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

Impacts of soil management practices on crop productivity, on indicators for climate change mitigation, and on the chemical, physical and biological quality of soil

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Table of contents

General information

Task(s) and Activity code(s):	Task 3.7, Activity 3.7.1:
Input from (Task and Activity codes):	Task 3.2, 3.3, 3.4, 3.5, 3.6
Output to (Task and Activity codes):	WP4, WP5, WP6
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Executive summary

Agricultural management practices are required to achieve high yields and to contribute to resource use efficiency. Furthermore, soil quality must be at least maintained and mitigation/ adaption to climate change (CC) will become increasingly important.

This work focuses on the analysis of the effects of improved practices on crop productivity, climate change and soil quality indicators, through an analysis of available European data sets and associated literature, mainly from long term experiments. It was carried out by five task groups, each group studying the effects of soil management practices on a particular goal - expressed in a set of indicators. The goals are crop productivity, mitigation of climate change (Carbon sequestration, reduction of greenhouse gases (GHG)), biological soil quality, chemical soil quality, and physical soil quality. This report merges the outcomes from the various task groups, highlights overriding patterns and discusses potential conflicts and synergies between the separate goals distinguished.

Each task group has identified suitable indicators, contributed to a comprehensive literature review and carried out data analyses. Data were taken both from literature and from own LTEs. Our evaluation was based on data derived from 291 mainly long-term field experiments (LTEs) – both from the partner countries and from the rest of Europe - which were included in an on-line database. Before the statistical analyses, comparisons between an assumed improved management practice and a baseline management were computed, forming either relative response ratios (RR), or absolute or relative differences for the single indicators. A multiple linear model using climate, soil texture/clay content, the duration of practice, the type of crop (for productivity indicators) and the investigated soil depth (for soil quality indicators) as nominal factors was performed to evaluate which conditions mostly affected the impact of a practice.

Based on this quantitative evaluation, the task groups carried out a qualitative assessment of agricultural management options. This report gives an overview, the more detailed results are provided in the deliverables D3.324 (Productivity), D3.334 (climate change mitigation, i.e. C-sequestration and reduction of greenhouse gases (GHG)), D3.344 (biological soil quality), D3.354 (chemical soil quality), and D3.364 (physical soil quality and conservation).

As expected, the indicator-based evaluation of agricultural management practices showed positive and negative effects. Overall (mean outcome across all data) none of the investigated practices could favourably contribute to all objectives, i.e. maintaining high yields and reducing cultivation costs, mitigating climate change and improving chemical, physical and biological soil quality.

Our analyses confirmed the results from practice and literature that suitable crop rotations are a precondition for good agricultural management. The inclusion of catch crops/cover crops/green manures in the crop rotation shows only positive or neutral effects on the investigated indicators.

Overall, the application of organic amendments was rated to be beneficial (sometimes neutral) regarding chemical, physical and, especially, biological soil indicators as well as on SOC accumulation. All practices that augment C input were beneficial (on average) for soil biology, and were more effective than reducing disturbance by tillage. If accumulating SOC is accounted as C being sequestered, the corresponding CC mitigating effect is often counteracted by extra N_2O emission in response to organic amendments. The balance between these in CO_2 equivalents remains unclear, due to different temporal and spatial scales of the respective measurements. The effects of organic amendments on productivity were evaluated at similar total N input (as in the reference, mineral fertiliser treatment) and were then slightly negative or neutral. Changed N dynamics call for optimal application techniques to minimize the disadvantage of N losses and lower N availability from organic sources.

Measures that reduce tillage compared to conventional ploughing were appreciated differently by the respective task groups. In general, a total omission of tillage enhanced biological and chemical soil quality. (Shallow) Non-inversion tillage was also beneficial for CC indicators, and for physical quality criteria. , However, effects of no-tillage on soil physical indicators depended very much on the farming system. Our analysis of no-tillage data covers both herbaceous (i.e., arable) and permanent crops. Although this distinction was not made in the report of outcomes, we wish to highlight that for Mediterranean conditions a clear difference exists between the soil responses (to no-tillage) for the two crop types. No-tillage (direct drilling) in arable crops presents relevant advantages compared to conventional tillage, especially in dry years. For tree crops, effects of no-till on physical soil quality were very unfavourable unless combined with cover crops. On average, all productivity indicators were scarcely but significantly adversely affected by reduced tillage, whereas they showed non-significant negative effects with no tillage. However, the variability of responses was high for both techniques and we registered both positive and negative effects depending on the site.

Management practices like weed control, specific measures for pest and disease control, water management and grassland management could not be evaluated due to insufficient data from LTEs. Furthermore, the evaluation of CC mitigation is often limited by the lack of data for continuous GHG emission measurements.

The most important single factor to influence the effect of any management practice seems to be the environmental zone (climate). For soil quality indicators, the responses often depend on the investigated soil depth. Furthermore, many effects on productivity and soil quality can be detected with statistical certainty only after many (more than 10) years, due to large temporal and spatial variations of weather and soil conditions.

The main conflicts between goals, in our view, relate to management practices that promote soil quality and C sequestration but may result in higher GHG emissions, especially of nitrous oxide. Examples are the incorporation of crop residues, the application of compost and slurry, and the omission of tillage.

More extensive assessments are still needed, which were not possible within the frame of this study. Entire life cycles of practices and farm inputs need to be considered, also beyond field and farm boundaries. Further, effects would have to be scaled per unit input to enable more precise comparisons among practices. Such more complete analyses should also consider alternative uses of farm produce, e.g. using crop residues to substitute for fossil fuels, versus incorporation to enhance soil organic carbon. Finally, the summation of beneficial and adverse effects that a practice may have on multiple indicators – as needed for an overall evaluation - remains a normative exercise when effects cannot be expressed in the same units.

Specific part

1 Introduction

Increasing crop production to feed a growing population was a major challenge to the agricultural community in the past few decades. As a result, management practices consisting of intensive tillage and high rate of fertilisation were used to increase crop production. Society must now accomplish the dual objectives of improving yield levels and food stability and of preserving the quality and quantity of ecosystem services. Farming practices which ensure a good use of resources, thus maintaining high yields, are to be promoted. Furthermore, best management practices are needed to maintain and improve physical, chemical and biological soil quality. Mitigation and adaption to climate change will play a crucial role in the near future.

A reduction of tillage intensity, the adoption of green manuring, of crop residue incorporation and the substitution of mineral with organic fertilisers are among the most used farm management practices to maintain soil quality.

Reduced tillage techniques, aim to minimise soil inversion and soil structure disruption, to increase soil organic matter (SOM) by reducing residue and organic matter mineralisation (Lal and Kimble, 1997; West and Post, 2002; Holland, 2004; Alluvione et al., 2009, Alluvione et al., 2010). Although uncertainty remains as to the soil organic carbon (SOC)-sequestering efficacy of such techniques (Baker et al., 2007; Lal, 2009; Luo et al., 2010), there is no doubt about their fossil fuel-saving benefit. Leguminous green manure, crop residue incorporation and organic fertilisers from animal wastes are known to represent viable options as mineral N fertiliser substitutes (Bøckman, 1997; Eriksen et al., 1999; N’Dayegamiye and Tran, 2001; Tejada and Gonzalez, 2003; Tejada et al., 2008, Alluvione et al., 2013). In addition to stimulating microbial activity, increasing soil fertility, controlling pests, and reducing soil erosion, green manures and crop residues can prevent nutrient leaching outside the growing season and can supply N to the subsequent crop at low energy cost (Crews and Peoples, 2004; Cherr et al., 2006). Organic fertilisation has not only a low groundwater N pollution risk (Erhart et al., 2007), if applied at a rate that meets crop needs but also great potential for nutritive element recycling (Ikumo, 2005) and soil C sequestering and protection (Spaccini et al., 2002; Piccolo et al., 2004; Lynch et al., 2006).

Crop rotation has always been used in agriculture to maintain the soil fertility over years. Long-term studies have shown that crop rotations are essential to maintain high production levels (Mitchell et al., 1991), which can be assured in monoculture only by the use of mineral fertilisers and pesticides (Crookston et al., 1991; Bullock, 1992). Monoculture often results in yield decreases (Power and Follett, 1987; Peterson and Varvel, 1989).

No tillage practices are promoted mostly to reduce costs and labour, but also because they may have positive effects on soil physical properties such as aggregate stability (Rhoton et al., 1993; Ghuman and Sur, 2001), number of biopores (Francis and Knight, 1993), and root growth (Martino and Shaykewich, 1994). There is little consensus as to whether tillage has any influence on the N balance of the soil (Mitsch et al., 1999; Smith et al., 1990).

Cover crops and catch crops are often used to reduce environmental problems caused by intensive cropping. They can take up mineral N during the winter period, in temperate climates (Lemaire et al., 2004). A soil cover can reduce wind and water erosion. When incorporated into the soil as green manures, they provide and extra source of energy and contribute to C-sequestration. Leguminous cover crops, in addition, fix N biologically and may improve the soil N fertility (Kuo and Sainju, 1998; Vaughan et al., 2000; Gselman and Kramberger, 2008).

Several authors conclude that C sequestration for climate change is limited (e.g. Körschens et al, 2013 and 2013, Powlson et al., 2011), because the stored C quantities are often small, the beneficial management must be maintained over time (Spiegel, 2012, Dersch and Böhm, 2001) and fluxes of other GHGs, especially N_2O and CH_4 may be adversely changed. Powlson et al. (2012) reported SOC increases between 50 and 180 kg C ha^{-1} yr^{-1}per tonne of dry solids added in the form of different kinds of biosolids (cereal straw, farm manure, green compost, paper crumble, digested biosolids). They warn against mistaking soil C accumulation for net CO_2 extraction from the atmosphere, and see potential for CC mitigation only with compost application, because it avoids disposal to landfill and reduces N_2O emissions.

