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Catch-C

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 biological soil quality

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Tommy D'Hose, Leendert Molendijk, Wim van den Berg, Hans Hoek, Willemien Runia

+all contributors to the database

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

Authors of this report and contact details

Name: Leendert Molendijk, Wim van den Berg, Hans Hoek, Willemien Runia Partner acronym: DLO
Address: Praktijkonderzoek Plant en Omgeving (PPO)
PPO Akkerbouw, Groene Ruimte en Vollegrondsgroente
Edelhertweg 1
8219PH, Lelystad, The Netherlands
E-mail: leendert.molendijk@wur.nl

Name: Tommy D’Hose Partner acronym: ILVO
Address: Institute for Agricultural and Fisheries Research (ILVO)
Plant Sciences Unit - Crop husbandry and environment
Burg. van Gansberghelaan 109
9820 Merelbeke, Belgium

E-mail: tommy.dhose@ilvo.vlaanderen.be

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Executive summary

Maintaining and improving soil quality is crucial if agricultural production and environmental quality are to be sustained for future generations. After all, due to legal constraints shortcomings in soil quality cannot be easily compensated anymore by large rates of mineral and/or organic fertilizers and pesticides. Possible tools for maintenance and improvement of soil quality include non-inversion tillage systems, crop rotations and cover crops and the use of compost. Traditionally, soil quality research has focused primarily on soil chemical and physical characteristics but more recently soil biology has been increasingly recognized as an indicator of soil quality. After all, soil biota play a major role in mineralization of nutrients by degradation of organic matter and in creating and maintaining a good soil structure. Furthermore, biological soil properties quickly change in response to a change in soil and crop management practices that affect soil quality and processes. Hence, biological indicators are critical when characterizing soil quality.

In this report the results of a large scale literature survey on the effects of good agricultural management practices on biological soil quality are presented. Experimental data on earthworm and nematode abundance, microbial biomass carbon and bacterial and fungal communities from more than 65 European long-term field experiments (LTEs) were extracted from peer reviewed scientific literature and national reports. The effects of management practices on the selected biological soil indicators were analyzed and through a subset regression it was evaluated whether climatic zone, soil texture and duration of practice influence these effects. The agricultural management practices that were considered in our study were the use of crop rotations (vs. monoculture), application of no- and non-inversion tillage (vs. ploughing), organic fertilization with farmyard manure, animal slurry or compost (vs. mineral fertilizer) and crop residue incorporation (vs. removal). Only for tillage and organic fertilization a sufficient amount of data was collected which allowed a thorough statistical analysis.

Overall, farmyard manure and compost amendment emerged as the best management practices for increasing soil biological quality. Apparently, soil biota benefit more from organic materials added to the soil, which serve as a food source, than from reduced soil disturbance and consequently a more

stable habitat. Further, the effect of a given management practice on soil biological quality was rarely influenced by climatic zone, soil texture or duration of practice. Amongst the biological indicators, earthworm abundance and microbial biomass carbon are frequently monitored in European LTEs and they tend to respond well to a change in crop and soil management. Data on the nematode, bacterial and fungal community are still rather scarce. In this study their response to management changes proved to be more difficult to interpret as we rather observed a shift in the community structure instead of a clear increase or decrease of a given species. However, because of the presence of nematodes in all trophical levels of the soil food web, nematode community indices still are likely candidates to become indicators of soil quality.

In general, it can be noted that soil biology, although known for its role in soil quality, is not often taken into account in soil research. There is a strong discrimination between physical, chemical and biological disciplines and most research is mainly focusing on one part of the puzzle. To make progress in understanding and steering soil quality, a multidisciplinary approach taking into account all soil disciplines, physics, chemistry and biology, is a requisite.

1 Introduction

Next to the physical and chemical properties, the soil food web is the driving force of plant production and other soil ecosystem functions such as e.g. mitigation of greenhouse gasses and sequestration of carbon. Some important functions of the soil food web are listed below (Ferris et al., 2001):

- Decomposition of organic matter
- Cycling of minerals and nutrients
- Redistribution of minerals and nutrients in space and time
- Reservoirs of minerals and nutrients
- Sequestration of carbon
- Detoxification of pollutants
- Modification of soil structure
- Biological regulation of pests

The absence or the presence below damage threshold levels of plant parasites or plant pathogens is a prerequisite of undisturbed and optimal crop production. Soil borne parasites and pathogens are just a minor fraction of soil live. The major part of bacteria, fungi, nematodes, insects and earthworms contribute substantially to both the physical and chemical qualities of a soil. Especially the excrements of soil life deliver the cement for soil aggregation and a stable soil structure. Soil live plays the lead role in the cycling of carbon and nutrients. Management practices that enhance the desired part of soil biology are the tools to approach sustainable agriculture. In this report the effects of management practices on soil biological indicators, being measures for soil quality, are investigated based on data from European long-term field experiments, owned by the Catch-C project partners or reported in literature.

2 Materials and Methods

2.1 Database

The data analysis was performed on the Catch-C online dataset which has been completed by the project partners. In the dataset 1913 records regarding soil biological quality indicators (earthworm and nematode (both plant-parasitic and free-living) abundance, microbial biomass carbon and bacterial and fungal PLFA (Phospholipid Fatty Acid) were present. All records were extracted from national reports and peer reviewed scientific literature which reported the results from European LTEs (LTEs that were established by the partners + LTEs found in literature). The LTEs and the corresponding management practices[1] and LTE characteristics that were studied in this report are listed in Table 1 and are based on (Anken et al., 2004; Berner et al., 2008; Birkhofer et al., 2008; Capowiez et al., 2009; Crecchio et al., 2007; D'Hose et al., 2014a; D'Hose et al., 2014b; D'Hose et al., 2014c; Edwards and Lofty, 1982; Emmerling, 2001; Garcia-Gil et al., 2000; Heinze et al., 2010; Heitkamp et al., 2009; Hoffmann et al., 1997; Hoffmann et al., 2002; Hoflich et al., 1999; Hynst et al., 2007; Jacobs et al., 2010; Jacobs et al., 2009; Jahangir et al., 2011; Janssens et al., 2012; Kautz

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[1] The definitions of the different management practices used in this report are given in Appendix 1

et al., 2004; Langer and Klimanek, 2006; Leroy, 2008; Lopez-Garrido et al., 2012; Madejon et al., 2009; Marwitz et al., 2012; Melero et al., 2009; Melero et al., 2011; Mikanova et al., 2009; Moeskops et al., 2012; Monaco et al., 2008; Nuutinen, 1992; Peigne et al., 2009; Piovanelli et al., 2006; Riley et al., 2008; Ros et al., 2006a; Ros et al., 2006b; Schjonning et al., 2002; Simon et al., 2013; Stockfisch et al., 1999; Tejada and Gonzalez, 2006; Van Den Bossche et al., 2009; van Eekeren et al., 2008; van Groenigen et al., 2010; Verlinden et al., 2005; Widmer et al., 2006; Witter et al., 1993) (Abaye et al., 2005; Bastida et al., 2008; Borjesson et al., 2012; Elfstrand et al., 2007; Houot and Chaussod, 1995; Lopez-Fando et al., 2007; Marschner et al., 2003; Runia et al., 2006; Sun et al., 2011; van Gastel-Topper et al., 2009).

Table 1: LTEs used in this report and the corresponding management practices compared in each experiment. The letter in the management practices columns indicates which biological soil properties were evaluated: e = earthworms, n = nematodes, b = bacterial and fungal PLFAs, m = microbial biomass carbon, all = all biological soil properties were determined in this LTE. The letter in the characteristics columns indicates the type of climate, soil and duration of practice for each LTE. Climate classes are N (nemoral), A (Atlantic), C (Continental) and M (Mediterranean); soil texture classes are C (clay), I (silt), A (sand), L (loam); duration (LTE duration at the time of sampling) is L (low), M (medium), H (high), and V (very high).

	Management practices									**Characteristics**		
Experiments	**Crop rotation**	**catch crop**	**green manure**	**no tillage**	**NIT**	**compost**	**FYM**	**slurry**	**return of crop residues**	**Climate class**	**Soil texture class**	**Duration**
Agramunt				m	m					M	I	M
Aiello del Friuli						m	m			M	A	L
Bad Lauchstädt							m			C	I	V
Berlin-Dahlem					m					C	A	V
Boxworth E.H. Farm				e	e					A	L	L,M
Brittany				e	e					A	L	L
Carlow					m,b					A	A	M
Cologne							b		b	A	I	V
Coria del Río				m	m					M	L	H
Court-St-Etienne					m					A	I	H
DE-Darmstadt							m		m	C	A	V
Dedelow					m					C	A	H
DOK						all	all	all		A	I	V
Eichenhof					e					C	I	L
Estrées-Mons					e					A	I	M
Fagna					m					M	L	M
Foggia				m					m	M	C	V
Frick					m	m		m		C	C	L
Germany_sugar beet					e					C	C	L
Gottingen					m					A	I	L
Göttingen HohesFeld					m					A	I	V
Grignon-36parcelles							m		m	A	L	V
Halle							m			C	A	V
Hangaar					e					A	A	L
Heestert					m					A	I	L
IOSDV Berlin-Dahlem							m		m	C	A	H

Jokioinen_1979					e				E	C	C	M
Keszthely							m			C	A	V
Kortrijkdorp					e					A	A	L
Kuttekoven				m						A	A	L
La Higueruela						m,n	m,n			M	L	M
Lange_weide					e					A	A	M
LTE 5 Vredepeel						n			n	A	A	L,M
LTE 7 BOPACT					e,m,n	e,m,n		e,m,n		A	A	M
LTE 9 FARMCO	e,m,n					e,m,n				A	A	M
LTE 10 Ferti						all	all	all		A	I	L,M
LTE 11 CROPRO	e,m,n	e,m,n	e,m,n							A	A	L
LTE 12 Tetto Frati	m	m					m	m		M	L	H
LTE 16 TOMEJIL				m	m					M	C	H,V
LTE 22 Compost					m	m				C	I	H
LTE 26 GarteSud					m					A	I	V
LTE Denmark	m						m	m	m	C	A	V
LTE Perugia									m	M	L	V
M66.01	e,m,n									A	A	V
Mest als kans						e	e	e		A	L	M
Mouhijarvi					e				e	C	L	M
Müncheberg V760					m		m	m		C	A	L,M
Murcia						b				M	L	V
Nieuwe stal					e					A	I	M
Pälkäne					e				e	C	A	M
Pays de la Loire				e	e					A	I	L
Praha-Ruzyne				m	m					C	L	M
Rhône Alpes				e	e					A	A	L
Riley	e				e			e		N	A	H
Ros Klammer						m				C	I	H
Ros Pascual						m				C	I	V
Rothamsted_tillage				e	e					A	L	L,M
SCRI, Dundee				m	m					A	A	M
SE-Ultuna			m,b				m,b		m,b	N	L	V
Tänikon				e	e					C	-	L
Trutnov							m		m	A	A	V
Vlaco.B97						e				A	L	M
Vlaco.M97						e				A	A	H
Widmer et al						m	m			A	C	V
Witter et al							m			N	C	V
Woburn							m	m	m	A	A	V
Woburn_1965				e						A	A	L,M
Zaragoza				m	m					M	I	H
Number of LTEs	**6**	**2**	**2**	**15**	**36**	**16**	**20**	**10**	**14**			

Table 1 shows that only on a few LTEs in the Catch-C database the influence of a specific crop rotation or the use of cover/green manure crops on soil biological quality has been studied. Consequently, a specific search was needed to collect enough data on this topic

2.2 Main indicators

The following biological soil quality indicators were used in this report:

- Earthworm abundance (both number and total biomass)
- Nematode abundance (both the amount of plant-parasitic and free-living (mainly bacterivorous and fungivorous) nematodes)

- Microbial biomass carbon (MBC)
- Bacterial and fungal PLFAs

Earthworms are considered to be one of the most important members of the soil fauna, possessing many features that make them useful biological indicators of soil quality (Blair et al., 1996). Earthworm population densities can be related to soil organic matter levels (Hendrix et al., 1992) and soil physical disturbances such as tillage (Lee, 1985). The population density of earthworms tends to increase with increasing organic matter inputs and decrease with soil disturbance. Further, through their feeding and burrowing activities, earthworms significantly alter soil structure and hydrologic properties (Tomlin et al., 1995) and make substantial contributions to nutrient mineralization (Didden et al., 1994). For these reasons, the possibility of manipulating earthworm populations to maintain soil quality in agro-ecosystems has received much attention during the past decades.

