*
	>30															
	Total		*2*	*24*		*26*		*26*			*26*	*4*	*20*	*2*		*26*
Duration	<5		2	2		*4*		4			*4*					
	5-10			20		*20*		20			*20*					
	11-20			2		*2*		2			*2*					
	>20															
	Total		*2*	*24*		*26*		*26*			*26*					
Soil texture	Clay															
	Loam		2	24		*26*										
	Sand															
	Silt															
	Total		*2*	*24*		*26*										

Tab. 3.4-3. Number of Nt data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10		2	1		*3*	3				*3*	2	1			*3*
	10-30		2	21		*23*		23			*23*	2	3	18		*23*
	>30				3	*3*		3			*3*		2	1		*3*
	Total		*4*	*22*	*3*	*29*	*3*	*26*			*29*	*4*	*6*	*19*		*29*
Duration	<5		4			*4*		4			*4*					
	5-10			4	2	*6*	2	4			*6*					
	11-20			18	1	*19*	1	18			*19*					
	>20															
	Total		*4*	*22*	*3*	*29*	*3*	*26*			*29*					
Soil texture	Clay				3	*3*										
	Loam		4	22		*26*										
	Sand															
	Silt															
	Total		*4*	*22*	*3*	*29*										

Tab. 3.4-4. Number of NtS data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10				16	*16*		16			*16*			2	14	*16*
	10-30		5		20	*25*		25			*25*			12	13	*25*
	>30															
	Total		*5*		*36*	*41*		*41*			*41*			*14*	*27*	*41*
Duration	<5															
	5-10															
	11-20		4		10	*14*		14			*14*					
	>20		1		26	*27*		27			*27*					
	Total		*5*		*36*	*41*		*41*			*41*					
Soil texture	Clay															
	Loam		5		36	*41*										
	Sand															
	Silt															
	Total		*5*		*36*	*41*										

Tab. 3.4-5. Number of C/N data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10		3	5	9	*17*		17			*17*	5	1	1	10	*17*
	10-30		1	5	5	*11*		9	2		*11*	4	1		6	*11*
	>30		1		2	*3*		1	2		*3*				3	*3*
	Total		*5*	*10*	*16*	*31*		*27*	*4*		*31*	*9*	*2*	*1*	*19*	*31*
Duration	<5		1	8		*9*		9			*9*					
	5-10			2		*2*		2			*2*					
	11-20		1			*1*		1			*1*					
	>20		3		16	*19*		15	4		*19*					
	Total		*5*	*10*	*16*	*31*		*27*	*4*		*31*					
Soil texture	Clay															
	Loam		5	10	12	*27*										
	Sand				4	*4*										
	Silt															
	Total		*5*	*10*	*16*	*31*										

Tab. 3.4-6. Number of K avail data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10		1			*1*		1			*1*	1				*1*
	10-30		1	24		*25*		25			*25*	3	2	20		*25*
	>30															
	Total		*2*	*24*		*26*		*26*			*26*	*4*	*2*	*20*		*26*
Duration	<5		2	2		*4*		4			*4*					
	5-10			2		*2*		2			*2*					
	11-20			20		*20*		20			*20*					
	>20															
	Total		*2*	*24*		*26*		*26*			*26*					
Soil texture	Clay															
	Loam		2	24		*26*										
	Sand															
	Silt															
	Total		*2*	*24*		*26*										

Tab. 3.4-7. Number of P avail data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10		6	13	3	*22*	1	12	2	7	*22*	7	7	8		*22*
	10-30		5	36	2	*43*	1	33	2	7	*43*	7	8	27	1	*43*
	>30		6			*6*	2			4	*6*	2		4		*6*
	Total		*17*	*49*	*5*	*71*	*4*	*45*	4	18	*71*	*16*	*15*	*39*	*1*	*71*
Duration	<5		6	10		*16*	3	11	2		*16*					
	5-10		1	10	4	*15*	1	12		2	*15*					
	11-20		10	29		*39*		22	1	16	*39*					
	>20				1	*1*			1		*1*					
	Total		*17*	*49*	*5*	*71*	*4*	*45*	4	18	*71*					
Soil texture	Clay		3		1	*4*										
	Loam		4	38	3	*45*										
	Sand			3	1	*4*										
	Silt		10	8		18										
	Total		*17*	*49*	*5*	*71*										

3.4.3 Influencing factors

We analysed the effects of climate, soil texture, sampling depth and duration of practice on the responses of our indicators to non-inversion tillage. The results are given in Tables 3.4-8 to 3.4-13. Significant effects were found for sampling depth on RR(Nt) and RR(NtS), for duration on RR(K avail). Surprisingly, of the factors tested only climate (not depth or duration) affected RR(P avail) significantly. These effects are discussed below.

As with no-tillage, non-inversion tillage also showed a stratification of Nt and P avail in the top layer, with values 10-20% higher in 0-10 cm than in 10-30 cm depth intervals (though for P avail the difference was n.s.). The same pattern is expected for K avail, but could not be evaluated for lack of data (all K avail data refer to the 10-30 cm interval). For K avail, the effect of duration on RR appears relatively large. Where no-inversion tillage was practiced for more than 10 years, the increase in K avail (relative to ploughing) exceeded 50%, whereas this increase was around 15% only in shorter-run trials (<10 years). However, the strong response of K avail to tillage – as well as the effect of duration – is largely determined by one single location (LTE) with multiple (time series) observations.

Experiments on K avail were conducted in eastern and western climates, on loamy soils and samples were taken from 0-30 cm soil layer (tab. 3.4-12).

RR(P avail) values were differentiated only by climatic zone (tab. 3.4-13). Significantly higher increases of P avail content were found in the Western climatic zones than in the Eastern ones. This is attributed to higher P inputs in the Western zones.

Tab. 3.4-8. Results of the linear multiple regression for the response RR of pH to non-inversion tillage

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern	-	-	clay	-	-	<10	23	1.00 a	<5	4	1.00 a
Western	2	1.00 a	loam	26	1.00 a	10-30	3	1.00 a	5-10	20	1.00 a
Eastern	24	1.00 a	sand	-	-	>30	-	-	11-20	2	0.99 a
Southern	-	-	silt	-	-	-	-	-	>20	-	-

Tab. 3.4-9. Results of the linear multiple regression for the response RR of Nt to non-inversion tillage

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern	-	-	clay	3	1.15 a	<10	3	1.14 a	<5	4	1.05 a
Western	4	1.05 a	loam	26	1.06 a	10-30	23	1.05 b	5-10	6	1.05 a
Eastern	22	1.06 a	sand	-	-	>30	3	1.15 a	11-20	19	1.07 a
Southern	3	1.15 a	silt	-	-	-	-	-	>20	-	-

Tab. 3.4-10. Results of the linear multiple regression for the response RR of NtS to non-inversion tillage

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern	-	-	clay	-	-	<10	16	1.23 a	<5	-	-
Western	5	1.04 a	loam	41	1.11	10-30	25	1.04 b	5-10	-	-
Eastern	-	-	sand	-	-	>30	-	-	11-20	14	1.02 a
Southern	36	1.12 a	silt	-	-	-	-	-	>20	27	1.16 a

Tab. 3.4-11. Results of the linear multiple regression for the response RR of C/N ratio to non-inversion tillage

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern	-	-	clay	-	-	<10	17	0.984 a	<5	9	1.00 a
Western	5	0.95 a	loam	27	0.96 a	10-30	11	0.96 a	5-10	2	1.01 a
Eastern	10	1.01 a	sand	4	1.05 a	>30	3	0.97 a	11-20	1	1.00 a
Southern	16	0.96 a	silt	-	-	-	-	-	>20	19	0.96 a

Tab. 3.4-12. Results of the linear multiple regression for the response RR of K avail to non-inversion tillage

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern	-	-	clay	-	-	<10	1	1.29 a	<5	4	1.14 b
Western	2	1.17 a	loam	26	2.33	10-30	25	1.47 a	5-10	2	1.15 b
Eastern	24	1.49 a	sand			>30			11-20	20	1.46 a
Southern	-	-	silt	-	-	-	-	-	>20	-	-

Tab. 3.4-13. Results of the linear multiple regression for the response RR of P avail to non-inversion tillage

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern	-	-	clay	4	1.25 a	<10	22	1.13 a	<5	16	1.07 a
Western	17	1.26 a	loam	45	1.07 a	10-30	43	1.06 a	5-10	15	1.01 a
Eastern	49	1.04 b	sand	4	1.00 a	>30	6	1.27 a	11-20	39	1.09 a
Southern	5	1.12 ab	silt	18	1.16 a	-	-	-	>20	1	1.10 a

3.5 Mineral fertilization

3.5.1 Expected results from the literature

Mineral fertilization enhances crop growth and C inputs from increased crop residue production. There exists numerous forms of synthetic fertilizers. They vary in their behavior during processes causing leaching and volatilization of nitrogen. The application of fertilizer N increases soil mineral nitrogen content. However, it has often little or no effect on SOC, which may be mostly due to the fact that N fertilization may stimulate soil microbes to mineralize SOM. Nitrogen fertilization has been found to promote SOC and SON accumulation particularly in soils that were originally poor in SOM (Whitehead, 1995). A positive effect of fertilizer N on SOM accumulation is also likely in poorly-drained clay soils, where the mineralization of plant residues is slow due to restricted aeration. On soils with a high C:N ratio, the addition of nitrogen may promote the biological breakdown of organic materials. N fertilization has been found to increase C sequestration primarily because of the higher plant productivity, leading to greater return of plant residues to the soil. It was found that mineral fertilizers, especially NH_4^+ sources, may acidify the soil. They increase also mineral nitrogen content. Higher level of nitrogen fertilization (100 versus 50 kg N/ha) may decrease the contents of total nitrogen, potassium and organic carbon in the whole soil profile and increase content of phosphorus in uppermost layer (Idkowiak and Kordas 2004). According to Koszański et al. (1995) the amounts of phosphorus and potassium clearly decreased in the treatments with high N doses, and Nt content and Corg increased. In the opinion of Panak et al. (1996), however, increasing nitrogen rates do not clearly influence soil P avail content. Mineral P fertilization resulted in a build-up of plant-available P in the top soil (Vogeler et al. 2009).

3.5.2 Description of cases and Reference treatment

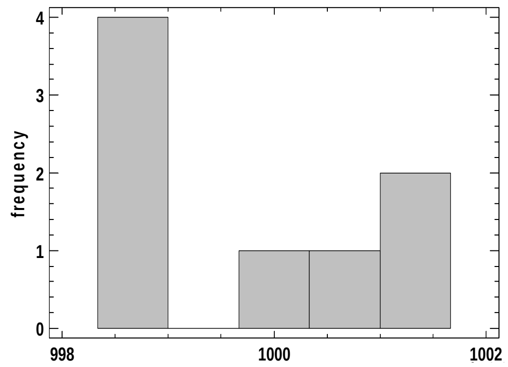
The responses of soil pH, Nt, C/N, N min, K avail and P avail to the application of mineral fertilization was studied. For each nutrient, we compared a given input level to a treatment where this nutrient was altogether withheld or, if such treatment was not included, to the lowest application rate of that nutrient in the trial. The results are given in Table 3.5-1.

As indicated by skewness and kurtosis values, RR was normally distributed for all indicators studied.

RR was greater than 1 in 33.3% (pH), 93.3% (Nmin), 61.2% (Nt), 44.4% (C/N), 100.0% (K avail), 100.0% (P avail) of the cases. Strongest responses to fertilizer application were found for the indicators P avail, K avail and N min. The overall increase (by 164%) of P avail due to the application of P fertilizers was based on 37 cases, the increase (by 133%) of K avail due to the application of K fertilizers was based on 26 cases and the increase (by 60%) of N min due to the application of N fertilizers was based on 30 cases.

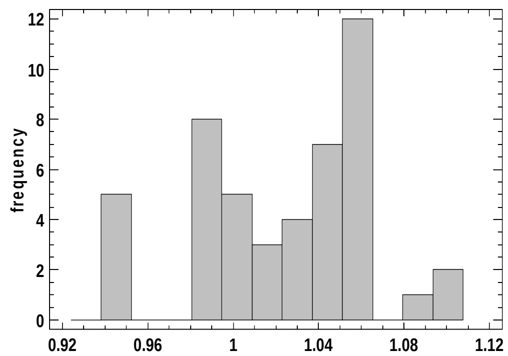
Tab. 3.5-1. Main descriptive statistics for the response RR of indicators to mineral fertilization.

