Geo 511 Master thesis

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Which alternative soil cultivation technique could best conserve the resource soil in Swiss arable farming under AP 14-17?

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Abstract/Zusammenfassung

This work investigates alternative soil cultivation techniques to conventional management within the context of Swiss agriculture. A meta-analysis of 80 agricultural field trials from within the cool temperate climate zone was conducted in order to compare alternative cultivation techniques. These alternatives are biochar application, intercropping, relay intercropping, controlled traffic farming, no tillage and reduced tillage. All of them except for relay intercropping showed significant improvements of more than one of sixteen investigated soil parameters compared to conventional management. Ten farmers from eight cantons in the Swiss Midlands were then asked about their opinion on these techniques and the effects of AP 14-17. Most of them apply plough and/or reduced tillage. Other techniques are not or less frequently applied. The reason is that chemical, physical and biological soil parameters are only three out of 24 explanatory variables in the decision of interviewees on soil cultivation techniques. Eight of them compose a minimum set, applying to all interviewees: Profitability and costs, weed and pest control, the direct payment system, availability/applicability of a technique, level of knowledge/experience, personal views and concepts, physical soil parameters and conservation of soil as basis of production.

Thus, even though five of the six investigated techniques clearly have a potential to improve soil quality, only reduced tillage seems to be a widespread alternative to conventional management. Based on the interviews it is concluded that the transfer of practical knowledge from agricultural research institutions needs to be improved in order to spread other alternatives as well. Also, the payment system should be adjusted; the recently implemented AP 14-17 probably favours set-aside rather than conserving management of arable land.

Diese Arbeit untersucht Bodenbearbeitungsmethoden, welche eine Alternative zur herkömmlichen Bewirtschaftung darstellen, im Kontext der Schweizer Landwirtschaft. Um verschiedene Alternativen zu vergleichen, wurde eine Metaanalyse von 80 landwirtschaftlichen Feldversuchen aus der kühltemperierten Klimazone durchgeführt. Diese Alternativen sind Anwendung von Pflanzenkohle (Biochar), Mischkultur, Untersaat, Bewirtschaftung mit permanenten Fahrgassen, Direktsaat und reduzierte Bodenbearbeitung. Bis auf die Untersaat haben alle Bewirtschaftungsformen zu einer signifikanten Verbesserung von mindestens einem der sechzehn untersuchten Bodenparameter geführt.

Es wurden zudem zehn Landwirte aus acht mittelländischen Kantonen zu ihrer Meinung über die verglichenen Bewirtschaftungsformen sowie zur Auswirkung der AP 14-17 befragt. Die meisten von ihnen pflügen und/oder wenden reduzierte Bodenbearbeitung an, die anderen Formen werden wenig oder gar nicht angewendet. Der Grund dafür ist, dass chemische, physikalische und biologische Bodenparameter lediglich drei der insgesamt 24 erklärenden Variablen für die Entscheidung der Bewirtschafter über Bodenbearbeitungsmethoden darstellen. Acht davon bilden ein minimales Set, welches auf alle Befragten zutrifft: Rentabilität und Kosten, Pflanzenschutz, Direktzahlungssystem, Verfügbarkeit und Anwendbarkeit der Methode, Wissens- und Erfahrungsstand, persönliche Ansichten und Meinungen, physikalische Bodeneigenschaften sowie der Erhalt des Bodens als Produktionsgrundlage.

Obwohl also fünf der sechs untersuchten Methoden klar das Potential haben, die Bodenqualität zu verbessern, scheint lediglich die reduzierte Bodenbearbeitung eine weitverbreitete Alternative zur herkömmlichen Bewirtschaftung zu sein. Aus den Interviews wird abgeleitet, dass der Transfer von praktischem Wissen von Seiten der landwirtschaftlichen Forschungsinstitutionen verbessert werden sollte, um auch andere Methoden zu verbreiten. Auch das Direktzahlungssystem sollte angepasst werden: Die kürzlich umgesetzte AP 14-17 fördert wohl eher Brachen als die schonende Bewirtschaftung von Ackerland.

Ich bedanke mich ganz herzlich bei den Landwirten und ihren Familien, die ihre Zeit und auch ihre Gastfreundschaft für mich zur Verfügung gestellt haben. Vielen Dank für eure Mithilfe.

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1 Introduction

Compared to the globe, topsoil, the uppermost skin of earth's terrestrial surface, is about one million times thinner than the shell of an egg compared to the egg itself (Müller 1985). As foundation of vegetation, this fragile layer provides the world's population, meaning you and me, with food: About 95% of our food is directly or indirectly produced on soil (FAO 2015a). While one third of soil has already degraded mostly as a consequence of poor management, food production on the remaining land has to increase by 60% by the year 2050 to feed us and the rest of the growing population (FAO 2015a). To give a fair warning, this year has been declared the international year of soils by the United Nation's Food and Agriculture Organisation (FAO 2015b). The FAO's suggestion: Sustainable soil management, especially in agriculture (FAO 2015a).

So, the FAO thinks it is about time to take care of our soils. I, personally, think so too, for one because I am studying geography which means to me studying the interactions of humans with their environment, for another because I grew up on a farm, experiencing the immediate connection of food production and soil. But does it also matter to anybody else, to us, here in Switzerland? Is there a need to deal with sustainable soil management? Apparently yes: In 2013, the Swiss National Science Foundation launched the national research program number 68 "Soil as a Resource" (NRP 68) with the main goal to increase knowledge about soil quality and find strategies for their sustainable use (SNSF 2015). The reason for the project are concerns about soil quality and quantity in Switzerland: About one square meter of soil is lost every second, increasing the pressure on remaining soil with its many functions such as food production, habitat, and water storage, to name just a few (id.).

In other words: There is a global and national double challenge of meeting food demands while at the same time sustaining other soil functions. According to the FAO (2015a), this is only possible by the adaption of alternative soil management techniques in agriculture. But which alternative method is best?

An approach to this kind of questions has been suggested by supporters of „evidence-based agriculture" (Fisher 2014). Following the example of the medical field, agriculture should be shaped by scientific evidence (id.). Well, does that mean agricultural soil management did lack scientific foundation so far? No, but up to date, according to Fisher (2014), trial data has not been used to its full extent and following the example of medicine, she suggests the adoption of systematic review and meta-analysis to make better use of already existing trials instead of launching yet another expensive experiment.

So, a meta-analysis can be used to systematically compare different techniques and figure out which one is best suited for soil conservation. But this is only half of the story; it does not tell us anything about the practical application of a technique. And if we truly want to look for techniques that could make agriculture more sustainable, we need to know the context of its application. For example, what do farmers think about a technique? Are there any constraints impeding its application?

When looking at Swiss agriculture, the direct payment system is probably its most inescapable feature. One of its purposes is to increase sustainability of agricultural production (BLW 2014). Its latest reform, called AP 14-17, became effective in January 2014, with new payments for soil conserving cultivation techniques (ODP 2013). So an attempt to favour sustainable techniques has already been made. Is it possible to already see impacts of its implementation?

The following work will look at supposedly more sustainable alternatives to conventional farming within the context of Swiss farming. The next chapter will show what exactly this means.

2 Unwrapping the question

Chapter abstract

The research question is given in the title: Which alternative soil cultivation technique could best conserve the resource soil in Swiss arable farming under AP 14-17? The following chapter examines individual components of this question in detail. It will show that:

- Soil is the basis of life of humans and most other terrestrial life forms (Hillel 2008) through its various functions (Scheffer & Schachtschabel 2010). Even though soil as a living body is able to renew (Wachter 2000), on a human timescale, soil can be seen as non-renewable resource (Jenny 1980). Therefore, its ability to regenerate should be conserved and prevented from negative impacts (Wachter 2000).
- "Conserving" is understood here as in the soil quality concept, referring to both, negative and positive changes in soil quality (Karlen et al. 2003). The definition of soil quality used here is based on White (2006b) and Karlen et al. (1997); it is the ability of a soil to sustainably provide productivity based on interaction and processes of its biological, chemical and physical components.
- Different techniques will be examined in the following chapters for their ability to conserve soil compared to conventional management. These techniques are reduced tillage, no tillage, controlled traffic farming, biochar application, relay intercropping, and intercropping. All of them can be applied in a cereal cropping system as it can be found in the Swiss Midlands.
- Agricultural policy in Switzerland has been reformed several times in the past (Baur 1999), with currently agricultural policy reform 2014-2017 being in force (Meier 2013). One of the hypotheses investigated here is whether or not the last reform motivated a shift from conventional to alternative cultivation forms.

2.1 Soil as a resource

Soil is a non-renewable resource and should be conserved. Conserving means that soil quality should be sustained or improved. Soil quality is the ability of a soil to sustainably provide productivity based on interaction and processes of its biological, chemical and physical components.

2.1.1 Is soil a resource?

Kissling-Näf and colleagues (2000) refer to resources as sum of nature's components used and valued by humans in past, present and future. It is the basis of production of goods and services (id.). Does soil fall under the definition of a resource? To answer this question, we need to know what soil actually is. Paraphrasing White (2006), soil is a natural body at the interface between the atmosphere and the lithosphere that is part of the biosphere and interacts with the hydrosphere. Soils have various functions (Scheffer & Schachtschabel 2010e):

- Habitat function: Soils are the basis of life for many life forms from microorganisms to higher plants and animals
- Regulation function: Soils act as storage, filter, buffer and transformer in material cycles
- Utilisation function: Soils are shaped by a variety of human land use and management
- Archive function: Soils preserve Earth's and human history

Our benefit of an unimpaired functioning of soils is obvious: 95% of the food of the world's population is directly or indirectly produced on soil (FAO 2015a). In brief, without soil, human beings and most terrestrial life could not exist (Hillel 2008). Therefore, to pick up on the initial definitions of resources, soil is not only "used" by humans; it is needed for their existence. Because of its nature as living body, soil can be seen as a renewable resource (Wachter 2000). On a human timescale, however, the resource soil is non-renewable (Jenny 1980).

2.1.2 Why should the soil resource be conserved?

When shrinking the Earth to the size of an egg, the uppermost part of the soil, the humus layer, would be one million times thinner than the eggshell (Müller 1985). From an ecological viewpoint, soil should be protected from all influences negatively affecting its ability to regenerate (Wachter 2000). One could even argue that soil conservation has implicit ethical aspects because of the provision of fundamentally important goods to human and non-human populations (Thompson 2011). From an economic viewpoint, soil can be seen as common pool resource requiring protection and management to avoid market failure (Wachter 2000). What does soil need to be protected from and when and how is protection needed? Wachter (2000) sees two aspects of conservation: quantitative (avoiding loss of areal extent) and qualitative (avoiding degradation). Since this work will treat management practices in agriculture, focus will be on qualitative aspects, while quantitative loss (e.g. by house construction) will not be discussed further.

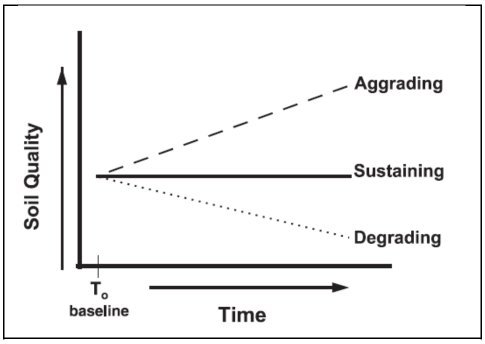


Figure 1 Illustration on impacts on soil within soil quality concept. Graph copied from Karlen et al. (2003)

In the following, the word "conserving" is used rather than "protecting". Wachter's (2000) definition of protection is underpinned by a concept of soil as having a natural state that can be degraded, focusing on negative impacts only. "Conserving" is a word used within the concept of soil quality, a concept explicitly taking both, positive and negative impacts into account (Karlen et al. 2003), as illustrated in Figure 1. This concept fits better to comparison of cultivation techniques (see section 2.2.4 and chapter 3), because in agriculture, the goal is to sustain and improve soil fertility for production which means mitigating negative impacts while favouring potentially yield increasing conditions (Diepenbrock et al. 2009).

2.1.3 What is soil quality?

There is no well accepted definition of soil quality. In its essence soil quality can be defined as "the capacity of soil to function" (Karlen et al. 1997). In the field of agriculture, fertility rather than quality is used to gauge soil (e.g. Diepenbrock et al. 2009). Fertility is the soils ability to provide adequate nutrient supply to plants and is perceived as a main driver of productivity (Foth & Ellis 1996). Other authors, outside of the agricultural field, do not agree with this view on soil quality that emphasises soil chemical properties as main driver of productivity and asked for a more comprehensive description of the condition of soils (White 2006b). According to Karlen et al. (2003), any assessment of soil quality has to reflect all of soils biological, physical and chemical properties and their processes and interactions that result in soils multiple functions and provision of essential ecosystem services. For this work, a definition based on both perspectives (agricultural and environmental science) has been created: Soil quality is the ability of a soil to sustainably provide productivity based on interaction and processes of its biological, chemical and physical components. One of the goals is to find out more about effect of cultivation techniques on soil quality.

2.2 Agricultural cultivation techniques

Cultivation techniques are compared to conventional management for cereal-based cropping systems. The alternative techniques are no tillage, reduced tillage, controlled traffic farming, relay intercropping, intercropping, and biochar application.

2.2.1 Conventional management

When talking about alternative cultivation, the question is: alternative to what? The investigated techniques are alternatives to those applied in conventional farming. Conventional farming is a way of agricultural production that developed during the second half of the twentieth century and manly bases on agrochemical inputs and modern machinery (Martin & Sauerborn 2006). It includes the use of mouldboard ploughs, also referred to as conventional tillage (Loomis & Connor 1992), random traffic on fields (Gasso et al. 2013), use of chemical weed control (Martin & Sauerborn 2006), application of synthetic fertiliser (id.), and sole cropping (Lithourgidis et al. 2011). Table 1 lists pro and contra arguments for mouldboard ploughing, since this will be taken up later on. Mouldboard ploughs tillage depths are usually between 20 and 25cm with about 10% of residues remaining on surface; it is usually followed and preceded by other cultivation steps such as disk harrowing (Loomis & Connor 1992).

Advantages	**Disadvantages**
Uniform seedbed (Loomis & Connor 1992)	high risk of erosion during crop period (Loomis & Connor 1992)
efficient weed control (Loomis & Connor 1992)	
good for heavy stubbles (Loomis & Connor 1992)	Plough pan as a barrier between topsoil and subsoil (Frede et al. 1994)
Low bulk density in topsoil (Frede et al. 1994)	

Table 1 Pro and contra arguments for conventional tillage

In Switzerland, the term conventional farming emerged along with the manifestation of organic farming in the nineteen-seventies and eighties as an alternative paradigm to back then common practice (Belz 1998).

Even though this way of agricultural management was able to increase global food production in the last 50 years drastically, it was accompanied by unwanted side effects such as soil depletion (FAO 2015a). Therefore, alternatives that allow for sustaining high productivity while at the same time sustaining soil quality are in great demand (id.).