Nematodes are the earth’s most abundant metazoa and are ubiquitous in the soil environment. They are sufficiently large to be identifiable by light microscopy and sufficiently small to inhabit water films surrounding soil particles. Nematodes can be found in all trophic levels of the soil foodweb. The presence and numbers in the different trophic and functional guilds is like a print of the activities in the niche they represent. E.g. the explosion in bacteria numbers after incorporating green manure crops is represented by the immediate increase of bacterivorous nematodes. A major fraction of fungal feeders compared to bacterial feeders make clear that a soil is fungi dominated. Each soil contains large number and a high diversity of nematodes and therefore a soil sample has a high intrinsic information value (Bongers and Bongers, 1998; Ferris et al., 2001). Further, many studies indicate that the abundance and composition of free-living nematodes (especially bacterivorous and fungivorous nematodes) can provide additional information about the microbial community and processes (e.g., Ferris et al., 2004). The group of plant-parasitic nematodes is an indicator of soil health on its own. In agronomic systems these pathogenic herbivorous species should be below damage threshold levels for the crops grown, to ensure optimal yield and quality. Plant-parasitic nematodes are a serious threat to crops causing an estimated yield loss worth US$ 100 billion per year (Martin, 2003; Noling and Becker, 1994).

Microorganisms (e.g. bacteria, fungi) play a key role in organic matter decomposition and nutrient cycling in soil. The total mass of living microorganisms (the microbial biomass) therefore has a central role as source, sink and regulator of the transformations of energy and nutrients in soil (Murphy et al., 2007). Further, soil micro-organisms perform a wide range of other functions: they degrade toxic residues, form symbiotic associations with plant roots (e.g. arbuscular mycorrhizae), act as antagonists to pathogens (by e.g. pre-emptive colonisation, the production of antibiotics and the direct predation of pathogens) and contribute to soil structure and aggregation through the production of mucus like substances by bacteria and the fungal hyphae (Pankhurst et al., 1997; Sparling, 1997). Soil microbial biomass and the microbial community structure (i.e., bacterial and fungal PLFAs), have been considered as suitable biological indicators of soil quality and have been successfully used for assessing and monitoring the effects of intensive land-use management on soil quality (Leroy, 2008).

The number of records and LTEs for each indicator of biological soil quality that were taken into consideration in this report are presented in Table 2. For earthworm number and biomass, and microbial biomass carbon content, a sufficient amount of data was present in the Catch-C database in order to perform a statistical analysis. For nematode abundance and bacterial and fungal PLFAs, very few LTEs were included in the database which prevents a thorough analysis. Consequently, the results that will be presented in this report on the effects of different management practices on nematode abundance and bacterial and fungal PLFAs will mainly be based on findings in literature. These facts lead us to the conclusion that although there was increasing interest in soil biological quality during the past decades, biological indicators are not always included when assessing soil quality in European LTEs.

Table 2: Number of records and LTEs in the Catch-C database for each biological indicator

Indicator	Number of records	Number of LTEs
Earthworm number	215	26
Earthworm biomass	162	22
Plant-parasitic nematode number	85	8
Bacterivorous nematode number	61	7
Fungivorous nematode number	43	6
Microbial biomass carbon content	472	44
Bacterial PLFAs	157	7
Fungal PLFAs	78	7

2.3 Statistical analysis

The following indicators were included in the analysis:

- Earthworm_biomass
- Earthworm_number
- MBC_content
- PPNEM (amount of plant-parasitic nematodes)
- BACNEM (amount of bacterivorous nematodes)
- FUNGNEM (amount of fungivorous nematodes)
- BAC_PLFA (bacterial PLFAs)
- FUNG_PLFA (fungal PLFAs)

For MBC_content, PPNEM, BACNEM, FUNGNEM, BAC_PLFA and FUNG_PLFA measurements, relative response ratios (RR) were calculated. For each best management practice (BMP), the measurements of each indicator within that particular BMP were divided by the measurements in the baseline management practice (MP, Table 3). The RR obtained is greater than 1 when the BMP implies an improvement in that indicator and lower than 1 when the indicator value is reduced (except for plant-parasitic nematodes where an improvement (i.e., a lower amount of plant-parasitic nematodes) results in a RR which is lower than 1).

For earthworm number and biomass, an absolute increase or decrease (DIFF) was calculated. For each BMP, the value of the baseline MP was subtracted from the measurements of each indicator within that particular BMP. The DIFF obtained is greater than zero when the BMP implies an improvement in that indicator and lower than zero when the indicator value is reduced.

The BMPs and the accompanying baseline MPs that were used in the analysis are listed in Table 3.

Table 3: BMPs and the accompanying baseline MPs used in the analysis

MP-category	BMP	Baseline MP
Crop rotation	Rotation (MP 2-3-4-5-6)	Monoculture (MP 1)
Fertilization	Compost (MP 29-30-31)	Mineral N fertilization (MP 26)
	Farmyard manure (MP 32)	Mineral N fertilization (MP 26)
	Slurry (MP 33-34-35)	Mineral N fertilization (MP 26)
Tillage	No tillage (MP 16-21)	Ploughing (MP 15)
	Shallow non-inversion tillage (MP 18)	Ploughing (MP 15)
	Deep non-inversion tillage (MP 19)	Ploughing (MP 15)
Crop residues	Return of crop residues (MP 36)	Removal of crop residues (MP 39)

Per BMP a histogram of the RR or DIFF is given, after which the RR and DIFF frequency distributions were tested for normality (Kolmogorov-Smirnov test) and their descriptive statistics were calculated.

A one-sample t-test (2 tails) was used to identify which RR means were significantly different from 1, and which DIFF means were significantly different from 0 ($p<0.05$).

With subset regression the influential factors from soil texture, climatic zone, sampling depth and duration on the RR or DIFF were selected using the Genstat procedure RSEARCH. The four factors were divided into different levels (Table 4). Climatic zones were those reported by Metzger et al. (2005) while for the soil texture classes, the USDA Textural Soil Classification was used.

When there was a significant effect of soil texture, climatic zone, sampling depth and duration (LTE duration at the time of sampling), analysis of variance was performed resulting in a F-probability and a Student pairwise t-test. Means without a common letter differ significantly ($P<0.05$).

Table 4: Levels of the four factors considered in the subset regression. ALN = Alpine north, BOR = Boreal, NEM = Nemoral, ATN = Atlantic North, ATC = Atlantic Central, ALS = Alpine South, LUS = Lusitanian, CON = Continental, PAN = Pannonian, ANA = Anatolian, MDM = Mediterranean mountains, MDN = Mediterranean North, MDS = Mediterranean South

Climatic zone	Soil texture (USDA)	LTE duration at the time of sampling	Sampling depth (cm)
NEM (Nemoral) (ALN, BOR, NEM)	clay (clay, silty clay)	< 5 yrs	< 10
ATC (Atlantic) (ATN, ATC, ALS, LUS)	loam (loam, clay loam, sandy clay loam, silty clay loam)	5-10 yrs	10-30
CON (Continental) (CON, PAN)	sand (sand, loamy sand, sandy loam)	11-20 yrs	> 30
MED (Mediterranean) (ANA, MDM, MDN, MDS)	silt (silt, silty loam)	> 20 yrs	-

3 Results and discussion

3.1 Crop rotation

3.1.1 Earthworms

3.1.1.1 Expected results from literature

Earthworm abundance has only been studied in relatively few European crop rotation LTEs. In general, the inclusion of crops, such as cereals, that leave substantial amounts of carbon rich residues on the field, encourage the buildup of earthworm populations more than legumes, which decompose quite rapidly. Root crops, for which most of the crop is removed, discourage the buildup of earthworm populations (Edwards and Bohlen, 1996).

Legumes as intercrop for cereal monocropping support much larger earthworm populations than those in conventional monocrops (Schmidt et al., 2001), which is probably a response to the increased food supply in the intercrops.

It is well established that grassland usually contains more earthworms than arable land (Edwards and Bohlen, 1996). Yeates et al. (1998) and Lamande et al. (2003) found earthworms to be more abundant and populations to have greater biomass under long-term pasture than under long-term arable cropping. This is not surprising as under permanent grassland (and temporary grassland) disturbance is limited and food is presumably more abundant, allowing earthworms to develop their population (Curry, 2004).

3.1.1.2 Results from European LTEs in Catch-C database

As only a few LTEs studied the effects of crop rotation on earthworm abundance, no statistical analysis could be performed. The most important finding of 1 LTEs is listed below.

M66.01: Permanent arable land was compared with permanent grassland and with a ley-arable crop rotation. Both earthworm number and biomass were significantly higher in the permanent grassland compared to the permanent arable land. In the ley-arable rotation, a period of three years of grassland (temporary grassland) was followed by a period of three years of arable land (temporary arable) land) and vice versa. In the first year of arable cropping in the rotation, the number of earthworms was already low and not different from continuous arable cropping. In the three-year grass ley, the abundance of earthworms returned to the level of permanent grassland in the second year. However, the restoration of earthworm biomass took a minimum of three years. Furthermore, the anecic species did not recover the dominance they had in the permanent grassland (van Eekeren et al., 2008).

3.1.2 Nematodes

3.1.2.1 Expected results from literature

Plant parasitic nematodes differ widely in their specialization on crops. Some species have only one plant family on which they can complete their life cycle, e.g. potato cyst nematode, *Globodera spp.*, which has only hosts within the family of *Solanaceae*. Other species are polyphagous and can propagate on a wide host range and belong to different plant families, e.g. root lesion nematode, *Pratylenchus penetrans*. The first group can be controlled by growing the host in wide rotations in a low cropping frequency. The second group can only be controlled by choosing the order of crops based on knowledge of the expected population dynamics of the present nematode species and the tolerance of the crops to nematode damage. Such a nematode control strategy is especially useful on light soils with ample species present in crops with high economic values. Both from the LTE's and literature it can be concluded that the awareness of farmers but also in extension and research is poorly developed. Only in Belgium and the Netherlands nematode control strategies are used actively (Molendijk and Mulder, 1996). In other countries there is mostly just a general feeling that broad rotations are important in the prevention of soil diseases. In this way the polyphagous groups are neglected and only the specialized species are taken into account.
Besides the direct effect on plant parasitic nematodes crops influence also the abundance and diversity of free-living nematodes. Dick (1992) concludes from an extensive review of literature that crop rotations have significantly higher levels of microbial biomass and soil enzyme activities and consequently a higher amount of bacterivorous nematodes than cropping sequences that are either continuously monocultured or have more limited crop rotations.