Indicator	*Count*	*Mean*	*St. dev.*	*Min*	*Max*	*Skewness*	*Kurtosis*	*Smirnov test*	*t-test*
RR(PH)	15	1.00	0.002	1.00	1.004	0.13	-1.35	0.613 ns	0.171 ns
RR(Nt)	49	1.02	0.04	0.92	1.13	-0.23	-0.22	0.572 ns	0.002
RR(C/N)	9	0.97	0.11	0.81	1.17	0.09	-0.68	0.997 ns	0.512 ns
RR(N min)	30	1.60	0.55	0.74	2.83	0.71	-0.29	0.709 ns	0.000
RR(K avail)	26	2.33	0.49	1.18	3.28	-0.15	0.22	0.919 ns	0.000
Pavail RR	37	2.64	1.01	1.35	4.85	1.08	0.19	0.116 ns	0.000



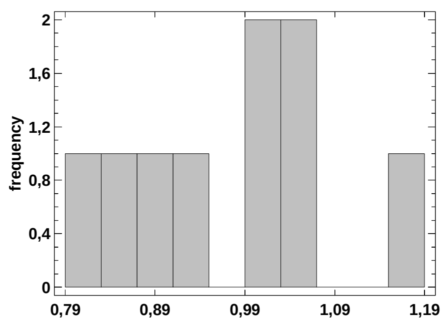
Mean = 1.00
Std. Dev = 0.002
N = 15

Fig. 3.5-1. Frequency distribution for the response RR of pH to mineral fertilization



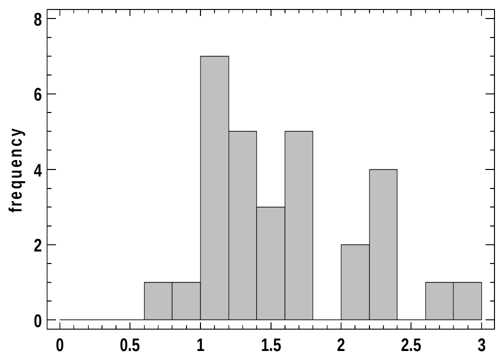
Mean = 1.024
Std. Dev = 0.044
N = 49

Fig. 3.5-2. Frequency distribution for the response RR of Nt to mineral fertilization



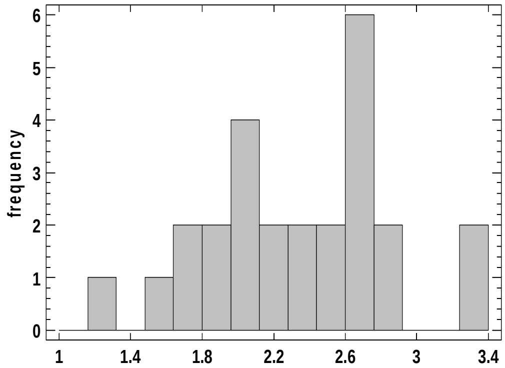
Mean = 0.97
Std. Dev = 0.11
N = 9

Fig. 3.5-3. Frequency distribution for the response RR of C/N to mineral fertilization



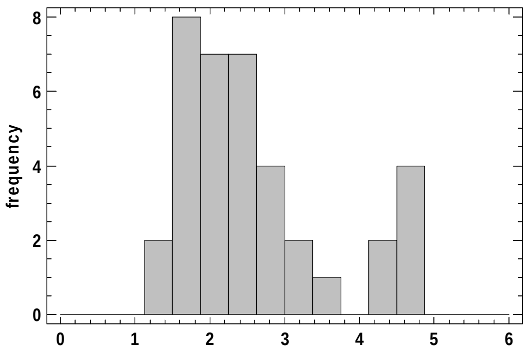
Mean = 1.60
Std. Dev = 0.553
N = 30

Fig. 3.5-4. Frequency distribution for the response RR of N min to mineral fertilization



Mean = 2.331
Std. Dev = 0.492
N = 26

Fig. 3.5-5. Frequency distribution for the response RR of K avail to mineral fertilization



Mean = 2.636
Std. Dev = 1.009
N = 37

Fig. 3.5-6. Frequency distribution for the response RR of P avail to mineral fertilization

Tab. 3.5-2. Number of pH data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10															
	10-30		2	13		*15*	1	14			*15*	2		12	1	*15*
	>30															
	Total		*2*	*13*		*15*	*1*	*14*			*15*	*2*		*12*	*1*	*15*
Duration	<5		2			*2*	2				*2*					
	5-10															
	11-20															
	>20			13		*13*		13			*13*					
	Total		*2*	*13*		*15*	*2*	*13*			*15*					
Soil texture	Clay		1			*1*										
	Loam			14		*14*										
	Sand															
	Silt															
	Total		*2*	*13*		*15*										

Tab. 3.5-3. Number of Nt in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10															
	10-30	26		5	17	*48*	5	43			*48*	5	15	27	17	*48*
	>30				1	*1*		1			*1*			1		*1*
	Total	*26*		*5*	*18*	*49*	*5*	*44*			*49*	*5*	*15*	*28*	*17*	*49*
Duration	<5			4	1	*5*		5			*5*					
	5-10					*15*	2	13			*15*					
	11-20			1		*29*	3	26			*29*					
	>20															
	Total	*26*		*5*	*18*	*49*	*5*	*44*			*49*					
Soil texture	Clay				5	*5*										
	Loam	26		5	13	*44*										
	Sand															
	Silt															
	Total	*26*		*5*	*18*	*49*										

Tab. 3.5-4. Number of C/N data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10		4			*4*		4			*4*				4	*4*
	10-30		3	2		*5*		5			*5*	2	2	1		*5*
	>30															
	Total		*7*	*2*		*9*		*9*			*9*	*2*	*2*	*1*	*4*	*9*
Duration	<5		2			*2*		2			*2*					
	5-10		1	1		*2*		2			*2*					
	11-20			1		*1*		1			*1*					
	>20		4			*4*		4			*4*					
	Total		*7*	*2*		*9*		*9*			*9*					
Soil texture	Clay															
	Loam		7	2		*9*										
	Sand															
	Silt															
	Total		*7*	*2*		*9*										

Tab. 3.5-5. Number of N min data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10															
	10-30			24		*24*		24			*24*			24		*24*
	>30		6			*6*		6			*6*	6				*6*
	Total		*6*	*24*		*30*		*30*			*30*	*6*		*24*		*30*
Duration	<5		6			*6*		6			*6*					
	5-10															
	11-20			24		*24*		24			*24*					
	>20															
	Total		*6*	*24*		*30*		*30*			*30*					
Soil texture	Clay															
	Loam		6	24		*30*										
	Sand															
	Silt															
	Total		*6*	*24*		*30*										

Tab. 3.5-6. Number of K avail data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10															
	10-30		2	24		*26*		26			*26*	2		24		*26*
	>30															
	Total		*2*	*24*		*26*		*26*			*26*	*2*		*24*		*26*
Duration	<5		2			*2*		2			*2*					
	5-10															
	11-20															
	>20			24		*24*		24			*24*					
	Total		*2*	*24*		*26*		*26*			*26*					
Soil texture	Clay															
	Loam		2	24		*26*										
	Sand															
	Silt															
	Total		*2*	*24*		*26*										

Tab. 3.5-7. Number of P avail data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10															
	10-30			37		*37*		37			*37*				37	*37*
	>30															
	Total			*37*		*37*		*37*			*37*				*37*	*37*
Duration	<5															
	5-10															
	11-20															
	>20			37		*37*		37			*37*					
	Total			*37*		*37*		*37*			*37*					
Soil texture	Clay															
	Loam			37		*37*										
	Sand															
	Silt															
	Total			*37*		*37*										

3.5.3 Influencing factors

We analysed the effects of climate, soil texture, sampling depth and duration of practice on the responses of our indicators to mineral fertilizer application. The results are given in Tables 3.5-8 to 3.5-13. Effects of these factors were either very small or not significant, like for the effect of climatic zone and duration of the practice on RR(pH) (tab.3.5-8). Significantly higher increases were found in western countries than in northern ones for Nt (tab. 3.5-9), and in eastern countries than in western ones for N min and K avail (tab. 3.5-11, tab. 3.5-12). The effect of duration of the practice is not clear, as slight increases were noted in both the short-term (<5 years) and long-term (>20 years) LTEs, but not in medium-term (11-20 years) LTEs. The duration of N mineral fertilization affected also RR(C/N) (tab. 3.5-10). However, due to small number of cases the interpretation should be dropped. Similarly, the effects of climatic zone and duration of the practice on RR (N min) and RR (K avail) could not be separated from each other, due to the confounded data structure (with all eastern data referring to long duration) (tab. 3.5-11, 3.5-12).

Tab. 3.5-8. Results of the linear multiple regression for the response RR of pH to mineral fertilizer application

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern	-	-	clay	1	1.001 a	<10	-	-	<5	2	1.003 a
Western	2	1.003 a	loam	14	1.001 a	10-30	15	1.00	5-10	-	-
Eastern	13	1.000 a	sand	-	-	>30	-	-	11-20	12	1.00 a
Southern	-	-	silt	-	-	-	-	-	>20	1	1.00 a

Tab. 3.5-9. Results of the linear multiple regression for the response RR of Nt to mineral fertilizer application

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern	26	1.01 b	clay	5	0.998 a	<10	-	-	<5	5	1.06 a
Western	5	1.06 a	loam	44	1.027 a	10-30	48	1.03 a	5-10		
Eastern	18	1.03 ab	sand	-	-	>30	1	0.95 a	11-20	27	1.03 ab
Southern	-	-	silt	-	-	-	-	-	>20	17	1.01 b

Tab. 3.5-10. Results of the linear multiple regression for the response RR of C/N to mineral fertilizer application

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern	-	-	clay			<10	4	0.95 a	<5	2	0.97 a
Western	7	0.97 a	loam	9	0.97	10-30	5	0.99 a	5-10	2	0.93 a
Eastern	2	0.99 a	sand	-	-	>30	-	-	11-20	1	1.17 a
Southern	-	-	silt	-	-	-	-	-	>20	4	0.95 a

Tab. 3.5-11. Results of the linear multiple regression for the response RR of N min to mineral fertilizer application

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern	-	-	clay	-	-	<10	-	-	<5	6	1.08 b
Western	6	1.08 b	loam	30	1.60	10-30	24	1.73 a	5-10	-	-
Eastern	24	1.73 a	sand	-	-	>30	6	1.08 b	11-20	24	1.73 a
Southern	-	-	silt	-	-	-	-	-	>20	-	-

Tab. 3.5-12. Results of the linear multiple regression for the response RR of K to mineral fertilizer application

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern	-	-	clay			<10	-	-	<5	2	1.40 b
Western	2	1.40 b	loam	26	2.33	10-30	26	2.33	5-10		
Eastern	24	2.41 a	sand	-	-	>30	-	-	11-20	24	2.41 a
Southern			silt	-	-	-	-	-	>20		

Tab. 3.5-13. Results of the linear multiple regression for the response RR of P avail to mineral fertilizer application

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern	-	-	clay			<10			<5		
Western	-	-	loam	37	2.64	10-30	37	2.64	5-10		
Eastern	37	2.64	sand			>30	-	-	11-20		
Southern	-	-	silt	-	-	-	-	-	>20	37	2.64

3.6 Fertilization with compost

3.6.1 Expected results from the literature

Compost is organic matter that has been decomposed and recycled as a fertilizer and soil amendment. According to study of Epstein et al. (1976) compost is easily applied organic fertilizer which produces a friable seedbed. As a result of the addition of compost the soil's cation exchange capacity increased as much as threefold. Nitrate-nitrogen levels were highest at the 15–20 cm soil depth but decreased sharply below this level. Available phosphorus was high during the 2-year study and appeared to be in excess of that needed for good crop growth. Soil NO_3^--N levels were not affected by compost applications (Schlegel 2013). Compost derived from animal manures is effective for maintaining or increasing soil phosphate status, without excessive accumulation of NO_3^-.