2.2.2 Choosing a cropping system

The next question is: What are techniques compared for? They are compared for their impact on soil quality in arable farming in Switzerland, at least that is what the title promises. Figure 2 shows the largest share of arable land in Switzerland is used for cereal production. Therefore, it makes sense to compare effects of techniques on soils in cereal cropping systems. On more than 50% of land used for cereals, wheat is produced, followed by barley (20%), grain maize (12%), and other cereals (11%) (BFS 2015c). Figure 2 also shows that most of the agricultural land in Switzerland is pasture, but taking a look at Figure 3 reveals strong regional differences: Arable land is concentrated in the Midlands, while pasture is predominant in the mountainous regions (BFS 2015b).

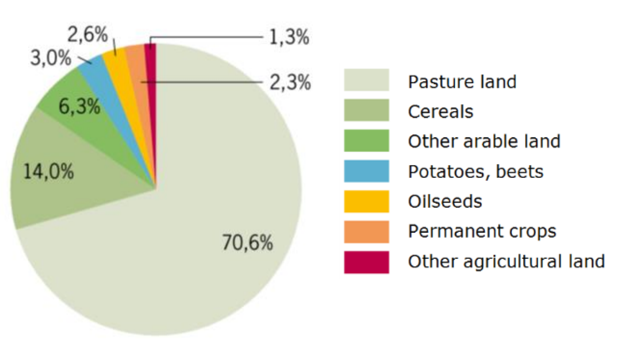


Figure 2 Usage of farmland (except alps) in Switzerland in 2013 in percent. Total area is 1'050'000ha (BFS 2015d)**. On arable land, cereal production is predominant**

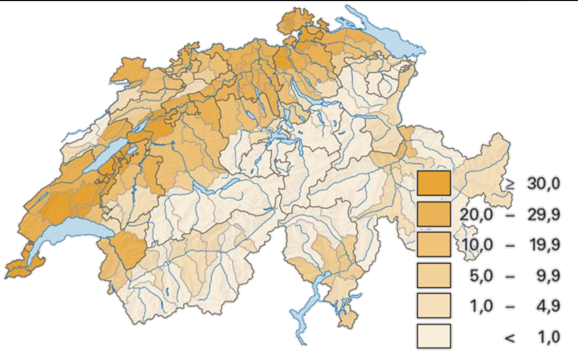


Figure 3 Share of total agricultural area (in %) used for grain cereal production per county in 2013, average is 14% (BFS 2015a)**. The production is predominant in Swiss Midlands**

2.2.3 Choosing techniques

A variety of alternatives to conventional management has been suggested in the literature. According to the FAO (2015a) alternative cultivation techniques should reduce soil disturbance, increase soil coverage and work with interactions between animals, plants, the environment and human beings. An explorative search of scientific literature and agricultural magazines was used to identify possible alternatives that match these requirements; they are shown in Table 2. Table 2 also gives a suggestion of how these techniques could be grouped by their most immediate effect on soil. Each effect is related to either a physical, chemical, or biological approach to soil management.

Approach	Immediate effect	Technique
Physical	Reducing physical soil disturbance (FAO 2015a)	No tillage, reduced tillage, controlled traffic farming, perennial crops, agroforestry
Biological	Favouring plant-soil interactions (Ehrmann & Ritz 2013; Pérez-Montaño et al. 2014)	Intercropping, relay intercropping, biofertiliser
Chemical	Adding amendment to directly alter chemical soil properties (Atkinson et al. 2010)	Biochar

Table 2 Techniques considered before starting the systematic literature search. Techniques are grouped by their most immediate effect which in turn corresponds to either a physical, chemical, or biological approach to soil management.

After a systematic search of scientific literature (described in detail in section 3.1.1.2), chosen techniques for further investigations are tillage forms, controlled traffic farming, forms of intercropping, and biochar application, while other techniques were dropped. For agroforestry, a number of field trials could be found, but in most cases, control treatments were not comparable to other studies. For example, experimental areas with trees are compared to areas with grass buffer stripes without trees, not to conventionally managed crop land (Udawatta et al. 2008). Perennial cereal crops are researched for at least 70 years (Suneson & Hall 1963), but today there are still only few published results of field trials available, and field trials that have been found to mostly focus on breeding and characterising different cultivars, e.g. Jaikumar et al. (2012) or Füle et al. (2005). Numerous effects of microorganisms in soil such as arbuscular mycorrhizal fungi have been studies, as extensive reviews show, e.g. Goslin et al. (2006), Nadeem et al. (2014), or Reddy and Saravanan (2013). However, many different types of these so called biofertilisers are in use (Reddy & Saravanan 2013) and taking all of them into account would go far beyond the scope of this work. Also, literature search did not reveal many agricultural field trials in cereal cropping systems. The chosen techniques are presented in the following section.

2.2.4 Definition of techniques

The following paragraphs define alternative cultivation techniques that will be investigated in the next chapters.

2.2.4.1 Reduced Tillage

Advantages	**Disadvantages**
High labour and power efficiency (Loomis & Connor 1992)	reduced weed control (Loomis & Connor 1992)
Increased infiltration (Loomis & Connor 1992)	Can have plough pan (Frede et al. 1994)
Increased erosion control (Loomis & Connor 1992) SOM enrichment in topsoil (Frede et al. 1994) Favourable life conditions for soil fauna (Frede et al. 1994)	

Table 3 Advantages and disadvantages of reduced tillage on soil and agriculture

The term “reduced” relates to conventional tillage (Loomis & Connor 1992). It is sometimes referred to as “conservation tillage” and includes all practices with less tillage intensity and more residues remaining on surface (id.). Chisel ploughs for example have a depth of 15-20cm and require less energy than a mouldboard plough, resulting in twice the labour productivity (id.). Field cultivators are an even lighter version of chisel, with a tilling depth of 15cm and up to 90% of residues remaining on surface (id.). They are typically used for stubble mulching, another method to control erosion by residues (id.). The definition by Loomis and Connor shows that reduced tillage is rather a negative definition (neither conventional nor no tillage) and encloses different machinery and tillage depth. In general, many effects of reduced tillage on soil were found to be in a spectrum between ploughing and no tillage (Frede et al. 1994).

2.2.4.2 No Tillage

Advantages	**Disadvantages**
excellent erosion control (Loomis & Connor 1992)	difficult weed control, dependant on herbicides (Loomis & Connor 1992)
Continuous biopores stimulate rooting (Frede et al. 1994)	Decrease in nutrient and OM content in subsoil (Loomis & Connor 1992)
Decrease of surface sealing (Frede et al. 1994)	
Increase in bearing capacity of the soil (Frede et al. 1994)	under temperate conditions: slow warming and drying of soil in spring (Loomis & Connor 1992)
further: same advantages as for reduced tillage	
	Increase in bulk density in topsoil (Frede et al. 1994)
	Slow N-mineralisation in spring (Frede et al. 1994)

Table 4 Advantages and disadvantages of no tillage for soil and agriculture

Crops are directly planted into the residues of previous crops. This method provides maximum erosion control, with high nutrient and organic content in the topsoil layer (Loomis & Connor 1992). There is a texture dependency of some effects: Compaction under no tillage is less pronounced in sandy soils and effects on available water capacity can even go in the opposite direction for sandy soils (decrease) compared to loess (increase) (Frede et al. 1994).

2.2.4.3 Controlled Traffic Farming

As opposed to conventional systems, controlled traffic farming (CTF) strictly and permanently separates trafficked and non-trafficked areas in a field by using established traffic lanes for all management activities (Taylor 1983). In practice, this means that Global Navigation Satellite Systems (GNSS) are used for steering and used machines closely match in width (Anken et al. 2012). CTF aims at reducing soil compaction: For this purpose, CTF was found to be more effective than for example subsoiling (Chamen et al. 2015). While under random traffic, wheeled area is up to 100% under conventional and up to 60% under reduced tillage, it is only up to 20% under CTF, resulting in improved physical soil properties and higher yield (Gasso et al. 2013). However, Chamen et al. (2015) point out that while many environmental benefits are associated with CTF, profitability of CTF (by reduction of operating costs) mostly arise from implementation of precise Global Navigation Satellite Systems (GNSS).

Advantages	**Disadvantages**
Less compaction by reduction of wheeled area (Gasso et al. 2013)	Modifications on machinery needed when track widths are not compatible (Gasso et al. 2013)
Reduced gaseous emissions from fields and from machinery (Gasso et al. 2013)	High entry cost, for example for auto-steer systems (Chamen et al. 2015)
Reduced water runoff (Gasso et al. 2013)	
Yield increase (Gasso et al. 2013)	
Improved traction (Taylor 1983) and reduction of inputs, e.g. fuel (Gasso et al. 2013)	

Table 5 Advantages and disadvantages of controlled traffic farming for soil and agriculture

2.2.4.4 Intercropping

Intercropping is a form of multiple cropping and means that two or more crops are grown at the same time on the same field (Andrews & Kassam 1976). In the tropics, intercropping has always been the prevailing cultivation method (Walker et al. 2011). In Europe, however, intercropping has disappeared due to intensification of agriculture but has recently been reintroduced (Hauggaard-Nielsen et al. 2001). The opposite of intercropping is sole cropping, meaning only one crop variety is grown at a time in normal density and as pure stand; sole cropping is not to be confused with monoculture, which is the repetitive cultivation of a sole crop on the same land (Andrews & Kassam 1976).

Many effects of intercrops are tied to the chosen crop combination: While intercropping faba bean with maize increase yield compared to sole cropped bean, intercropping with wheat significantly reduced yield (Fan et al. 2006). Also, while some crops support each other's growth (facilitation), others compete for space, nutrients and light (Ehrmann & Ritz 2014).

Intercrops were found to increase soil enzyme activities, related to other increases in soil micro fauna (Ehrmann & Ritz 2014). It is assumed but not certain that increased biological activity suppresses pests and diseases (id.).

Advantages	Disadvantages
Higher yield compared to sole crop (Lithourgidis et al. 2011)	Complex interactions, not fully understood (Ehrmann & Ritz 2014)
Nitrogen transfer from legumes to other crop, facilitation between crops (Ehrmann & Ritz 2014)	Difficult to find appropriate species and sowing densities (Lithourgidis et al. 2011)
Increased physical stability of crops (Lithourgidis et al. 2011)	Additional costs for grain separation, planting, crop management (Lithourgidis et al. 2011)
Soil conservation by coverage (Lithourgidis et al. 2011)	Competition between crops (Ehrmann & Ritz 2014)
Reduce in nutrient leaching (Ehrmann & Ritz 2014)	
Favouring of soil fauna (Ehrmann & Ritz 2014)	

Table 6 Advantages and disadvantages of intercropping for soil and agriculture

2.2.4.5 Relay intercropping

There are many similarities to intercropping as described in the previous paragraph, two or more crops are grown simultaneously, but only during parts of their life cycle: A second crop is undersown in the first crop (Andrews & Kassam 1976). In general, many of the advantages of intercropping also do apply for relay intercropping, but as with intercropping, not all interactions are fully understood (Ehrmann & Ritz 2014).

Advantages	Disadvantages
Good weed control (Brust et al. 2011)	Competition effects (Amossé et al. 2013)
Improved soil structure (Brust et al. 2011) Favouring soil life (Brust et al. 2011)	Mechanical damage to main crop when undersowing legume (Reinbott et al. 1987)
N supply to main crop (if second crop is a legume) (Ehrmann & Ritz 2014)	Complex interactions, not fully understood (Ehrmann & Ritz 2014)
Facilitation between crops (Ehrmann & Ritz 2014)	

Table 7 Advantages and disadvantages of relay intercropping for soil and agriculture

2.2.4.6 Biochar

Biochar "is generally considered to comprise biomass-derived char intended specifically for application to soil, that is, according to its purpose" (Sohi et al. 2010, p. 49). Since "Terra Preta" has been described in the nineteen-sixties, biochar has been promoted as a mean to mitigate a variety of environmental and agronomic problems (A. Mukherjee & Lal 2014). One of the advocated advantages of biochar is yield increase, which was found to be on average +10%, but with a wide range of -28% to +39%, depending on soil and other conditions (Jeffery et al. 2011). Also, biochar impacts on soil were found to be most beneficial for humid tropics (Crane-Droesch et al. 2013). Mukherjee and Lal (2014) observe a growing advocacy for biochar worldwide, a development they criticise for having inadequate scientific knowledge basis. In 2013, Switzerland allowed application of biochar in farming and gardening as the first country in Europe (Klimastiftung Schweiz 2013). Biochar application will therefore be included in the meta-analysis as one of the newest, but probably also most controversial, alternatives among available soil amendments in Switzerland.

Besides direct benefits for the soil, biochar is assumed to sequester carbon (Sohi et al. 2010). However, many processes related to soil and biochar interactions are yet to be fully determined (id.). Also, biochar was often found to increase pH, which is not desirable under all soil conditions (A. Mukherjee & Lal 2014). In general, there are many uncertainties about the impact of biochar on chemical, physical, and biological soil properties under field conditions because only few field trials exist (id.).

Advantages	Disadvantages
Yield increase, however with wide range, decrease possible (Jeffery et al. 2011)	Uncertainties because of lack of field data (A. Mukherjee & Lal 2014)
Increase in water holding capacity (Sohi et al. 2010)	Uncertainties regarding profitability (Spokas et al. 2012)
Increase in cation exchange capacity, favouring nutrient storage (Sohi et al. 2010)	

Table 8 Advantages and disadvantages of biochar application in agriculture

2.3 Swiss direct payment system

When looking at agriculture in Switzerland, the direct payment system cannot be left out: It is the core element of Swiss agricultural policy (BLW 2015b). In the latest reform, new payments for certain tillage methods have been introduced. It is hypothesised here that payments influence decision on techniques in cereal cropping systems in the Swiss Midlands (this will be addressed in chapter 4). The following subsections explain how the direct payment system has been formed until now and which its components are.

2.3.1 Agricultural reforms

From the nineteen fifties to the nineties, agricultural policy mostly consisted in subsidising prices to maintain domestic agricultural production (Baur 1999). The consequence was a drastic increase of federal expenses on agriculture, intensification of production, decrease of imports and negative environmental impacts (id.). Starting from 1992, reforms on existing agricultural policy were initiated to disentangle price and income policy and to promote ecology (id.). As a consequence of globalisation of agricultural markets and its associated reduction of trade barriers (resulting from multilateral agreements within WTO), experts expected prices for agricultural products to decrease but also feared a decline of positive externalities of agriculture (Wolf & Lehmann 1996). Direct payments were seen as efficient tool to internalise externalities (id.), meaning to compensate societal and environmental services of agriculture which are not covered by market prices (Baur 1999). This is also referred to as multifunctionality of agriculture (id.). Ever since, the direct payment has been further developed and adjusted (id.), continuously reducing product-oriented subsidies (Lanz et al. 2010). The system proved successful, as for example ecological compensation areas or animal-friendly production increased (id.). However, direct payments as a pure instrument for compensation without well-defined performance goals did not turn out to be a good tool to fulfil all goals of agricultural policy, improvements were called for (id.). This issue is addressed by the current reform stage of agricultural policy for 2014 to 2017, commonly referred to as AP 14-17 which implied substantial adjustments of the direct payment system (Meier 2013). Changes came into force on January the first, 2014 (id.), and are based on the Ordinance on Direct Payments (ODP 2013). Other legal bases are the Agricultural Act (AA 1998) and ultimately the Federal Constitution, article 104 on agriculture (SFC 1999).