This report presents the results of an extensive meta-analysis on data from long term experiments, as well as the results of the associated literature review. Our study was performed to verify the hypotheses that “best management practices” are not only effective in maintaining high yields, in reducing cultivation costs, and in mitigating climate change, but also contribute to improving chemical, physical and biological soil quality.

The effects of agricultural practices can be assessed properly only in long-term experiments, where small changes can accumulate over the years to become detectable (as often occurs in soil organic matter changes), and interaction with meteorological variability can be assessed. Johnston (1994) stated that long-term or continuing experiments are the best practical way of assessing the sustainability of an agricultural system. However, it should be recognised that – by relying on those long-term experiments - new management practices, e.g. the application of biochar products or digestates, are hardly included in our evaluations.

This work focuses on the analysis of the effects of improved practices on crop productivity, climate change and soil quality indicators, through an analysis of available European data sets and associated literature, mainly from long term experiments. It was carried out by five task groups, each group studying the effects of soil management practices on a particular goal (expressed in a set of indicators). The goals are crop productivity, mitigation of climate change (C-sequestration, reduction of greenhouse gases (GHG)), biological soil quality, chemical soil quality, and physical soil quality. This report merges the outcomes from the various task groups, highlights overriding patterns and discusses potential conflicts and synergies between the separate goals distinguished. The underlying reports are Catch-C deliverables D3.324 (Zavattaro et al., 2014), D3.334 (Spiegel et al., 2014), D3.344 (D´Hose et al., 2014), D3.354 (Pecio et al., 2014), and D3.364 (Guzmán et al., 2014).

2 Materials and Methods

2.1 Indicators and Management practices

Each of the five task groups created an extensive list of possible indicators (MS321, 331, 341, 351, 361; numbers refer to milestones in the project workplan). Some indicators were shared among task groups. For example, soil organic carbon (SOC) is essential for chemical, physical and biological soil quality. However, for the topic of C sequestration by enhancing SOC stocks, which is discussed to mitigate climate change, SOC is very much a key indicator. Thus, SOC contents and SOC stocks were evaluated in the task group “Carbon sequestration and GHG emissions for CC mitigation”. The indicators are depicted in Tab. 3.1-1.

A standard list of management practices (MPs) was first developed (see Table in the Appendix) to enable a uniform approach across the task groups in WP 3. The same list served as a common frame for WP 4, too. Depending on the availability of data, the task groups used selected MPs for their indicator-based evaluations. Certain MPs served as a baseline (reference) management (bl) for the assessment of a presumably improved management practice (“BMP”), see Tab. 2.1-1. (We retained the original acronym for Best Management Practice from our workplan, in spite of our recognition that ‘improved’ could be a more appropriate qualification, even if still debatable.)

Tab. 2.1-1.Reference treatments and comparisons (in bold letters those comparisons that are reported within this report)

Code	Assumed improved management practice (“BMP”)	Baseline management practice (“bl”)
ROT	**rotation**	**monoculture**
ROT	rotation with tuber/root crops	rotation without tuber/root crops
ROT	rotation with legume crops	rotation without legume crops
ROT	rotation with grassland	rotation without grassland
Intercrop	**intercropping**	**without intercropping**
Catch Cr	**catch crops (harvested)**	**without CatchCr**
Cover Cr	**Cover crops (in permanent crops)**	**without CoverCr**
GM	**green manure(not harvested but left on field or incorporated)**	**without GM**
NIT=MT and RT	**minimum and reduced (shallow) non inversion tillage**	**ploughing (CT)**
DNIT	**deep non-inversion tillage to the depth of ploughing (in Belgium)**	**ploughing (CT)**
NT	**no tillage**	**ploughing (CT)**

COMP	**compost application**	**mineral N fertiliser (similar total N supply)**
FYM	**farmyard manure**	**mineral N fertiliser (similar total N supply)**
S	**bovine slurry**	**mineral N fertiliser (similar total N supply)**
CR	**incorporation of crop residues**	**removal of crop residues (includes selling, feeding and burning of crop residues)**
IRR	**high efficiency irrigation methods**	**surface irrigation**
MIN	**mineral fertilisation**	**no fertilisation**
WEED	mechanical weeding	herbicides
GRASS	grazing	mowing
GRASS	grazing	growing of silage maize and other fodder crops in monoculture

Preferably, medium- and long-term effects of such practices on a set of indicators were considered important for the WP 3 evaluations. Therefore, mainly stabilised and long-term experiments (LTEs) situated in European countries were taken into consideration. For, e.g. CO_2, CH_4 and N_2O emissions, data from long-term experiments were scarce. For these variables shorter duration experiments (instead of LTEs) and laboratory experiments were included in the evaluation.

The data for evaluating the effects of the mentioned practices on the proposed indicators were collected from various sources: peer-reviewed scientific papers, national language scientific or technical papers, grey literature (project reports), unpublished data held by partners. However, peer-reviewed scientific journals provided most of the data.

2.2 Shared library and data base

Papers were first collected in a shared on-line library and then analysed by the different task groups. This activity resulted in a metadatabase (MS322, 332, 342, 352, 362), which was the starting point for developing, next, the Catch-Con-line shared database. The latter was constructed to store and retrieve data of single indicator values inserted by all project partners.

The on-line shared library on the free platform, Zotero (www.zotero.org), was progressively filled by all partners. It contains 733 papers and allows all project partners an easy and fast access to original papers, which were used to fill the database.

Expected results from the literature were extensively provided in the reports (deliverables) D3.324, D3.334, D3.344, D3.354 and D3.364.

The data analysis was then conducted on the Catch-C online dataset which has been filled in by all the project’s partners. Preliminary results of the data analyses carried out by the different task groups have been provided earlier in the midterm report (MS 323 to 363). Furthermore, the above deliverables provide information on the data set (e.g. numbers of records regarding the indicators) used by the respective task groups and a list of European LTEs, which were used for the evaluations.

2.3 Data treatment

The data analyses were executed separately by the respective task groups. For each indicator a comparison between an assumed improved management practice (“BMP”) and a baseline management was carried out. The effect of some practice, with respect to the reference practice, was either expressed as the response ratio (RR) or as a difference or relative difference (DIFF or rel DIFF, see chapter 2.4 and Table 3.1-1). DIFF was chosen, when unscaled changes (e.g. number of earthworms) were more informative to express improvement or deterioration between the compared MPs.

$$\text{RR}=\frac{\boldsymbol{Indicator} treatment\ (BMP)}{\boldsymbol{Indicator} reference treatment\ (bl)},$$

i.e. observed indicator value divided by the indicator value found in the reference treatment

$$\text{DIFF}=\boldsymbol{Indicator}\ treatment(BMP)-\boldsymbol{Indicator}\ reference\ treatment(bl),$$

i.e. indicator value found in the reference treatment subtracted from observed indicator value.

Rel DIFF=

$$(\boldsymbol{Indicator}\ treatment-\boldsymbol{Indicator}\ reference\ treatment)/\left|\ \boldsymbol{Indicator}\ reference\ treatment\ \right|$$

Relative differences were computed only for CH_4 emissions. Soils may act as a source or a sink regarding CH_4. So, unlike the other indicators, CH_4 fluxes were either positive or negative. As a result, the use of the alternative quantifiers (RR and DIFF) can be confusing. The detailed descriptions of the analyses of each indicator are provided in the respective reports from the task groups (Zavattaro et al., 2014; Spiegel et al., 2014; Pecio et al., 2014; Guzmán et al., 2014; D`Hose et al., 2014).

Furthermore, each task group evaluated which conditions (sometimes referred to as co-variate factors) mostly affected the performance of each practice.The following factors were analysed:

- Climate (Environmental zones, ENZs, according to Metzger et al., 2005)
- Soil texture or clay content
- Duration of the experiment
- Sampling depth for selected soilparameters
- Kind of crop (Task « Productivity » and « CC Mitigation »)
- Kind of experiment (field or lab) for GHG emissions

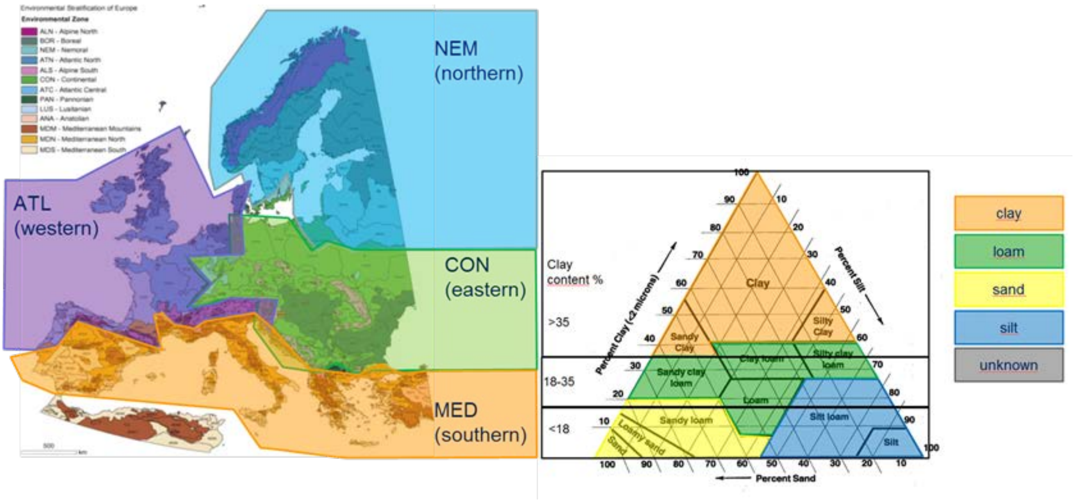
Table 2.4-1and Figure 2.4-1indicate the factors considered in the analyses of the respectivetask groups.