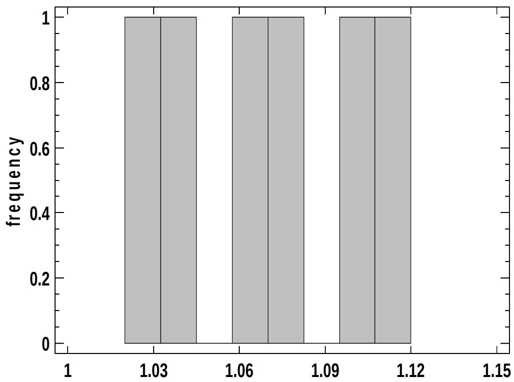
3.6.2 Description of cases and Reference treatment

In our study the effects of plant, bio-waste and sludge composts were determined by comparison with reference treatments that received similar amounts of plant available N or K (not total N or K), given as mineral fertilizer (tab. 3.6-1).

All studied indicators: RR(pH), RR(Nt), RR(C/N), RR(N min) and RR(K avail) showed a positive response to compost application (tab. 3.6-1, fig.3.6-1 to 3.6-5). The strongest response was that of Nt (+14%). Another significant response was that of pH. RR(Nt) and RR(pH) were >1 in all cases, and RR(N min) in 77.8% of the cases, and RR(C/N) in 54.5% of cases. It should be noticed that RR(N min) data belong to one experiment. RR(K avail) data were too few to justify statistical analysis.

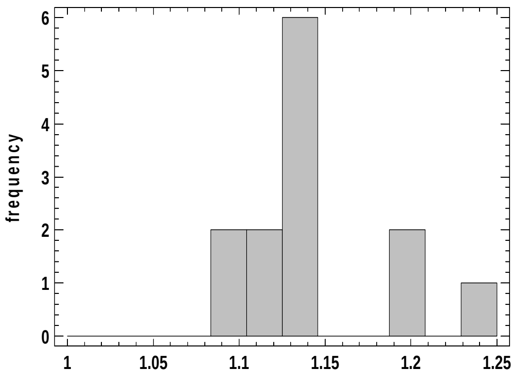
Tab. 3.6-1. Main descriptive statistics for the response RR of indicators to fertilization with compost.

Indicator	*Count*	*Mean*	*St. dev.*	*Min*	*Max*	*Skewness*	*Kurtosis*	*Smirnov test*	*t-test*
RR(PH)	6	1.07	0.03	1.03	1.11	-0.12	-1.36	0.996 ns	0.003
RR(Nt)	13	1.14	0.04	1.09	1.23	1.04	0.42	0.241 ns	0.000
RR(C/N)	11	1.03	0.06	0.96	1.12	0.65	-1.12	0.760 ns	0.106 ns
RR(N min)	9	1.09	0.13	0.86	1.29	-0.39	0.04	0.994 ns	0.065
RR(K avail)	4	1.04	0.05	0.98	1.10	-0.57	-0.26	0.999 ns	0.199 ns



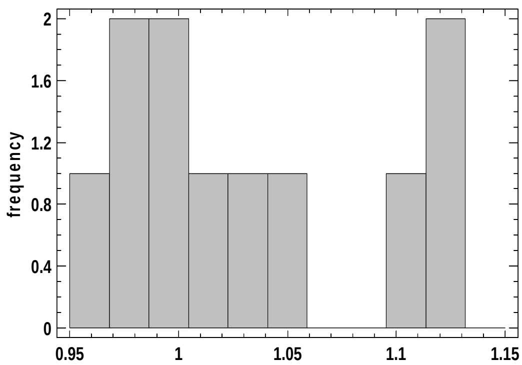
Mean = 1.07
Std. Dev = 0.032
N = 6

Fig. 3.6-1. Frequency distribution for the response RR of pH to fertilization with compost



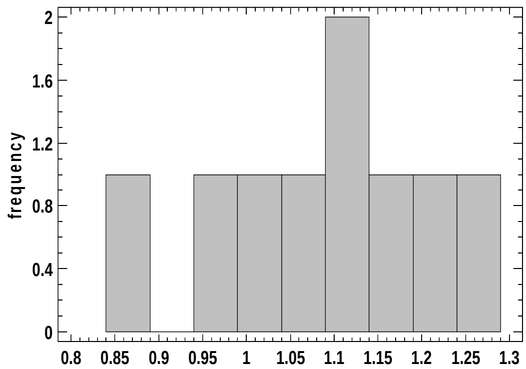
Mean = 1.145
Std. Dev = 0.042
N = 13

Fig. 3.6-2. Frequency distribution for the response RR of Nt to fertilization with compost



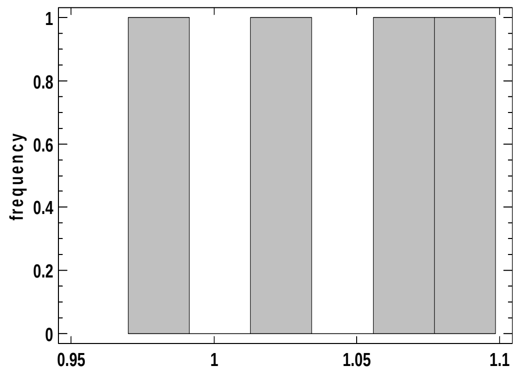
Mean = 1.031
Std. Dev = 0.058
N = 11

Fig. 3.6-3. Frequency distribution for the response RR of C/N to fertilization with compost



Mean = 1.092
Std. Dev = 0.129
N = 9

Fig. 3.6-4. Frequency distribution for the response RR of N min to fertilization with compost



Mean = 1.043
Std. Dev = 0.051
N = 4

Fig. 3.6-5. Frequency distribution for the response RR of K avail to fertilization with compost

Tab. 3.6-2. Number of pH data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10															
	10-30		6			6					6	3	3			6
	>30															
	Total		6			6		6			6	3	3			6
Duration	<5		3			3		3			3					
	5-10		3			3		3			3					
	11-20															
	>20															
	Total		6			6		6			6					
Soil texture	Clay															
	Loam		6			6										
	Sand															
	Silt															
	Total		6			6										

Tab. 3.6-3. Number of Nt data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10															
	10-30		7	6		13	6	7			13	3	3	6	1	13
	>30															
	Total		7	6		13	6	7			13	3	3	6	1	13
Duration	<5		3			3		3			3					
	5-10		3			3		3			3					
	11-20			6		6	6				6					
	>20		1			1		1			1					
	Total		7	6		13	6	7			13					
Soil texture	Clay			6		6										
	Loam		7			7										
	Sand															
	Silt															
	Total		7	6		13										

Tab. 3.6-4. Number of C/N data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10															
	10-30		4	7		11	3	8			11	3	4	3	1	11
	>30															
	Total		4	7		11	3	8			11	3	4	3	1	11
Duration	<5		3			3	3				3					
	5-10		1	3		4		4			4					
	11-20			3		3		3			3					
	>20			1		1		1			1					
	Total		4	7		11	3	8			11					
Soil texture	Clay		3			3										
	Loam		1	7		8										
	Sand															
	Silt															
	Total		4	7		11										

Tab. 3.6-5. Number of N min data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10															
	10-30															
	>30		9			9		9			9	9				9
	Total		9			9		9			9	9				9
Duration	<5		9			9		9			9					
	5-10															
	11-20															
	>20															
	Total		9			9		9			9					
Soil texture	Clay															
	Loam		9			9										
	Sand															
	Silt															
	Total		9			9										

Tab. 3.6-6. Number of K avail data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10															
	10-30		4			4		4			4	4				4
	>30															
	Total		4			4		4			4	4				4
Duration	<5		4			4		4			4					
	5-10															
	11-20															
	>20															
	Total		4			4		4			4					
Soil texture	Clay															
	Loam		4			4										
	Sand															
	Silt															
	Total		4			4										

3.6.3 Influencing factors

The effects of climate, soil texture, sampling depth and duration of practice on the responses of our indicators to compost application were analysed. The results are given in Tables 3.6-7 to 3.6-11. Effects of these factors were either very small or not significant. Of all possible effects of covariate factors on indicator responses, only duration of practice on RR(pH) was significant, with longer-term duration (5-10 years) of compost application increasing pH more than short-term (<5 years). No effect of covariate factors on RR(Nmin) could be assessed as all data came from one experiment.

Tab. 3.6-7. Results of the linear multiple regression for the response RR of pH to fertilization with compost

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern			clay			<10			<5	3	1.05 b
Western	6	1.07	loam	6	1.07	10-30	6	1.07	5-10	3	1.10 a
Eastern			sand			>30			11-20		
Southern			silt			-			>20		

Tab. 3.6-8. Results of the linear multiple regression for the response RR of Nt to fertilization with compost

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern			clay	6	1.16 a	<10			<5	3	1.17 a
Western	7	1.13 a	loam	7	1.13 a	10-30	13	1.15	5-10	3	1.11 a
Eastern	6	1.16 a	sand			>30			11-20	6	1.16 a
Southern			silt			-			>20	1	1.15 a

Tab. 3.6-9. Results of the linear multiple regression for the response RR of C/N to fertilization with compost

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern			clay	3	1.07 a	<10			<5	3	1.00 a
Western	4	1.03 a	loam	8	1.02 a	10-30	11	1.03	5-10	4	1.00 a
Eastern	7	1.03 a	sand			>30			11-20	3	1.07 a
Southern			silt			-			>20	1	1.12 a

Tab. 3.6-10. Results of the linear multiple regression for the response RR of N min to fertilization with compost

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern	-	-	clay	-	-	<10	-	-	<5	9	1.09
Western	9	1.09	loam	9	1.09	10-30	-	-	5-10	-	-
Eastern	-	-	sand	-	-	>30	9	1.09	11-20	-	-
Southern	-	-	silt	-	-	-	-	-	>20	-	-

Tab. 3.6-11. Results of the linear multiple regression for the response RR of K avail to fertilization with compost

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern	-	-	clay	-	-	<10			<5	4	1.04
Western	4	1.04	loam	4	1.04	10-30	4	1.04	5-10	-	-
Eastern			sand			>30	-	-	11-20		
Southern			silt	-	-	-	-	-	>20	-	-

3.7 Farmyard manure application

3.7.1 Expected results from the literature

Application of organic fertilizers is an efficient measure to increase the SOM pool. The addition of large amounts of nitrogen and carbon in farm manure will contribute more to the organic matter and total N content of the soil than fertilizers (Johnston and Mattingly, 1976). The advantage of organic fertilizers compared to inorganic ones is the slow and continuous release of N, and the presence of many other (than N) macro and micro nutrients.
In a study by Uhlen (1991), application of farm manure resulted in somewhat higher N and C contents in the soil comparing with inorganic fertilizer treatments. The main explanation for higher N is that the percentage of utilization in the year of application is usually less for farm manure than for fertilizer nitrogen. Farm manure applications caused a significant increase in C:N ratios. Livestock manures are a valuable source of plant available P and K (Chambers et al., 1999; Anon., 2000). The manure additions resulted in a proportional upward increase in the extractable K content of the topsoil. Manure K availability was proportional to the total manure loading rate (typically 90% of manure K is available for uptake by the following crop; Anon., 2000).

3.7.2 Description of cases and Reference treatment

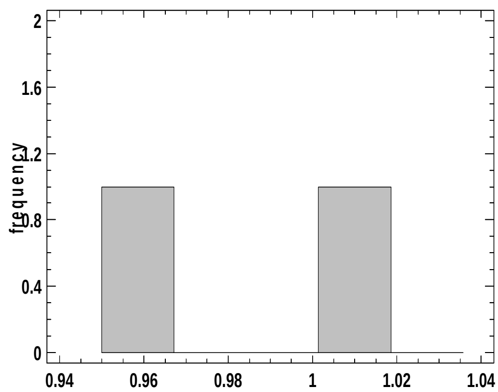
In our study the effects of FYM were determined by comparison with reference treatments that received similar amounts of plant available N or K (not total N or K), given as mineral fertilizer (tab. 3.7-1).