2.3.2 Current direct payment system

Figure 4 gives an overview on the current direct payment system; individual elements are explained in the following. All information in this section relays directly on the Ordinance on Direct Payments (ODP 2013). In order to apply for payments, farmers need to meet a number or requirements, such as professional education in the field of agriculture, a maximum number of animals on farm, or a maximum age of 65 years. Also, the farm has to fulfil requirements of Proof of Ecological Performance (PEP). PEP includes requirements regarding animal welfare, nutrient balance, share of ecological compensation areas, management of objects in the inventory of national significance (such as moors), crop rotation, soil conservation, buffer stripes, and pesticides.

Cultural landscape payments:

For keeping cultivated landscape open, e.g. to avoid scrub encroachment, cultivating areas with steep slope (starting from 18%), grape production on steep slopes (starting from 30%), alpine farming, and summer grazing.

Security of supply payments:

Base payment for areas used for food production and payment for management obstacles on areas used for food production and for cropped area and permanent crops (only food crops).

Biodiversity payments:

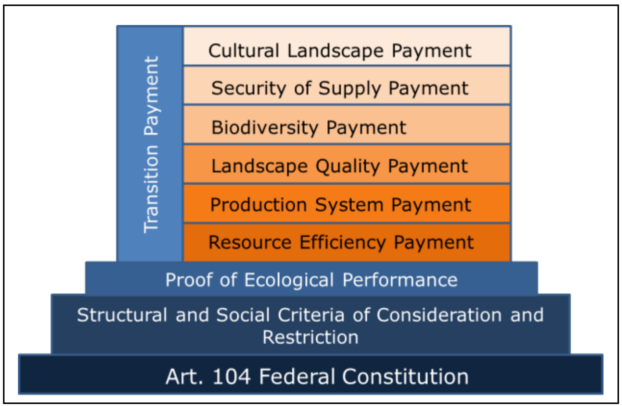


Figure 4 Schematic overview of direct payment system, adapted from BLW (2015b)

Payments are issued for a number of areas that aim at increasing biodiversity, such as wildflower set-aside, standard fruit trees, extensive meadow etc. Two quality levels are defined and payments increase with increasing quality. Cantons can issue additional payments with federal support for cross-linking biodiversity areas.

Landscape quality payments:

Cantonal programs with federal support for conservation, promotion and development of cultural landscape diversity. Programs are applied within a region of the canton and last for eight years.

Production system payments:

For extensive production of cereals, sunflower, protein peas, field beans, and canola (meaning no insecticides, fungicides, plant growth regulator or plant health regulator are applied), organic production, grassland-based milk and meat production, and animal welfare measures.

Resource efficiency payment:

For emission-reducing application technique of liquid farm fertiliser, soil conserving cultivation techniques plus an additional payment if no herbicides are applied alongside, and precise application technique for pesticides, only onetime, until 2019.

Transition payment:

For each farm a base value is defined which is the difference between amount of payments before and after the implementation of AP 14-17. Transition payments are calculated by multiplying base value with a factor defined by the Federal Office of Agriculture (BLW). Payments are limited by a maximum farm income. Transition payments are meant as social measure to lower financial impacts of change of system and will decrease with increasing participation of farmers in voluntary programs (BLW 2015b).

2.3.3 Payments for soil conserving cultivation

Of most interest for the research question are resource efficiency payments which are listed in Table 9:

Technique	Payment (CHF)	Definition
Direct seed	250	No tillage with maximum 25% of soil surface being disturbed during sowing.
Strip seed	200	Strip tillage or strip milling (minimum tillage) with maximum 50% of soil surface being disturbed during sowing and tilling and a maximum depth of 20cm. Maximum two passes are allowed for sowing.
Mulch seed	150	Reduced, shallow tillage with chisel, short disc harrow, skimmer plough etc. 100% of soil surface (covered with plant residues) can be cultivated, but only to 10cm depth.

Table 9 Soil conserving cultivation techniques that are entitled for resource efficiency payments (ODP 2013)**.**

Mulch seed is almost congruent with reduced tillage as defined in 2.2.4.1. The difference is that mulch tillage comes with a depth restriction, while reduced tillage simply means that no mouldboard plough is used for tilling.

2.4 Addressing the research question

Neither a purely qualitative nor quantitative approach is suited to address the research question. Fortunately, geography provides all the tools needed.

2.4.1 Research question and hypothesis

The research question is: Which alternative soil cultivation technique could best conserve the resource soil in Swiss arable farming under AP 14-17? Or in other words: Many techniques have been suggested as alternatives to conventional management, but how do they compare, are they actually better than conventional management and do they also fit in the context of Swiss agriculture?

Hypothesis I

All of the alternatives show significant positive effects on soil parameters compared to conventional cultivation

Conventional cultivation has been found to have negative impacts on soil quality (FAO 2015a). Section 2.2.4 on pro and contra arguments showed that all of the alternatives are supposed to have positive effects on soil quality. So, it is assumed that alternatives significantly improve soil quality.

Hypothesis II

AP 14-17 motivates farmers to shift from conventional to alternative techniques

Section 2.3.3 showed that special payments for soil conserving management (no tillage, minimal tillage and reduced tillage) were introduced with the AP 14-17 reform of the direct payment system. So, an effect on these techniques is expected in particular, but maybe payments also motivate in general to apply alternative cultivation methods.

2.4.2 A mixed approach

We need to know two things to answer the research question. First, how do alternatives compare to conventional techniques and second, how do they fit into the Swiss context? The first question calls for a quantitative comparison of scientific publications on cultivation techniques which is presented in chapter 3, the second for a qualitative investigation among farmers in Switzerland which is shown in chapter 4.

Qualitative research in geography admits subjective experience and focuses on meaning when for example investigating how social and spatial relations intersect, with qualitative interviews being just one out of many possible methods of inquiry (Dyck 2001). According to Dyck (2001), "a common interest in qualitative research is to enhance understanding through description and concepts grounded in the perspective of those studied". This is exactly the reason why a qualitative approach was chosen in combination with quantitative literature analysis: While meta-analysis cannot reveal more than what scientist already know about certain techniques, interviews with those who apply these techniques shed light on motivations and reasons for applying them. In order to answer the research question it is important to know both what effects techniques have on soil but also if and why they are applied.

The meta-analysis compares field trials from within the temperate zone. Results therefore relate to the entire temperate zone, not to Switzerland in particular. Interviews should then help to put results into the context of Swiss agriculture within reform phase AP 14-17.

3 Meta-analysis of field trials from the temperate zone

Chapter abstract

This chapter explains methods and presents results of a meta-analysis on agricultural field trials in the temperate zone with focus on cereal production. In a meta-analysis, results of several studies are summarised (Chang 2011). 80 publications of agricultural field trials were analysed. The field trials investigated the effect of a technique on soil parameters. Investigated techniques are biochar application, controlled traffic farming, reduced tillage, no tillage, intercropping and relay intercropping. Sixteen parameters were analysed. However, only for no tillage and biochar treatment there are values for each of the sixteen parameters available. Least information is available for relay intercropping (four parameters) and intercropping (three parameters).

There are two purposes for this analysis: First, assess the effect of a technique compared to its control and second, to compare different soil management techniques with each other. The goal is to find out which technique has the most impact on soil parameters. The effect measure or "currency" used for comparison is the response ratio, a ratio formed by dividing results from experiments by results from controls in studies. This effect measure has been suggested for meta-analysis by Hedges et al. (1999), who also suggested a procedure for analysis based on data weighted with their precision (standard error). Since many studies did not report precision at all or not in a suitable way, data were analysed without weighting, as it was done by Chivenge et al. (2011) that were facing the same problem. In addition to the analysis of unweighted data, an analysis of weighted data was calculated after estimating missing values. In other words: Since the dataset impeded using the best suited analysis, two second-best approaches were combined instead.

For soil organic carbon content, pH, total nitrogen content, yield, soil water content, bulk density, and total porosity, significant differences were found between two or more techniques. For soil organic carbon content, total nitrogen content, yield, and bulk density, techniques were among explanatory variables in a multiple regression. Compared to conventional management, all alternatives except for relay intercropping significantly improve soil quality.

3.1 Methods

"Meta-analysis is a statistical technique of performing integrated analyses by combining results of several independent studies to answer specific questions" and often aim at "summarising existing evidence" (Chang 2011, p. 175). "The unit of currency in a meta-analysis" is the effect size, "a value which reflects the magnitude of the treatment effect or (more generally) the strength of a relationship between two variables" (Borenstein et al. 2009a, p. 3).

3.1.1 Literature search

Field trials from within the cool temperate agro-ecozone were searched. 216 publications were found based on keyword search, but only 80 met all the criteria for data extraction. The dataset is not impeccable: Analysis of bias suggests that studies with significant effects and from English speaking countries are overrepresented.

3.1.1.1 Climatic demarcation: Temperate zone

Swiss Midlands are within the cool temperate zone according to FAO agro-ecological zones (FAO & IIASA 2012b), see Figure 5. Selected field studies are all from within this zone or from the cold or warm edge of the zone.

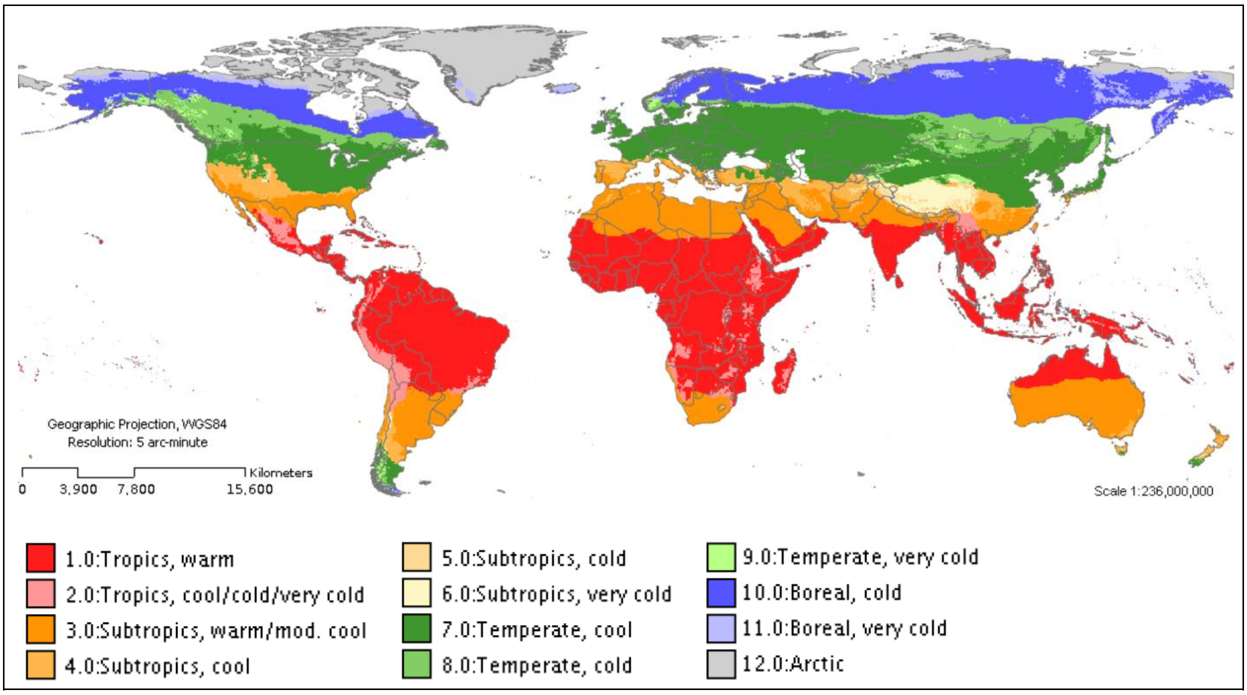


Figure 5 Global agro-ecological zones (FAO & IIASA 2012b)**: Thermal zones based on period from 1961 to 1990**

Also, studies where cereal fields are irrigated on a regular basis were not taken into account: Switzerland is within a zone where high wheat yields are possible in rain-fed agriculture (FAO & IIASA 2012a), see Figure 6 ,but also for other cereal crops such as oats or barley.

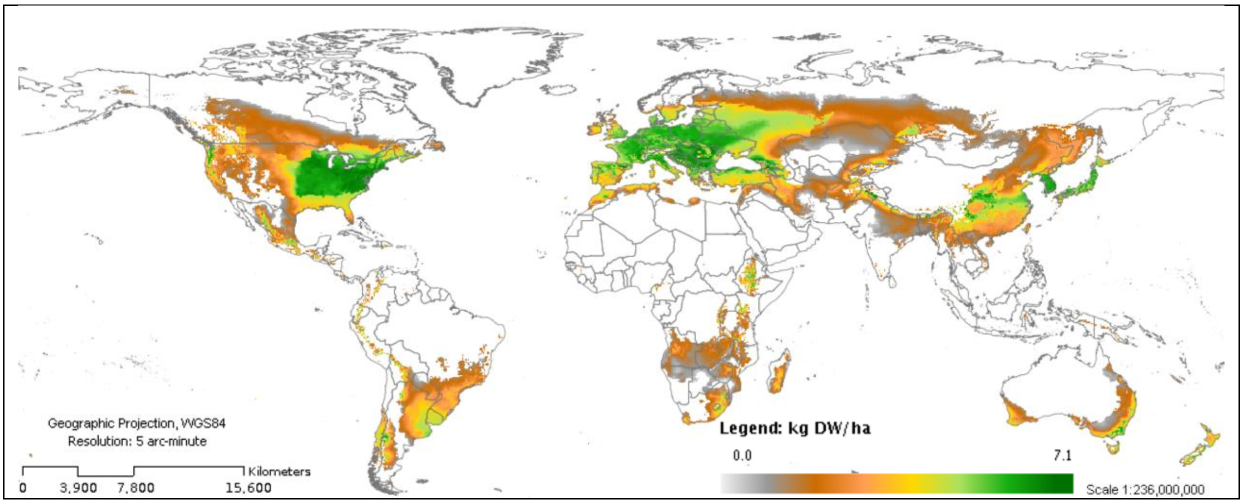


Figure 6 Agro-climatically attainable yield for intermediate input level rain-fed wheat for baseline period 1961-1990 (FAO & IIASA 2012a)

Figure 7 shows in which areas of the world field trials were located from which data was used for meta-analysis. Locations are all within the temperate cool zone or at its southern or northern edge. One site in Canada seems to be outside of the zone, but in fact is in one of the “islands” of temperate cool zone within the temperate cold zone (see Figure 5).