Tab. 2.4-1. Levels of the four factors considered in the linear multiple regression. Climate types were those reported by Metzger et al., 2005.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.

num.	climate	soil texture class	duration of practice	crop
1	northern (ALN, BOR, NEM)	clay (clay, sandy clay, silty clay)	low (< 5 yrs)	barley
2	western (ATN, ATC, ALS, LUS)	loam (loam, clay loam, sandy clay loam, silty clay loam)	medium (5-10 yrs)	wheat
3	eastern (CON, PAN)	sand (sand, loamy sand, sandy loam)	high (11-20 yrs)	minor small grain cereals
4	southern (ANA, MDM, MDN, MDS)	silt (silt, silty loam)	very high (> 20 yrs)	grain legume
5		unknown	unknown	maize grain
6				maize/sorghum (total)
7				rapeseed
8				potato/beet
9				sunflower
10				legume/grass ley
11				vegetables
12				various (average)

Fig. 2.4-1. Levels of the four factors considered in the linear multiple regression. a) Climate (acronyms as in Tab. 2.3-1), from Metzger et al., 2005, modified according to Zavattaro et al., 2014; b) soil texture classes and clay content classes (modified according to Zavattaro et al., 2014).

a) Climate b) texture



2.4 Statistical analyses

RR and (rel.) 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 statistically significantly different from 1 ($p<0.05$), and which DIFF means were statistically significantly different from 0 ($p<0.05$). Where effects are considered relevant but lack statistical significance, we refer to them as ‘a tendency’.

A multiple linear model (e.g. generalized linear model procedure of the SPSS software) using climate, crop, soil texture class and duration of practice as single nominal factors (without interactions) was performed to evaluate which conditions mostly affected the performance of each practice, separately. As mentioned above, climate, soil and duration of practice were divided into 3 to 4 levels each. For the task group “productivity” 12 different crop types were considered. As not all soil texture and duration of practices were known from the literature, a separate class ‘unknown’ was also considered.

3 Results and Discussion

Tab. 3.1-1.: Mean (across LTE's) indicator responses of assumed improved management practices compared to the respective baseline management practice as relative ratio (RR), as difference (DIFF) or as a relative difference (relDIFF). Significant responses at $p<0.05$ (one-sample t-test, 2 tails) are indicated with *.

Category of practice	Management practices/Indicators	Task group Productivity (P)				Task group Climate Change (CC)					Task group Chemical Soil Quality (SQC)							Task group Physical Soil Quality (SQP)						Task group Biological Soil Quality (SQB)							
		Yield (RR)	N uptake (RR)	NUE (RR)	N surplus (DIFF)	SOC concentrations (RR)	SOC stocks (RR)	CO_2 emissions (RR)	N2O emissions (RR)	CH_4 emissions (rel DIFF)	pH (RR)	Nt cont (RR)	Nt stock (RR)	C/N (RR)	N min (RR)	K avail (RR)	P avail (RR)	Bulk density (RR)	Penetration resistance (RR)	Permeability (RR)	Aggregates stability (RR)	Runoff yield (RR)	Sediment yield (RR)	Earthworm number (DIFF)	Earthworm biomass (DIFF)	MBC (RR)	PPNEM (RR)	FUNGNEM (RR)	BACNEM (RR)	BACPLFA (RR)	FUNGPLFA (RR)
Rotation	*Monoculture (baseline)*	*1.00*	*1.00*	*1.00*	*0.0*	*1.00*	*1.00*				*1.00*	*1.00*		*1.00*		*1.00*	*1.00*	*1.00*			*1.00*										
	Crop rotation	1.05*	1.03	1.38	-43.9	1.00	0.99				0.99	1.04		0.96*		0.76*	0.95	1.04*			0.77*										
	Without Green manure/catch crop/cover crop (baseline)	*1.00*	*1.00*	*1.00*	*0.0*	*1.00*	*1.00*	*1.00*	*1.00*	*0.0*	*1.00*	*1.00*	*1.00*	*1.00*		*1.00*		*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*								
	Cover crops																	1.02	0.64*	1.74*	1.05	0.55*	0.39*								
	Harvested catch crop/cover crop	1.05*	1.19	1.19	-3.9						0.99	0.98	1.04*	0.99		0.81															
	Incorporated green manure	1.00	0.99	0.99	1.5																										
	Catch crop/cover crop/ green manure					1.16	1.10	1.64	1.81*	0.95*																					
Tillage	*Conventional tillage (baseline)*	*1.00*	*1.00*	*1.00*	*0.0*	*1.00*	*1.00*	*1.00*	*1.00*	*0.0*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*0*	*0*	*1.00*					
	No tillage	0.96	0.95	1.06	-4.2	1.03	1.07*	1.28*	3.24*	0.70	1.00	1.02	0.94	0.94	1.15	0.97	1.30*	1.04*	1.54*	0.74	1.44*	1.90*	1.92	22*	39*	1.29*					
	Shallow non inversion tillage/reduced + minimum tillage	0.97*	0.91*	0.91*	12.6*	1.08*	1.06*	1.09	1.02	-0.13	1.00	1.07*	1.11*	0.97	0.87	1.46*	1.10*	1.02*	1.65*	1.23	1.12*	0.94	0.76	20*	13*	1.17*					
	Deep non-inversion tillage																							13	12*	1.1					
	Deep ploughing																	1.01	1.57*												
	Direct drilling																	1.02	1.32*	0.38*	1.88*	0.53	0.24*								
Nutrient management: mineral fertiliser and organic fertiliser	*Mineral fertiliser (mineral N – baseline)*	*1.00*	*1.00*	*1.00*	*0.0*	*1.00*	*1.00*	*1.00*	*1.00*	*0.0*	*1.00*	*1.00*		*1.00*	*1.00*	*1.00*		*1.00*		*1.00*	*1.00*			*0*	*0*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*
	Organic fertiliser- FYM	0.94*	1.00	0.92	23.9	1.23*	1.17*	1.04	0.83	-0.19	1.01	1.10*		1.12*	1.48*	1.28		0.96*		4.53*	2.30			320*	71*	1.29*	1.05	0.56*	2.14*	1.38*	1.08
	Organic fertiliser-slurry	0.98	0.92*	0.92	28.2	1.21*	1.26*	1.32*	5.13*	60.3		1.13*		1.01	1.25*									283*	42*	1.35*	0.62*	0.56*	3.82	1.15	0.98
	Organic fertiliser-compost	0.95	1.04	1.04	18.7	1.37*	1.31*	1.39	5.15	-0.84	1.07*	1.14*		1.03	1.09	1.04								75*	15*	1.25*	0.93	0.85	1.19	1.34*	1.07
	No mineral fertiliser (baseline)					*1.00*	*1.00*	*1.00*	*1.00*	*0.0*	*1.00*	*1.00*		*1.00*	*1.00*	*1.00*	*1.00*														
	Mineral N fertiliser					1.07*	1.03		3.63*	9.02	1.00	1.02*		0.77	1.60*	2.33*	2.64*														
Residue management	*Residue removal (baseline)*	*1.00*	*1.00*	*1.00*	*0.0*	*1.00*	*1.00*	*1.00*	*1.00*	*0.0*		*1.00*		*1.00*	*1.00*	*1.00*	*1.00*					*1.00*									
	Residue incorporation	0.93*	0.95	1.36	-16.6	1.07*	1.07*	5.88*	12.08*	0.057		1.02*		1.07								0.53*									
	Residue burning	1.03*	1.05	1.04	-6.2																										
Crop protection	*Chemical control (baseline)*																	*1.00*		*1.00*	*1.00*	*1.00*									
	Mechanical control																	1.01		0.68	1.01	1.67*									

Tab. 3.1-2. : Qualitative evaluation (based on Table 3.1-1) of assumed improved management practices (++: very favourable effect;+: favourable effect; 0: neutral effect; -: unfavourable effect; --: very unfavourable effect; +/- favourable and unfavourable effects: compared to the baseline (reference) treatment (in grey cells).