3.1.2.2 Results from European LTEs in Catch-C database

As only a few LTEs studied the effects of crop rotation on nematode, no statistical analysis could be performed. The most important findings of 2 LTEs are listed below.

M66.01: Permanent arable land was compared with permanent grassland and with a ley-arable crop rotation. The amount of plant-parasitic and fungivorous nematodes was significantly higher in the permanent grassland while the arable treatments were dominated by bacterivorous nematodes (van Eekeren et al. 2008). Further, the numbers of herbivorous and free-living nematodes in the ley-crop rotation reached similar levels to those in the permanent treatments within one to two years (van Eekeren et al., 2008).

LTE 11 CROPRO: In this experiment, a monoculture of silage maize was compared with a maize/field pea/potato rotation and a ley-arable rotation. After six years, none of the above mentioned cropping systems significantly altered the nematode community (both plant-parasitic and free-living nematodes) compared to the monoculture (D'Hose et al., 2014a)

3.1.3 Microorganisms

3.1.3.1 Expected results from literature

The use of crop rotations results in a greater range of root exudates which supports a diverse microbial population (Abbott and Murphy, 2007). Crop rotation presents soil organisms with varied living conditions and a greater variety of substrates. Plants regulate the activities of soil biota (Swift and Anderson, 1996) both directly and indirectly. The roots modify the soil structure, and alter the vertical distribution of nutrients, water and soil organisms. The quantity and quality of above- and below- ground residues determines the composition of microbial and faunal communities. Populations and the activities of microorganisms are strongly influenced by residues, root exudates, and products of decomposition. Therefore, diversified crop rotations are essential for creating a suitable environment for enhanced biological fertility.

Haynes (1999) found a higher biomass in grassland soil than in arable soil. Comparisons of maize cropping systems grown continuously and in rotation with soybean generally show an increase in microbial biomass in the rotation (Omay et al., 1997). Dick (1992) concludes from an extensive review of literature that crop rotations have significantly higher levels of microbial biomass and soil enzyme activities than cropping sequences that are either continuously monocultured or have more limited crop rotations.

3.1.3.2 Results from European LTEs in Catch-C database

As only a few LTEs studied the effects of crop rotation on microorganisms, no statistical analysis could be performed. The most important findings of 2 LTEs are listed below

M66.01: Permanent arable land was compared with permanent grassland and with a ley-arable crop rotation. Bacterial biomass was found 50% higher in permanent grassland than in permanent arable land. Fungal biomass, averaged over the years, also tended to be higher in grassland with four times less fungal biomass in permanent arable land than in permanent grassland, and a clear decrease in the order permanent grassland > temporary grassland > temporary arable land > permanent arable land. After three years of grass on the temporary grassland plots, fungal biomass was significantly higher than after three years of arable farming (van Eekeren et al., 2008).

LTE 11 CROPRO: In this experiment, a monoculture of silage maize was compared with a maize/field pea/potato rotation and a ley-arable rotation. After six years, none of the above mentioned cropping systems significantly altered the microbial biomass carbon content compared to the monoculture (D'Hose et al., 2014a).

3.2 Cover/catch/green manure crop

There were only three LTEs dealing with the use of cover/catch/green manure crops (Table 1). Consequently, no further analysis was conducted. However, as the effect of different cover/catch/green manure crops on plant-parasitic nematode abundance is an important research topic, the main findings from interesting reviews on that topic are listed below.

3.2.1 Nematodes

3.2.1.1 Expected results from literature

The review article of Thoden et al. (2011) gives a comprehensive overview of research done on all type of organic amendments and their influences on plant-parasitic and free-living nematodes. The authors conclude that there is no unambiguous conclusion possible on the effect of green manure crops on plant-parasitic nematodes. Both positive and negative effects are found in numerous experiments. The most important aspect of green manure crops is their host status for the plant-parasitic species present. When green manure crops are good hosts the infestation levels rise considerably and can reach damage levels. The choice of the green manure crop is therefore for each field and rotation a tailor made decision. In general it can be concluded that green manure crops often enhance growing conditions of the following crop and make them less sensitive to nematode damage. This mechanism is an indirect effect and is not based on nematode control as such. Some green manure crops are intrinsic non-hosts, or selected cultivars with resistance against some nematode species which are developed in resistance breeding programs, e.g. white mustard and fodder radish. These resistant green manure varieties are an valuable tool within the nematode control strategy. Another known mechanism is the release of nematotoxic compounds like organic acids, nitrogenous compounds after chopping and mixing the crop into the furrow. The effectiveness of organic acids and ammonia is very pH dependent. The first is only effective at low pH while ammonia is only toxic at high pH (Rodriguezkabana, 1986). A specific group of *Brassicaceae* is used because of the production of glucosinolates within the tissues. After incorporating, enzymes can convert these glucosinolates into nematotoxic isothiocyanates and result in nematode control. This process is called biofumigation (Kirkegaard and Sarwar, 1998). Until now it is questionable whether this process can be managed in such a way that lethal amounts of the active ingredients are formed (Vervoort et al., 2014) and that these green manure crops are reliable tools in nematode control. Vervoort et al. (2014) also concluded that the substantial shifts in nematode populations after incorporating the green manure crops are probably caused by disruption at tillage and the breaking down of the fresh material. Green manure crops can be advised as a best management practice but the ultimate choice of crop and variety should be tailor made.

3.3 Non-inversion tillage (deep and shallow) and no tillage

3.3.1 Earthworms

3.3.1.1 Expected results from literature

The level of direct mortality associated with cultivations depends on the severity and frequency of soil disturbance (Curry, 2004). Ploughing does not always appear to cause serious mortality: Cuendet (1983) estimated that 5 to 10% of the earthworm biomass was brought to the surface by plowing, with about 25% of these earthworms mortally wounded. Rotary cultivation can reduce numbers by 60 to 70% (Bostrom, 1987). Populations generally recover within 1 year from less-severe forms of cultivation, provided the disturbance is not repeated. Larger anecic earthworm species such as L. terrestris which require a supply of surface litter and have relatively permanent burrows, are the species most adversely affected by repeated soil disturbance; smaller endogeic species such as A. chlorotica are less affected and can benefit from plowed-in crop residues (Edwards, 1983). In conclusion, earthworms are favored by reduced tillage and direct drilling compared with conventional methods of cultivation (Edwards and Lofty, 1982). Earthworm populations are almost always higher under no-till than under conventional tillage practices (Wardle et al., 1995). Numerous examples from research plots (Edwards and Lofty, 1982; House and Parmelee, 1985; Mackay and Kladivko, 1985) and producers fields (Kladivko et al., 1997; Valckx et al., 2009) support the conclusion that reduction of tillage intensity encourages earthworm populations. According to Valckx et al. (2009), especially the larger, deep-burrowing species are encouraged by the application of non-inversion tillage. Moldboard ploughing and no-till represent the two extremes of tillage systems, and systems with intermediate levels of soil disturbance usually have intermediate levels between the two extremes (Kladivko, 2001). In no-till systems, the residues on the soil surface are available as a food supply to the earthworms. In addition, the surface residues serve as a mulch and slow the rate of soil drying in late spring and freezing in late autumn. No-till is even more important for deep-burrowing species than for shallow-dwelling earthworms as the deep-burrowers feed primarily on residues at the surface. Consequently, a clean-till system is not conducive to deep-burrowers. The surface food supply is not available in ploughed soils and the top portion of the permanent burrow must be reformed after each tillage operation.

3.3.1.2 Results from European LTEs in Catch-C database

In the Catch-C database, 18 LTEs compared different types of reduced tillage (i.e., shallow non-inversion tillage (SNIT), deep non-inversion tillage (DNIT) and no tillage (NT)) with conventional tillage (i.e., ploughing; CT) and reported the effects on earthworm number and biomass.

The main statistics of the analyzed data on earthworm number and biomass DIFF are shown in Table 5, Table 6, Figure 1 and Figure 2.

Table 5: Main descriptive statistics for earthworm number DIFF (ind.m^{-2}) in the different tillage types. The t-test indicates if DIFF mean is significantly different from 0 ($p<0.05$) (n: number of records).

Tillage type	n	min	max	mean	stdev	skewness	kurtosis	normality test	t-test
SNIT	34	-30	90	13	29	1.36	1.09	0.000***	0.012*
DNIT	13	-44	128	20	46	0.98	1.23	0.200ns	0.129ns
NT	26	-25	140	22	34	2.34	6.83	0.000***	0.003**

SNIT: shallow non-inversion tillage; DNIT: deep non-inversion tillage; NT: no tillage

Table 6: Main descriptive statistics for earthworm biomass DIFF (g.m^{-2}) in the different tillage types. The t-test indicates if DIFF mean is significantly different from 0 ($p<0.05$) (n: number of records).

Tillage type	n	min	max	mean	stdev	skewness	kurtosis	normality test	t-test
SNIT	24	-10	45	13	16	0.52	-0.92	0.021*	0.001**
DNIT	13	-10	48	12	19	1.09	-0.02	0.103ns	0.046*
NT	12	0	118	39	41	1.10	0.04	0.049*	0.007**

SNIT: shallow non-inversion tillage; DNIT: deep non-inversion tillage; NT: no tillage

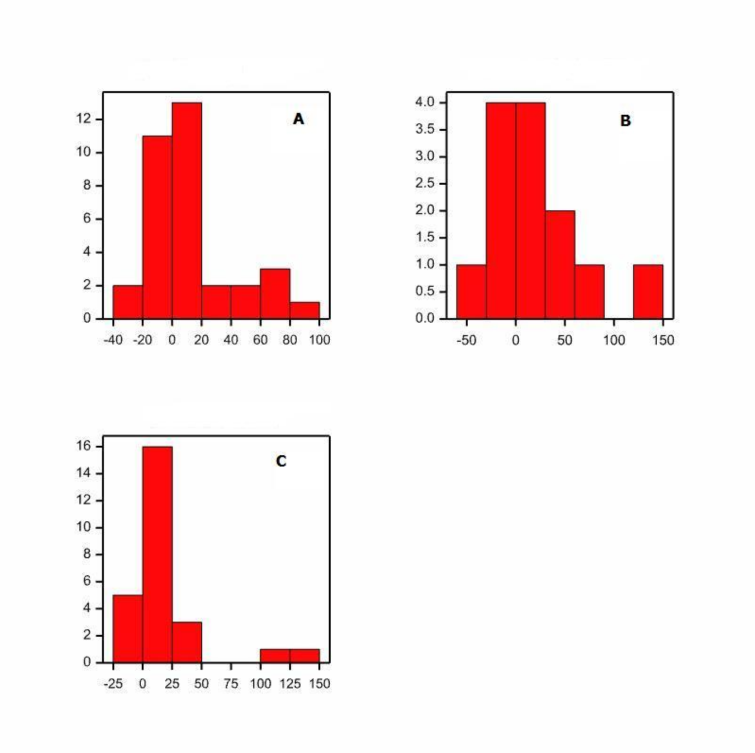

Figure 1: Frequency distribution of earthworm number DIFF in A) shallow non-inversion tillage, B) deep non-inversion tillage and C) no tillage

Overall, our analysis shows that the application of both shallow non-inversion tillage and no tillage significantly increased earthworm number and biomass (mean earthworm number and biomass DIFF differed significantly from 0). For deep non-inversion tillage, only earthworm biomass was significantly increased (Table 5 and Table 6).