All studied indicators: RR(pH), RR(Nt), RR(C/N), RR(N min) and RR(K avail) showed positive response to FYM application (Table 3.7-1). However, the response of RR(pH) was rather small and the high mean values of 1.48 for RR(N min) and 1.28 for RR(K avail) represent small numbers of cases only. Further, significant responses to FYM application were found for RR(C/N) and RR(Nt). 88.9% of RR(C/N) cases and 81.8% of RR(Nt) cases were greater than 1.

The tested indicator responses showed normal distributions (fig. 3.7-1 to 3.7-4).

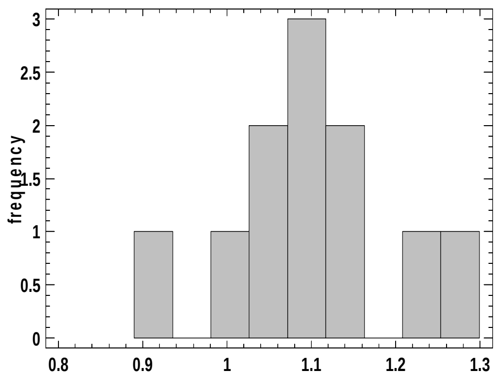
Tab. 3.7-1. Main descriptive statistics for the response RR of indicators to farmyard manure application.

Indicator	*Count*	*Mean*	*St. dev.*	*Min*	*Max*	*Skewness*	*Kurtosis*	*Smirnov test*	*t-test*
RR(PH)	4	1.01	0.04	0.96	1.05	-0.81	-1.03	0.975 ns	0.524 ns
RR(Nt)	11	1.10	0.10	0.92	1.28	0.29	0.85	0.838 ns	0.008
RR(C/N)	10	1.12	0.15	0.99	1.44	1.57	1.64	0.434 ns	0.033
RR(N min)	3	1.48	0.11	1.41	1.61	1.67			0.017
RR(K avail)	1	1.28		1.28	1.28				



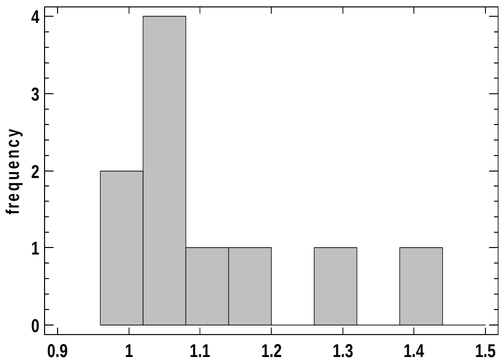
Mean =1.014
Std. Dev = 0.039
N = 4

Fig. 3.7-1. Frequency distribution for the response RR of pH to farmyard manure application



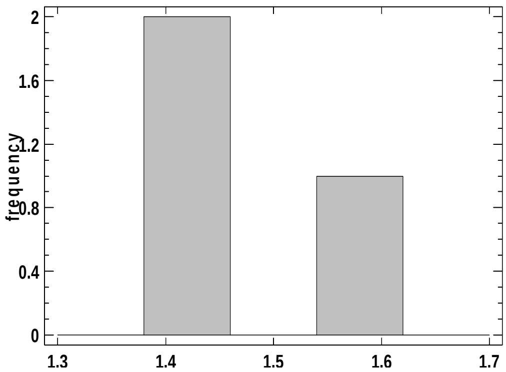
Mean = 1.099
Std. Dev = 0.099
N = 11

Fig. 3.7-2. Frequency distribution for the response RR of Nt to farmyard manure application



Mean = 1.117
Std. Dev = 0.146
N = 10

Fig. 3.7-3. Frequency distribution for the response RR of C/N to farmyard manure application



Mean = 1.482
Std. Dev = 0.109
N = 3

Fig. 3.7-4. Frequency distribution for the response RR of N min to farmyard manure application.

Tab. 3.7-2. Number of pH data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10															
	10-30			4		*4*	*4*				*4*				4	*4*
	>30															
	Total			*4*		*4*	*4*				*4*				*4*	*4*
Duration	<5															
	5-10															
	11-20															
	>20			4		*4*	4				*4*					
	Total			*4*		*4*	*4*				*4*					
Soil texture	Clay			4		*4*										
	Loam															
	Sand															
	Silt															
	Total			*4*		*4*										

Tab. 3.7-3. Number of Nt data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10															
	10-30	4	4	3		11	3	8			11	2	1		8	11
	>30															
	Total	4	4	3		11	3	8			11	2	1		8	11
Duration	<5			2		2	2				2					
	5-10															
	11-20			1		1	1				1					
	>20	4	4			8		8			8					
	Total	4	4	3		11	3	8			11					
Soil texture	Clay			3		3										
	Loam	4	4			8										
	Sand															
	Silt															
	Total	4	4	3		11										

Tab. 3.7-4. Number of C/N data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10		2			2	2				2	1		1		2
	10-30		2	6		8	1	7			8		3		6	8
	>30															
	Total		4	6		10	3	7			10	1	2	1	6	10
Duration	<5		1			1	1				1					
	5-10		2			2	2				2					
	11-20		1			1		1			1					
	>20			6		6		6			6					
	Total		4	6		10	3	7			10					
Soil texture	Clay		3			3										
	Loam		1	6		7										
	Sand															
	Silt															
	Total		4	6		10										

Tab. 3.7-5. Number of N min data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10															
	10-30															
	>30		3			3		3			3	3				3
	Total		3			3		3			3	3				3
Duration	<5		3			3		3			3					
	5-10															
	11-20															
	>20															
	Total		3			3		3			3					
Soil texture	Clay															
	Loam		3			3										
	Sand															
	Silt															
	Total		3			3										

3.7.3 Influencing factors

The effects of climatic zone, soil texture, sampling depth and duration of FYM application on RR(pH), RR(Nt), RR (C/N) and RR(N min) were investigated (tab. 3.7-6 to 3.7-9). RR(Nt) was the most clearly affected by these factors. LTEs in western countries showed higher values than those in northern and eastern countries. The response on loamy soils was higher than on clay soils and shorter time (<5 years) of the practice application favoured Nt more than longer (>11 years) duration (the latter was due to higher N inputs in the short term experiment) RR(C/N) was affected by sampling depth. The higher values can be expected in shallow (<10 cm) soil layers than in deeper (10-30 cm) layers. In the case of RR(pH) the duration of practice was the only factor which differentiated the response to FYM application. Longer duration (5-10 years) increased the pH response more than short-time (<5 years) duration.

Tab. 3.7-6. Results of the linear multiple regression for the response RR of pH to farmyard manure application

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern			clay			<10			<5	3	1.05 b
Western	6	1.070	loam	6	1.070	10-30	6	1.070	5-10	3	1.10 a
Eastern			sand			>30			11-20		
Southern			silt			-			>20		

Tab. 3.7-7. Results of the linear multiple regression for the response RR of Nt to farmyard manure application

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern	4	1.08 b	clay	3	1.00 b	<10			<5	2	1.26 a
Western	4	1.20 a	loam	8	1.14 a	10-30	11	1.10	5-10		
Eastern	3	1.00 b	sand	-	-	>30			11-20	1	1.15 ab
Southern			silt	-	-	-	-	-	>20	8	1.05 b

Tab. 3.7-8. Results of the linear multiple regression for the response RR of C/N to farmyard manure application

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern			clay	3	1.02 a	<10	2	1.37 a	<5	1	1.02 a
Western	4	1.21 a	loam	7	1.16 a	10-30	8	1.05 b	5-10	2	1.06 a
Eastern	6	1.05 a	sand	-	-	>30	-	-	11-20	1	1.16 a
Southern			silt	-	-	-	-	-	>20	6	1.15 a

Tab. 3.7-9. Results of the linear multiple regression for the response RR of N min to farmyard manure application

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern	-	-	clay	-	-	<10	-	-	<5	3	1.48
Western	3	1.48	loam	3	1.48	10-30	-	-	5-10	-	-
Eastern	-	-	sand	-	-	>30	3	1.48	11-20	-	-
Southern	-	-	silt	-	-	-	-	-	>20	-	-

3.8 Slurry application

3.8.1 Expected results from the literature

Pig slurry provides a valuable source of C, N, P and K and is a low-cost alternative to mineral fertilizers (Sharpley and Smith, 1995). With respect to the non-amended soil, the pig slurry-amended soils had larger pH, available P and K contents, and slightly larger total N concentration (Plaza et al., 1997). Heavy dressing with slurry increased the soil pH also in contrast with mineral NPK fertilisers (Kaszubiak et al. 1983). No considerable differences were observed between soils slurry and NPK-treated soils in the content of NH_4 and total N. However, uncontrolled application of slurries to soil can generate, among others, an excess of nitrates (Spaeding and Exner 1993, Gangbazo et al., 1995) and phosphorus (Anderson and Wu 2001).

3.8.2 Description of cases and Reference treatment

In our study cattle slurry application was compared to the similar supply of plant available N or K, respectively, in mineral fertilizer as a reference treatment (tab. 3.8-1).

All studied indicators: RR(pH), RR(Nt), RR(C/N), RR(N min) and RR(K avail) showed positive response to organic fertilization. However, due to the small number of cases no further statistical analysis was made.

Tab. 3.8-1. Main descriptive statistics for the response RR of indicators to slurry application.

Indicator	*Count*	*Mean*	*St. dev.*	*Min*	*Max*	*Skewness*	*Kurtosis*	*Smirnov test*	*t-test*
RR(PH)	1	1.05		1.05	1.05				
RR(Nt)	4	1.13	0.06	1.09	1.21	1.14	0.16	0.927 ns	0.017
RR(C/N)	3	1.01	0.03	0.98	1.04	-1.24		0.966 ns	0.441 ns
RR(N min)	3	1.25	0.05	1.19	1.28571	-1.61		0.880 ns	0.014
RR(K avail)	1	1.30		1.30	1.30				

Tab. 3.8-2. Number of Nt data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10															
	10-30		2	2		4	2	2			4	2		2		4
	>30															
	Total		2	2		4	2	2			4	2		2		4
Duration	<5		2			2	2				2					
	5-10															
	11-20			2		2		2			2					
	>20															
	Total		2	2		4	2	2			4					
Soil texture	Clay		2			2										
	Loam			2		2										
	Sand															
	Silt															
	Total		2	2		4										

Tab. 3.8-3. Number of C/N data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10															
	10-30															
	>30		2	1		3	1	1			3	1	1	1		3
	Total		2	1		3	1	2			3	1	1	1		3
Duration	<5		1			1		1			1					
	5-10		1			1		1			1					
	11-20			1		1	1				1					
	>20															
	Total		2	1		3	1	2			3					
Soil texture	Clay			1		1										
	Loam		2			2										
	Sand															
	Silt															
	Total		2	1		3										

3.8.3 Influencing factors

Too few records were obtained to assess effects of covariate factors on the responses RR of our indicators. Nevertheless, the outcomes are given below (tab.3.8-4 to 3.8-5).

Tab. 3.8-4. Results of the linear multiple regression for the response RR of Nt to slurry application

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern			clay	2	1.09 a	<10			<5	2	1.18 a
Western	2	1.18 a	loam	2	1.18 a	10-30	4	1.13	5-10		
Eastern	2	1.09 a	sand	-	-	>30			11-20	2	1.09 a
Southern			silt	-	-	-			>20		

Tab. 3.8-5. Results of the linear multiple regression for the response RR of C/N to slurry application

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern			clay	1	1.037 a	<10			<5	1	0.99 a
Western	2	1.004 a	loam	2	1.004 a	10-30	3	1.02	5-10	1	1.04 a
Eastern	1	1.037 a	sand	-	-	>30	-	-	11-20	1	1.02 a
Southern			silt	-	-	-	-	-	>20		

Tab. 3.8-6. Results of the linear multiple regression for the response RR of N min to slurry application

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern	-	-	clay	-	-	<10	-	-	<5	3	1.25
Western	3	1.25	loam	3	1.25	10-30	-	-	5-10	-	-
Eastern	-	-	sand	-	-	>30	3	1.25	11-20	-	-
Southern	-	-	silt	-	-	-	-	-	>20	-	-

3.9 Incorporation of crop residues

3.9.1 Expected results from the literature

Residues contribute to a long-term maintenance of the soil's organic matter and fertility (Sparrow et al. 2006). The principal plant nutrients contained in different residues are K, N and Ca. Cereals possess a higher content of monovalent elements such as K, while legumes have a higher concentration of N (Rodriguez-Lizana et al. 2010).
In long experiments presented by Uhlen (1991), ploughing in of cereal straw every year resulted in somewhat higher soil C and soil N and C:N ratios compared with the non-straw treatment. Approximately, 30-40% of the N in straw was conserved as organic N in the topsoil layer. In the studies of (Rasmussen and Collins, 1991; Duff et al., 1995; Grace et al., 1995), a strong positive relationship between crop residue incorporation and soil total N has been found.