Category of practice	**Management practices/Indicators**	**Task group Productivity (P)**				**Task group Climate Change (CC)**					**Task group Soil Quality Chemical (SQC)**							**Task group Soil Quality Physical (SQP)**						**Task group Soil Quality Biological (SQB)**							
		Yield (RR)	**N uptake (RR)**	**NUE (RR)**	**N surplus (DIFF)**	**SOC concentrations (RR)**	**SOC stocks (RR)**	**CO_2 emissions (RR)**	**N2O emissions (RR)**	**CH_4 emissions (rel DIFF)**	**pH (RR)**	**Nt cont (RR)**	**Nt stock (RR)**	**C/N (RR)**	**N min (RR)**	**K avail (RR)**	**P avail (RR)**	**Bulk density (RR)**	**Penetration resistance (RR)**	**Permeability (RR)**	**Aggregates stability (RR)**	**Runoff yield (RR)**	**Sediment yield (RR)**	**Earthworm number (DIFF)**	**Earthworm biomass (DIFF)**	**MBC (RR)**	**PPNEM (RR)**	**FUNGNEM (RR)**	**BACNEM (RR)**	**BACPLFA (RR)**	**FUNGPLFA (RR)**
Rotation	*Monoculture (baseline)*	*1.00*	*1.00*	*1.00*	*0.0*	*1.00*	*1.00*				*1.00*	*1.00*		*1.00*		*1.00*	*1.00*	*1.00*			*1.00*			*0*	*0*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*
	Crop rotation	+	0	+	+	0	0				0	0		-		-	0	--			--			+	+	+	+/-	-	+	0	0
	No intercropping (baseline)	*1.00*	*1.00*	*1.00*	*0.0*																										
	Intercropping	-	+	+	+																										
	Without Green manure/catch crop/cover crop (baseline)	*1.00*	*1.00*	*1.00*	*0.0*	*1.00*	*1.00*	*1.00*	*1.00*	*0.0*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*0.00*	*1.00*	*1.00*	*1.00*	*0*	*0*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*
	Cover crops																	-	++	++	+	++	++								
	Harvested catch crop/cover crop	+	+	+	0						0	0	+	0		0								+	+	+	+/-	+	+	+	0
	Incorporated green manure	0	0	0	0																			++	++	++	+/-	0	+	++	0
	Catch crop/cover crop/ green manure					+	+	0	--	--																					
Tillage	*Conventional tillage (baseline)*	*1.00*	*1.00*	*1.00*	*0.0*	*1.00*	*1.00*	*1.00*	*1.00*	*0.0*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*0.00*	*1.00*	*1.00*	*1.00*	*0*	*0*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*
	No tillage	0	-	0	0	+	++	-	--	-	0	0	0	0	++	0	++	--	--	-	++	--	-	+	+	+	+/-	+/-	+/-	0	0
	Shallow non inversion tillage/reduced + minimum tillage	-	--	--	-	++	++	0	-	+	0	+	++	0	0	++	+	--	--	+	++	+	+	+	+	+	+/-	+/-	+/-	0	0
	Deep non-inversion tillage																							+	+	0	+/-	+/-	+/-	0	0
	Deep ploughing																	-	--												
	Direct drilling																	-	--	--	++	+	++								
Nutrient management: mineral fertiliser and organic fertiliser	*Mineral fertiliser (mineral N – baseline)*	*1.00*	*1.00*	*1.00*	*0.0*	*1.00*	*1.00*	*1.00*	*1.00*	*0.0*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*0.00*	*1.00*			*0*	*0*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*
	Organic fertiliser- FYM	-	0	-	-	++	++	0	+	+	0	++		++	++	+		++		++	+			++	++	++	0	-	++	++	0
	Organic fertiliser-slurry	0	-	-	-	++	++	-	--	-	0	++		0	++	0								+	+	++	+	-	0	0	0
	Organic fertiliser-compost	-	0	0	0	++	++	0	-	+	+	++		0	+	0								+	+	++	0	0	0	+	0
	No mineral fertiliser (baseline)	*1.00*	*1.00*	*1.00*	*0.0*	*1.00*	*1.00*	*1.00*	*1.00*	*0.0*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*														
	Mineral N fertiliser					++	+	0	--	-	0	+		0	++	++	++														
Residue management	*Residue removal (baseline)*	*1.00*	*1.00*	*1.00*	*0.0*	*1.00*	*1.00*	*1.00*	*1.00*	*0.0*		*1.00*		*1.00*			*1.00*					*1.00*	*1.00*	*0*	*0*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*
	Residue incorporation	-	-	0	+	++	++	-	--	-		+		+			0					++		+	+	+	+/-	0	+	+	0
	Residue burning	+	+	0	0																										
Crop protection	*Chemical control (baseline)*	*1.00*	*1.00*	*1.00*	*0.0*													*1.00*		*0.00*	*1.00*	*1.00*									
	Mechanical control																	-		-	+	--									
Water management irrigation-drainage	-	0	0	0	0																										

Qualitative evaluation of the management practices: procedures

There are three criteria (statistical significances, size of effects and experts knowledge) that were all used to produce the final evaluation of table 4.1-1. Statistical significance and size of effects were mainly used to produce table 3.1-2 from results reported in Table 3.1-1. Expert knowledge was added as a further criterion to synthesize single indicators into Table 4.1-1, when indicators within the different tasks were contradictory.

The effects of the changes of management practices were grouped in the following five classes both in Table 3.1-2 and in the final Table 4.1-1:

++: very favorable effect

+: favorable effect

0: neutral effect

-: unfavorable effect

--: very unfavorable effect of management practices.

For the Task group Productivity (P), the qualitative evaluations were assigned according to the general scheme outlined above. A threshold value of +5% was used to discriminate between favorable and very favorable effect, and -5% to discriminate between unfavorable and very unfavorable effect. Significance at $p < 0.05$ was also considered. Quantitative scores were taken into account as much as possible, but then an expert judgment was used to adjust evaluations when the dispersion of RRs around the mean was high.

For the Task group Climate Change (CC), the evaluation was made in the following way:

\+ positive effect

++ positive effect and significant differences ($t < 0.05$)

\- negative effect

-- negative effect and significant differences ($t < 0.05$)

0 + and - are in a balance or the RR = 1 or no data available

In Table 3.1-2 “very favorable/unfavorable” judgments were assigned when recorded effects were statistically significant or very large in size. “Favorable/unfavorable” judgments were assigned when a clear effect was noticed but it was neither significant nor very large in size. “Neutral” judgment was used when effects were negligible in practice. For the Task group Climate Change (CC), in most of the cases, the values of the RRs were added or subtracted based on their positive or negative effect as described above. If the result of the operation was positive, the overall evaluation was equal to + or ++ (depending on the number of indicators which presented significant differences $t < 0.05$). The opposite happened with the - and --. An overall evaluation equal to 0 implied a neutral judgment. For the Task group Soil Quality Physical (SQP), the same evaluation scheme as for the Task group CC was used; in some cases, an overall evaluation equal to 0 was assigned when data were lacking. For the Task group Soil Quality Chemical (SQC), + and - assignments do not relate directly to significance levels but more on expert judgment. For the Task group Soil Quality Biological (SQB), the quantitative scores were taken into account as much as possible and statistical significance was used to assign a qualitative score. When a positive effect was observed, significance at $p<0.05$ resulted in + while significance at $p<0.01$ resulted in a ++. When a negative effect was observed, significance at $p<0.05$ resulted in – while significance at $p<0.01$ resulted in a --. No significant effect resulted in a 0 score. Expert judgment was used to adjust evaluations when a quantitative score for a certain ‘BMP x indicator-combination’ was missing or when the quantitative score was based on a low number of observations. Further, the class ´+/-´ was added for scoring the effect of certain BMPs on nematode populations as the effect depends strongly on species.

To compose table 4.1-1, results of all indicators of table 3.1-2 were aggregated within each task. The different indicators were mediated expressing the final score in the same five classes, depending on the prevailing score. Expert judgment became more important to rank the relative importance of different indicators. Regarding Productivity, yield was considered more important than the other indicators about nitrogen, and NUE was considered less compelling due to its variability. Regarding Climate Change, CO_2 emission was not considered as important as N_2O because it is under discussion within the research community, whether the measured CO_2 is entirely emitted as a GHG or included in the terrestrial C-cycle (uptake by soil organism/plants) again. In all other task groups, consolidated expert knowledge was the main criterion used when quantitative data for each ‘BMP x indicator-combination’ did not allow a more rigorous procedure.

3.1 Crop rotation

The comparison of rotation versus monoculture was performed for different LTEs, climate conditions, soil texture/clay contents and durations. Rotations analysed in this study were very variable in length or crops involved. The duration of a rotation varied from 2 to 6 years. Main crops were generally maize, wheat, barley or other small grains cereals, while secondary rotated crops were grain legumes (e.g. faba bean, pea), forage legumes (lucerne, clover, vetch), grass, root and tuber crops (e.g. potato, sugar beet), or minor cereals.

Rotation has a positive impact on the productivity of the major crops. Yield is increased by 5% on average (Tab. 3.1-1). However, while the main crop productivity can be increased in a rotation, the overall yield of the entire rotation is generally lower than that of the main single crop in monoculture. This could result in a reduction of farmers’ income that is apparently not compensated by the gain of fertility. N efficiency indicators referred to the main crops are also improved.

Soil organic carbon is not affected by rotation, while total soil N tended to increase. Most soil physical properties are aggravated: increase in bulk density and reductions in aggregate stability.

Soil biological properties are also improved, as an increase in earthworm number and biomass and in microbial biomass carbon indicate. This positive effect is especially noticed when crops, such as cereals and horticultural crops, that leave substantial amounts of residues on the field or (temporary) grassland are included in the rotation.

Therefore, rotation is a recommended practice under most of the considered viewpoints, however, due to a lack of data, no GHG emission comparisons could be included. There is an urgent need to gain such data in the near future.

3.2 Intercropping

In the condition of European agriculture intercropping means growing two crops at the same time for at least part of their cycle, typically undersowing of legume cover crops in growing winter wheat. No analyses could be performed due to the lack of data, at least no yield reduction is expected when using this practice.