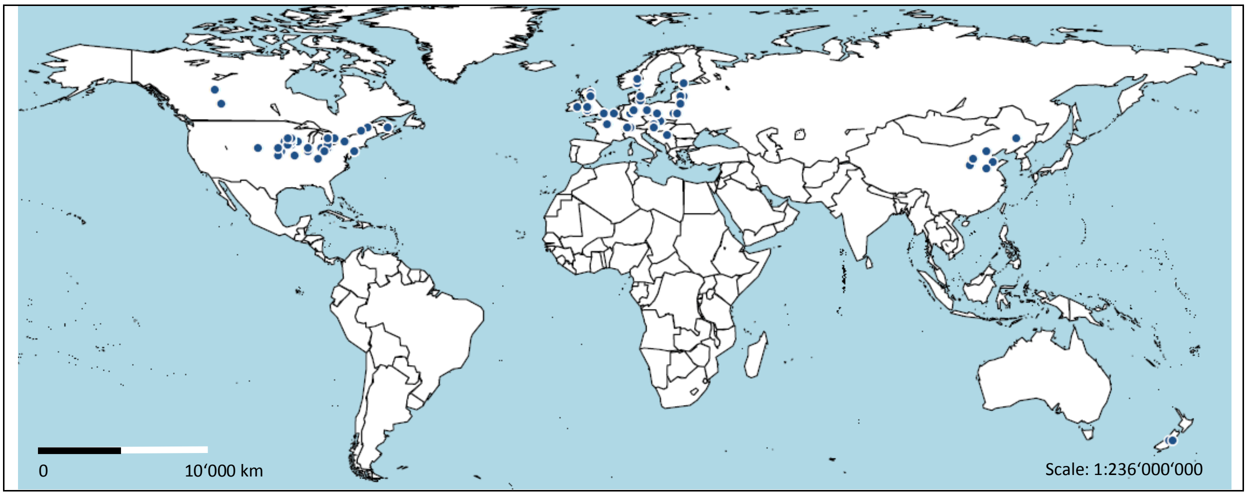


Figure 7 Political map with locations of field trials from which data was used for meta-analysis. Data of trials from 18 different countries were used.

3.1.1.2 Collecting and sorting out of studies

Selecting studies was a two-stage process: In a first round, studies were collected based on content of title and abstract. In a second round, studies not fulfilling criteria in Table 11 were sorted out based on trial description in the article.

First round: Collecting

Overall objective of the literature search was to find a sample of relevant field trials for each technique. A study was considered relevant in the search if title and abstract indicated that the field trial investigates the effect of at least one technique on physical, chemical and/or biological soil parameters. A list with keywords and detailed explanations on literature search are shown in Appendix A1 and A2. Table 10 shows how many publications were collected per technique.

Technique	**C**	**U**	**Ratio**
Reduced tillage	33	23	70%
No tillage	49	31	63%
CTF	28	6	21%
Biochar	43	25	58%
Relay intercropping	63	11	37%
Intercropping		12	

Table 10 Number of publications collected during literature search (C) and number of publications used in meta-analysis (U). Total number of studies collected is 216; number of studies used is 80. Some publications could be used for more than one technique.

Second round: Sorting

An overview on number of studies per technique is given in Table 10 "Collected" studies are those from the first round, "used" refers to studies data was extracted from and used for meta-analysis after sorting out. The table furthers expresses numbers of studies used as a percentage of total studies collected. This "success-ratio" ranges from about two third to less than one third for CTF. This could indicate that keywords for some techniques were more appropriate than for others and that literature search could have been improved. In total, 37% of all studies collected could be used for data analysis.

Criterion	**Comment**
Climate	Cool temperate agro ecological zone as shown in Figure 5
Field trials	Studies in labs and greenhouses or studies based on modelling are excluded
Trial set-up	Field trials with only one replicate are not used
Study focus	Studies not aiming at comparing management forms are not used

Table 11 Criteria to sort out studies

Table 11 summarises criteria used to sort out studies based on their methods section. Most often, studies were not used because they followed a different focus than comparing two techniques. For example, some studies on CTF were not comparing CTF to conventional management with random traffic, but instead compared non-trafficked areas to tracks within the same field under CTF (e.g. Blanco-Canqui et al. 2010).

3.1.1.3 Publication bias

Borenstein et al. (2009b) and Song et al. (2010) point out several sources of bias in meta-analysis that can result in unwanted overestimation of effect size. The following paragraphs discuss some of the sources of bias that apply to literature search in this work:

Grey literature

“Grey literature”, meaning literature in electronic or printed form not under control of commercial publishers, is likely to be underrepresented in meta-analysis (Borenstein et al. 2009d). ScienceDirect by Elsevier and Web of Science by Thomson Reuters clearly favour exclusion of grey literature, but also of journals from other publisher. Therefore, literature was also searched for via Google Scholar. Despite using Google Scholar, only two studies not published in a scientific journal could be found. Grey literature therefore is underrepresented. According to Song et al. (2010, p. 28), studies published in the field of health tend to be “more positive about the effectiveness of interventions than corresponding grey literature”. This finding likely applies for other fields as well.

Significant results

Studies attesting a low or non-significant effect size are less likely to be published than studies with high, significant effect sizes (Song et al. 2010). Since most of the studies used for analysis were published in scientific journals, they are likely biased.

Language

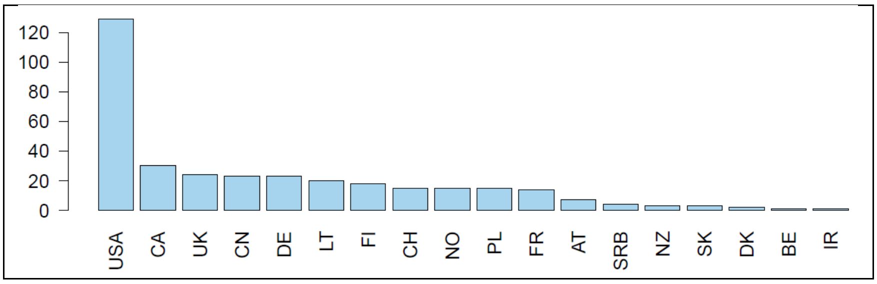


Figure 8 Number of data points used in meta-analysis per country of origin.

The effect of excluding studies not published in English is not clear, an assessment is impossible unless non-English and English studies are compared directly (Song et al. 2010, p. 31). Only English studies are included here, meaning that studies published in national journals in local language are neglected, for example Chinese studies. A further effect of language bias is shown in Figure 8. Studies from English-speaking countries are overrepresented compared to other countries; many European countries are missing completely.

Assessing bias

A funnel plot can give a graphical hint for biased data (Higgins & Green 2011). It is a kind of scatter plot with effect size on the x-axis and precision on the y-axis (id.). If there is no bias, one would expect the result to look like an inverted, symmetrical funnel with small studies (low precision) near the bottom and large studies (with high precision) near the top (id.). If there is asymmetry, bias is likely (id.). Funnel plots were produced for all soil parameters in the dataset used for meta-analysis, one example is shown in Figure 9. The same asymmetric pattern was found for other parameters as well, suggesting that the dataset is biased.

According to Borenstein et al. (2009b, p. 280), there is not much to do about that except for performing a "truly comprehensive search of the literature, in hopes of minimising the bias" by finding "unpublished, and difficult to find studies". That statement already illustrates the main problem: It is rather difficult to determine at what point enough "difficult to find studies" have been found. Literature search could potentially be improved by including more national publications and non-published reports.

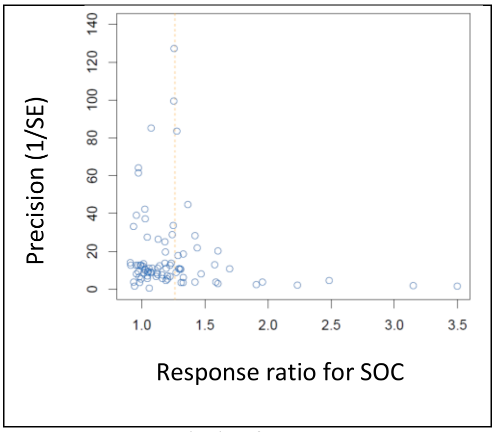


Figure 9 Funnel plot for parameter SOC. X-axis shows response ratio, y-axis shows precision, expressed as inverse of standard error. Each data point is represented as a circle; the dashed line represents the mean of all data points. A response ratio of one would mean that no difference between experiment and control values exists.

3.1.2 Data extraction

Soil parameter values measured in experiments and controls of studies were extracted along with meta data on trials. However, much information was missing or not provided in a usable form. Most problematic for the analysis are missing indications on standard deviations of measured parameter values.

The selection of data did not follow a predefined scheme, but was based on the data itself: All parameters that were measured in studies and focus on soil were extracted. Besides numerical values of soil parameters, metadata describing the field study was collected. The approach was to collect as much data as available in a study, to further select later on.

Figure 10 gives an overview of extracted parameter values; in total, 451 measurements were extracted. The figure shows two things. First, none of the parameters was gathered in all measurements. Second, some publications did not report individual parameter values for experiments and controls, but a pooled value. These generalised values could not be used for meta-analysis.

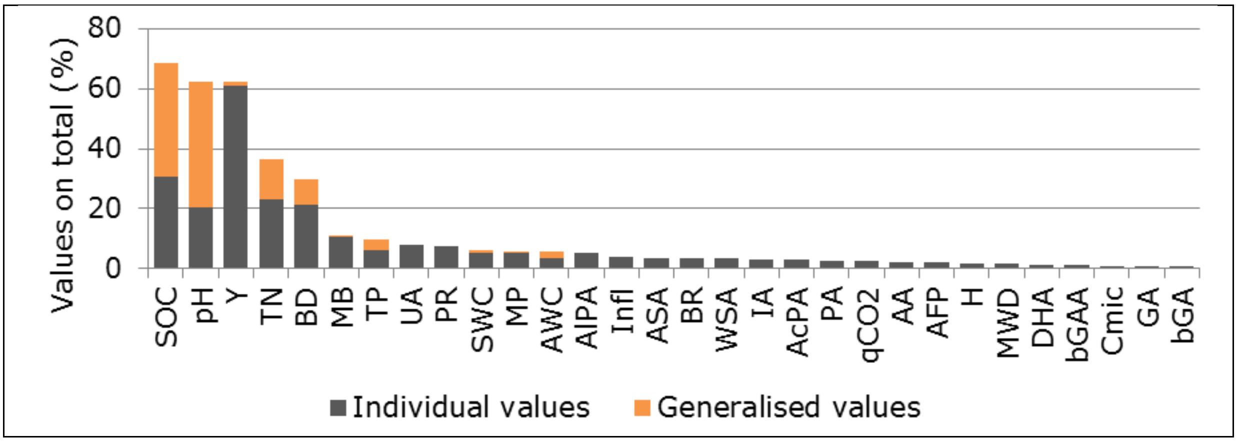


Figure 10 Percentages of measurements per soil parameter with values for both, experiment and control group (individual values), and with one value only (generalised value). 100% are 451 datasets (before merging). None of the parameters has been measured in all studies: The maximum is 61%; the minimum is 0.9% of sets with parameter values measured on total number of datasets. Abbreviations of parameters are explained in Table 12.

Meta-data extraction followed the minimum dataset that has been suggested for meta-analysis (Brouder & Gomez-Macpherson 2014):

- General information on location, precipitation, temperature, agro-ecozone, soil classification, cropping history prior to experiment establishment
- Experimental design description
- Treatment description including information on tillage, residue management, rotation, planting, weed control, and any other soil modification that was done
- Crop performance metrics: at least yield (grain and other aboveground biomass) and harvest date or date of physiological maturity

Brouder and Gomez-Macpherson (2014) suggested that this information should be included in all agronomic field trial publications to allow for their efficient use in meta-analysis, but found only few studies to do so. The same is true for the publications used here. For each study, metadata characterising field site according to Brouder and Gomez-Macpherson (2014) was extracted along with soil parameter values and missing data was estimated where possible. A detailed list of meta-data with information on handling of missing data is given in Appendix B3.

3.1.3 Dataset characteristics

Predominant soil types and median values of climatic variables of the dataset agree well with conditions in the Swiss Midlands. Median nitrogen application rate of the dataset is clearly below recommendations for cereal production in Switzerland however. The full dataset can be found in Appendix B1.

3.1.3.1 Controls and experiments

Controls vary a lot between different publications. Where controls were not explicitly declared as such in a publication, the treatment closest to conventional management as described in section 2.2.1 was used as control. This means for example that not all the control treatments include mouldboard ploughing as tillage method. The effect of different tillage forms in controls on parameter values was tested, since reduced tillage and no tillage are investigated techniques. Conventional tillage (CT) was applied in 201, reduced tillage (RT) in 88 and no tillage (NT) in 58 cases (see Figure 16). The median of annual nitrogen application rate is 73kg per hectare compared to 80kg per hectare in controls, because in some experiments experimental plots received less fertiliser than control plots or even no fertiliser at all. These N application rates are below recommendations for conventional wheat production in Switzerland which are between 110-150kg N per hectare (IP-Suisse 2014).

3.1.3.2 Trial characteristics

The datasheet was derived from 80 different publications on 113 trials (marked by different IDs in the data table, see Appendix A3). In total, 451 datasets were extracted from publications and merged to 347 cases by merging values from same sites but different soil horizons (this is explained in Appendix B2). Figure 11 gives an overview on characteristics of trials and trial sites. Soil types are mostly luvisols and cambisols, types that are common in the Swiss Midlands (FAO/UNESCO 1981). Soils investigated in trials have a wide range in texture, from clay-rich soils to sandy soils. Precipitation ranges from 383mm to 1190mm per year with a median of 769mm. Mean annual temperatures range from 0°C to 13.9°C with a median of 8.5°C. In comparison, mean annual precipitation in Bern is 911mm, annual mean temperature is 8.8°C (AmbiWeb 2015), which means that conditions at trial sites agree well with temperature conditions in the Swiss Midlands, but less with precipitation. Latitude (in absolute values to include southern latitudes) ranges from 35° to 61°, in comparison, latitude of Bern is about 47°N (KOGIS 2015). Trial area (including all replicates) varies substantially with a median of 1080m^2, a maximum of 5ha, and a minimum of only 24m^2. Trial duration varies from one to 21 years with a median of two years. Maximum soil depth samples were taken from varies from 2.5cm to 60cm with a median of 15cm. In 159 cases, herbicides were applied, while no chemical weed control was applied in 88 cases. Trials were published between 1980 and 2015, with 50% published between 2007 and 2015.