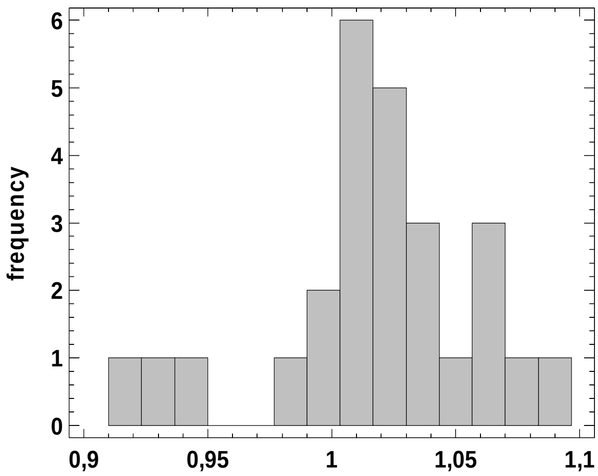
3.9.2 Description of cases and Reference treatment

We studied how the incorporation of crop residues affected our indicators for soil chemical quality. Most of the studies dealt with cereals and maize straw, and residues of hops and sugar beets. In calculations of the response ratio RR, the treatments of specific experiments were compared with reference treatments where crop residues were removed.

Both Nt and C/N responded positively to incorporation of crop residues (tab. 3.8-1), but effects were small. RR(Nt) was larger than 1 in 76.9% of the cases (fig. 3.8-1), and RR(C/N) in 75 % of the cases (fig. 3.8-2). No analyses could be performed for RR(pH) and RR(Pavail) because of the low number of observations.

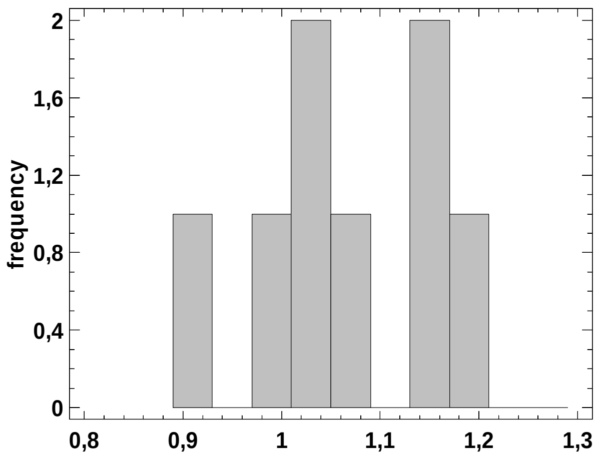
Tab. 3.9-1. Main descriptive statistics for the response RR of indicators to response to residue incorporation

Indicator	*Count*	*Mean*	*St. dev.*	*Min*	*Max*	*Skewness*	*Kurtosis*	*Smirnov test*	*t-test*
RR(PH)	1	0.96		0.96	0.96	-	-	-	-
RR(Nt)	26	1.02	0.04	0.92	1.09	-0.79	0.77	0.170 ns	0.029
RR(C/N)	8	1.07	0.096	0.91	1.19	-0.38	-0.45	0.197 ns	0.066
RR(P avail)	1	1.0	-	-	-	-	-	-	-



Mean = 1.018
Std. Dev = 0.040
N =26

Fig. 3.9-1 Frequency distribution for the response RR of Nt to residue incorporation



Mean = 1,074
Std. Dev = 0,096
N = 8

Fig. 3.9-2 Frequency distribution for the response RR of C/N to residue incorporation

Tab. 3.9.2. Number of Nt data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10															
	10-30	18	6		2	*26*	4	20	2		*26*		4	11	11	*26*
	>30															
	Total	*18*	*6*		*2*	*26*	*4*	*20*	*2*		*26*		*4*	*11*	*11*	*26*
Duration	<5															
	5-10		4			*4*	2		2		*4*					
	11-20	8	1		2	*11*	2	9			*11*					
	>20	10	1			*11*		11			*11*					
	Total	*18*	*6*		*2*	*26*	*4*	*20*	*2*		*26*					
Soil texture	Clay		2		2	*4*										
	Loam	18	2			*20*										
	Sand		2			*2*										
	Silt															
	Total	*18*	*6*		*2*	*26*										

Tab. 3.9-3. Number of C/N data in each combination of factors.

		Climatic zone					Soil texture					Duration				
		N	W	E	S	Total	Clay	Loam	Sand	Silt	Total	<5	5-10	11-20	>20	Total
Depth	<10	1				*1*		1			*1*				1	*1*
	10-30	1	1	4	1	*7*	1	6			*7*			5	2	*7*
	>30															
	Total	*2*	*1*	*4*	*1*	*8*	*1*	*7*			*8*			*5*	*3*	*8*
Duration	<5															
	5-10															
	11-20			4	1	*5*	1	4			*5*					
	>20	2	1			*3*		3			*3*					
	Total	*2*	*1*	*4*	*1*	*8*	*1*	*7*			*8*					
Soil texture	Clay				1	*1*										
	Loam	2	1	4		*7*										
	Sand															
	Silt															
	Total	*2*	*1*	*4*	*1*	*8*										

3.9.3 Influencing factors

We analysed the effects of climate, soil texture, sampling depth and duration of practice on the responses RR of our indicators to the incorporation of crop residues. The results are given in Tables 3.9-4 to 3.9-5. Significant effects were found of climate, texture, and duration on RR(Nt); and of climate and duration on RR(C/N). These are discussed below.

For Nt, the mean RR to incorporation was found to be larger in southern climatic zones than in northern or western zones. While we consider the number of data in the southern zones too small for this outcome to be reliable, it should be noted here that all (=2) southern cases refer to clay soil. For the soil texture effect, the larger RR in fine textured soils observed here is consistent with general understanding that building up organic matter (and associated N) is easier in fine textured than in sandy soils. However, RR values for all classes are near to 1, and only in the loam class do we have a considerable number of observations. Longer duration (>10 years) of the incorporation practice contributes to larger accumulation of Nt resulting from crop residue incorporation, as expected.

RR(C/N) showed strongest and positive responses in both western and northern climatic zones, and after long (>10 years) period of applying this practice (tab. 3.9.5). We do not know why the incorporation of residues reduced the C/N in southern zone (1 case, maize straw), while the opposite was true of the other zones.

Tab. 3.9-4. Results of the linear multiple regression for the response RR of Nt to residue incorporation

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern	18	1.03 b	clay	4	1.02 a	<10	-	-	<5	-	-
Western	6	0.98 c	loam	20	1.03 a	10-30	26	1.02	5-10	4	0.95 b
Eastern	-	-	sand	2	0.94 b	>30	-	-	11-20	11	1.04 a
Southern	2	1.08 a	silt	-	-	-	-	-	>20	11	1.03 a

Tab. 3.9-5. Results of the linear multiple regression for the response RR of C/N to residue incorporation

Climatic zone			Soil texture			Sampling depth (cm)			Duration of practice (years)		
	n	mean		n	mean		n	mean		n	mean
Northern	2	1.16 a	clay	1	0.91 a	<10	1	1.16 a	<5	-	-
Western	1	1.19 a	loam	7	1.10 a	10-30	7	1.06 a	5-10	5	1.01 b
Eastern	4	1.04 b	sand	-	-	>30	-	--	11-20	3	1.17 a
Southern	1	0.91 c	silt	-	-	-	-	-	>20	-	-

4. Conclusions

All tested practices influenced soil chemical quality indicators. Both positive and negative effects were observed. A summary of the results presented in previous sections is given in Table 4-1 and Fig. 4-1 and 4-2.

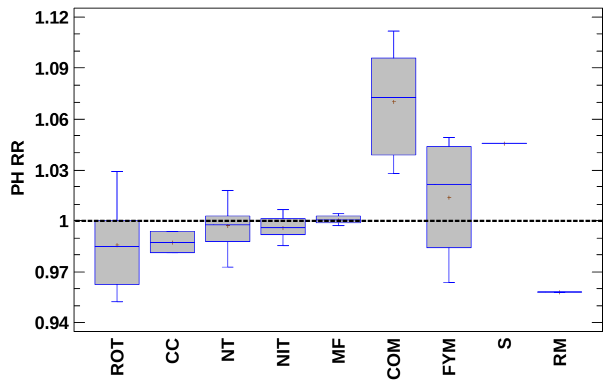
Tab. 4-1. Summary of main effects of management practices on soil chemical quality indicators (***p<0.02; **0.02≤p<0.05; *0.05≤p<0.1).
The effect is expressed as the mean response ratio (RR) of the respective soil quality indicators listed in the first row.

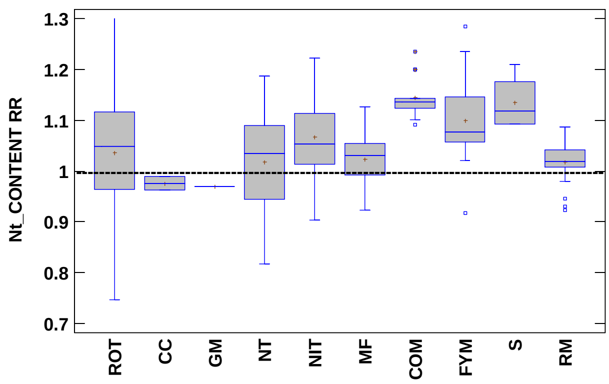
		pH	Nt cont	NtS	C/N	N min	K avail	P avail
Crop rotation	Monoculture (reference treatment)	1.00	1.00	n.d.	1.00	n.d.	1.00	1.00
	Crop rotation	0.99	1.04	n.d.	0.96**	n.d.	0.76***	0.95
Cover crops and green manures	No cover crops (reference treatment)	1.00	1.00	1.00	1.00	n.d.	1.00	n.d.
	Catch crop/Cover crops (harvested)	0.99	0.98	1.04**	0.99	n.d.	0.81	n.d.
	No green manure (reference treatment)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	Green manures (incorporated)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Tillage	Conventional tillage (reference treatment)	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	No tillage	1.00	1.02	0.94	0.94	1.15*	0.97	1.30***
	No-inversion tillage	1.00	1.07***	1.11**	0.97	0.87	1.46***	1.10***
Nutrient management	No fertilizer (reference treatment)	1.00	1.00	n.d.	1.00	1.00	1.00	1.00
	Mineral fertilizer	1.00	1.02***	n.d.	0.77	1.60***	2.33***	2.64***
	Mineral fertilizer (minN) (ref. treatment)	1.00	1.00	n.d.	1.00	1.00	1.00	1.00
	Compost	1.07***	1.14***	n.d.	1.03	1.09*	1.04	n.d.
	FYM	1.01	1.10***	n.d.	1.12**	1.48**	1.28	n.d.
	Slurry	n.d.	1.13***	n.d.	1.01	1.25***	n.d.	n.d.
Residue management	Residue removal (reference treatment)	1.00	1.00	n.d.	1.00	n.d.	n.d.	n.d.
	Residue incorporation	n.d.	1.02**	n.d.	1.07*	n.d.	n.d.	n.d.
Crop	-	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Water management irrigation	-	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

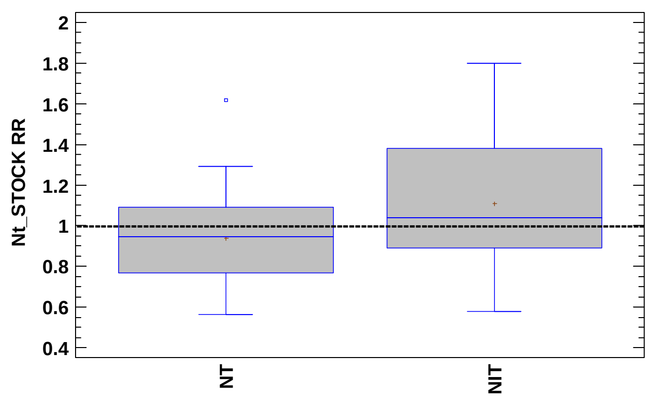
n.d. – no data

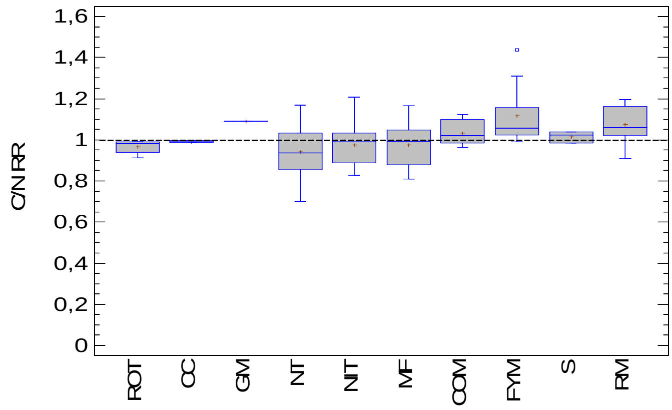
Fig. 4-1. Box plot graphs of RR(pH), C/N RR, MIN_N RR, RR(Nt) and RR(NtS) obtained adopting the different improved management practices. ROT = rotation, CC = cover crop, NT = no-tillage, MT = no-inversion tillage, MF = mineral fertilizer, COM = compost, FYM = farm yard manure, S = slurry, RM = incorporation of crop residues.