3.3 Catch crops (harvested), cover crops (in permanent crops) and green manure (not harvested)

3.3.1 Task group results under consideration of co-variate factors

Catch-crops are fast-growing crops sown to reduce nutrient losses when the main crop is absent from the field. Cover crops are generally planted to prevent soil erosion, again in the absence of the main crop. When the biomass produced is incorporated into the soil (or left at the soil surface, in the case of no tillage), then this practice is called green manure. Leguminous catch crops can supplement nitrogen (N) by fixing N_2 from the atmosphere. Non-leguminous catch crops exploit the residual nitrogen left after harvest of the main crop and their value as green manure can be as high as that of leguminous crops. All these practices are here considered altogether and compared to rotations without them.

An increase in yield of 5% was found when catch/cover crops are included in the crop rotation. Additionally, a statistically insignificant increase in N uptake and N use efficiency (NUE) and a reduction in N surplus (Tab. 3.1-1) could be observed, even when N fertiliser is applied at the same rate. Chemical N supply can be reduced, especially when a legume is used as a cover crop. However, several studies found that cover crops may cause an initial decrease in yield of the subsequent crop and a positive effect in later years (e.g. Torstensson and Aronsson (2000)). SOC concentrations and stocks tended to increase. As in many cases in which a source of easily degradable organic matter is applied, CO_2 and N_2O emissions are increased. CH_4 emissions increased as well.

Cover crops in permanent cropping systems are grown during autumn and winter, either sown in early autumn or obtained via regeneration of the natural vegetation after the onset of rains. They are controlled by tillage, mowing or spraying with herbicide in early spring to prevent competition with the olive tree for water and nutrients (Gómez et al., 2009). As a result of the data analysis, they are beneficial to soil physical characteristics. All the indicators evaluated but bulk density, show an improvement of soil physical quality. A slightly increase of bulk density is found due to the natural consolidation of soil therefore, occasional tillage to alleviate compaction could be a beneficial complement for this practice.

Based on literature results (e.g. Thoden, 2011), the effect of green manure crops on plant-parasitic nematodes is various and depends on 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 should therefore be a tailor made decision, to fit local conditions of field and rotation. In general, however, we can conclude that green manure crops often enhance growing conditions of the following crop, and make that crop less sensitive to nematode damage.

3.3.2 Conflicts (trade-offs) and synergies

The cultivation of catch/cover crops, both when harvested and when used as a green manure revealed positive or neutral effects on the investigated indicators for productivity and soil quality and can, thus, be confirmed as a recommended practice regarding these objectives. However, concerning climate change mitigation, elevated GHG emissions may outreach the positive effect of SOC increases.

3.4 No Tillage – NT

3.4.1 Task group results under consideration of co-variate factors

The practice of No-tillage (NT) was compared to conventional tillage (ploughing in most cases), see Tab. 3.1-1. NT has been studied all throughout Europe, especially in southern and western countries. Reasons to adopt no tillage are mostly economic (to save fuel, machinery and labour costs) or to protect the soil (from compaction, erosion, excessive mineralisation). The positive effects of no-till are often others than to increase productivity. However, the overall analysis showed a tendency for a yield decrease.

Among the tested factors, soil texture class was the only one which appeared to significantly affect yield response. Only in silt soils yield increases occurred with NT.

On average, no-tillage increased SOC concentrations and SOC stocks by 3% and 7%, respectively. The overall CO_2 emissions rose by 28%, however, great differences occurred between field and lab studies, the latter revealing lower increases (the median decreased). Possible contradictions between a concurrent rise in CO_2 emissions and SOC may be explained by the fact that the increases in SOM may exceed the increase in CO_2 emissions– caused by heterotrophic respiration mostly by soil microorganisms (Janzen, 2004). Furthermore, NT resulted in an overall significant more than 3fold increase of N_2O emissions. Based on only few experimental results, NT showed slightly higher CH_4 emissions, however, in the majority of measurements the soil acted as a sink for CH_4.

SOC concentrations increased under NT only in ATL and MED, whereas they decreased in the CON zone. The SOC concentrations tended to increase in heavy-textured soils and to decrease in coarse-textured soils. The highest increases occurred in the soil depths ≤ 10 cm.

The increases of N_2O emissions without tillage were statistically significantly higher in the ATL climate compared to MED. This does not entirely confirm the findings of van Kessel et al. (2013), who found higher N_2O emissions in the first 10 years (this was also a tendency here) and in dryer climates. CH_4 emissions increased in the first 5 years and afterwards decreased.

Among soil chemical indicators only available phosphorus (Pavail) gave a significant response to No-tillage. Pavail increased, on average, by 30%. This is largely attributed to the accumulation of fertiliser and manure-P in the topsoil, in absence of mechanical soil mixing.

Significant effects occurred for sampling depths on the RR for pH, with slightly decreased pH values in the top soil. One reason could be the accumulation of organic matter, increased microbial activity and an enhanced production of organic acids (Spiegel et al., 2007). Another may be the acidifying effect of fertilisers (not mixed into soil in absence of tillage). The other significant effects, e.g. of experimental duration on RR of N_t stocks, for texture on RR of Kavail and for all factors (climate, texture and duration) on RR of Pavail, could not be readily explained and may be due to the unbalanced data structure (Pecio et al., 2014).

The task group on soil physical quality reported that NT induces soil consolidation and a certain degradation of the top soil structure, indicated by the bulk density and penetration resistance ratios. Furthermore, other indicators such as permeability, runoff and sediment yields are aggravated under this practice due to soil natural compaction. This compaction is not easily alleviated by surface harrowing at a shallow depth. No tillage as has been detected by an increase in bulk density especially at the short term. At the same time, runoff and sediment yield significantly increase at the medium term (5-10 yr) and loamy soils. The only indicator that seems to be improved by this practice is the aggregates stability especially at the short term (< 5 yr) and in sandy soils.

Furthermore, the task group on soil physical quality mentioned that NT (or direct drilling as it is called in many parts of the world) can be the best management practice for arable crops under the Mediterranean conditions due to the improvement of soil water balance, reduction of soil erosion, maintenance of biodiversity and mitigation of production cost (Guzmán et al., 2014).

NT significantly increased earthworm number and biomass, which is mainly attributed to minimal soil disturbance (preservation of earthworm burrows) and the presence of residues on the soil surface (food supply to the earthworms). The effect on nematode populations is reported very differently in the literature. It was reported that the effect of tillage on nematode populations is very limited and variable. Populations depend far more on crop rotation, cover/green manure crops and the build-up and distribution of organic matter.

3.4.2 Conflicts (trade-offs) and synergies

The practice of NT was appreciated by the working groups very differently. Beneficial effects (Tab. 3.1-2) were stated regarding chemical and biological indicators. Main benefits are increases of plant available nutrients and SOC and an improvement of soil biota. Furthermore, no significant yield decreases compared to conventional tillage occurred, NUE was better and N surplus decreased. However, these positive and neutral effects were more than outweighed by an increase of the GHG emissions (CO_2, N_2O, CH_4) and by a deterioration of physical soil conditions. The latter was - due to a lack of data in other regions - mainly confined to Mediterranean areas with their long, hot and dry summer period.

3.5 Non-inversion Tillage – Minimum tillage

In our first evaluations we have differentiated between reduced and minimum tillage (see Glossary) compared with conventional ploughing. However, there was no clear distinction between the definitions of these two management practices, so we summarised them into “non-inversion tillage” (NIT). Only the task group “Productivity” preferred the term “minimum tillage”, because in their LTE’s analysed, not all reduced and minimum tillage practices were non-inversion techniques. Another deviation – from our convention to pool all non-inversion tillage practices – was made for a number of Belgian LTEs on soil biology. There, a differentiation between shallow and deep non-inversion tillage was made.

3.5.1 Task group results under consideration of co-variate factors

Minimum tillage influenced all productivity indicators unfavourably, i.e. yields, N uptake, NUE and N surplus (Tab. 3.1-1 and Tab. 3.1-2). Less negative effects (also compared to the full omission of tillage) could be stated regarding CC indicators. Overall, with shallow non inversion tillage SOC concentrations and stocks increased significantly (favourable), CO_2 and N_2O emissions increased only slightly. However, these (unfavourable) increases occurred only in the first 5 years, after longer periods the CO_2 and N_2O emissions decreased with NIT compared to conventional ploughing revealing RRs below 1. Furthermore, the nutrient contents (N_t, plant available P and K) increased. N_{min} contents tended to decrease. Nevertheless, the overall evaluation of soil chemical quality was positive (more distinct than for NT). As mentioned in D3.354 (Pecio et al., 2014), the near surface accumulation of P (and other nutrients, e.g. N_t) can be an advantage for early crop growth under favourable moisture conditions. However, under dry conditions the nutrients may be inaccessible for plant uptake and prone to erosion and runoff losses. For the physical indicators the evaluation was less consistent. Minimum tillage resulted in a beneficial effect on most of the indicators as permeability, aggregates stability and runoff and sediment yields. However, compared to conventional tillage bulk density (especially up to a depth of 10 cm) and penetration resistance (mainly observed at the short term) were significantly higher.

Similar to NT, shallow non-inversion tillage significantly increased earthworm number and biomass, for deep non-inversion tillage only earthworm biomass was significantly increased compared to CT. Overall, all kinds of tillage reduction increased microbial biomass C (MBC) in the order NT > Shallow NIT > deep NIT compared to CT. However, significant differences with soil depth occurred. While both, Shallow NIT and NT resulted in a distinct increase of the MBC in the topsoil layer (0-10 cm) compared to ploughing, the – less pronounced - reverse effect has been observed in the subsoil (10-30 cm).