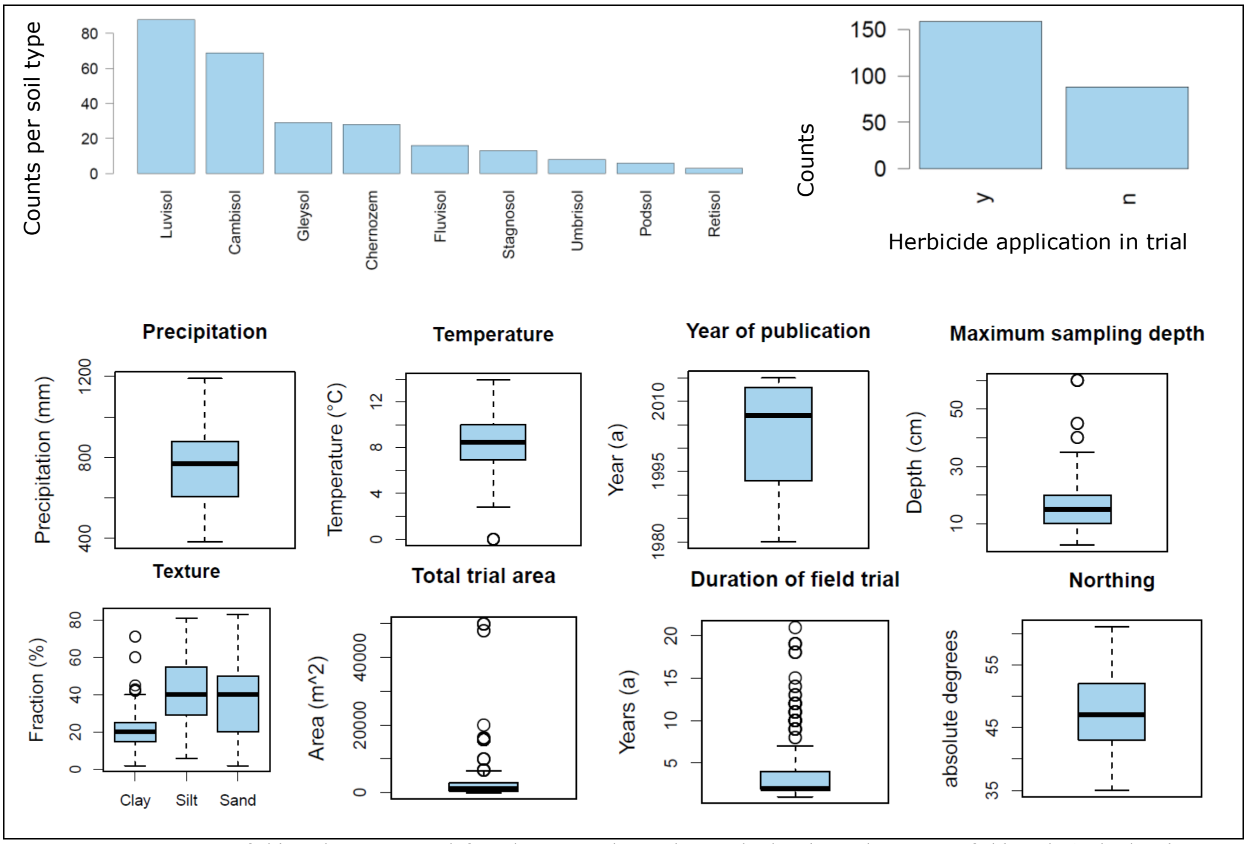


Figure 11 Overview on field trials. From top left to bottom right: Soil type, herbicide application in field trials (y=herbicides applied, n=no herbicides applied), precipitation, temperature, year of publication, maximum sampling depth, texture, trial area, trial duration, northing (and southing respectively). In the boxplots, whiskers enclose 95% of values, the box encloses 50% of values, and the black bar marks the median.

3.1.3.3 Parameter values

Figure 12 shows values of experimental and control plots summarised in boxplots. In total 30 parameters were extracted, based on their occurrence in publications and with units most often used in those publications. SOC, pH, and total nitrogen are in the following referred to as chemical parameters, microbial biomass through qCO2 as biological parameters, and soil water content to available water content as physical parameters. Figure 12 is meant to give an idea on how experiments and controls compare to each other, not to study absolute values. A detailed analysis and interpretation of absolute values does not make sense because measurement methods or concepts are not identical for all studies investigated. For example pH: In seven cases, pH was measured in calcium chloride, in 15 cases potassium chloride was used, in 29 cases pH was measured in water and for all other 296 cases, medium for pH measurement was not reported in publications. Even though a linear relationship between the three medias exists, measured values for the same sample are not the same for all three medias (Van Lierop 1981). This is another reason for choosing response ratio as a relative measure for analysis rather than directly analysing absolute values of experiments.

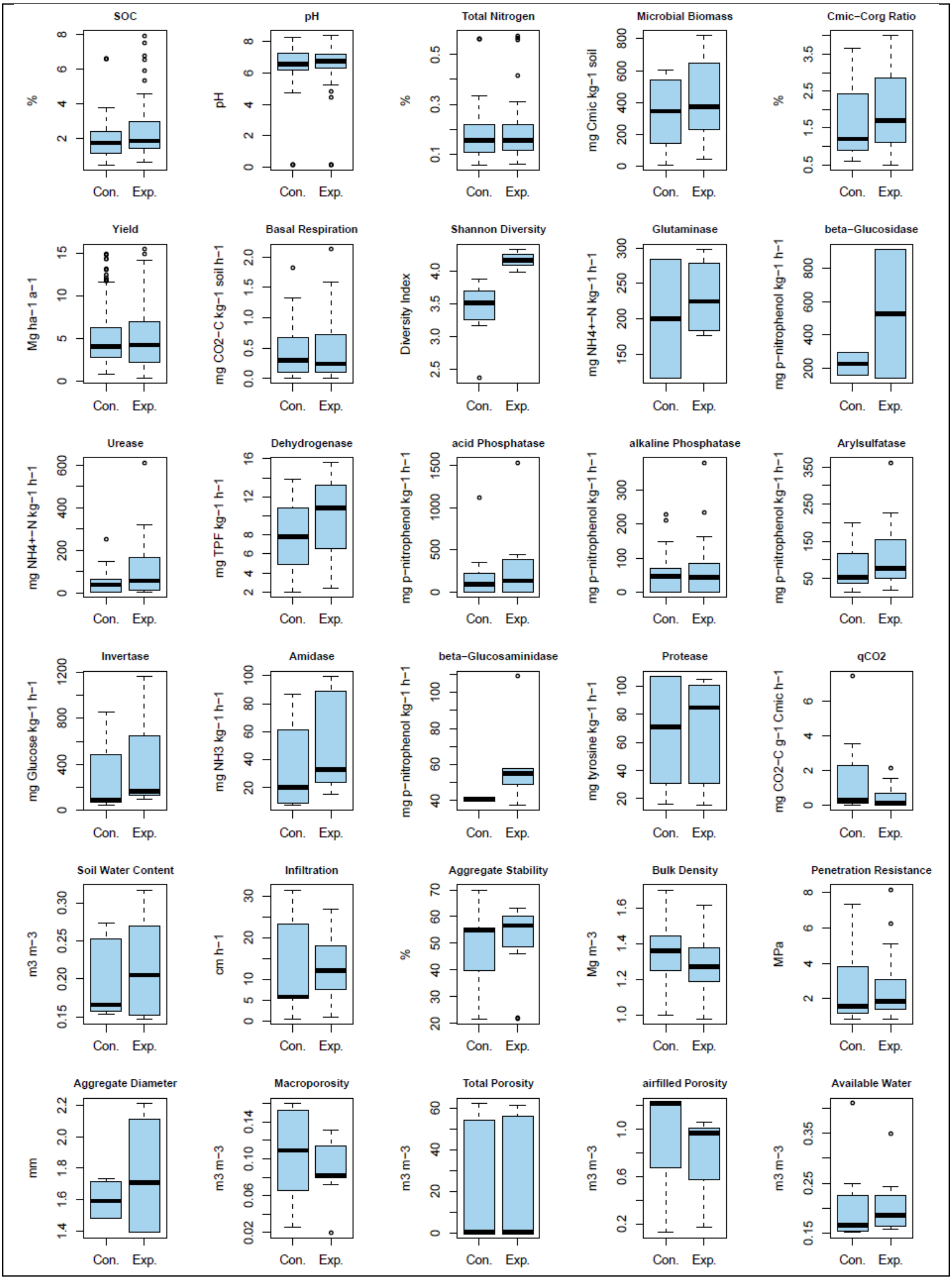


Figure 12 Boxplots for all parameters extracted from 80 publications. “Con.” are all parameter values measured in control plots in field trials, “Exp.” are all the values measured in experimental plots in the field trials. The boxes show the range of data: Whiskers enclose 95% of values, the box encloses 50% of values, and the bar denotes the median.

3.1.4 Response ratio as measure of effect

The “currency” used for the meta-analysis is the response ratio which was calculated for all extracted parameter values. The response ratio is used because it fits the type of data used here.

According to Chang (2011, p. 175), meta-analyses should be “cohesive”, meaning that substantial heterogeneity among studies should not lead to development of “ad hoc approaches”. Also, developing a new approach would go far beyond the scope of this work. Therefore, response ratio was chosen as effect size: Response ratio as effect size was suggested by Hedges, Gurevitch and Curtis (1999) for analysing studies in experimental ecology. The effect size characterise differences between a treated and a control group (Borenstein et al. 2009c), it is the currency to compare different studies in a meta-analysis (Borenstein et al. 2009b). Response ratio is the ratio of measured quantities in experimental and control groups, such as relative yield (Hedges et al. 1999). It is a suitable effect measure for studies where values measured on a physical scale with a natural zero point and means and standard deviations are reported (Borenstein et al. 2009a). For example, response ratio as measure of effect were used in a meta-analysis where fertiliser influences on maize productivity have been studied (Chivenge et al. 2011). This perfectly fits to data of field trials used here where effect of a technique on a certain parameter compared to control was measured. Per study, response ratio is calculated for each technique and each parameter investigated according to Hedges et al. (1999):

$R = \frac{X_e}{X_c}$ with Xe being the mean of outcome of experimental group and Xc being the mean of outcome of control group. Then, all values from the same trial but several soil horizons were merged so that each data point in the file represents all horizons sampled in a trial. The compiled dataset is shown in the Appendix B1 with some further explications on merging (B2).

3.1.5 Analysis of response ratios

Ideally, response ratios would be weighted by precision of measurement values. This was not possible, because for up to 39% of parameter values precision was not reported in publications. Therefore, a combined analysis approach was applied instead with unweighted response ratios and response ratios weighted by an estimate of precision.

3.1.5.1 Dealing with missing data

All parameter values are associated with error. So, when analysing response ratios, individual ratios should be weighed with their error, giving more weight to studies with small error or in other words high precision (Hedges et al. 1999). Weighting data by precision is generally seen as a sign of quality of a meta-analysis (Philibert et al. 2012). The problem is that not all the studies included here did report on precision: Figure 13 shows that for the parameters in the dataset, up to 39% of parameter values did not come with a standard deviation that would allow for calculating precision. How to deal with that? Chivenge et al. (2011) encountered the same problem when calculating response ratios of soil

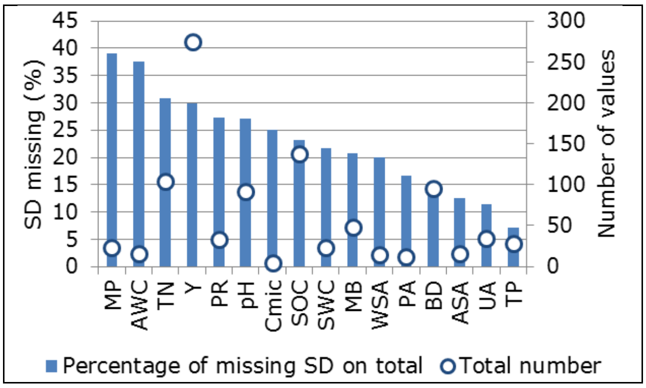


Figure 13 Percentage of values with missing standard deviation on total number of values per parameter. Parameters without any missing values are not shown in the plot. Circles mark total number of values per parameter, the maximum possible number is 347 (right y-axis). Bars indicate the percentage of those values with missing standard deviation (left y-axis). Percentages vary from 7% to 39%.

organic carbon for their meta-analysis. They decided in favour of a larger dataset and analysed the unweighted response ratios instead.

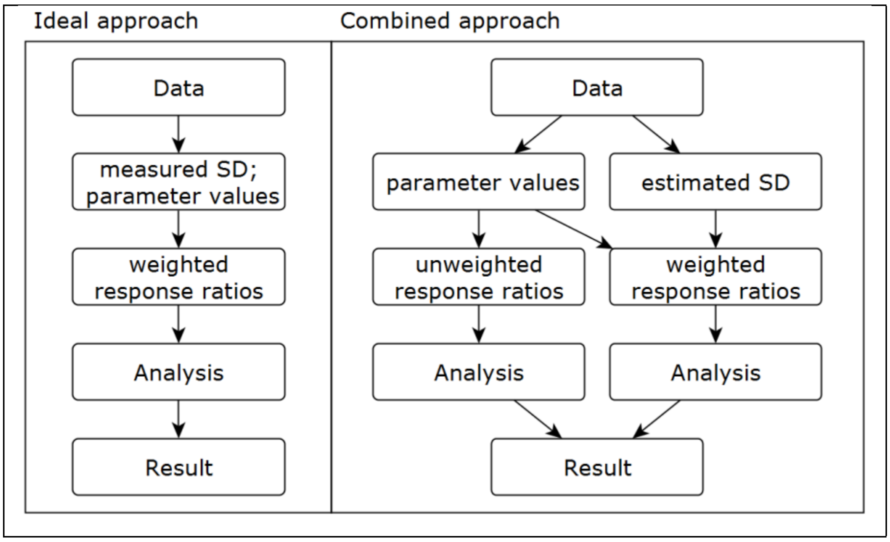


Figure 15 Ideal approach for analysing response ratios according to Hedges et al. (1999) **and the combined approach with both weighted and unweighted response ratios used in this work because standard deviations (SD) were not available for all parameter values extracted from the field trial publications**

Figure 13 shows the approach that was finally applied: Unweighted response ratios were analysed, but combined with a weighted analysis which is based on estimated standard deviations. Details are given in Appendix B5, but in brief, a mean coefficient of variance was calculated for each parameter based on existing standard deviations. The mean coefficient of variance was then used to estimate missing standard deviations. The results of the weighted analysis are weighted mean response ratios per parameter and technique which were compared with an F-test (Stahel 2008d). The advantage is that at least a part of the real error can be taken into account that way compared to only analysing unweighted response ratios. The advantage of analysing unweighted response ratios is that this allows for a variety of tests that cannot be applied on the weighted means. They are explained in the next paragraphs. So, by combining both, the dataset can be used to its fullest extent, despite missing data.

3.1.5.2 Analysis steps for unweighted response ratios

The analysis of unweighted response ratios followed the scheme in Figure 14. More details are given in Appendix B7.

First, all parameters with data for only one technique were removed. Also, parameters with only two techniques but less than three data points per technique were removed. This ensured that all tests could be applied, the Shapiro Wilk test for normal distribution for example requires a minimal sample size of three (R Core Team 2015c). Table 12 shows all the parameters with enough data available for analysis.