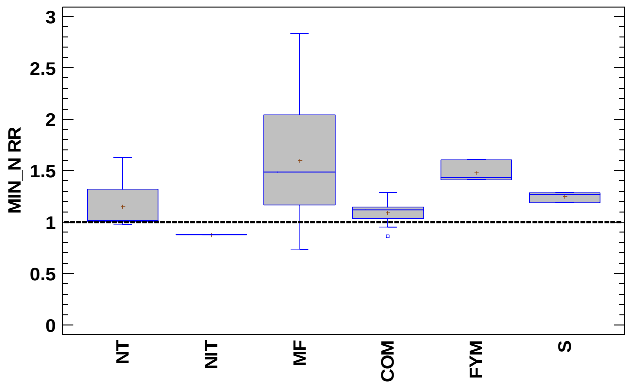
The three values (on vertical axis) that mark each box are the 25, 50 and 75% percentiles. Whiskers represent the minimum and maximum values found in the population.

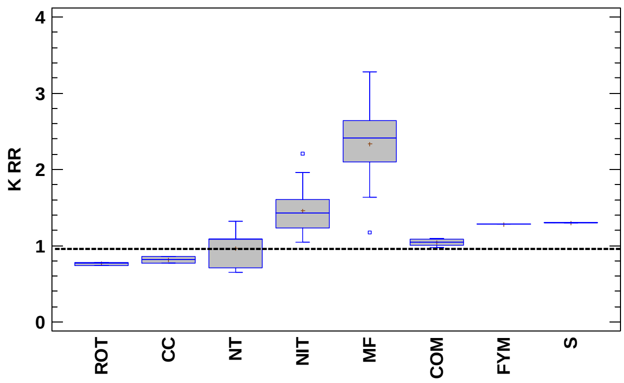







C/N RR
1,6
1,4
1,2
1
0,8
0,6
0,4
0,2
0
ROT
CC
GM
NT
NIT
MF
COM
FYM
S
RM


MIN_N RR
3
2.5
2
1.5
1
0.5
0
NT
NIT
MF
COM
FYM
S


K RR
4
3
2
1
0
ROT
CC
NT
NIT
MF
COM
FYM
S

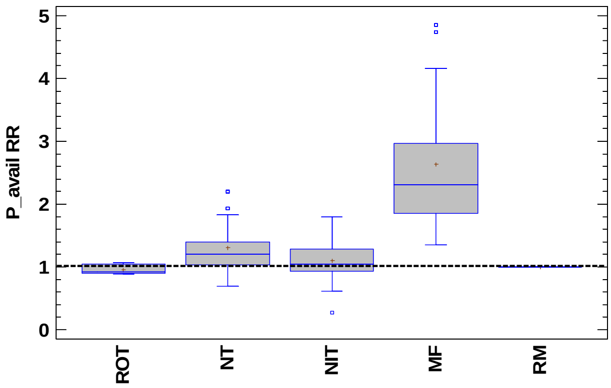

P_avail RR
5
4
3
2
1
0
ROT
NT
NIT
MF
RM

Figure 4-2 is the graphical image of mean RR values included in table 4-1. An RR value of 1 means that on average there was no response of the indicator to the management practice. The highest values of Nmin, Kavail and Pavail RRs indicate the strongest response to mineral fertilization. Besides increase of available forms of nutrients, fertilization with FYM, non-inversion tillage, compost and slurry application and crop rotation were effective for total N indicators. Compost was the only practice which significantly improved soil pH. It was effective also for Nt content. Fertilization with FYM and residue incorporation increased C/N ratio.

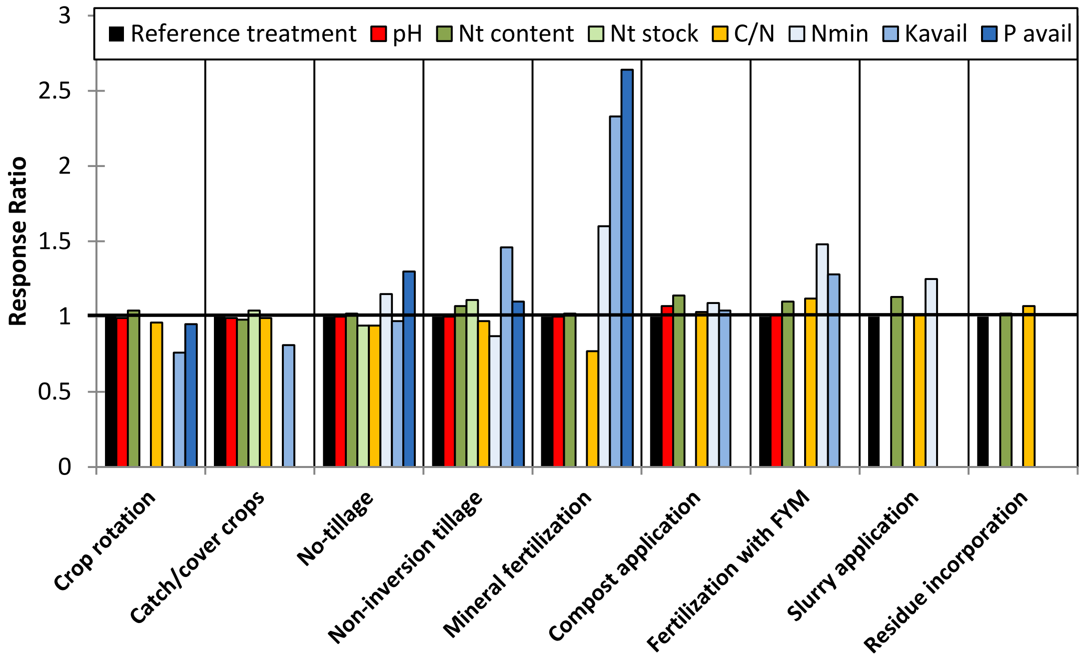


Fig. 4-2. Impacts of soil management practices on chemical soil quality indicators.

Evaluation of management practices

All tested practices influenced soil chemical quality indicators. Both positive and negative effects were observed. When the means of seven soil chemical quality indicators were considered in an overall evaluation (tab.4-1)– based on significance level, the number of indicators positively affected and (next) the size of the effects - the best practices among those tested were:

- farmyard manure application,
- non-inversion tillage,
- compost application,
- mineral fertilization, and
- no-tillage.

Farmyard manure (relative to mineral N or K fertilizer, at same plant available nutrient amounts) significantly increased Nt content, content of available (mineral) nitrogen, and the C/N ratio (promoting accumulation of carbon over nitrogen). Available potassium was strongly increased , too, but this refers to one case only (hence insignificant in the meta-analysis). The response of pH to FYM was similar to the reference rate of mineral fertilization, but slightly higher RR values were found as the duration of this practice increased. The increase of Nt content was greater in western climatic zones (than north and east), and greater on loam than on clay. Surprisingly, the Nt content response was larger in three cases of short duration (<20 years) than in cases of >20 years duration. This can hardly be generally valid, and may be due to the unbalanced nature of the data set. It shows, however, that positive responses to FYM can be found within relatively short time frame (obviously depending on application rates, too). All data of C/N ratio refer to western and eastern climate zones, and clay and loam texture classes. While none of the covariate factors (except sampling depth) affected RR(C/N ratio) significantly, larger RR values were found in the western than in the eastern zone, and larger values on loam than on clay. Higher RR values were found for shallow soil layers, and longer duration (>10 years) of FYM application. A high response ratio of N min was noted, but this refers to 3 cases only. Nevertheless, it shows that FYM can substantially contribute to accumulation of N min, and therefore also to nitrate leaching losses. Effects of covariate factors on RR (N min) could not be assessed as all data refer to only one class of each factor.

Non-inversion tillage compared to conventional ploughing positively influenced N total content and stock and content of available forms of K and P, all significantly. The results are based on a considerable number of data. Responses of K avail refer to only the eastern climatic zone, loamy soil and the depth interval 10-30 cm soil depth. For Nt stock and K avail, highest increases were found after long (>20 years) of non-inversion tillage application. Available phosphorus was differentiated only by climatic zones, responses being stronger in the western than in the eastern zone. Effects of non-inversion tillage on this parameter were already found within 5 years.

Application of compost (relative to mineral fertiliser at same plant available nutrient levels) significantly increased soil pH, Nt content, N min content and showed a tendency (n.s.) to increase C/N ratio and K avail content. Longer time (5-10 years) of compost application promoted the pH increase more than short time (<5 years). The positive responses of Nt content and C/N ratio were not different between western and eastern countries, nor between clay and loamy soils. These two parameters showed no significant effect of duration, though for C/N ratio there was a tendency of stronger responses at longer duration (>10 years). The positive effect of compost on N min and K avail content was found in western countries, in deep (>30 cm) (10-30 cm for K avail) soil layer of loamy soils and already after short (<5 years) of the compost application. For all indicators it must be noted that their response to compost application will be largely determined by the composition of the compost itself.

Mineral fertilizers (relative to *zero* dose) were effective especially in increasing available phosphorus, potassium and nitrogen, and also total N content. All phosphorus data and virtually all potassium data refer to the eastern climatic zone, soil layer of 10-30 cm, loamy soil, and long-term duration (>20 years) of fertilizer application. A less pronounced response of available potassium was found in two short run (<5 years) cases, which both refer to the western zone. The same pattern is seen for mineral nitrogen fertilizers: stronger mean response for the larger data set that pertains to the eastern zone, 10-30 cm depth, and long duration (11-20 years), than to the LTE's that pertain to the western zone and to short duration (<5 years). The response of Nt content to application of mineral fertilisers was very small (but significant).

Slurry application (relative to mineral fertiliser) increased only Nt content and N min significantly. The other indicators: RR(pH), RR(C/N ratio), RR(K avail) were represented by small number of cases. Effects of covariate factors could not be assessed here.

No-tillage (relative to conventional ploughing) was ranked lower because it affected (significantly) only available phosphorus and N min contents. No tillage did not clearly enhance either of the total N indicators. There were (n.s.) tendencies for no tillage to increase Nt content and to decrease Nt stock and C/N ratio. The (positive) response of P avail was clear and based on a reasonable number of data. It was most pronounced in the southern zone, but also clear in the northern zone, and only weak in the eastern zone. It was more expressed on sandy soils than loam soils, and least on silty soil (few data and no effect on silty soils). Effects were strongest in the shallow layer (<10 cm) than in the 10-30 cm layer. Responses of P avail content in short duration cases (<5 years) were similar to those in long term cases (11-20 and >20 years). All N min content data referred to the southern zone, sandy soil, and long duration (>20 years) of the no-tillage practice. The observation that no tillage gave only a weak (an slightly negative) response of K avail, while the response to non-inversion tillage was strong (and positive), is confusing. It must be noted, however, that all (5) no tillage results (for K avail) refer to the southern climate zone, whereas the effects of non-inversion tillage on K avail (26, mostly from one LTE) refer to the eastern climate zone. It remains difficult to judge these two practices against one another, with respect to their impact on K avail.