3.5.2 Conflicts (trade-offs) and synergies

Similar to NT, (shallow) non-inversion tillage enhanced the chemical and biological quality of the top soil, all evaluations done in comparison to CT (Tab. 3.1-2).NIT led to less physical soil deterioration than NT in arable systems. For tree crops, there were insufficient data to evaluate the effect of NIT on physical parameters. It must be emphasised that also the indicators of GHGs emissions responded- with lower average increases of CO_2 and N_2O emissions and less CH_4emissions compared to CT - more favourably to NIT than to NT. However, all productivity indicators showed significant deterioration compared to CT, and mostly worse than under NT.

Although omission of tillage may have positive effects on indicators other than productivity, it is productivity – and especially its monetary consequences – that is the major driver for farming.This may be a reason, why NIT is not commonly accepted by the farmers. However, for an overall assessment, the savings of fuel, labor and, possibly, fertiliser costs, which depend on farm and site conditions, must be further taken into account.

3.6 Mineral N fertilisation

3.6.1 Task group results under consideration of co-variate factors

The task group SQC has investigated the effects of mineral fertilisation (N, P, K) compared to the omission on their indicators (pH, N_t content, C to N ratio (C/N), N_{min}, plant available P and K), see Tab. 3.1-1. The CC task group has only evaluated (high) N fertiliser rates versus ’no fertilizer’, for consequences on SOC (concentrations and stocks) and GHG emissions. Comparisons between organic manures and mineral fertilisers (the latter serving as reference) are presented in Sections 3.7-3.9 of this report.

The strongest overall responses to fertiliser application occurred for the indicators available P and K and N_{min}. The N_t content enhanced only slightly but significantly. The increase of N_{min} contents was more distinct in the first 30 cm soil depth, the eastern climate zone and after more than 10 experimental years. The two latter facts were also the case for available K.

The application of mineral nitrogen fertiliser increased, based on the mean value, the SOC concentrations significantly by 7% and the SOC stocks tended to increase (by 3%), compared with N omission.Our evaluations revealed an overall significant, more than 3.5-fold increase of N_2O emissions. Strong variations, between increase and decrease, were observed for all these indicators.

There is an ongoing discussion about the effect of mineral N fertilisation on SOC. Results of Austrian long-term field experiments showed that appropriate mineral N fertilisation resulted in a slight SOC increase (Dersch und Böhm, 2001). In contrast, studies from US report a decrease of organic matter following mineral N fertilisation (Khan et al., 2007). Worldwide evaluations of field experiments show a retardment of degradation or a marginal increase of SOM with mineral N (Ladha et al., 2011).

In general, the application of mineral N-fertilisers, regardless of its type, leads to elevated N_2O emissions in the field (e.g. Abdalla et al. (2012)). This occurs, because a higher amount of available nitrogen allows higher concentrations of nitrate or other nitrogen compounds, being involved in denitrification processes depending on site conditions (Weier et al., 1993). At intermediate water filled pore space values (65%), nitrous oxide emissions are reported to peak (Sehy et al., 2003).Consecutive N_2O measurements at the same site in different years have shown that there is a wide range of emission values within similar treatments (Flechard et al. 2007). Emission data of different sites throughout the United Kingdom of the same year were compiled by Smith et al. (2012) and identified a high variation in the fluxes as well. It seems that weather conditions at and after the fertiliser application determine the N_2O emission rates in a strong way.

However, the main focus should not only be on the total applied N but also on the amount of N not used by the crops and, thus, the timing of fertilisation. Any extension of the time period in which an ammonium-containing fertiliser is prone to nitrification, or a nitrate-containing fertiliser to denitrification, in absence of a growing crop that can act as a strong sink for N, increases the N_2O-emission probability. Furthermore, NUE and operation income will decrease. The application of fertilisers containing nitrification inhibitors may contribute to a reduction in N_2O-emissions. Since hardly any scientific measurement data exist, we strongly recommend to implement more continuous GHG emission measurements in field experiments to allow appropriate evaluations.

3.6.2 Conflicts (trade-offs) and synergies

Mineral N fertilisation plays a crucial role in terms of productivity, because N is the most important limiting factor for the growth of crops. Optimal N fertilisation management places special demands on the skill of the farmer with respect to the fertilisation form, amount, timing, kind of application, knowledge of soil-plant processes (see chapter 3.6.1) etc. This is necessary to minimise N losses to the water and to the atmosphere.

3.7 Fertilisation with compost

3.7.1 Task group results under consideration of co-variate factors

The final composition, i.e. the chemical and biophysical characteristics, of the composts depends on the basic materials. The evaluation comprised very different kinds of compost (e.g. plant, biowaste, sludge), thus, the results showed a great variability. Compared to a similar N fertilisation level using mineral fertilisers, the RR revealed an average non-significant 5% yield decrease with compost application (Tab. 3.1-1). Furthermore, SOC concentrations and stocks were significantly enhanced by 37% and 31%, respectively. A limited amount of GHG emission measurements showed increased CO_2 and N_2O emissions in ATL and CON (only CO_2) and decreased emissions in the MED climate.

Compost amendments resulted in an increase of earthworm number and biomass - however, (far) less so than with FYM and slurry. It is believed 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 (Leroy 2008). Compost application tended to decrease plant-parasitic and fungivorous nematodes and to enhance bactivorous nematodes. On an individual basis, compost effects on soil biota were reported to depend on the C/N ratio of the organic amendment. Those with lower C/N, indicating more readily mineralisable compounds, will preferentially be used by soil bacteria, those with higher C/N ratio will be mainly decomposed by fungi (Marschner et al., 2003).

The application of composts enhanced average pH and N_t content significantly and tended to increase plant available K contents, the C/N ratio and N_{min} contents and in the soil. These increases of N indicators fit very well to the findings of the productivity task group. They stated – albeit based on few comparisons only in the ATC climate -that the N uptake and the N use efficiency were enhanced with compost application as well, coherent with decreasing N surplus in the same specific cases. One short-term trial in MED climate, however, showed an increased N surplus (N input minus removal) in response to compost application. The most important influencing factors were the duration of practice (e.g. for yields, pH) and the climate (e.g. yields). Yield and pH increases after compost application only occurred after (more than) 5 years of compost application. SOC increases were highest in the upper 10 cm soil depth and became more pronounced after more than 10 experimental years. The reduction of plant-parasitic nematodes due to compost was more effective in a sandy soil (decrease by 9%) than in a silt soil, where almost no effect was observed.

3.7.2 Conflicts (trade-offs) and synergies

With compost organic material is applied to soils. Depending on the amounts of organic matter and its nutrient contents, compost application will result in an increase of SOC and plant nutrients, especially N, which is primarily beneficial for productivity in the long-term and for soil quality. However, the mineralisation of organic matter will lead to a retarded nutrient, especially N, discharge. Thus, our analyses confirmed findings of the literature that composts act as "slow release" fertilisers with a well-known slow but nevertheless effective N mineralisation, which should be adequately controlled. Based on only few comparisons, our evaluations have shown a decrease of CH_4 and an increase of N_2O emissions. Despite the above mentioned trade-offs, compost application can be recommended as BMP.

3.8 Farmyard manure application

3.8.1 Task group results under consideration of co-variate factors

We compared FYM application versus mineral N fertilisers, based on the same amounts of total N, except for the chemical indicators where comparisons were on 'equal plant available nutrients' basis. On average of 60 long-term experiments (>10 years), a significant yield reduction by 6% was observed after FYM application (Tab. 3.1-1). However, this seems to be due to the great data variability, because the mean effect on yield found for each crop group was positive– except for legumes/grass ley (RR 0.97). Vegetables and potato benefited more of manure additions than wheat and barley. Climate and soil texture class significantly affected the RR of yields. Results obtained in northern Europe on fodder maize were extremely positive (RR1.56), although the absolute yield was rather low (<5.5 t ha^{-1} of DM in the manured plots). Conversely, 8 cases in the Atlantic climate showed a reduction in marketable production (RR 0.74). Coarse-textured soils, where mineralisation proceeds faster, created more favourable conditions for manured treatments. Summer crops tended to benefit more from the N mineralisation of organic fertilisers, because their N uptake patterns are more synchronous with the mineralisation curve of organic manures. Furthermore, statistically insignificant reductions of NUE and increases in N surplus (calculated as N input minus N removal) could be shown.

SOC concentrations and stocks increased significantly. Also a slight insignificant increase in CO_2 emissions could be stated, whereas N_2O emissions slightly decreased, CH_4 emissions behaved differently in two field experiments.

For soil physical quality and due to the lack of data farmyard manure, green manure, compost, etc., were grouped under the general name of organic fertilization in order to be compared to mineral fertilization. However, most of the data came from farm yard manure trials in the Atlantic climate zone. Despite not many data were available, in all the cases evaluated, organic fertilization reduced significantly bulk density, penetration resistance and aggregates stability. For the case of the aggregates stability, it was increased mainly at the top soil (< 10 cm) and in loamy soils.