The distribution of earthworm number DIFF was normal around a mean of 13, 20 and 22 for SNIT, DNIT and NT, respectively (Figure 1 and Table 5). This means that an overall increase in earthworm number of 13, 20 and 22 per m² is expected when SNIT, DNIT and NT are applied, respectively.

The distribution of earthworm biomass DIFF was normal around a mean of 13, 12 and 39 for SNIT, DNIT and NT, respectively (Figure 1 and Table 5). This means that an overall increase in earthworm biomass of 13, 12 and 39 g.m^{-2} is expected when SNIT, DNIT and NT are applied, respectively.

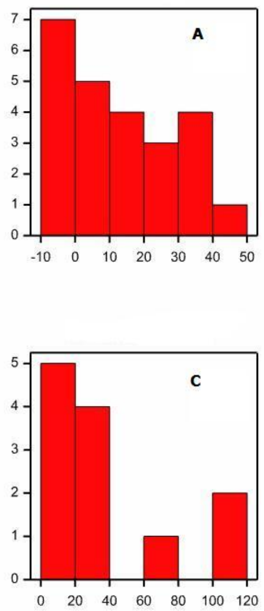

Figure 2: Frequency distribution of earthworm biomass DIFF in A) shallow non-inversion tillage, B) deep non-inversion tillage and C) no tillage

In accordance with findings in literature, it seems that earthworm abundance was higher under no tillage than under non-inversion tillage. The difference between no tillage and the two non-inversion tillage practices was higher for earthworm biomass than for earthworm number. Probably, larger earthworms (i.e., anecic species) are favored more under no tillage as soil disturbance is limited compared to non-inversion tillage. The two types of non-inversion tillage (i.e., SNIT and DNIT) differed in earthworm number but not in earthworm biomass. We assume that, due to the difference in soil disturbance, in the shallow tilled plots larger earthworms occur (i.e., anecic species) while in the deep tilled plots smaller earthworms are present (i.e., endogeic species). However, no statistical analysis was performed to support those hypotheses, so future research seems required. Further, specific literature research on earthworm species instead of on merely earthworm number and biomass is also required to confirm this hypothesis.

3.3.1.3 Influencing factors

By means of subset regression, it was investigated if the factors soil texture, climatic zone, sampling depth and duration of the LTE at sampling time, were influencing the effect of tillage practices on both earthworm biomass and number DIFF.

Climatic zone emerged as an influential factor, both for earthworm number DIFF and earthworm biomass DIFF when DNIT was applied.

It seems that the effect of DNIT on earthworm abundance is more pronounced in the CON (Continental) climatic zone compared to the ATC (Atlantic) climatic zone (Table 7). However, as the results for CON are based on only 2 observations, no sound conclusions could be drawn.

Table 7: Results of the subset regression for earthworm number and biomass DIFF in deep non-inversion tillage (n: number of records).

Climatic zone	Earthworm number DIFF		Earthworm biomass DIFF	
	n	mean	n	mean
NEM	-	-	-	-
ATC	11	6	11	5
CON	2	104	2	48
MED	-	-	-	-

NEM: Nemoral; ATC: Atlantic; CON: Continental; MED: Mediterranean

3.3.2 Nematodes

3.3.2.1 Expected results from literature

The direct influence of disruption of soil by plowing or cultivating is very little. Just the bigger species as Xiphinema sp. and Longidoridae are killed by intensive soil preparation. This species will build up higher populations in no till or reduced till management systems. The effect on nematode populations is very variable and depends far more on crop rotation, green manure crops grown, buildup and distribution of organic matter (Holland, 2004). In northern regions no-till usually allows earlier drilling of winter-sown crops but will give lower soil temperature and higher moisture content in spring causing delayed drilling of spring-sown crops (Soane et al., 2012). It can be expected that changes in cultivation practices of crops will have its effect on damage relations and population dynamics of plant parasitic nematodes. No information is available whether these effects are positive or negative. In the USA the investigation of the effects of tillage on plant parasitic nematodes has a long tradition. Minton concluded that the effects are very species, crop and tillage type dependent. No general conclusion can be drawn (Minton, 1986).

3.3.2.2 Results from European LTEs in Catch-C database

Only two LTEs (LTE 7 BOPACT and La Higuerela) on the effects of non-inversion tillage on plant parasitic nematodes have been found in the Catch-C database. In those LTEs, the number of plant-parasitic nematodes was increased in the non-inversion tilled plots (Mean RR: 1.42 ± 0.25). However, as only 2 LTEs were included in the analysis, no sound further analysis was conducted.

3.3.3 Microorganisms

3.3.3.1 Expected results from literature

Many studies on the impact of tillage on soil microorganisms have shown that different communities respond differently to tillage regime. In general, both the abundance and diversity of soil microbial communities increase with decreasing tillage intensity (El Titi, 2003). This assumption was endorsed by Wardle (1995) who reviewed several studies on the effect of reduced tillage on microflora and found less soil microbial biomass in conventional tillage than in no tillage. Greater microbial biomass under no tillage than under conventional tillage is likely due in part to cooler, wetter conditions and less fluctuation in temperature and moisture under no tillage. Further, one generalization often made is that at the microfoodweb scale, no tillage systems tend to be fungal dominated whereas conventional tillage systems tend to be bacterial dominated. However, regardless of the microorganism considered, responses to tillage regime are highly variable (Kladivko, 2001). Another effect of changes in tillage regime is the major modifications observed in the vertical distribution of microorganisms when plowing is abandoned.

3.3.3.2 Results from European LTEs in Catch-C database

In the Catch-C database, 18 LTEs compared different types of reduced tillage (i.e., shallow non-inversion tillage (SNIT), deep non-inversion tillage (DNIT) and no tillage (NT)) with conventional tillage (i.e., ploughing; CT) and reported the effects on soil microbial biomass C (MBC).

The main statistics of the analyzed data on microbial biomass C RR are shown in Table 8 and Figure 3). Table 8 shows that in general, MBC increases significantly with decreasing tillage intensity. MBC RR had a mean of 1.17 and ranged from 0.25 to 2 when SNIT was applied while, a mean MBC RR of 1.29 with a range of 0.64 to 2.12 was noticed when NT was applied. Both SNIT and NT did not show a normal distribution though. As there were only two observations for DNIT, no further analysis was conducted on this tillage type.

Table 8: Main descriptive statistics for microbial biomass C RR in the different tillage types. The t-test indicates if RR mean is significantly different from 1 (p<0.05) (n: number of records).

Tillage type	**n**	**min**	**max**	**mean**	**stdev**	**skewness**	**kurtosis**	**normality test**	**t-test**
SNIT	71	0.25	2.99	1.17	0.58	1.40	1.85	0.000***	0.016*
DNIT	2	0.88	1.33	1.10	0.32	-	-	-	0.722ns
NT	23	0.64	2.12	1.29	0.41	0.69	-0.16	0.002**	0.002**

SNIT: shallow non-inversion tillage; DNIT: deep non-inversion tillage; NT: no tillage

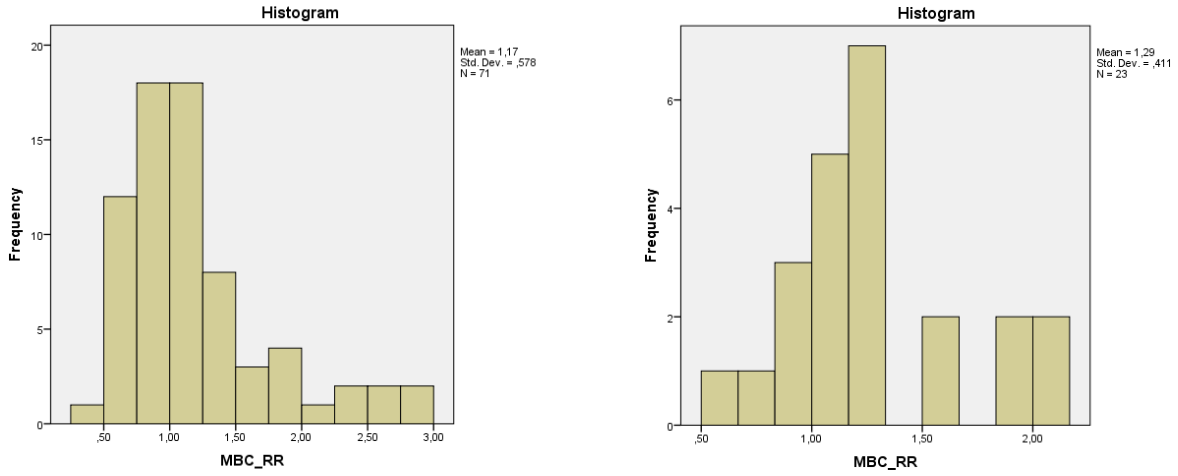

Figure 3: Frequency distribution of microbial biomass C RR in shallow non-inversion tillage (left) and no tillage (right)

Table 9: Results of the subset regression for MBC RR in SNIT and NT (n: number of records).

Sampling depth (cm)	SNIT		NT	
	n	mean	n	mean
< 10	38	1.43b[1]	12	1.51b
10-30	26	0.85a	6	0.94a
> 30	6	0.88a	3	1.20ab

[1] Different letters within one column indicate a significant difference at the 5% level

Table 9 shows that both SNIT and NT result in an increase of the MBC (+43% in SNIT; +51% in NT) in the topsoil layer (0-10cm) compared to ploughing, while in the subsoil (10-30 cm) the reverse effect has been observed with a decrease of 15 and 6% in, respectively SNIT and NT compared to ploughing.

This is perhaps no surprise as during conventional tillage, the soil and consequently the microorganisms are mixed to a depth of 30 cm while in the non-inversion tilled plots, the microorganisms remain in the topsoil. Moreover, in the non-inversion tilled plots, the microorganisms benefit more from crop residues and organic fertilizers that remain on the soil surface or in the topsoil.

3.4 Organic amendments

3.4.1 Earthworms

3.4.1.1 Expected results from literature

Organic manures benefit earthworms by providing additional food, by their mulching effects and by stimulating plant growth and litter return. Farmyard manure is a particularly beneficial form of organic amendment (Whalen et al., 1998). Furthermore, the nutritional value for earthworms of farmyard manure is considered to be higher than that of compost in which the applied organic matter is more decomposed and stabilized (Leroy, 2008). Heavy applications of animal wastes as slurry containing high levels of ammonia and organic salts can be toxic (Curry, 1976). However, any adverse effects of moderate slurry applications are transitory, and the long-term net population response is positive (Curry, 1976).

3.4.1.2 Results from European LTEs in Catch-C database

In the Catch-C database, 7 LTEs compared different types of organic amendments (i.e., farmyard manure (FYM), compost (COMP) and animal slurry (S) with the application of mineral N fertilizer and reported the effects on earthworm number and biomass.

Table 10: Main descriptive statistics for earthworm number DIFF (ind.m^{-2}) in the different organic amendments. The t-test indicates if DIFF mean is significantly different from 0 (p<0.05) (n: number of records).

Organic amendment	n	min	max	mean	stdev	skewness	kurtosis	normality test	t-test
COMP	29	8	238	75	73	1.04	0.49	0.065ns	0.005**
FYM	7	58	569	320	255	-0.08	-3.2	0.141ns	0.027*
S	6	-6	591	283	266	-0.01	-2.69	0.200ns	0.048*

COMP: compost application; FYM: farmyard manure application; S: animal slurry application

The main statistics of the analyzed data on earthworm number and biomass DIFF are shown in Table 10, Table 11, Figure 4 and Figure 5.