Incorporation of crop residues (versus removal) raised both Nt content and C/N ratio by small, yet significant, amounts. The strongest response for Nt content (RR=1.08) was found in the southern climatic zone, but was based on two cases only, both clay soils and 11-20 years. Overall, mean positive effects of incorporation on Nt content were only found at sites running for more than 10 years. For C/N ratio, data were too few to assess effects of covariate factors. There was a tendency, however, for stronger increases in cases with 11-20 years duration than in cases with <5 years duration.

Crop rotation tended to increase (n.s.) Nt content, but negatively affected both available potassium and C/N ratio. In general, evaluation of rotation effects on soil fertility should take into account nutrient balances (input minus offtake), which was not possible in this study.

The indicators influenced by *catch and cover crops and green manures* were represented by too few data to be considered in the analysis.

Indicator responsiveness to management practices

If we rank our indicators by the number of practices by which they are affected, (tab. 4-2, fig. 4.1), the resulting ‘responsiveness ranking’ (ignoring the magnitude of the responses) is:

- Nt content and N min content (affected by five practices),
- P avail content, K avail content
- C/N ratio (affected by two practices)

Nt content
All organic fertilisers (compost, slurry and FYM) had stronger impacts on Nt content than had mineral fertilisers (the reference for the above, at same total N dose).. Less pronounced, but also positive, was the response of Nt content to non-inversion tillage and, then, to no-tillage. The effect of rotation will generally depend, of course, mostly on the choice of individual crops in the rotation and associated nutrient balances. It cannot, in our view, be generalised based on this study.

N min
Mineral soil N, too, responded stronger to organic inputs (FYM, slurry and compost) than to fertiliser-N (the reference). This can only be generally true, in our view, for observations outside the growing season, when mineralisation of N from organic stocks proceeds in absence of crop uptake. Mineral fertiliser application itself (relative to zero dose) also had a clear positive effect on N min, as had the no-tillage practice.

P avail and K avail
These indicators responded most strongly – among practices – to inputs (of P and K, respectively) as mineral fertilisers. (Only few observations refer to organic inputs, effects of which are expected to be similar.) Note that the apparently stronger response to mineral K

fertilisers (than to organic inputs; Fig.4.1) arises from their different respective baselines: organic sources are evaluated against mineral fertilisers, but mineral fertilisers were evaluated against zero input rate. Weaker but relevant responses of P avail and K avail were found for reduced tillage (no-tillage and non-inversion) practices: these favour the accumulation near the soil surface of nutrients from inputs and crop residues. This is regarded an advantage for early crop growth under favourable moisture conditions, but turns into a disadvantage when the topsoil dries out and renders these nutrients inaccessible for uptake. We regard the contrast between the two reduced tillage practices (no-tillage affecting P avail, and non-inversion tillage affecting K avail) as not generally representative (no direct comparison of both practices on these indicators is possible here).

C/N ratio

The C/N ratio was increased by the application of FYM, and by the incorporation of crop residues.

pH

Responses of pH were weak for all practices. The positive response to compost application must be regarded as a side effect, and pH responses will more generally depend on the nature of the compost itself.

Tab. 4-2. Qualitative assessment of main effects of management practices on soil chemical quality indicators (- response by: <10%+; 10-50%++;>50%+++; n.d.–no data).

		pH	Nt	NtS	C/N	N min	K avail	P avail	Total
Crop rotation	Crop rotation	0	0	n.d.	- -	n.d.	-	0	0
	Catch crop/Cover crops (harvested)	0	0	+	0	n.d.	0	n.d.	0
	Green manures (incorporated)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	
Tillage	No tillage	0	0	0	0	++	0	++	+
	No-inversion tillage	0	+	++	0	0	+++	++	++
Nutrient management	Mineral fertilizer	0	0	n.d.	0	+++	++	++	++
	Compost	+	++	n.d.	0	+	0	n.d.	+
	FYM	0	++	n.d.	++	++	+	n.d.	++
	Slurry	0	++	n.d.	0	++	0	n.d.	++
Residue management	Residue incorporation	n.d.	+	n.d.	+	n.d.	n.d.	0	+
Crop protection	-	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	
Water management irrigation-drainage	-	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	

It should be noted that the responses of Nmin to FYM and slurry are given here as relative to mineral fertilisers (at the same rate of plant available N), whereas the response of Nmin to mineral fertilisers takes zero N rate as the baseline (reference). So, the ++ listed for FYM and slurry refers to a larger absolute Nmin response than the +++ listed for mineral fertilisers, if all are evaluated against zero N rate as reference. The same holds for Kavail.

Appendix

General introduction on soil fertility indicators

Alicja Pecio, Mariusz Fotyma, Zuzanna Jarosz

Soil pH

Soil reaction - which indicates soil acidity or alkalinity - is the most important, single parameter of soil fertility. The degree of acidity or alkalinity is determined by the concentration of H^+ in soil solution and expressed in negative logarithm of this concentration or pH values, ranging from 0 to 14. In the upper layer most soils exhibits the reaction between pH 4.5 and 7.5. However, it must be stressed upon the methodology of pH measurement. In the European countries three different methods are used. They are pH in water, in calcium chloride or in potassium chloride .The pH values measured in the same soil decreased in the order pH_{KCl} <pH_{CaCl2} <pH KCl. The difference between two extreme methods may amount to 1 pH unit. Therefore referring to pH it is necessary to precise which method has been used. The soil reaction has a direct and indirect effect on plant growth and development. The direct effect in soils with pH below 4.5, classified as very strongly acid is manifested by the toxicity of ions H^+ and Al^{++} , possibly also Fe^{++} and Mn^{3+} being in excess in soil solution. The indirect effect of soil pH relies on influencing the availability of plant nutrients. In the pH range of 5.0-6.0 almost all nutrients are available in optimal amounts. In alkaline soils, pH above 7.0 the concentration of calcium, magnesium and potassium ions is very high, but the concentration of phosphorus and most of micronutrients is diminishing so far as to deficiencies (Kim H. Tan, 2009).

Development of soil reaction depends on many internal and external factors. All the soil processes which contribute to releasing H^+ and/or Al^{3+} contribute to soil acidity. Water is a source of small amount of H^+, respiration of plant roots to produce CO_2 which can react with water forming H_2CO_3, mineralisation of soil organic matter with subsequent nitrification of NH_4^+ to NO_3^-.oxidation of S are internal sources of H^+. Among external factors the most serious is acidic deposition, (Nilsson, 2003), which influences negatively the growth of above-ground plant's parts and provides H^+ to the soil (Prihar et al., 2000). From the other side soils containing free carbonates are sustaining the pH in slightly acid or even slightly alkaline range .It results from the hydrolysis of carbonate which in this process set free Ca^{2+}, $2OH^-$ and CO_2. Cations of calcium can exchange H^+ ions from the exchange soil complex and thus contribute to saturate this complex with the base. However in humid regions the percolating water removes the soluble Ca^{2+} and the soil remains saturated with H^+. Therefore the pH of soils in these regions seldom surpass 7,0. In arid regions adsorbed cations are not leached away and the exchange soil complex s left fully saturated with base. In continental zone the pH of soils depends mainly on its texture. Heavy soils rich in clay commonly maintain pH levels between 6.0 and 7.0. Soils with coarser texture such as sandy soils and organic soils are maintained at pH 5.0-5.5. Management practices, with exception of mineral and organic fertilizers have a very limited impact on soil pH. Nitrogen fertilizers, particularly those containing ammonium, decrease the soil pH. Ammonium undergoes the process of nitrification and H^+ ions are produced, which acidify the soil.

The acidifying effect of fertilizers follows the order ammonium sulfate > ammonium nitrate > anhydrous ammonia > urea > calcium nitrate (Bouman et al., 1995). The degree of acidity caused by a fertilizer is modified by soil characteristics, cropping systems, and environmental variables. Fertilization may also cause acidification by the export of basic cations (Bolan et al., 1991). Acidification is accelerated when the harvested crop removes an excess of basic cations (Ca^{2+}, Mg^{2+}, K^+, Na^+) over anions (Cl^-, SO_4^-, NO_3^-). Organic fertilizers, particularly manure influence positively the soil base saturation and hence contribute to sustaining soil pH , at least at the initial level. These fertilizers contribute significantly to raise the content of organic substance in the soil and thereby to increase the soil exchange capacity. Practically the only management practice that contributes substantially to raising soil pH is liming, i.e. application of limestone $CaCO_3$ or dolomitic limestone $CaCO_3$ $MgCO_3$. The neutralization of an acid soil using $CaCO_3$ is illustrating by the series of reactions, of which the first one is as follow: $CaCO_3 + 2H^+ - Ca^{2+} + H_20 + CO_2$. In the successive reactions Ca^{2+} exchanges with H^+ and Al^{3+} in soil exchange complex and then precipitates the insoluble aluminium hydroxide. The lime requirement could not be based on soil pH, which is a measure of active i.e. in soil solution of H^+ ions only. Calculating the amount of limestone the exchangeable soil acidity must be taken into consideration (Essington M.E. 2004).

Total nitrogen content and stock, C:N ratio, mineral nitrogen content

Practically all nitrogen in soils occurs in organic form as nitrogenous compounds arising from the decomposition of plant material and microorganisms and added organic matter (e.g. manure in agricultural systems). The total content of N ranges from 0.2 – 5 g N kg^{-1} soil with a median value of 0.8 g N kg^{-1}. Organic forms of nitrogen account for approximately 90 % of the total one, of which 10-15 % is associated with the «living» soil biomass and 75-80 % with »dead» soil organic matter SOM (Essington, 2004). The mineral nitrogen forms – ammonium and nitrate, directly available for plants, occurs in a very small amounts only. Nitrogen in complex combination with the organic matter i.e. the humus fraction becomes available to crops after breakdown to simple mineral form in process of mineralization. This type of transformation is mostly biological in nature. Mineralization of soil nitrogen generally refers to the conversion of organic nitrogen to inorganic nitrogen and in practice refers to production of ammonium and nitrate and other inorganic forms that are usually transitional. Mineralization is largely microbiological process, the organic nitrogen being first changed to ammonium and then via nitrite to nitrate nitrogen (nitrification process). Organic nitrogen is always bound to carbon in different compounds of which the major pools make amino acids, amino sugars and their associated polymeric forms. The most stable forms of SOM are humic substances i.e. humic acid, fulvic acid and humins of highly complex character. The average share of carbon in SOM is 58% and those of nitrogen 4.7%, hence the average ratio C:N amounts to 12.3:1.

The C:N ratio in arable soils varies however in the range 10:1 to above 12:1. As a general rule, organic materials with C:N ratio greater than 30 ensure immobilization of nitrogen during the initial decomposition process. Ratios between 20 and 30 seem to be optimal for decomposition. When materials with a wide C:N ratio (70:1) like wheat, straw, low in nitrogen is added to soil, immobilization exceeds mineralization, the net effect being disappearance of mineral nitrogen with rapid increase in organic nitrogen during early stages of decomposition. After addition of rich in nitrogen materials of narrow C/N (15:1) as alfalfa, soybean and other legumes, mineralization exceeds immobilization and the overall effect being increase in inorganic nitrogen with decline in organic nitrogen content.

The ratio C:N is sufficiently stabile to use interchangeably the terms SOM and N org. The content of SOM depends mainly on external conditions i.e. soil type and climate. The close correlation has been found between SOM and soil texture (Johnston et al., 2009) Heavy soils contain more SOM in comparison to coarse-textured ones. It can be explained by protection role of soil colloid (clay) for SOM against the processes of mineralization. For the same reason - i.e. slowing down the process of mineralization - the content of SOM decreases while moving from cold and dry to warmer and humid regions, in spite of the fact that in dry cold regions the formation of new SOM is slower as well. SOM content depends very much and can be even to some extent regulated by proper management practices (Peterson et al., 1998). The biggest role plays the type of land use and on arable land the type of crop rotation. The content of SOM is higher or much higher under the permanent grassland then under the arable land. In the process of transformation the grassland into arable one the content of SOM diminishes systematically in course of the years (Peterson et al., 1998). The negative impact of arable soil utilization can be partly diminished or even halted by the proper management practices first and foremost by soil tillage method and fertilization.