Biological soil quality indicators, such as earthworm number, earthworm biomass and microbial populations and chemical soil quality indicators (N_t and N_{min} contents, plant available K) were positively affected after (long-term) FYM application. The C/N increase was significantly higher in the soil depth 0-10 compared to 10-30 cm. This fact also indicates conclusively that adding FYM - with assumed higher C/N ratios than arable soils – significantly changes (chemical) soil indicators revealing changes in soil organic matter dynamics

3.8.2 Conflicts (trade-offs) and synergies

FYM fertilisation was positively evaluated due to the yield increases for all investigated crops (except for legumes/grass ley) and improvements in chemical and biological soil quality, decreases of N_2O emissions were measured as well (Tab. 3.1-2). However, the build-up of total and plant available mineral nitrogen seemed to result in an N surplus, the decrease of the NUE indicated slow release N sources. These dynamics should be taken into account to avoid N losses to the groundwater and the atmosphere. The positive effects, stated by almost all task groups, led to an overall favourable assessment of FYM application as BMP.

3.9 Slurry application

3.9.1 Task group results under consideration of co-variate factors

We compared slurry application versus mineral N fertilisers, based on the same amounts of total N, except for the chemical indicators where comparisons were on ‘equal plant available nutrients’ basis. Application of cattle slurry resulted in similar yields (RR 0.98), a decrease of N uptake by 8%, and similar values of NUE and N surplus (calculated as N input minus N removal)compared to a similar rate of mineral N (Tab. 3.1-1).

Crop yield responses to slurry application were mainly influenced by the soil texture class. Best results were obtained in coarse-textured soils (RR1.07 in sandy soils) and poorer results in silt soils (RR 0.73), thus confirming that no yield decrease is expected in conditions that promote mineralisation.

Cattle slurry application resulted in a significant SOC increase. However, based on a limited amount of comparisons, the emissions of all analysed GHGs (CH_4, CO_2, and N_2O) increased as well. On average CO_2 emissions increased by 32 % and N_2O emissions were enhanced 5-

fold, but these figures are based on a limited amount of comparisons (5 and 9, respectively). Additionally, N_t (+13%) and N_{min} contents (+25%) increased significantly. As stated, however, these latter indicators were assessed on 'equal plant available nutrient' basis.

Similar to FYM (and compost), the amendment of cattle slurry led to an improvement of biological soil quality, as earthworm number, earthworm biomass and microbial biomass C increased significantly. Furthermore, the amount of both, plant-parasitic and fungivorous nematodes was significantly reduced. It is not clear whether or not a change in the amount of fungal-feeding nematodes is favourable or unfavourable. Negative impacts on mycorrhizal fungi were reported after drastic increases in fungivorous nematodes while other studies suggest fungivorous nematodes to be positive because their feeding stimulates the regrowth of fresh fungal hyphae with higher metabolic activity (Thoden et al. 2011).

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3.9.2 Conflicts (trade-offs) and synergies

Slurry application improved SOC and other chemical and, above all, biological soil indicators (Tab. 3.1-2). It affected crop yields neither positively nor negatively. However, all investigated N indicators showed a change in the N dynamics compared to mineral N application. Although a build-up of total and plant available mineral nitrogen pools was observed, N uptake was reduced and consequently N surplus was slightly increased. Furthermore, the simultaneous decrease in N uptake and NUE suggests the danger for N losses into the ground water with NO_3 enrichments. Another pollution risk that should be mentioned, although it was not investigated here, is the ammonia loss, which can be remarkable if slurry is not rapidly incorporated into the soil.

GHG (CO_2 and N_2O) emissions increased significantly, however, the relevant enhanced N_2O emissions were measured in a limited amount of (three) field experiments comprising 7 comparisons. Improved application time and techniques are options to reduce environmental and climate (at least indirect N_2O emissions) relevant N losses to the water and the atmosphere for this MP that, on the other hand, has positive effects on soil quality. Thus, the qualitative evaluation of the single task groups (Tab. 4.1-1) qualified slurry application as a favourable MP, if the manure management (storage, spreading) is carried out properly (e.g. Sommer et al., 2009).

3.10 Crop residue incorporation

3.10.1 Task group results under consideration of co-variate factors

The incorporation of crop residues - compared to the removal of crop residues from the field - resulted in an overall 7% crop yield decrease and a slight decrease in N uptake (Tab. 3.1-1). Furthermore, an increase of SOC by 7%, of N_t contents by 2% and a significant increase of the C to N ratio was observed. However, the GHG emissions, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) were significantly enhanced as well. Based on few experimental results, the residue incorporation showed beneficial effects regarding earthworm abundance and weights. Residue incorporation reduced the runoff generated due to the change of soil roughness and micro-topography compared to the removal of residues, especially at the surface (< 10 cm) and loamy soils.

The increase of SOC tended to be highest in the northern ENZ (attributed to retarded mineralisation), in soils with high clay contents and after longer experimental duration (>20 years). The incorporation of cereal crop residues showed a significantly lower increase of

$CO_2$and N_2O emissions compared to leafy crop residues. The increases of CO_2 field emissions were significantly higher in the ATL (western) compared to the MED (southern) climate. In contrast, N_2O field emissions were more enhanced in the MED experiments with soils containing higher clay contents compared to the ATL experiments with coarsely textured soils. That fits well with the observation that – albeit based on one to two comparisons- incorporation of crop residues gave strongest responses of N_t contents (increasing) and C/N (decreasing) in the southern environmental zones.

The increase of SOC concentration and stocks as well as for N_t contents were higher with longer duration (> 10 years) of this management practice compared to short-term application.

3.10.2 Conflicts (trade-offs) and synergies

The separate task groups detected unfavourable effects of crop residue incorporation (e.g. some yield decreases, increases of GHG emissions and of penetration resistance) as well as beneficial increases of SOC, N_t, aggregate stability and of earthworm number and/or biomass. Thus, the qualitative evaluation (Tab. 3.1-2) stated neutral to positive overall effects of this MP compared to the removal of crop residues. Finally, this practice can be further recommended as a BMP.

3.11 Burning of crop residues

3.11.1 Task group results under consideration of co-variate factors

Burning of crop residues was addressed only by the productivity task group (Tab. 3.1-1). It is a cheap technique to remove crop residues from the field and still widely adopted by farmers in Mediterranean areas. It has been studied in some LTEs where it was compared with incorporation but not with removal (and therefore could not be used for this analysis). The 9 cases reported were mainly located in Atlantic climate.

Burning had an overall slightly positive but significant effect on yield, +3%, with a very limited variability around this value. N uptake was also slightly (but not significantly) increased and consequently N surplus was slightly reduced (see Tab. 3.1-1).

3.11.2 Conflicts (trade-offs) and synergies

Burning of crop residues surprisingly resulted in an improvement of all productivity indicators. However, many adverse effects of crop residue burning are known, e.g. impacts on aerosol properties, increases of greenhouse gas (GHG) emissions, such as CO_2, CH_4 and N_2O. Thus, the emissions of these GHGs associated with the burning of residues are taken into consideration in the national GHG inventories (IPCC, 2006).

In some European countries or provinces the burning of crop residues is not allowed.

3.12 Irrigation

Due to D3.324 (Zavattaro et al. 2014) no evidence was found of long-term experiments or medium-term experiments (less than 5 years), regarding the comparison between irrigation systems, and in particular sprinkler or drip irrigation, compared with surface distribution methods. Some studies compare irrigation with a control without irrigation (e.g. Flink et al., 1995).

Dersch and Böhm (2001) observed losses of 2.4 t carbon per ha caused by additional irrigation compared to the rain fed system for sugar beet and maize in a rotation with cereals in a 21 years period in the Pannonian climate.

No other publications were found comparing different kinds of irrigation regarding the listed CC indicators and the indicators of the other task groups.

3.13 Crop protection

The mechanical control of weeds was compared to the chemical control of weeds to evaluate a possible difference – only - in soil physical properties. Mechanical control of weeds seems to improve aggregates stability although the effect of this management is negative as indicated by the reduction of permeability and the increase of bulk density and runoff yield, significantly. These negative effects might be explained by the soil compaction caused by the machinery used for the mechanical control.

However, not many data (and only representative of the Mediterranean conditions) were available for performing this analysis. However, aggregates stability seems to be improved (Guzmán et al., 2014).

4 Conclusions

Tab. 4.1-1.: Overall qualitative evaluation (++: very favourable effect; +: favourable effect; 0: neutral effect; -: unfavourable effect; --: very unfavourable effect) of management practices.

Category of practice	Management practices/Indicators	Qualitative evaluation of the task groups				
		Productivity	**Climate change mitigation**	**Soil chemical quality**	**Soil physical quality**	**Soil biological quality**
Rotation	*Monoculture (baseline)*					
	Crop rotation	++	**0**	**0**	**0**	+
	No intercropping (baseline)					
	Intercropping	**0**				
	Without Green manure/catch crop/cover crop (baseline)					
	Cover crops				++	
	Harvested catch crop/cover crop	+		**0**		+
	Incorporated green manure	**0**				++
	Catch crop/cover crop/ green manure		-			
Tillage	*Conventional tillage (baseline)*					
	No tillage	**0**	-	+	--	+
	Shallow non inversion tillage/reduced + minimum tillage	--	+	++	++	+
	Deep non-inversion tillage					**0**
	Deep ploughing				**0**	
	Direct drilling					
Nutrient management: mineral fertiliser and organic fertiliser	*Mineral fertiliser (mineral N – baseline)*					
	Organic fertiliser- FYM	-	++	++	++	++
	Organic fertiliser-slurry	-	**0**	++		+
	Organic fertiliser-compost	**0**	+	+		++
	No mineral fertiliser (baseline)					
	Mineral N fertiliser		**0**	++		
Residue management	*Residue removal (baseline)*					
	Residue incorporation	**0**	**0**	+	**0**	+
	Residue burning	+				
Crop protection	*Chemical control (baseline)*					
	Mechanical control				-	
Water management irrigation-drainage	-	**0**				

Tab. 4.1-2: Three BMPs suggested by each task group

Suggested BMPs for P	**Suggested BMPs for CC**	**Suggested BMPs for SQC**	**Suggested BMPs for SQP**	**Suggested BMPs for SQB**
Crop rotation	FYM application	FYM application	Organic fertilization	FYM application
Catch crop (harvested)	Crop rotation	Non-inversion tillage	Non-inversion tillage	Compost application
Burning crop residues	Non-inversion tillage	Compost application	Cover crops (water erosion control)	Incorporation of a green manure crop

The indicator-based evaluation of agricultural management practices carried out as comparisons between an improved (“BMP”) and a prevalent current practice showed positive and negative effects (Tab. 4.1-1). As expected, none of the investigated practices could comply with all objectives simultaneously, i.e. maintaining high yields and reducing cultivation costs, mitigating climate change and improving chemical, physical and biological soil quality. Furthermore, often substantial variation in the responses of one indicator to the same practice between LTEs occurred, which we could not explain with the help of our co-variate factors. Not only the size of the response varied, but the response itself was sometime favourable, sometimes unfavourable.