Table 11: Main descriptive statistics for earthworm biomass DIFF ($g.m^{-2}$) in the different organic amendments. The t-test indicates if DIFF mean is significantly different from 0 ($p<0.05$) (n: number of records).

Organic amendment	n	min	max	mean	stdev	skewness	kurtosis	normality test	t-test
COMP	26	2	35	15	10	0.77	-0.04	0.200ns	0.001**
FYM	4	66	85	71	9	1.99	3.96	-	0.001**
S	5	0	73	42	27	-0.95	1.50	0.200ns	0.026*

COMP: compost application; FYM: farmyard manure application; S: animal slurry application

In accordance with findings in literature, all organic amendments significantly increased both earthworm number and biomass. The application of FYM resulted in the highest increase while compost amendment resulted in the lowest increase. Slurry application resulted in intermediate values. These results confirm the hypothesis of Leroy (2008) who assumed that the nutritional value for earthworms of both animal slurry and farmyard manure (‘fresh’ organic amendments) are higher than that of composts, in which the applied organic matter is more decomposed and stabilized, due to the aerobic composting for several weeks or months.

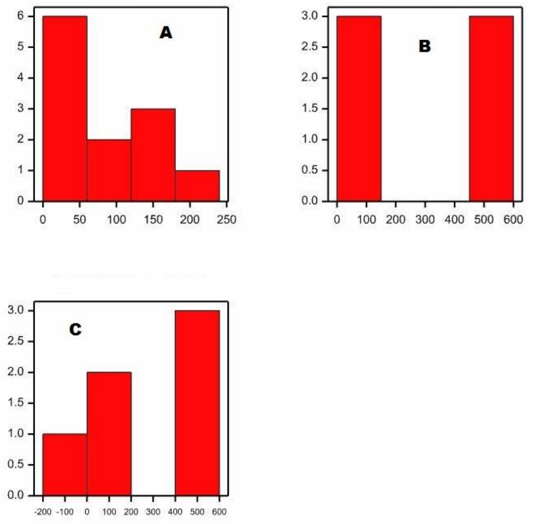

Figure 4: Frequency distribution of earthworm number DIFF in A) compost, B) farmyard manure and C) animal slurry

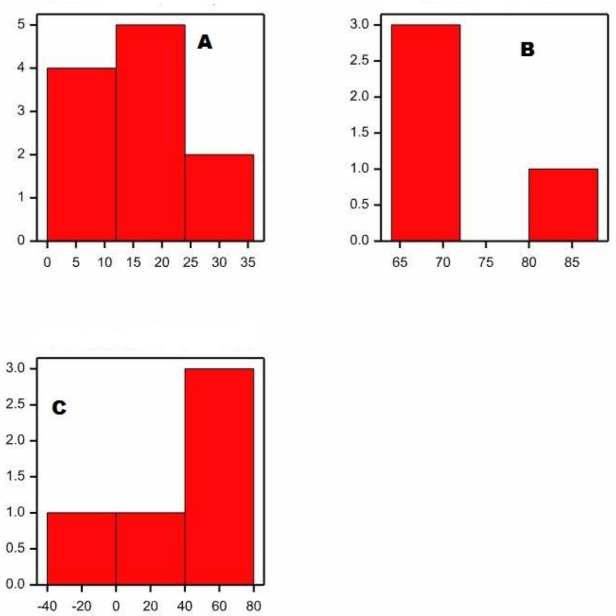

Figure 5: Frequency distribution of earthworm biomass DIFF in A) compost, B) farmyard manure and C) animal slurry

3.4.1.3 Influencing factors

The subset regression pointed out soil texture as an influencing factor both for earthworm number DIFF and earthworm biomass DIFF when compost was applied.

Table 12: Results of the subset regression for earthworm number and biomass DIFF in compost application (n: number of records).

Soil texture	Earthworm number DIFF		Earthworm biomass DIFF	
	n	mean	n	mean
Clay	-	-	-	-
Loam	3	14a[1]	2	8a
Sand	2	39a	5	11a
Silt	4	161b	4	23a

[1] Different letters within one column indicate a significant difference at the 5% level

From Table 12, we can conclude that the positive effect of compost on earthworm abundance is more pronounced in a silt soil compared to a loam and sandy soil. However, the four observations on a silt soil were all gathered from the same LTE. Furthermore, the effect of soil texture on earthworm biomass was found not significant. Consequently, we should be careful with generalizing these results.

3.4.2 Nematodes

3.4.2.1 Expected results from literature

Inorganic fertilizers containing ammoniacal nitrogen or formulations releasing this form of N in the soil are most effective for suppressing plant-parasitic nematode populations. Anhydrous ammonia has been shown to reduce soil populations of *Tylenchorhynchus claytoni*, *Helicotylenchus dihystera*, and *Heterodera glycines*. The rates required to obtain significant suppression of nematode populations are generally in excess of 150 kg N/ha. Urea also suppresses several nematode species, including Meloidogyne spp., when applied at rates above 300 kg N/ha. Additional available carbon must be provided with urea to permit soil microorganisms to metabolize excess N and avoid phytotoxic effects (Rodriguezkabana, 1986). Mineral fertilizer does not only diminish plant parasitic nematodes but also free-living species (Verschoor, 2001). It is not conclusive whether the positive effect of plant parasitic control is overruled by negative effects on the diminished diversity of soil life.

Especially bacterial soil life is capable of mobilization of N and P from organic amendments (mineralisation). Bacterial soil life is stimulated by amendments with a low C/N ratio (Ferris and Matute, 2003). Subsequently, this facilitates the development of bacterial-feeding nematodes that make N and P available to plants. Farmyard manure, animal slurries but also chitin and legumes have low C/N ratios and are therefore excellent food sources for bacteria. Next to the nutritional effect of amendments there can be direct nematicidal effects. The ideal C/N ratio for organic fertilizer and for any organic amendment to achieve these nematicidal effects is lying between 10 and 15. Lower than 10 is phytotoxic and higher than 20 no nematicidal effects are found (Rodriguezkabana et al., 1987). This phyto toxicity is really killing plants and is not just growth retardation because of N immobilizaton.

Long-term research in Switzerland showed that farmyard manure revealed the strongest influence on microbial biomass, diversity indices and microbial community structures. These farmyard manure effects were far stronger than the effects of the preceding crop or the management system (conventional, organic) used (Esperschuetz et al., 2007). It can be expected that these differences will also be true for the nematode abundance and diversity.

Application of organic amendments to the soil is also expected to increase the fungal population and hence the amount of fungivorous nematodes. However, this will mostly be the case (1) when, following bacterial decomposition, the remaining organic matter is more recalcitrant, (2) when organic amendments that are less easily decomposed are added to the soil, or (3) when soil conditions are not favorable for bacteria mediated decomposition, e.g. low pH or lower nutrient concentrations (Chen and Ferris, 2000).

Also the use of various types of compost showed variable results. The superficial amendment of compost in the seeding or planting row can prevent some damage caused by Trichodorids and Tobacco Rattle Virus (Zoon et al., 2002). Also the compost amendment-induced improvement of physical and chemical soil parameters may stimulate plant growth and vitality, rendering them more resistant to nematode attack. However, a stimulation of root growth may result in more feeding sites for plant-parasitic nematodes resulting in higher final population densities. Antagonists and predators can be stimulated by the addition of organic matter to the soil. Thoden et al. (2011) found several articles showing that organic amendments in general can enhance bacterial-feeding nematodes. This group releases considerable amounts of N and P which is otherwise captured within the bacterial fauna. No proof can be found on a general enhancement of soil suppressiveness due to compost. This is also the case for fungal soil diseases (Termorshuizen et al., 2006). The use of compost should be regarded as a best management practice. Not because of proven direct effects on soil health but because of indirect effects on soil quality and improvement of growing conditions.

3.4.2.2 Results from European LTEs in Catch-C database

Plant-parasitic nematodes

In the Catch-C database, four LTEs compared different types of organic amendments (i.e., farmyard manure (FYM), bovine slurry (S) and compost (COMP)) with the application of mineral N fertilizer and reported the effects on the amount of plant parasitic nematodes. The main statistics of the analyzed data on plant-parasitic nematode RR are shown in Table 13 and Figure 6.

Table 13: Main descriptive statistics for plant-parasitic nematode RR in the different organic amendments. The t-test indicates if RR mean is significantly different from 1 (p<0.05) (n: number of records).

Organic amendment	n	min	max	mean	stdev	skewness	kurtosis	normality test	t-test
COMP	12	0.63	1.23	0.93	0.18	0.05	-0.91	0.200ns	0.215ns
FYM	4	0.58	1.78	1.05	0.51	-	-	-	0.864ns
S	3	0.53	0.72	0.62	0.10	-	-	-	0.022*

COMP: compost application; FYM: farmyard manure application; S: animal slurry application

Our analysis seems to confirm the literature findings that especially organic fertilizers with low C/N values, which is the case for animal slurry, show nematicidal effect. Table 13 shows that in general, the application of animal slurry (S) results in a significant reduction of the amount of plant-parasitic nematodes of 38% while the application of farmyard manure increases (not significantly though) the plant-parasitic nematode abundance with 5%. However, our results are based on only four LTEs so we should be careful when extrapolating these results.

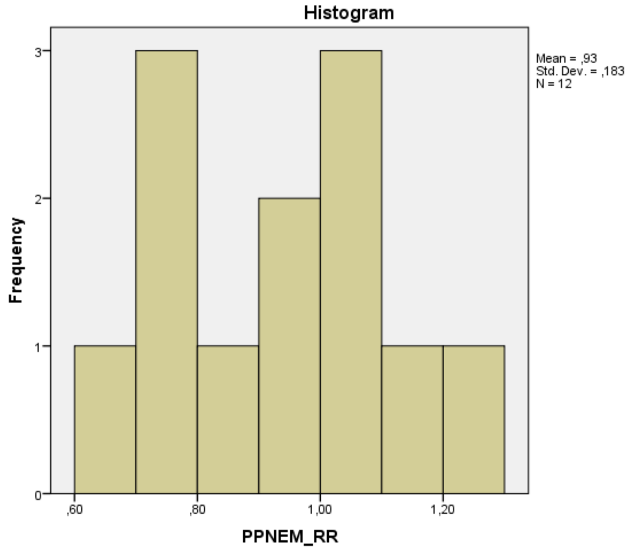

Figure 6: Frequency distribution of plant-parasitic nematode (PPNEM) RR in the compost treatment

Free-living nematodes (i.e., bacterial and fungal feeders)

In the Catch-C database, three LTEs compared different types of organic fertilizers (i.e., farmyard manure (FYM), bovine slurry (S) and compost (COMP)) with the application of mineral N fertilizer and reported the effects on the amount of bacterivorous and fungivorous nematodes. The main statistics of the analyzed data on both bacterivorous and fungivorous nematodes RR are shown in Table 14 and Figure 7.

Table 14: Main descriptive statistics for both bacterivorous and fungivorous nematodes RR in the different organic amendments. The t-test indicates if RR mean is significantly different from 1 (p<0.05) (n: number of records).