Response ratios were then transformed. Data transformation

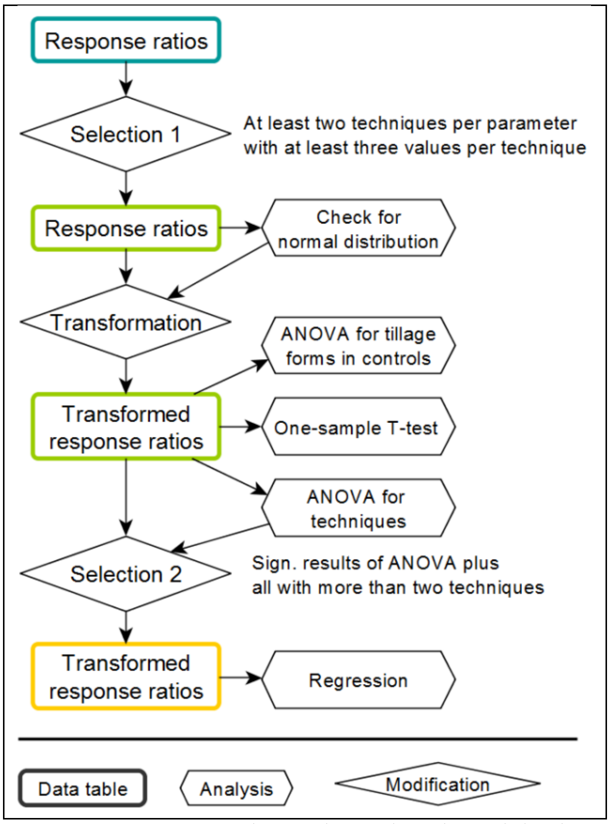


Figure 14 Overview on data analysis. The colour of the data table corresponds to the colour code used in Figure 20. The key to the element shapes is below the black line.

is necessary when data are not normally distributed, but there are good reasons for keeping outliers in the dataset, meaning that the outliers are actually data points and not mistakes (Osborne 2002). Data used here have been extracted from published studies, so removing outliers for suspecting them to be measurement errors did not seem appropriate.

Group	Parameter	Abbrev.	Unit
Chemical	Soil organic carbon content	SOC	% weight of soil organic carbon per weight of soil
	pH	pH	-
	Total nitrogen content	TN	% weight of total nitrogen per weight of soil
Biological	Microbial biomass carbon	MB	mg Cmic kg-1 soil
	Cmic-Corg ratio	Cmic	% microbial biomass carbon per total organic carbon
	Yield	Y	Mg crop ha-1 a-1
	Basal respiration	BR	mg CO2-C kg-1 soil h-1
	Shannon diversity index	H	- ,Index for diversity of microbial community
	Glutaminase activity	GA	mg NH4+-N kg-1 soil h-1
	Beta-glucosidase activity	bGA	mg p-nitrophenol kg-1 soil h-1
	Urease activity	UA	mg NH4+-N kg-1 soil h-1
	Dehydrogenase	DHA	mg TPF kg-1 h-1
	Acid phosphatase activity	AcPA	mg p-nitrophenol kg-1 soil h-1
	Alkaline phosphatase activity	AlPA	mg p-nitrophenol kg-1 soil h-1
	Arylsulphatase activity	ASA	mg p-nitrophenol kg-1 soil h-1
	Invertase activity	IA	mg Glucose kg-1 soil h-1
	Amidase activity	AA	mg NH3 kg-1 soil h-1
	Beta-glucosaminidase activity	bGAA	mg p-nitrophenol kg-1 soil h-1
	Protease	PA	mg tyrosine kg-1 soil h-1
	qCO2	qCO2	mg CO2-C g-1 Cmic h-1, quotient of basal respiration per microbial biomass carbon
Physical	Soil water content	SWC	m3 water m-3 soil
	Infiltration capacity	Infl	cm water h-1
	Water stable aggregates	WSA	% weight of water stable aggregates on weight of aggregates
	Bulk density	BD	Mg soil m-3 soil
	Penetration resistance	PR	MPa
	Mean weight aggregate diameter	MWD	mm
	Macroporosity	MP	m3 pore space m-3 soil
	Total porosity	TP	m3 pore space m-3 soil
	Air-filled porosity	AFP	m3 pore space m-3 soil
	Available water content	AWC	m3 water m-3 soil

Table 12 Parameters extracted from studies with abbreviation used in the datasheet and units. Parameters highlighted in grey were used for data analysis, for others too few data points were available. Units were used according to their frequency in the literature.

After transformation, the effect of different tillage forms in controls was evaluated with an analysis of variance, or anova (R Core Team 2015a). Trial set ups vary substantially between different studies and neither experiments nor controls were set up in a common way. Tillage forms are treated as own techniques in the data comparison and ignoring differences in control might have an impact on data analysis in the end. Figure 16 shows which tillage form was applied in controls per technique and how often.

For each parameter and technique (with at least two values available), a one-sample T-test was calculated to compare the mean response ratio to a response ratio of 1. A response ratio of 1 means that there is no difference between experiments and control, or in other words, that the technique has no influence on a parameter value. In the following, a response ratio of 1 will therefore be referred to as “point of zero effect”. Then, an anova was calculated to compare techniques for each parameter and a post-hoc test (de Mendiburu 2015, p. 83) was used to differentiate between individual techniques.

Finally, multiple regressions were calculated for all parameters for which techniques significantly defer and for all parameters with data points for more than two techniques (Selection 2 in Figure 14).

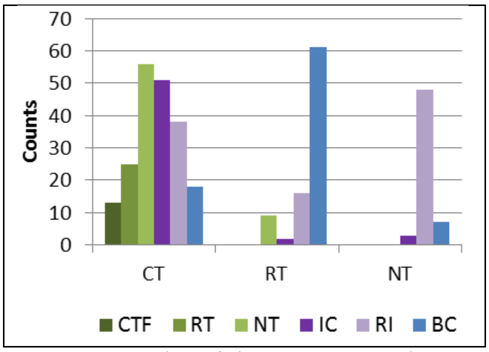


Figure 16 Number of data points per technique and tillage form in controls. In total of all techniques, in 201 cases conventional tillage was applied in control, in 34 cases reduced tillage was applied and in 112 cases no tillage was applied in control.

3.1.6 Quality control

All of the quality attributes of a meta-analysis by Philibert et al. (2012) could be addressed, but not all of them to the same extent. However, the main impairment of quality is the fact that publications did not contain all the desired information.

For meta-analysis in the field of agronomy, Philibert et al. (2012) defined a set of criteria to check quality. These criteria are summarised and commented in Table 13.

Quality criterion	**Comment**
“Repeatable procedure for the selection of papers”	The procedure of the literature search is explained in section 3.1.1; more details are provided in Appendix A1
References: “A list of the references used for the meta-analysis is provided”	Literature used for meta-analysis is shown in appendix A3 and A4
Heterogeneity: „The origins of the variability of the results are analysed“, meaning within-study and between-study variability is analysed	This is not possible due to incomplete reporting on variance in studies (see Figure 13). Missing standard deviations were estimated to study variability.
Sensitivity Analysis: „The sensitivity of the conclusion to observations or methods is analysed“	Two analysis methods, one using unweighted and one using weighted response ratios, are compared
Bias: “The publication bias is studied”, for example by funnel plots	Funnel plots were used, a discussion of possible publication bias can be found in section 3.1.1.3
Weighting: „Observations are weighted according to their level of accuracy in the statistical model“	Analysis was performed on unweighted data but completed with a weighted analysis based on estimated standard deviations. See section 3.1.5.1 and Appendix B4 – B6

Availability of the dataset: "The dataset is available in an electronic format or published directly in the paper"	The dataset is in Appendix B1
Availability of the program: "The program used for statistical analysis is made available"	The program used for analysis is R (R Core Team 2015b), the code is shown in Appendix C

Table 13 Discussion of quality check for meta-analysis defined by Philibert et al. (2012)

All of the quality criteria could be addressed, but not all of them to the same extent: Heterogeneity has been assessed with an F-test on weighted data, but only after missing standard deviations have been estimated, see section 3.1.5.1. Philibert et al. (2012) further suggest analysing sensitivity of results to changes in data or in analysis assumptions. For some parameters, there are only few data cases per technique. To further split up the dataset (e.g. removing outliers) and run the analysis on subsets, a larger dataset would be required. Sensitivity of results to assumptions has not been analysed (these assumptions are shown in Appendix A2 and B3). There are two reasons for that. First, there is a time constraint for this work and priority was given to comparison of different statistical methods (analysing weighted and unweighted response ratios). Second, the main quality issues about this meta-analysis arise from the dataset itself: Missing information in publications is the reason for assumptions in the analysis in the first place. For example, where information on temperature and precipitation in the trial year was missing, it was estimated with long-term means (see Appendix B3). In order to conduct the meta-analysis as suggested by Hedges et al. (1999), at least measurements of experiments and controls with their individual standard error per parameter are needed. In order to compare techniques among each other and to meta-data, the minimum dataset suggested by Brouder & Gomez-Macpherson (2014) (see section 3.1.2) would be desirable. Together with publication bias (see section 3.1.1.3), missing information adds up to an unquantifiable component of uncertainty in the analysis.

That much about actually available data. What about data, that could not be found in the 80 studies used in this analysis or in other words, are the parameters shown in Table 12 appropriate to assess the impact of techniques on soil quality? Bastida et al. (2008) listed parameters which had been suggested in fifteen different studies on soil quality indices for agricultural soils around the world. For biological and physical parameters, there is much overlap, but not for chemical parameters: Cation exchange capacity is mentioned twice, electrical conductivity three times and nutrients besides nitrogen even seven times in the fifteen reviewed indicators (id.). This suggests that chemical parameters are underrepresented in the analysis.

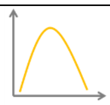
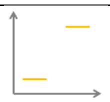
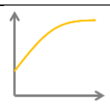
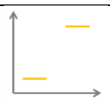
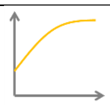
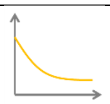
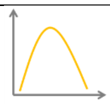
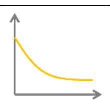
To sum it up, the quality of this meta-analysis could have been improved by more extensive sensitivity analysis. However, the main problem is insufficient reporting on results and trial conditions in publications, necessitating assumptions in the dataset. Also, some chemical parameters are underrepresented from the start.

3.2 Results and discussion

3.2.1 The meaning of parameters

{ An increasing response ratio for a parameter does not mean that soil quality is increasing. Table 14 helps to interprete changes in parameter values and hence changes in response ratios. }

Table 14 briefly explains each of the analysed parameters. The graphical summaries (in the column "Evaluation") are generalisations; often, there is no extensive agreement on the interpretation of a parameter among scientists. Especially parameters related to soil microbial community have been criticised: "The extensive focus of soil quality indices on microbial ecology and dynamics is disturbing given that microbiologists acknowledge that critical roles and functions of soil microorganisms are yet to be fully explained" (Sojka & Upchurch 1999, p. 1044).

Abbr.	**Description**	**Evaluation**
SOC	SOC contents are strongly connected to soil organic matter (SOM) (Scheffer & Schachtschabel 2010f). High SOM contents in soils are related to high nutrient storage, high porosity, low bulk density, high aggregate stability, high water storage capacity, and fast warming of the soil in spring (id.). SOM adsorbs toxins and heavy metals (id.), but at the same time also chemicals intended for weed and pest control, reducing their effect (Sojka & Upchurch 1999).	
TN	Total nitrogen contents are closely related to SOC contents (Scheffer & Schachtschabel 2010a). Nitrogen is one of the main nutrients of plants and microorganisms and can therefore be a limiting factor for plant growth in agriculture (id.). However, not all of the total nitrogen in soil is plant available (id.).	
pH	For agricultural soils, pH values should at least be higher than 5 to avoid aluminium toxicity (Scheffer & Schachtschabel 2010d). Depending on clay contents, optimal values are between 5 and 6.5 (id.). With increasing pH, plant availability of some nutrients is decreasing (id.).	
MB	Microbial biomass is lower under agriculture than under forest and grasslands (Scheffer & Schachtschabel 2010c). There are a number of positive influences of microbial biomass on plants, such as plant growth promoting bacteria (id.). However, it is yet unclear how biomass could be used as an indicator of soil quality (Bending et al. 2004).	
Y	Yield is an integrated measure for all site conditions and crop management factors (Scheffer & Schachtschabel 2010b). Yields depend on yield potential of a soil (id.), which means that a minimum or optimum value cannot be generally defined.	
BR	"Basal respiration of a soil reflects the overall activity or energy spent by the indigenous soil microbial pool" (Anderson & Domsch, 1990, in Lupwayi et al. 1999, p. 274). It is used to assess the reaction of the microbial community to changes (Quilliam et al. 2012), there is no optimum value.	
UA AcPA AlPA PA	"In principle, it is assumed that high values of enzymatic activity are evidence of good quality of soil, while low values indicate an incorrect run of biological processes in the soil" (Oleszczuk et al. 2014, p. 10). High enzyme activities are related to accelerated nutrient cycling and therefore higher availability of nutrients (Mbuthia et al. 2015).	
qCO2	qCO2 was found to increase with increasing disturbance in soil management and was interpreted as reaction of the soil microbial community to stress (Haynes 1999).	
SWC	Plants extract water until the permanent wilting point is reached, even if there is still water in the soil (Scheffer & Schachtschabel 2010g). Total soil water content therefore is only an approximate measure for plant available water. Soil moisture depends a lot on site conditions (id.); the optimal soil water content therefore depends on soil and site conditions.	
BD	Depending on soil texture, certain bulk densities pose a limit to plant root growth (Arshad et al. 1996). These limits range from 1.4gcm^{-3} for clay texture to 1.8gcm^{-3} for sandy texture (id.). However, such an immediate relationship between root growth and bulk density has been	

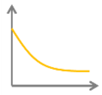
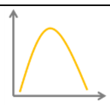
	questioned (Kaufmann et al. 2010).	
PR	Penetration resistance of 2MPa (Arshad et al. 1996) or 3MPa (Atanu Mukherjee & Lal 2014) have been found to be growth restricting. However, growth restrictions are not immediately tied to penetration resistance: Soil with undisturbed macropores have less growth limitations at same PR as disturbed soils (Arshad et al. 1996).	
MP	Soils with a macropore volume of less than 10% were found to be at risk of water logging, soils with more than 15% were found to be too loose (Anken et al. 2004).	
TP	Porosity depends on factors such as texture and soil formation (Scheffer & Schachtschabel 2010g), an ideal number is therefore difficult to indicate. The pore system is responsible for gas and water exchange in soils (id.); low volumes are therefore not desirable.	

Table 14 Evaluation of analysed parameters for their effect on soil quality. Four different types are distinguished here. For type A parameters, soil quality increases with increasing parameter value (up to a plateau); type B parameters behave the opposite. Type C means there is an optimum parameter value. Type D parameters are used for comparison of two states, a functional relationship between parameter value and soil quality is not known.