Our analyses confirmed the results from practice and literature that a suitable crop rotation is a precondition for good agricultural management (Tab. 4.1-2). The inclusion of catch crops/cover crops/green manures in the crop rotation shows overall positive or neutral effects on the investigated indicators.

Overall, the application of organic amendments was rated to be beneficial/neutral regarding chemical, physical and, especially, biological soil indicators. Among the indicators for climate change mitigation, SOC is favourably promoted, but some amendments (e.g. slurry) enhance CO_2 and N_2O emissions (in a limited amount of measurements). Changed N dynamics and the importance of optimal application techniques require special attention by the farmer as organic N sources tend to be less effective than mineral fertiliser (the reference here) at the same total N input rate. Further experimentation is needed to assess the trade-off between SOC increments and GHG losses.

Reducing tillage compared to conventional ploughing was appreciated differently by the respective task groups. In general, a total omission of tillage (NT) enhanced biological and chemical soil quality. (Shallow) Non-inversion tillage - i.e. a reduced number and depth of cultivation passes and avoidance of inversion, in short, less soil disturbance - was again good for biological and chemical quality, but was in addition also beneficial for CC and SPQ indicators. For soil physical indicators, however, benefits of no-tillage depended very much on the farming system. This practice was rated as very unfavourable for SPQ indicators under permanent crops, despite its enhancement of aggregate stability. Nevertheless, for arable crops under Mediterranean conditions, direct drilling is a favourable practice since it improves soil water balance, keeps biodiversity, attenuates soil erosion losses, and reduces production costs.

On average, all productivity indicators were scarcely but significantly adversely affected by reduced tillage, whereas they showed non-significant negative effects with no tillage. However, the variability of responses was high for both techniques and we registered both positive and negative effects depending on the site. Management practices like weed control, specific measures for pest and disease control, water management and grassland management could not be evaluated due to insufficient data from long-term experiments.

Furthermore, the evaluation of CC mitigation is often limited by the lack of data from – preferably - continuous GHG emission measurements. Thus, more long-term field studies are needed to better assess the CO_2, (CH_4) and, especially, N_2O emissions following practices such as reduced tillage, the addition of organic fertilisers and crop residue incorporation, which favour SOC-accumulation. Also, SOC accumulation should be weighed against potential replacement of fossil fuels, had organic inputs been used for energy. Such comprehensive analyses could enable full assessment of overall net CO_2- emission associated with a given practice, as was requested by DEFRA, 2010.

The most important factor affecting the impact of a management practice seems to be the environmental zone (climate). For soil quality indicators, the responses to practices often depend also on soil texture and sampling depth. Furthermore, many effects for productivity and soil quality can be detected with statistical certainty only after many (more than 10) years, due to great temporal and spatial variations of climate and soil conditions.

Furthermore, this study has shown that ‘best’ or ‘better’ or ‘improved’ MPs do hardly exist if all goals are considered simultaneously. What is a ‘Best Practice’ is largely determined by context and by the specific goals that the farmer - or the consumers or the civil environment - wish to maximise. Furthermore, where different goals are expressed in different units, an ‘overall best practice’ cannot be defined without assigning normative values to the respective goals. This is beyond the scientific perspective.

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Acronyms

BMP	Assumed improved management practices
CH_4	Methane
CO_2	Carbon dioxide
CT	Conventional tillage
ENZ	Environmental zone(s)
MP	Management practice(s)
N	Nitrogen
NT	No tillage
NIT	Non-inversion tillage
NUE	Nitrogen use efficiency
N_2O	Nitrous oxide
RR	response ratio(s)
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
DIFF	differences
rel DIFF	relative differences

Appendices

Definitions/Descriptions for the used terms of the management practices:

Category of practice	**Sub-category of practice**	**Management practice**	**Definitions/descriptions**
A. Rotation	**A1.crop rotation**	Monoculture	The growing of a single arable crop species on a field year after year, for at least 9 to 10 years.
		Rotation with cereals	The growing of different species of crops in a crop rotation with >50% coverage with cereals.
		Rotation with legume crops	The growing of different species of crops in a crop rotation with >25% coverage with legume crops.
		Rotation with tuber or root crops	The growing of different species of crops in a crop rotation with >25% coverage with tuber or root crops.
		Rotation with fallow land	The growing of different species of crops in a crop rotation with >25% fallow.
		Rotation with grassland	The growing of different species of crops in a crop rotation with >50% grassland.
	A2. intercropping/green manure/catch crop	Intercropping	The growing of two or more different arable crops simultaneously in different rows in the same field.
		Rotation with cover/catch crops	The growing of different species of crops in a crop rotation with >25% coverage with cover/catch crops. Double cropping (two different crops grown on the same area in one growing season) is here included. Cover/catch crops are harvested.
		Rotation with green manures	The growing of different species of crops in a crop rotation with >25% coverage with green manure crops. Green manure crops are incorporated into the soil.
B.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.
C. Tillage		Conventional tillage	The conventional tillage consists of **ploughing the soil** (e.g. ± 30 cm), which causes turning, loosening, crumbling and aeration of the topsoil. This should result in a clean field surface.
		No / Zero tillage	No tillage.

		Shallow non inversion tillage/reduced tillage	Tillage **without inversion**, **at a reduced depth** (e.g. 5-15 cm)**, with specific equipment** (e.g. grubber/cultivator) **more than once a year**. About 30% of soil cover after seeding (or the incorporation of organic matter >1120 kg/ha).
		Shallow non inversion tillage/minimum tillage	Tillage **without inversion**, **at a reduced depth** (e.g. 5-10 cm)**, with specific equipment** (e.g. rotovator) **only once a year**. About 30% of soil cover after seeding (or the incorporation of organic matter >1120 kg/ha).
		Deep non inversion tillage	Tillage **without inversion, on a soil depth of ± 30 cm** and **with specific equipment (e.g. grubber/cultivator)** more than once a year. About 30% of soil cover after seeding (or the incorporation of organic matter >1120 kg/ha).
		Deep ploughing	The deep ploughing describes the use of the plough, where the soil is ploughed > 35 cm. It causes a turn, loosening, crumbling and aeration of the topsoil and parts of the subsoil. Furthermore, deep ploughing is used as a measure for agricultural land improvement or cultivation of peat.
		Direct drilling	Direct drilling results in sowing without tillage. The residues of the plant material remain usually as mulch in the field.
		Contour ploughing	Parallel ploughing to the contours of hill slopes.
		Terrace farming	The term describes the use of graded terrace steps of sloped land, used to farm on hills and mountainous area.
		Controlled traffic farming	Controlled traffic farming means using similar traffic lanes for different application within one year and the same traffic lanes between years, often applying a navigation system.
E. Crop protection	**E1. Crop protection - weeds**	Mechanical weeding	The mechanical weeding uses technical tools to bury, cut or uproot the existing weeds. For this mechanical method, straight-row planting is essential.
		Herbicide application	The application of herbicides to combat weeds and protecting crops.
	E2. Crop protection - pests	Push-pull strategies	Push-pull technology is a method of biological pest control. Within cultures, crops are cultivated with repellent effects and outside the cultures crops are grown with attractive effects. This makes it possible to pull or to push the insects from the crops.
		Patches or stripes of natural vegetation	Patches or stripes of natural vegetation are included in the field. They serve as a refuge for beneficial insects for biological pest control, for promotion of soil-field weeds, and to avoid erosion and prevent leaching of

			nutrients.
		Pheromones application	The application of pheromones to influence plant growth.
		Insecticide application	The application of insecticides to protect crops.
		Fungicide application	The application of fungicides to protect crops.
		Nematode application	The application of nematodes to protect crops.
		Soil fumigation	After covering the soil the application of gaseous pesticides by specialized devices are used to control pests inside the soil.
		Soil solarization	Covering the soil to trap solar energy and heat the soil to control pests.
F. Water management	**F1. Water management - irrigation**	Surface irrigation	Application of water to the field by surface irrigation.
		Drip irrigation	Application of water under low pressure through a piped network in a pre-determined pattern, applied as a small discharge to each plant or adjacent to it and adjustable by irrigation nozzles.
		Sprinkler irrigation	Application of water to the field by sprinkler irrigation.
	F2. Water management - drainage	Subsurface drainage	Artificial systems of furrows, ditches, pipes, etc. to improve drainage of excess water from the sub-soil.