Organic amendment	n	min	max	mean	stdev	skewness	kurtosis	normality test	t-test
Bacterivorous nematodes									
COMP	6	0.83	1.55	1.19	0.30	0.00	-2.46	0.200ns	0.180ns
FYM	4	1.83	2.59	2.14	0.32	-	-	-	0.006**
S	3	2.50	6.38	3.82	2.22	-	-	-	0.158ns
Fungivorous nematodes									
COMP	6	0.49	1.12	0.85	0.21	-0.88	2.04	0.200ns	0.133ns
FYM	4	0.27	0.86	0.56	0.24	-	-	-	0.036*
S	3	0.46	0.72	0.56	0.14	-	-	-	0.030*

COMP: compost application; FYM: farmyard manure application; S: animal slurry application

Table 14 shows that all organic amendments clearly increased (only significant for farmyard manure) the amount of bacterivorous nematodes. Overall, the application of cattle slurry resulted in the highest increase (+ 282%) while the lowest increase was observed in the compost treatments (+ 19%). Farmyard manure application resulted in an intermediate increase. This is no surprise as it was shown in literature that bacterial soil life, and consequently bacterivorous nematodes, is especially stimulated by amendments with a low C/N ratio.

The amount of fungivorous nematodes was reduced significantly in both the farmyard manure and slurry treatments. Overall the reduction was similar for farmyard manure and cattle slurry (- 44%), while in the compost treatments the reduction amounted -15 % (not significant)

The observed trends can probably be linked with the quality or decomposability of the applied amendments. Compost with a usually higher C/N ratio contains more recalcitrant compounds, which remain rather stable after the composting process over several months and are mainly decomposed by fungi. In contrast, readily decomposable compounds, such as organic acids and carbohydrates present in farmyard manure and animal slurry with a lower C/N ratio are preferentially utilized by soil bacteria (Marschner et al., 2003).

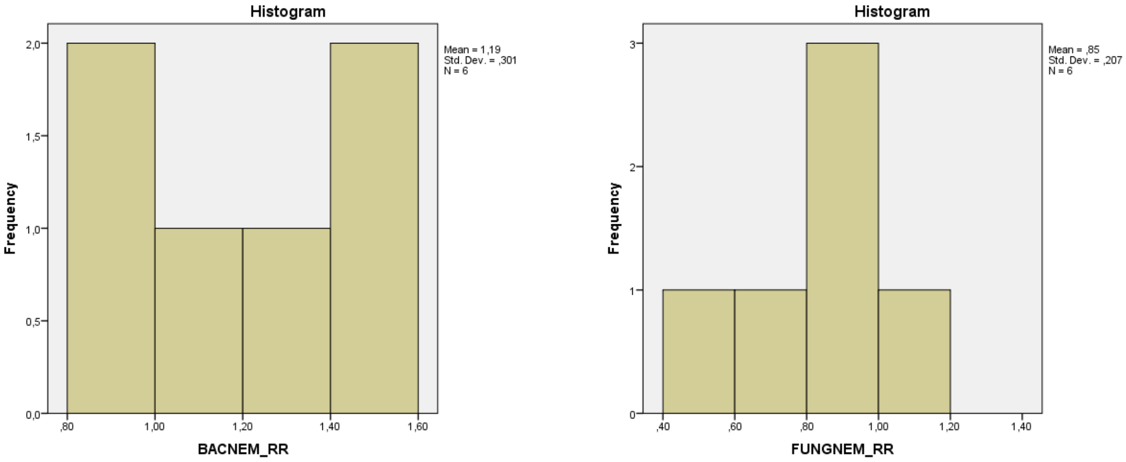

Figure 7: Frequency distribution of bacterivorous (BACNEM) (left) and fungivorous (FUNGNEM) (right) nematodes RR in the compost treatment

3.4.2.3 Influencing factors

Plant-parasitic nematodes

As there were only a few observations for FYM and S, no further analysis was performed.

Soil texture emerged as an influencing factor for plant-parasitic nematode RR when compost was applied.

Table 15: Results of the subset regression for plant-parasitic nematode RR in compost application (n: number of records).

Soil texture	n	mean
Clay	-	-
Loam	-	-
Sand	9	0.91a[1]
Silt	3	0.99b

[1] Different letters within one column indicate a significant difference at the 5% level

Table 15 shows that the reduction in plant-parasitic nematodes after applying compost is most effective in a sandy soil. However, as these findings are based on only a few LTEs, no sound conclusions should be drawn.

Free-living nematodes (i.e., bacterial and fungal feeders)

By means of subset regression, the influential factors from soil texture, climatic zone, sampling depth en duration on the RR-values for both bacterivorous and fungivorous nematodes were selected. However, due to the very low number of observations, none of the above mentioned factors emerged as an influential factor.

3.4.3 Microorganisms

3.4.3.1 Expected results from literature

In general, microbial populations are enhanced after the application of organic amendments. Several long-lasting experiments have demonstrated that soil biological properties such as microbial biomass C are significantly improved by application of organic amendments, including farmyard manure and all types of compost (Chang et al., 2007; Diacono and Montemurro, 2010). The application of amendments can thus affect microbial biomass, but can also cause shifts in the soil microbial community structure (Zelles et al., 1992). Soil faunal groups may increase or decrease depending on residue quantity and quality (Abbott and Murphy, 2007).

3.4.3.2 Results from European LTEs in Catch-C database

Microbial biomass C

In the Catch-C database, 22 LTEs compared different types of organic fertilizers (i.e., farmyard manure (FYM), bovine slurry (S) and compost (COMP)) with the application of mineral N fertilizer and reported the effects on the microbial biomass C (MBC). The main statistics of the analyzed data on MBC RR are shown in Table 16 and Figure 8.

Table 16: Main descriptive statistics for MBC RR in the different organic amendments. The t-test indicates if RR mean is significantly different from 1 (p<0.05) (n: number of records).

Organic amendment	n	min	max	mean	stdev	skewness	kurtosis	normality test	t-test
COMP	25	0.97	2.01	1.25	0.23	1.95	5.15	0.008**	0.000***
FYM	32	0.88	2.13	1.29	0.30	1.15	1.22	0.041*	0.000***
S	15	1.09	1.92	1.35	0.24	1.77	2.52	0.009**	0.000***

COMP: compost application; FYM: farmyard manure application; S: animal slurry application

In accordance with findings in literature, all three organic amendments significantly increased the MBC. The highest increase was noticed in the slurry treatments (+ 35%), while the lowest increase was reported in the compost treatments (+ 25%). Farmyard manure application showed intermediate values (+ 29%).

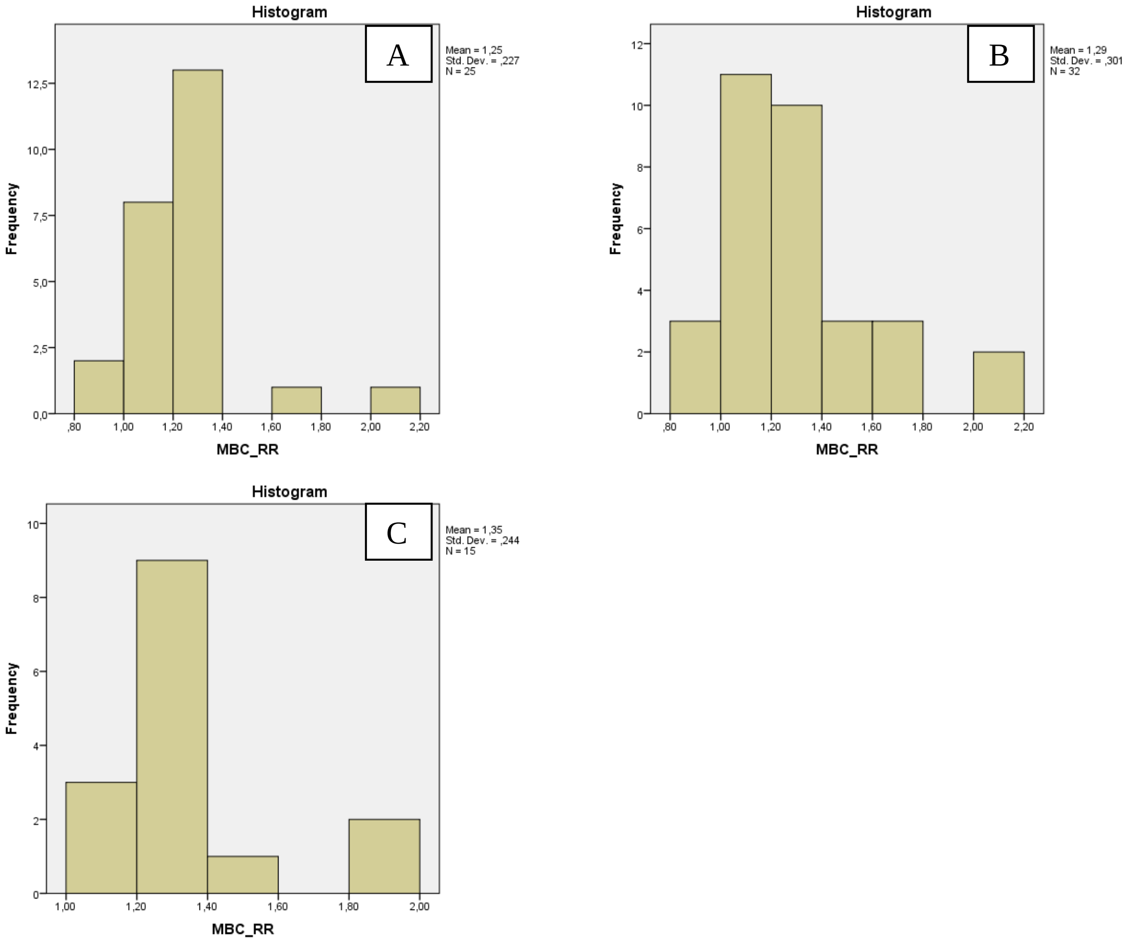

Figure 8: Frequency distribution of MBC RR in A) compost, B) farmyard manure and C) animal slurry

Bacterial and fungal PLFA

In the Catch-C database, five LTEs compared different types of organic fertilizers (i.e., farmyard manure (FYM), bovine slurry (S) and compost (COMP)) with the application of mineral N fertilizer and reported the effects on the amount of bacterial and fungal PLFA. On each LTE, several bacterial and fungal groups were grouped and consequently for each LTE one RR was calculated.

Table 17: Main descriptive statistics for both bacterial and fungal PLFA RR in the different organic amendments (n: number of records).

Organic amendment	n	min	max	mean	stdev	skewness	kurtosis	normality test	t-test
Bacterial PLFA									
COMP	9	1.11	2.17	1.34	0.34	2.31	5.82	0.073ns	0.016*
FYM	11	1.12	1.72	1.38	0.19	0.48	-0.77	0.200ns	0.000***
S	7	0.04	1.83	1.15	0.54	-1.25	3.04	0.049*	0.505ns
Fungal PLFA									
COMP	9	0.51	2.05	1.07	0.44	1.43	3.17	0.156ns	0.637ns
FYM	11	0.64	1.81	1.08	0.33	0.85	1.03	0.200ns	0.443ns
S	6	0.66	1.27	0.98	0.20	-0.37	1.64	0.200ns	0.844ns

COMP: compost application; FYM: farmyard manure application; S: animal slurry application

Table 17 shows that all three amendments increased (significant for compost and farmyard manure) the bacterial PLFA. The lowest increase was registered in the animal slurry treatments (+ 15%) while the increase after farmyard manure and compost application was quite similar. The amount of fungal PLFA was slightly lowered in the animal slurry treatments (- 2%) compared to mineral fertilizer. For farmyard manure and compost, a slight increase has been observed (+ 7-8%). However, none of the organic amendments significantly altered the amount of fungal PLFA.