Tillage

Tillage is one of the factors which directly impact the soil status. It affects the composition processes through the physical disturbance and mixing of soil, by exposing soil aggregates to disruptive forces, and through the distribution of crop residues in the soil. Among tillage-induced changes in soil properties are bulk density, infiltration rate, aggregation, microbial activity, species diversity and SOM and nutrient profile (Prihar et al., 2000). Tillage also impacts carbon and nitrogen sequestration. There are two general categories of tillage practices: conventional and conservation tillage. Both practices have different effects on soil properties. For both practices, the initial content of C and N in the soil determines the direction of changes in soil strategies after tillage activities. A general trend seems to be increased effluxes of CO2, after conventional and increased emission of N2O after conservation tillage practices. Most of agricultural soils in temperate climates have lost significant amounts of SOC due to excessive tillage. Conservation tillage practices that include reduced and no-tillage farming and increased cropping intensity, along with reseeding of marginal croplands to permanent cover, can increase SOM and store a significant portion of C from the atmosphere.

Plough tillage systems incorporate crop residues and distribute organic matter evenly throughout the plough layer. The process of tillage may affect the SOM pool in two ways. SOM from deeper layers and from the interior of aggregates is brought to the surface (Whitehead, 1995; Lal, 2004). Subsequently, mineralization rates increase, due to aeration and availability to microorganisms. However, SOM from the surface (as zone of more active mineralization) is transferred to deeper layers with lower turnover rates, thus contributing to the soil's humus pool (Nieder et al., 2003; Lal, 2004). Increased tillage frequency results in loss of SOM due to higher aeration and microbial activity (Grant, 1997). In the long term, the SOM content of mineral soils with constant rotation is in a state of quasi-equilibrium if the ploughing frequency and depth are approximately constant. Under such circumstances, soils attain a balance between gains and losses of C, N, S and P. Carbon and nutrients are temporarily liberated but the amounts released are compensated for by incorporation of equal amounts into newly formed humus.

Conservation tillage is defined as a system having at least 30% or more crop residues covering the soil at planting (CTIC, 2000). Conservation tillage practices can be subdivided in no-tillage (pure no-tillage or strip-tillage), ridge tillage (building ridges with in-season cultivation), minimum tillage and mulch tillage (field-wide tillage). The mulch cover is a substantial requirement in achieving the positive effects of conservation tillage practices. In the past 2 decades, conservation tillage (zero tillage and various reduced tillage management systems) have received increased attention owing to the potential of these management systems for abating soil erosion, conserving soil moisture, enhancing water quality, and cutting monetary and energy inputs of crop production systems. In Europe, less than 5% of the cropland area was in conservation tillage in the 1990s (Nieder, 1998), and presently there is only a slightly increasing tendency. In the United States in 1992, conservation tillage was used on 31% of the cropped land (Cannel and Haves, 1994). By 2010, this portion is expected to increase to 63-82% (OTA, 1990).

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The influence of tillage management on SOC and SON has been investigated intensively throughout the world. Most studies have examined changes in concentration of SOC (Dick, 1983; Karlen et al., 1994; Frede et al., 1994; Salinas-Garcia et al., 1997). Few studies have examined the changes in the mass of SOC (Campbell et al., 1995; Reicosky et al., 1995; Van den Bygaart et al., 2002). Generally, SOC and SON concentrations in the surface 15 cm of no-tilled soils are greater than in tilled soils, especially when they are mouldboard ploughed.

Conservation tillage induces not only stratification of SOM and related nutrients but also enhances the size of soil microbial biomass in the upper part of the surface soil (Logan et al., 1991). The magnitude of these changes depends on soil texture, climate and cropping system. The new equilibrium in soil properties by conversion from plow-till to no-till may be attained over a period of 10-20 years (Kern and Johnson, 1993; Frede et al., 1994). The equilibrium status may be reached more quickly in coarse-textured soils of the tropics than in heavy-textured soils of the temperate climate. According to Van den Bygaart et al. (2002), there are numerous factors that affect the dynamics of SOC under no-tillage including climate, management history, soil type and landscape processes. The initial SOC (and SON) content also play an important role for the dynamics of SOC (and SON) after the introduction of conservation tillage systems.

Fertilization

Fertilizers are the most widely used form of chemicals in agriculture. Application of organic fertilizers that do not only contain N and other nutrients, but also C in their organic tissues is one possibility to enhance SOC. In addition to direct effects of fertilization on C inputs, high N availability may also enhance the formation of recalcitrant humic substances in soils.

Positive effects on the soil C balance particularly have been observed due to increased synthetic N application rates. With every 1 Mg ha^{-1} increase in SOC pool in the root zone, crop yields can be increased by 20-70 kg ha^{-1} for wheat, 10-50 kg ha^{-1} for rice, and 30-300 kg ha^{-1} for maize (Lal, 2005). Recently, Benbi and Chand (2007) showed that contribution of 1 Mg SOC ha^{-1} to wheat productivity in subtropical India ranged from 15 to 33 kg ha^{-1}. The wheat productivity per Mg of SOC declined curvi-linearly as the native SOC concentration increased. Adoption of recommended management practices on agricultural lands and degraded soils enhance soil quality including water holding capacity, cation exchange capacity, soil aggregation, and susceptibility to crusting and erosion. However, inappropriate or excessive fertilizer application can lead to increased losses of N from soils. Losses can occur through runoff, leaching or as gaseous N compounds. Losses in gaseous forms can have negative impacts on the global climate, especially as N2O (Harrison, 2003).

Organic fertilizers are mainly applied as manure and sewage in solid and liquid form, and crop residues. The faeces of farm animals consists mostly of undigested food that has escaped bacterial action during passage through the body. This undigested food is mostly cellulose or lignin fibers (Nieder et al., 2003). Animal wastes are more concentrated than the original feed in lignins and minerals. The faeces also contain the cells of microorganisms. Nitrogen in manure solids occurs largely in organic forms (undigested proteins and the bodies of microorganisms). The N:C ratio in farmyard manure is usually 15-30. Liquid manure may also contain significant amounts of NH4+ which has been formed from urea through hydrolysis. The manure applied to cropland varies greatly in nutrieNt, depending on animal type, ration fed, amount and type of bedding material, and storage condition. Both N content and availability of the N to plants decreases with losses of NH_3 through volatilization and NO3-through leaching. Manures aged by cycles of wetting and drying and subjected to leaching with rainwater may have lost so much N that very little will be available to the crop in the year of application.

Sewage sludge from biological treatment of domestic sewage, is a stabilized product with an earthy odor and which does not contain raw, undigested solids. Liquid sewage sludge is blackish and contains colloidal and suspended solids. Most sludges, as produced in a sewage treatment of roughly equal parts of organic and inorganic material. Heavy metals like Zn, Cu, Pb, Cd, Hg, Cr, Ni may occur in quantities sufficient to adversely affect plants and soils. The availability of any given metal in soil will be influenced by pH, SOM content, type and amount of clay, content of other metals, cation exchange capacity, variety of crops grown, and others. The organic component is a complex mixture consisting of digested constituents that are resistant to anaerobic decomposition, dead and live microbial cells, and compounds synthetized by microbes during the digestion process. The organic material is rather rich in N, P, and S and the C:N ratio of digested sludge ranges from 7-2. N availability in sludges decreases as the content of NH4+ and NO3-decreases and as the organic N becomes more stable as a result of digestion during biological waste treatment. Conservation of the N that often volatilizes as NH_3would greatly increase the value of sewage sludge as an N source.

Manure applications have been observed to increase C sequestration. However, changes in SOM contents due to altered organic fertilizer application run very slowly. If the changes are in dimensions relevant to practice, it may take more than 10 years until they can be proved. With the extension of the experimental question of the Static Fertilization Experiment Bad Lauchstaedt (near Halle, central Germany), there was the chance to quantify the changes in the C and N contents in a chernozem following extreme changes in fertilization (Körschens and Müller, 1996). At a high starting level the annual decrease is 0.013% C equalling to 0.5 Mg C ha-1 year-1 and 0.0011 % N corresponding to 44 kg ha-1 year-1. This amount corresponds roughly with the difference in the N uptake comparing the nil treatment and the previously completely fertilized treatment. As concerns the previously unfertilized treatment, the annual C increase is lower, reaching 0.0081% year-1, the amount of N increased by 0.0012 year-1. It becomes apparent that it will take several decades to reach new equilibrium SOM levels.

Crop residues

Crop residues incorporated into the soil are decomposed (broken down or changed) by bacteria. Bacteria break down corn, wheat, and grain sorghum (all in the grass family) residues quite slowly, whereas alfalfa, soybean, and clover (all in the legume family) residues decompose more rapidly. The principal reason for the difference in decomposition between the two groups is the amount of nitrogen (in protein form) in the residue. Legumes are high in nitrogen, whereas grasses are low in nitrogen. If it is ever desirable to speed up the decomposition or breakdown of a low-nitrogen residue, adding nitrogen fertilizer should help.

In long-term experiments it was found that different crop rotations, applications of farm manure and fertilizer-N, and annually ploughed-in cereal straw have an effect on the total-N and total-C contents of the topsoil (Uhlen 1990). C: N ratios remained unaffected by different crop rotations in a 31-year experiment on loam soil, but a long-term increase in N in relation to C seems to have occurred.

Soil phosphorus and potassium

The total content of phosphorus in the soil is on average below 1g P kg^{-1}. Phosphorus appears both in organic and mineral compounds. The organic form prevails in organic soil mainly as phospholipides and phytin and its share may be well above 60 % of total P. Organic

phosphorus behaves as nitrogen and is available for plants after mineralization of SOM only. The balance of mineralization – immobilization processes of phosphorus depends on the C:P ratio which in undisturbed soils is in the range 50-80:1. If the ratio is about 100:1
available phosphorus is immobilised by microorganisms which generally have higher demands for this element in comparison to plants. In the mineral soils most phosphorus is bound with aluminium, iron and/or calcium making compounds of very low solubility. The concentration of phosphate ions in the soil solution is pretty low and depends strongly on soil pH, being the highest in the pH range 5.5 – 6.5. The availability of phosphorus for plants is estimated by means of chemical tests, using across the European countries different extraction procedures [Meille, 2012]. The amounts of phosphorus estimated by these tests applied to the same soil is very different. However, there is generally a good correlation between the tests which makes possible to generalize the results of experiments carried on in different countries. In the half of the last Century most soils in Europe was deficient in phosphorus, but later on due to regular application of fertilizers the content of available phosphorus in soils increased considerably. At present there is even concern about excessive accumulation of P in soils, which increases P leaching losses to surface water, leading to eutrophication and subsequent biodiversity loss of these waters. Excessive accumulation may occur in areas with intensive livestock production. Here the import of P via animal feed and fertilizers is often much larger than the export of P via animal products and crop products. The management practices which influence the content of available phosphorus are application of mineral and organic fertilizers and soil liming. Reduced and particularly no tillage systems contributes considerably to stratification of phosphorus in the soils. Phosphorus from fertilizers accumulated in upper soil layer , which depending on water conditions, may be favourable or unfavourable for crops.

Potassium is one of the most abundant element in the Earth's crust and hence in soils. The average content of potassium is 26g K kg^{-1} soil. Potassium in soils appears exclusively in forms of hydrated (in soil solution) or unhydrated (adsorbed or built into aluminium silicate mineral) ions. The transformation processes of potassium are therefore much simpler in comparison to nitrogen and phosphorus. The content of total potassium depends on the soil texture and it is much higher in heavy than in coarse structured soils. It must not be true for available potassium because the heavy soils show considerable adsorption power for potassium ions. For this reason most of the soil tests account for soil texture. The only management practice which influences the potassium status in soils is application of mineral and organic fertilizers. The potassium balance i.e. difference between K output in plant products and input in fertilizers is a base for fertilizer recommendations and predicting the changes of soil fertility with respect to this element.

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