3.2.2 The effect of a technique

A technique has a significant effect on a parameter if the 95% confidence interval does not overlap the line of zero effect (a response ratio of one). When taking the weighted response ratios into account, confidence intervals are much wider. This raises doubts about the significance of effects, but confirms many trends.

In Figure 17, all techniques with a significant effect on parameter values are highlighted in grey. However, the effect of sample size interferes: For total porosity for example, biochar application (sample size: 10) was found to have an effect significantly different from zero, while this is not the case for reduced tillage (sample size: 3), even though the mean response ratio for reduced tillage is bigger than for biochar application. The larger the number of measurements in a sample, the higher the chance that the null hypothesis is rejected in a statistical test (Stahel 2008c). Therefore, confidence intervals are used instead to decide whether or not an effect is considered significant. A confidence interval is a range of plausible parameter means, with a significance level of 5%, there is a 95% chance that the true parameter mean is within this interval (Stahel 2008e). They are more useful than tests, because they not only show the mean but also indicate if the effect could be zero or even going in the opposite direction (id.). So, instead of relying on the T-test, an effect is considered significant if the confidence interval does not overlap with the point of zero effect in Figure 17. This means that for all parameters there is at least one technique that has an effect, except for basal respiration, protease and macroporosity. When comparing to the weighted analysis, shown in Figure 18, there are two obvious observations: First, the patterns overall look similar to the unweighted analysis. Second, the confidence intervals are much wider and more often overlapping with the point of zero effect.

A closer look at the means reveals that for some techniques the direction of the effect changed for some parameters, meaning that where an increasing effect of a technique on a parameter was found in the unweighted analysis there is now a decreasing effect and vice versa. This behaviour is interpreted as a sign for no effect of a technique. It occurs with

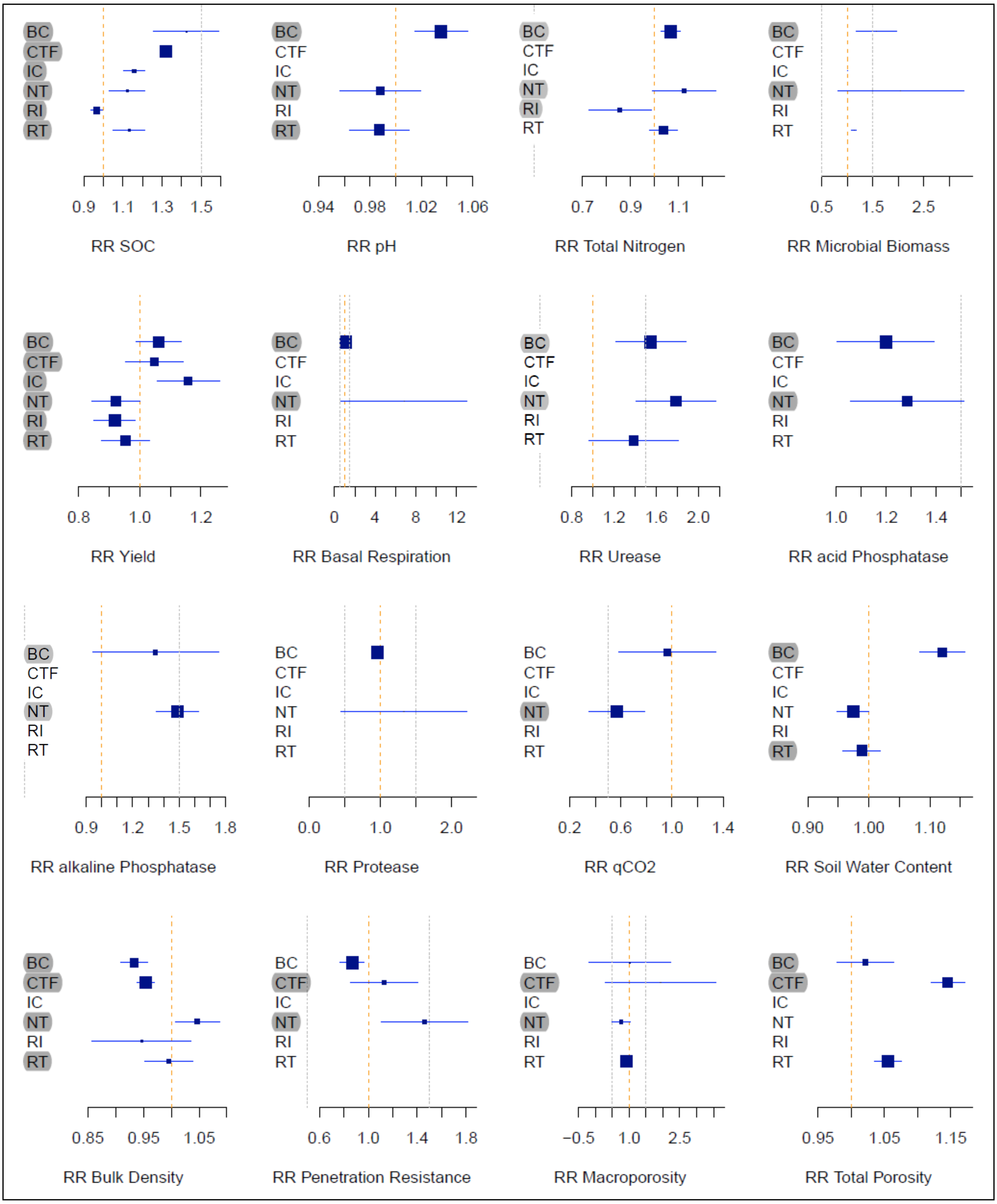


Figure 17 Forest plots for *unweighted* means of response ratios. The blue square marks the mean; its size is proportional to the precision: the smaller the standard error, the bigger the square. The blue bars mark the 95% confidence interval of the mean. The orange dashed line highlights a response ratio of one. The techniques are: Biochar application (BC), controlled traffic farming (CTF), intercropping (IC), no tillage (NT), relay intercropping (RI), and reduced tillage (RT). Values are response ratios; the point of zero effect is at a value of one. Grey highlights indicate that the mean for a technique was found significantly different from the point of zero effect in a one-sample T-test. Grey dashed lines mark a 50% increase and decrease respectively in response ratio compared to the point of zero effect. Exact values of mean response ratios are listed in Appendix C1.

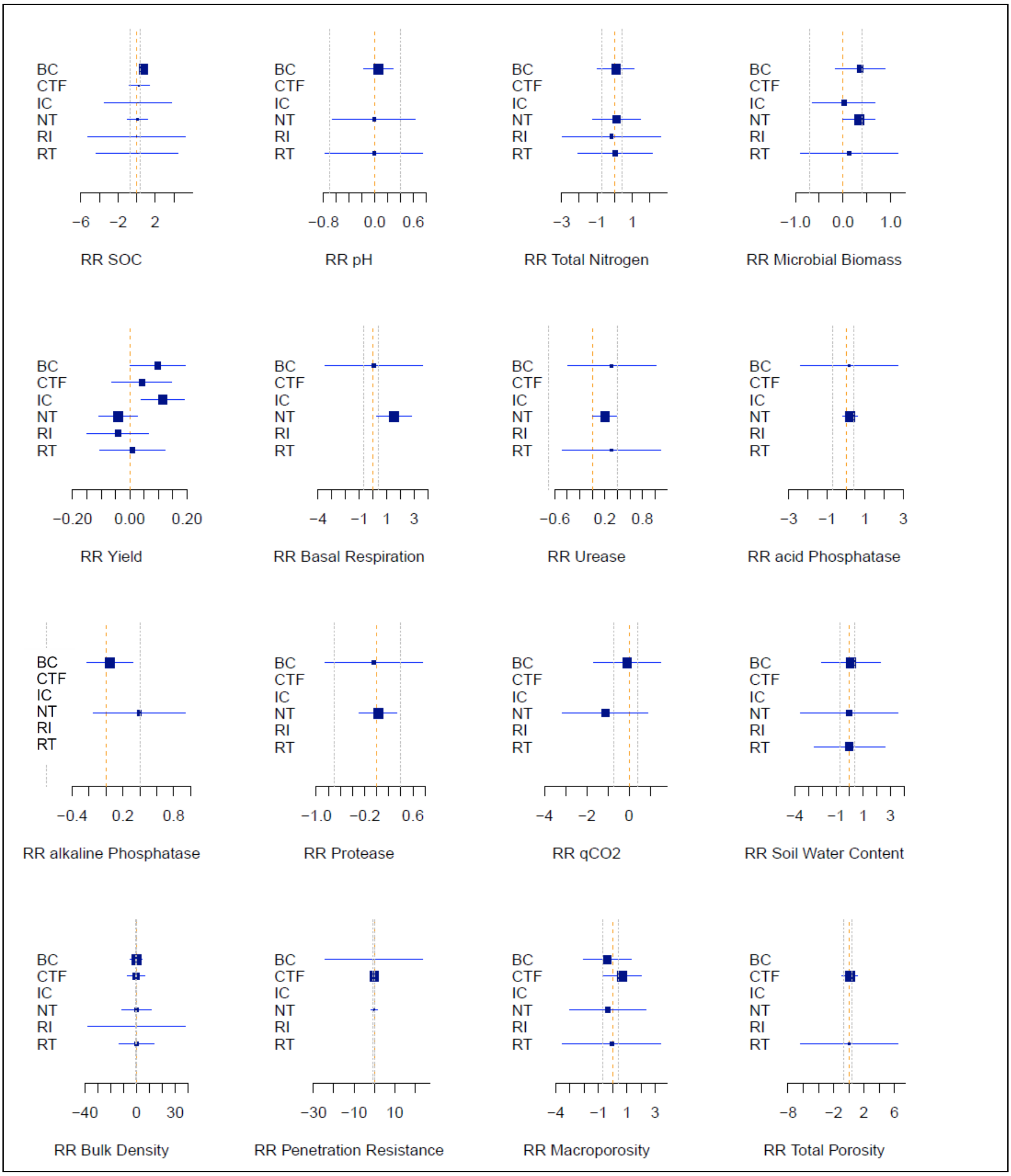
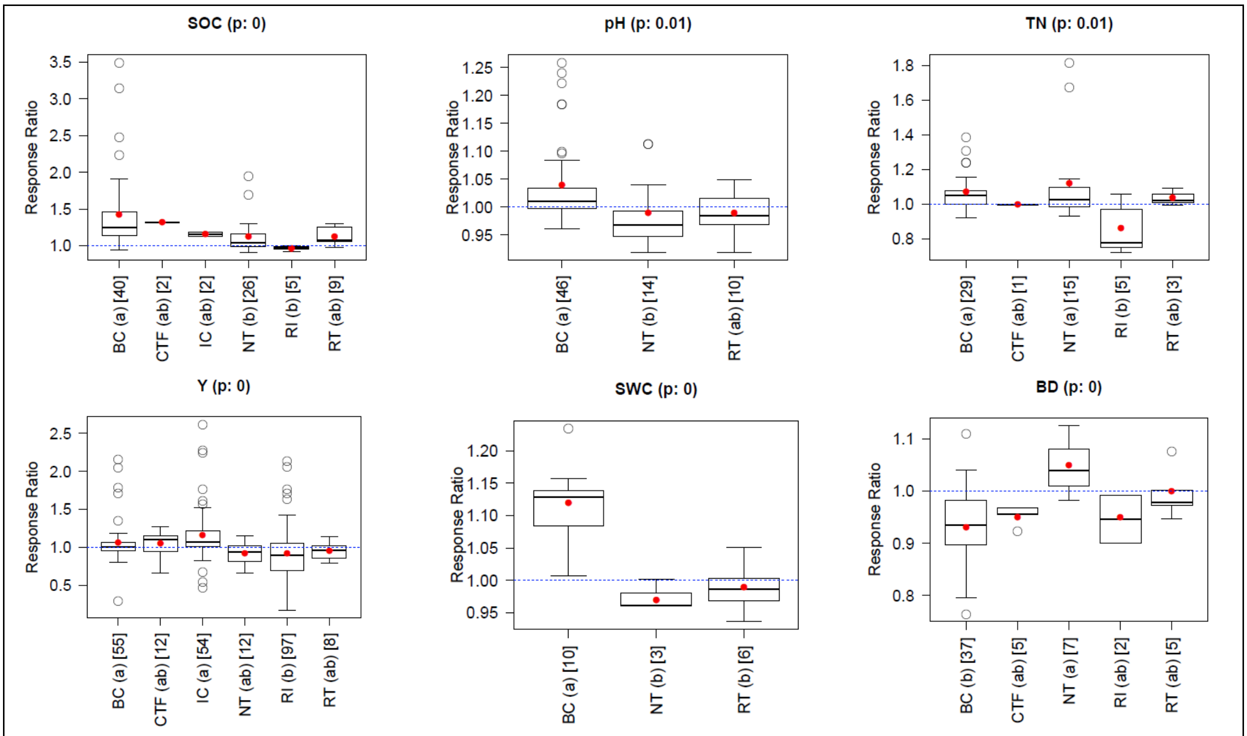


Figure 18 Forest plots for *weighted* means of logarithmic response ratios. The blue square marks the mean; its size is proportional to the precision: the smaller the standard error, the bigger the square. The blue bars mark the 95% confidence interval of the mean. The orange dashed line highlights a response ratio of one. The techniques are: Biochar application (BC), controlled traffic farming (CTF), intercropping (IC), no tillage (NT), relay intercropping (RI), and reduced tillage (RT). Values are natural logarithms of response ratios, meaning a value of 1 corresponds to a response ratio of 2.7; the point of zero effect is at a value of zero. The grey dashed lines mark a 50% increase and decrease respectively compared to the point of zero effect. Exact values of mean response ratios are listed in Appendix C2.

reduced tillage for yield, for controlled traffic farming and no tillage for penetration resistance and for biochar application for macroporosity. Overall, taking the true precision of data into account diminished differences between techniques and also effects of techniques, but at the same time affirm trends.

3.2.3 Differences between techniques

For seven parameters (of totally sixteen), significant differences between techniques could be found in the unweighted analysis: For soil organic carbon content (SOC), pH, total nitrogen content (TN), yield (Y), soil water content (SWC), soil bulk density (BD), and total porosity (TP). For weighted response ratios, none of the differences were significant because of large within-group variability, thus qualifying the results from the unweighted analysis.



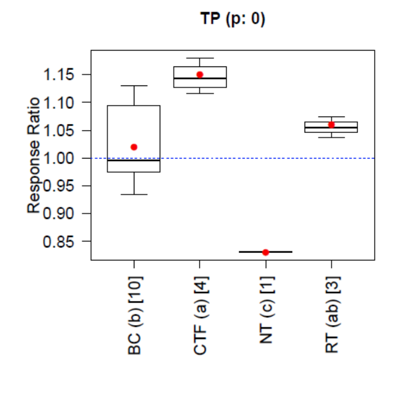


Figure 19 Boxplots with anova outputs for those parameters with significant differences between techniques. The number in the title is the p-value of the anova (significance level of 0.05). Numbers in brackets show number of data points per technique, letters in parenthesis show the result of the LSD (Bonferroni) post-hoc test. The blue dashed line marks the value of zero difference between experiment and control. Values above the line mean that the parameter value measured in the experiment was higher than in the control, values below mean the opposite. The box encloses 50% of data points; the black line represents the median, the red dot the average. Whiskers enclose 95% of data points.