The observed trends can partly be linked with the quality or decomposability of the applied amendments. Compost with a usually higher C/N ratio contains more recalcitrant compounds, remaining after the composting process over several months, which are mainly decomposed by fungi, while readily decomposable compounds such as organic acids and carbohydrates present in farmyard manure and animal slurry with a lower C/N ratio are preferentially utilized by soil bacteria (Marschner et al., 2003). This assumption is not completely true for our results though as Table 17 clearly shows that farmyard manure application results in an equal increase in fungal PLFA as compost. However, as the compost and farmyard manure treatments were not always located in the same LTE, a difference in soil conditions (e.g., pH) could have influenced this results. After all, it was stated by Chen and Ferris (2000) that certain soil conditions (e.g., high pH) are not favorable for fungi mediated decomposition. Further, animal slurry amendment, which possesses the lowest C/N ratio, resulted in the lowest increase in bacterial PLFA. Further research is required though. After all, our results are based on data of only five LTEs.

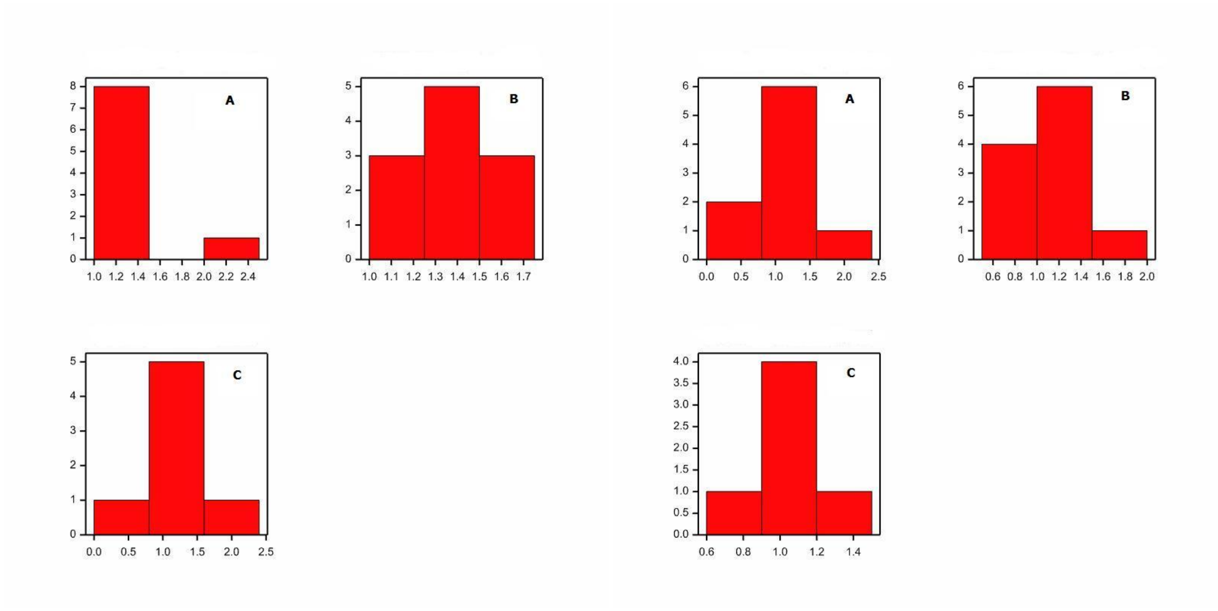

Figure 9: Frequency distribution of bacterial (left) and fungal (right) PLFA RR in A) compost, B) farmyard manure and C) animal slurry

3.4.3.3 Influencing factors

Microbial biomass C

The subset regression pointed out soil texture as an influencing factor for MBC RR when compost was applied.

Table 18: Results of the subset regression for MBC RR in compost application (n: number of records).

Soil texture	n	mean
Loam	3	1.10a[1]
Silt	15	1.17a
Sand	6	1.50b

[1] Different letters within one column indicate a significant difference at the 5% level

Table 18 indicates that the positive effect of compost application is more pronounced in a sandy soil.

Bacterial PLFA

By means of subset regression, climatic zone emerged as influential factor for compost application while duration was pointed out as influential factor for animal slurry applicaton. For farmyard manure amendment, no influencing factors were detected.

Tabel 19: Results of the subset regression for bacterial PLFA RR in compost application (n: number of records).

Climatic zone	n	mean
ATC	6	1.19a[1]
CON	-	-
MED	1	2.17b
NEM	2	1.38a

[1] Different letters within one column indicate a significant difference at the 5% level

NEM: Nemoral; ATC: Atlantic; CON: Continental; MED: Mediterranean

Tabel 20: Results of the subset regression for bacterial PLFA RR in animal slurry application (n: number of records).

Duration (years)	n	mean
< 5	5	1.35b[1]
5-10	1	1.20b
11-20	-	-
> 20	1	0.05a

[1] Different letters within one column indicate a significant difference at the 5% level

Tabel 19 reveals a more pronounced positive effect of compost application on bacterial PLFA in the MED climatic zone while

Tabel 20 indicates that the positive effect of animal slurry application on bacterial PLFA is mainly a short-medium term effect (+ 20% after 10 years; - 95% after 20 years and more). However, as our results are based on very few observations, one should be carefull when generalizing this results.

Fungal PLFA

For compost application, subset regression pointed out climatic zone as an influential factor, while for slurry and farmyard manure application, no influential factors emerged.

Table 21: Results of the subset regression for fungal PLFA RR in compost application (n: number of records).

Climatic zone	n	mean
ATC	6	1.02a[1]
CON	-	-
MED	1	2.05b
NEM	2	0.72a

[1] Different letters within one column indicate a significant difference at the 5% level

NEM: Nemoral; ATC: Atlantic; CON: Continental; MED: Mediterranean

From Table 21 we can conclude that the positive effect of compost application on fungal PLFA is more clear in the MED climatic zone while a negative effect is noticed in the NEM climatic zone. However, as these findings are based on only 1 and 2 observations for MED and NEM climatic zone, respectively, this can hardly be called a sound conclusion.

3.5 Crop residues

3.5.1 Expected results from literature

In general, residue removal can result in detrimental changes in many biological soil quality indicators indicating loss of soil function, particularly reduced nutrient cycling, physical stability, and biodiversity (Andrews, 2006). Karlen et al. (1994) found that 10 years of residue removal under no-till continuous corn, resulted in deleterious changes in many biological indicators of soil quality including lower soil carbon, microbial activity, fungal biomass and earthworm populations compared with normal or double rates of residue return. In addition, some disease-producing organisms are enhanced by residue removal, others by residue retention. Residue effect on pests and disease would depend on cropping practice, climate, and local pest or disease incidence.

3.5.2 Results from European LTEs in Catch-C database

Several LTEs in the Catch-C database reported results on the effect of incorporating crop residues on soil biological quality indicators. However, the number of observations for each indicator was too low to perform a thorough statistical analysis. The most important finding of several LTEs are listed below.

LTE 9 FARMCO: In a crop rotation of potato, fodder beet, silage maize and Brussels sprouts, earthworm abundance was remarkably higher in the Brussels sprouts plots compared to the silage maize plots. The beneficial effects of Brussels sprouts were attributed to the crop residues (fallen leaves) which served as an extra food supply for the earthworms (D'Hose et al., 2014c)

Jokioinen 1979: Earthworm communities were studied in a factorial experiment in which spring cereals were grown in autumn mouldboard ploughed, autumn stubble cultivated and spring stubble cultivated soils where straw residue was either chopped and left or removed. The experiment was conducted on different soil types in southern Finland. Handling of straw had a discernible effect only in silty clay, where leaving the straw in the field on average doubled the total dry weight of earthworms (Nuutinen, 1992).

LTE 11 CROPRO: In this experiment, a silage maize in monoculture was followed by Italian ryegrass as a cover crop during winter period. In spring, the entire grass sward was either turned under after which the maize was sown or was harvested after which the stubble was destroyed. After six years, earthworm abundance was clearly higher when the entire Italian ryegrass cover crop was incorporated. The authors assumed that the grass sward served as a food source which enabled the earthworm population to recover faster from the cultivation practices (D'Hose et al., 2014a).

4 Conclusions

Our analysis showed that for each biological indicator a different management practice can emerge as the ‘Best Management Practice’. In this section, we try to give an overview of the different identified BMPs for the different biological indicators. For each indicator, the mean DIFF or RR (depending on the indicator) is given for each potential BMP that was analyzed within this report. Within each indicator, the BMP is highlighted. We did not take into account the potential influencing factors for this analysis. An overall mean was calculated for each potential BMP within an indicator.

Table 22: Mean effects of the different management practices on the soil biological indicators

Management practices	Indicator	Earthworm number	Earthworm biomass	MBC	PPNEM	FUNGNEM	BACNEM	BACPLFA	FUNGPLFA
Tillage	Conventional tillage	0	0	1.00	1.00	1.00	1.00	1.00	1.00
	No tillage	22**	39**	1.29**	na	na	na	na	na
	Shallow non-inversion tillage	20*	13**	1.17*	na	na	na	na	na
	Deep non-inversion tillage	13	12*	1.1	na	na	na	na	na
Nutrient management	Mineral fertilizer (mineral N)	0	0	1.00	1.00	1.00	1.00	1.00	1.00
	Farmyard manure	320*	71**	1.29***	1.05	0.56*	2.14**	1.38**	1.08
	Animal slurry	283*	42*	1.35***	0.62*	0.56*	3.82	1.15	0.98
	Compost	75**	15**	1.25***	0.93	0.85	1.19	1.34*	1.07

*, ** indicate if the mean effects are significantly different from 0 or 1(depending on the indicator) at the 5% or 1% significance level, respectively; na: not available

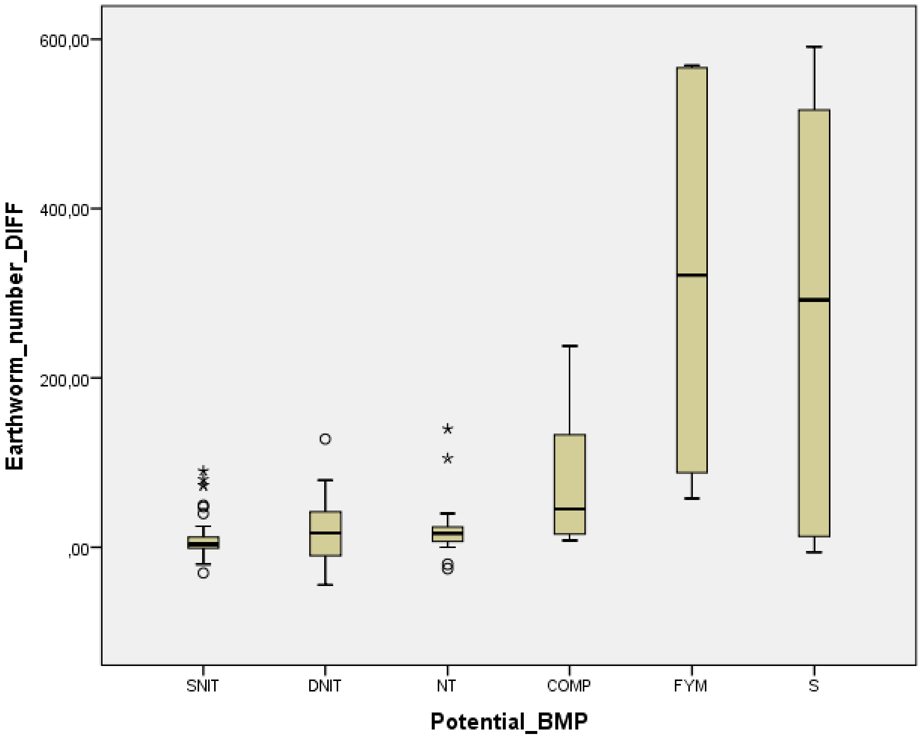

Figure 10: Boxplot graph of earthworm number DIFF obtained adopting the different potential BMPs

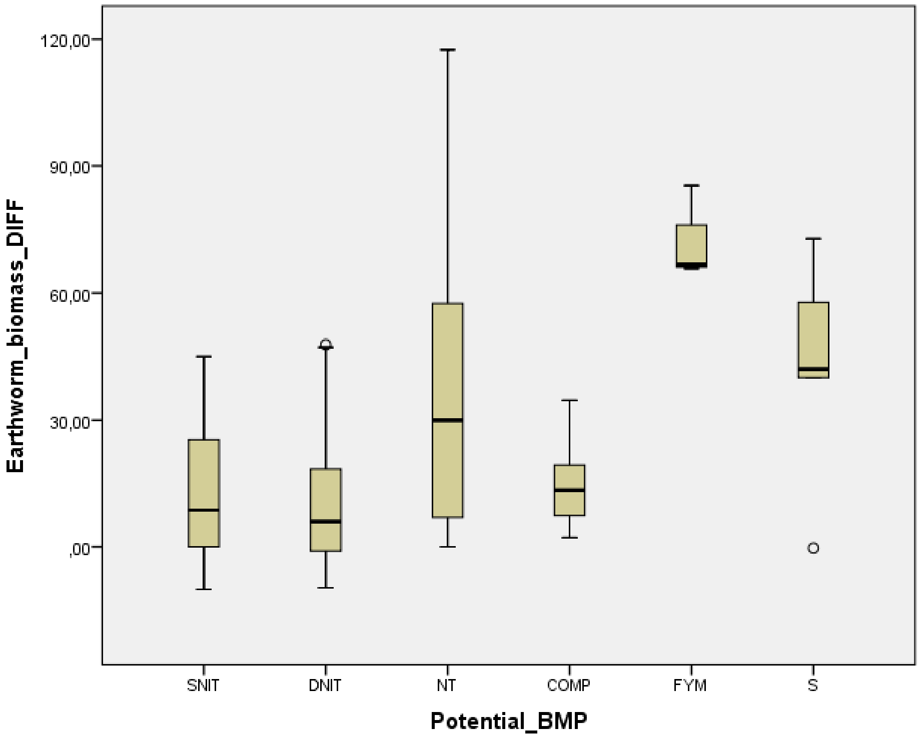

Figure 11: Boxplot graph of earthworm biomass DIFF obtained adopting the different potential BMPs

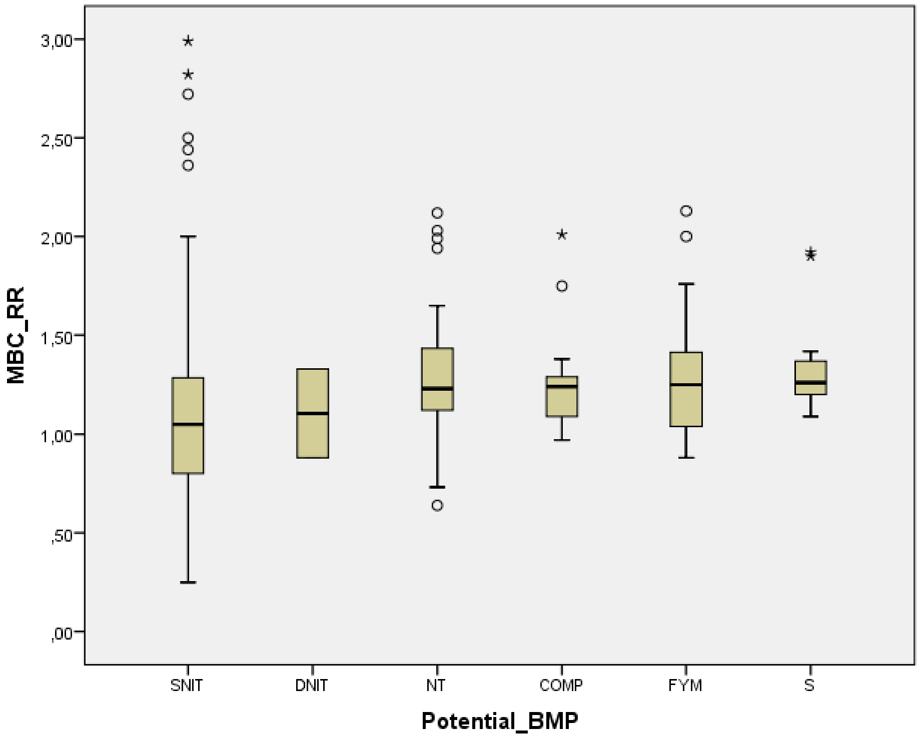

Figure 12: Boxplot graph of MBC_RR obtained adopting the different potential BMPs (unrealistic low or high RR values were dropped from the database)

From Table 22 and Figure 10, Figure 11 and Figure 12 we can conclude that the application of organic amendments increases soil biological quality to a higher extent compared with reduced or no tillage practices. Apparently, soil biota benefit more from organic materials applied to the soil, which serve as a food source, than from reduced soil disturbance and consequently a more stable habitat. Thoden et al. (2011) concludes that the overall positive effects of organic amendments, inter alia, is due to increases in populations of free-living nematodes and their very significant influence on microbial parameters, mineralization, nutrient supply and plant vitality. Based on the little biological data available to make a thorough statistical analysis we conclude that from our analysis it can be confirmed that organic amendments either as compost or organic manure have positive effects on the biological aspects of soil quality. Among the organic amendments, farmyard manure is pointed out as BMP for the greater part of the biological indicators.

Table 23:Overall qualitative assessment of the different management practices on soil biological quality

Management practices	**Indicators**	**Earthworm number**	**Earthworm biomass**	**MBC**	**PPNEM***	**FUNGNEM**	**BACNEM**	**BACPLFA**	**FUNGPLFA**	**OVERALL SBQ**
Rotation	Monoculture									
	Crop rotation	+	+	+	+/-	-	+	0	0	+
	Intercropping	na	na	na	na	na	na	na	na	na
	Without Green manure/catch crop/cover crop									
	Harvested catch crop/cover crop	+	+	+	+/-	+	+	+	0	+
	Incorporated green manure	++	++	++	+/-	0	+	++	0	++
Grassland	Grassland management	na	na	na	na	na	na	na	na	na
Tillage	Conventional tillage									
	No tillage	+	+	+	+/-	+/-	+/-	0	0	+
	Shallow non-inversion tillage	+	+	+	+/-	+/-	+/-	0	0	+
	Deep non-inversion tillage	+	+	0	+/-	+/-	+/-	0	0	0
Nutrient management	Mineral fertilizer (mineral N)									
	Farmyard manure	++	++	++	0	-	++	++	0	++
	Animal slurry	+	+	++	+	-	0	0	0	+
	Compost	+	+	++	0	0	0	+	0	++
Residue management	Residue removal									
	Residue incorporation	+	+	+	+/-	0	+	+	0	+
	Residue burning	na	na	na	na	na	na	na	na	na
Crop protection	-	na	na	na	na	na	na	na	na	na
Water management	-	na	na	na	na	na	na	na	na	na

*: for plant-parasitic nematodes, a positive effect is regarded as a decrease in the amount of nematodes.
+: positive effect; ++: very positive effect; 0: neutral effect; -: negative effect , +/- depends strongly on species and choices made (all compared to the reference management practice which is indicated in grey)
MBC: microbial biomass carbon; PPNEM: amount of plant-parasitic nematodes; BACNEM: amount of bacterivorous nematodes; FUNGNEM: amount of fungivorous nematodes; BACPLFA: bacterial PLFA; FUNGPLFA: fungal PLFA; SQB: soil biological quality; na: not available

If all soil biological indicators are considered in an overall qualitative evaluation, the following management practices are identified as the BMPs for increasing soil biological quality (Table 23):

- Farmyard manure application
- Compost application
- Incorporation of a green manure crop

Although our statistical analysis pointed out FYM application as the BMP for improving most of the soil biological properties (Table 22), we argue that farmers should consider adopting a combination of different potential BMPs instead of only one. After all, research has shown that the quantity and quality of organic matter input and soil disturbance are the factors that most affect soil biota (Swift, 1994). Consequently, the use of reduced or no tillage together with diversified cropping practices, crop rotations, cover/green manure crops and organic amendments will likely enhance soil biological fertility to the highest extent. However, in this report, we focused on individual management practices instead of on a combination of MPs. As a result, the additional effect of applying two or more potential BMPs at the same time was not addressed in this report.

In general, it can be noted that soil biology, although known for its role in soil quality, is not often taken into account in soil research. There is a strong discrimination between physical, chemical and biological disciplines and most research is mainly focusing on one part of the puzzle. To make progress in understanding and steering soil quality, a multidisciplinary approach taking into account all soil disciplines, physics, chemistry and biology, is a requisite.

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Appendix 1: Definitions of the different management practices

Rotation	Monoculture	The growing of a single arable crop species on a field year after year
	Crop rotation	The growing of different species of crops (e.g., cereals, tuber crops, legume crops, grassland) in consecutive years on a field
	Intercropping	The growing of two or more different arable crops simultaneously in different rows in the same field
	Rotation without cover/catch/green manure crops	No cover/catch/green manure crop is sown after the harvest of the main crop. The soil is left bare during winter,
	Rotation with cover/catch crops	The growing of a cover crop after the harvest of the main crop. Cover/catch crops are harvested.
	Rotation with green manures	The growing of a green manure crop after the harvest of the main crop. Green manure crops are incorporated into the soil.
Grassland management	Permanent grazing	Continuous feeding on standing vegetation by livestock.
	Rotational grazing	Rotational feeding (i.e. changing the grazed parcels) on standing vegetation by livestock.
	Zero grazing	No grazing but only mowing to harvest grass.
Tillage	Conventional tillage	Ploughing the soil to a depth of 25-30cm
	No / Zero tillage	No tillage
	Shallow non-inversion tillage	Tillage without inversion, at a reduced depth (e.g., 5-15 cm)
	Deep non-inversion tillage	Tillage without inversion, at the same depth as ploughing (e.g., 25-30 cm)
Nutrient management	Mineral fertilization	Applications of mineral N, P or K fertilizers
	Compost application	Application of plant, biowaste or sludge compost
	Farm yard manure (FYM) application	Application of manure from livestock which is a mixture of excrements (faeces and urine) of animals with a binding medium such as usually straw
	Animal slurry	Application of cattle, pig or poultry slurry
Residue management	Residue removal	Crop residues (e.g. stubble and roots) that remain after harvesting are removed from the field
	Return of crop residues	Crop residues (e.g. stubble and roots) that remain after harvesting and are ploughed in.
	Burning of crop residues	Straws are left on the soil and set to fire after harvesting