Results of analysis of variance (anova) for parameters with significant differences between techniques are shown in the boxplots in Figure 19. For other parameters, there are also noticeable differences, but they did not turn out to be significant at the 5% level. They will be discussed in the following subsections. The significance is questioned by the results of the F-test for weighted response ratios: None of the differences turned out significant because of large within-group variabilities. Yield was the only parameter for which differences at least were somewhere near the significance level. This is not surprising after having seen the confidence intervals in Figure 18.

3.2.3.1 Chemical parameters

Biochar increases soil organic carbon content significantly (+42%) more than no tillage (+12%), reduced tillage (+13%) and relay intercropping (-3%). The percentages express the effect of a technique in relation to the control, all values are listed in Appendix C3. For pH, a significant difference between biochar (+4%) and no tillage (-1%) was found. For total nitrogen content, the pattern is very similar to soil organic carbon content: Biochar (+7%) and no tillage (+12%) leads to a significantly higher content than relay intercropping (-14%). The similar pattern is not surprising, since soil carbon and nitrogen contents are both linked via soil organic matter (Scheffer & Schachtschabel 2010f).

3.2.3.2 Physical parameters

On the physical properties, there is a trend for no tillage treatment: Bulk density (+5%) and penetration resistance (+46%) are increased under no tillage treatment, soil water content (-3%), macroporosity (-24%), and total porosity (-17%) are decreased. These are mostly negative effects (see Table 14). Trends for soil water content, bulk density and total porosity are significant. The effect of biochar application is opposite to no tillage, with significant differences for the same parameters.

3.2.3.3 Biological parameters

Again, a pattern shows up for no tillage treatment. Enzyme activities are increased, qCO2 is decreased, both are seen as a sign for increased soil quality (Haynes 1999; Oleszczuk et al. 2014). However, yield is decreased by 8%. Yield is also decreased by relay intercropping (-8%) and reduced tillage (-5%). Yield is increased by controlled traffic farming (+5%), biochar application (+6%) and intercropping (+16%). In comparison: Annual wheat yield increase due to breeding is 0.9% (Fischer & Edmeades 2010).

3.2.4 Effect of techniques compared to other variables

Regression models were calculated to compare techniques to other potentially explanatory variables for changes in response ratios. Variance in organic carbon content, total nitrogen content, bulk density and yield is explained to a significant part by techniques. These parameters seem to respond stronger than others to changes in techniques.

Regression model		corr. R2	p-value	Assumptions
SOC ~	0.48 + 0.25*Biochar application - 0.20*Umbrisol - 0.46*Herbicide application	0.66	0.00	Violated
TN ~	−0.007 + 0.27*SOC − 0.15*Relay intercropping + 0.29*Gleysol + 0.20*Soybean	0.46	0.00	Violated
Y ~	0.80 + 0.03*Temperature − 0.16*no herbicide application + 0.09*Luvisol + 0.12*Plant residues removed (e) − 0.21*Relay Intercropping	0.65	0.00	Violated
BD ~	2.10 − 1.09*TP + 0.10*Controlled traffic farming	0.85	0.00	Violated

Table 15 Regression models where one of the techniques is among the explaining variables with the corrected coefficient of determination (corr. R2) and p-value of the model (p-values are defined in Appendix B7). The last column shows whether the main model assumptions are fulfilled or not.

For those parameters with data on more than two techniques a multiple regression model was calculated in order to find out if technique is still an explanation for variation in data when taking other variables into account. Technique significantly matters for SOC, TN, yield, and BD. Regression models are shown in Table 15. However, all models lack a normal distribution of errors, which means the model assumptions are violated (Stahel 2008b). The reason for that are outliers and even applying more robust models did not help overcome this problem. Therefore, the models are certainly not valid for prediction of parameter values. However, the corrected coefficient of determination still indicates how well the variance of the target variable can be explained by the model coefficients (Stahel 2008d). So, the conclusion from the regression models is the following: On SOC, TN, yield, and BD, the influence of farming techniques seems to be of equal relevance as site conditions and trial set-up. Compared to other parameters, these four parameters seem to be more sensitive to changes in technique and are therefore more relevant for comparison.

3.2.5 Discussion of meta-analysis results

Figure 21 summarises the effect of the six techniques on the soil parameters (information on three to sixteen parameters are available per technique). It can be used to derive a site-specific ranking of techniques. Except for relay intercropping, all techniques have a significant positive effect on at least one of the parameters compared to conventional methods. This means that the initial hypothesis I is partially confirmed.

3.2.5.1 Parameters included in the analysis

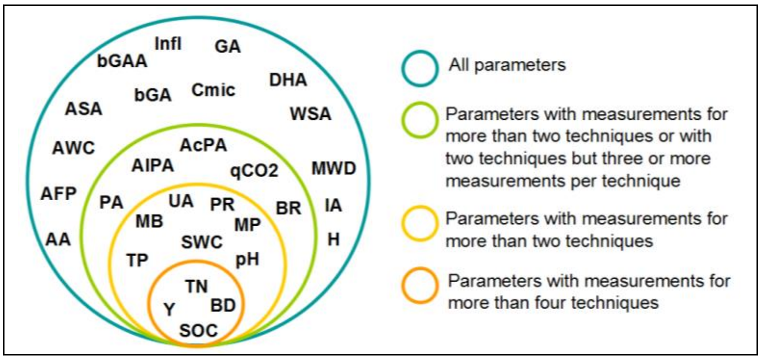


Figure 20 Overview on all parameters extracted from the literature regarding number of values per technique.

Figure 20 illustrates the path of parameters through the analysis of unweighted data. The majority (82%) of biological parameters drop out early in the analysis (are not part of the yellow group in Figure 20) because of too few data. The same is true for half of the physical parameters. A possible explanation is that there is little consent among scientists about the use and interpretation of these parameters for farming techniques (another explanation, of course, is the literature search failing in finding the relevant studies). Especially enzyme activities stand out: Of 30 parameters extracted from the literature, eleven were enzyme activities from which ten dropped out due to data scarcity. However, high enzyme activities are thought to be linked to an improvement in soil quality and to be influenced by agricultural management practices (Mbuthia et al. 2015). So, even though they dropped out of the analysis does not mean these parameters do not respond to techniques or are irrelevant for soil quality. The 16 soil parameters were analysed because the data were available, not because they comprehensively define soil quality. In consequence, this means that the research question cannot be answered in an absolute way: Whatever technique will be found to “best” conserve soil quality will only be best in relation to parameters investigated here.

3.2.5.2 Evaluating techniques

Figure 21 summarises the effects of each technique found in the meta-analysis. The following paragraphs relate to it.

Biochar application

For all parameters except macroporosity, the weighted analysis confirms the direction of the effect of biochar application. Not surprising, soil organic carbon is significantly increased, also compared to other techniques. More interesting is the significant yield increase which is well supported by the weighted analysis. However, biochar application rates in some experiments were high, maximum rate was 95.8 t per hectare (Rogovska et al. 2014), the mean is 25.9 t per hectare. 25.9t of biochar bought from a commercial supplier in Switzerland would cost about 22’000 CHF (Swiss Biochar 2015). In comparison, the only commercial trial included in the meta-analysis applied only 3.9t per hectare (Husk & Major 2010). In total, there is a significant positive effect on seven of sixteen parameters and one significantly negative effect.

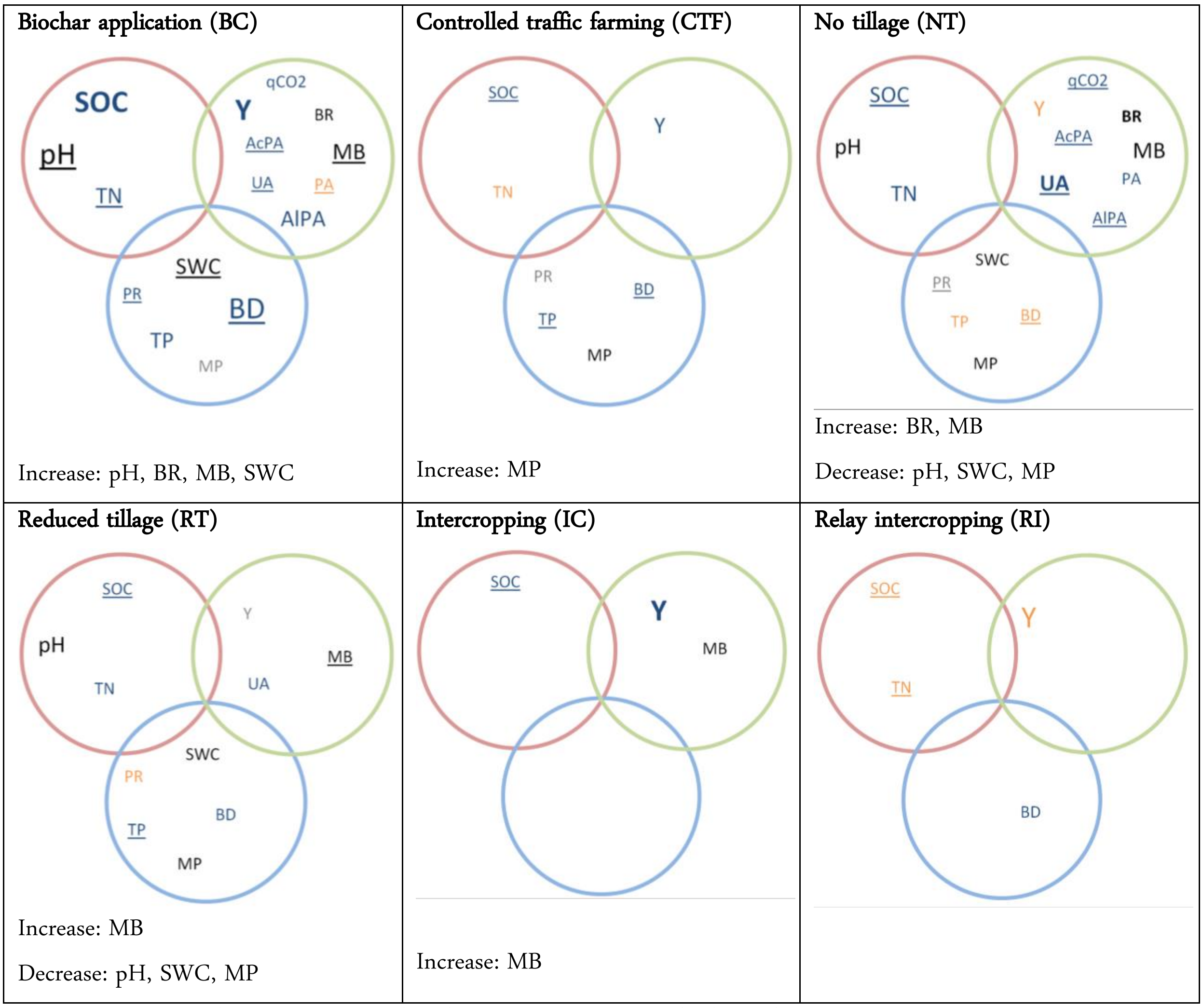
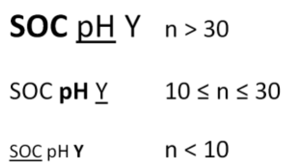


Figure 21 Summary plots for effect of each technique on parameters and other techniques. The red, green, and blue circles enclose chemical, biological, and physical parameters respectively. The colours of parameters correspond to the effect of the technique: blue = positive, orange = negative, black = not determined (see Table 14). For parameters printed in black, it is written below the plot whether the response ratio was found to increase or decrease. For parameters printed in grey, the weighted and unweighted analyses contradict each other on the direction of the effect. The font size of the parameter abbreviations corresponds to the number of values in the dataset for that parameter; the key is indicated on the right side. Underlines mean that confidence intervals of parameters do not overlap the point of zero effect in the analysis of unweighted data. Bold print means the same, but for the analysis of weighted data. Parameter abbreviations are explained in Table 12.



Controlled traffic farming

Unfortunately, there are only few parameters available for comparison and for each of them, only few measurements could be extracted from the literature (the maximum is twelve for yield). The effects on physical parameters are rather distinguished and in the desired direction. This agrees well with the propagated purpose of this technique, which is reduction of soil compaction in agriculture (Gasso et al. 2013). In the literature review by Gasso et al. (2013), no clear effect on SOC was found. Here, a clearly positive effect on SOC was found, however, based on only two measurements. In total, there is a significant positive effect on three out of seven parameters with no significant negative effects.

No tillage

Most effects are found for biological and chemical parameters. Effects on physical parameters are often distinct, but not in the desired direction. However, it should be noticed that soil erosion was not part of this analysis (because no measurements on erosion could be found in the publications used) which is thought to be among the key advantages of this technique (see section 2.2.4.2). The increasing effect of no tillage on enzyme activity agrees well with recent findings from a long-term field trial (Mbuthia et al. 2015). In total, there is a significant positive effect on five out of sixteen parameters and one significantly negative effect.

Reduced tillage

Not much can be said on behalf of reduced tillage treatment: Some of the findings for physical parameters are contradicting (decreasing bulk density with increasing penetration resistance) and for yield, no clear direction of effect could be found. This could be related to heterogeneity of practices: Different machinery (for example rotating and pulled machines) is all unified under the term reduced tillage. Maybe this group should be further differentiated in the dataset. In total, there is a significant positive effect on two out of eleven parameters with no significantly negative effects.

Intercropping

Least parameters were available for comparison of intercropping. Nevertheless, the yield increasing effect of intercropping is well confirmed by both weighted and unweighted analysis. This agrees well with suggested advantages of this method (see section 2.2.4.4). In total, there is a significant positive effect on two of three parameters with no significantly negative effects.

Relay intercropping

This technique comes off rather badly: Out of four measured parameters, relay intercropping significantly affected three of them negatively. However, as in the case of controlled traffic farming, the main advantages attributed to this technique (see section2.2.4.5) cannot be investigated with the available parameters. So, either effects of this technique are inadequately captured by the available parameters in this analysis or negative effects are in fact predominant. In total, no positive significant effect on one of the four parameters was found but two significantly negative effects.

3.2.5.3 Now, which technique is the best?

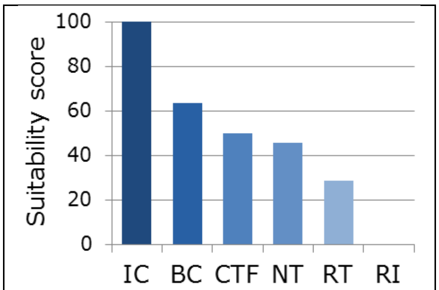


Figure 22 Suitability score to compare techniques: Figure 21 can be used to create rankings of techniques based on a set of criteria

It was pointed out in section 3.2.5.1 that the results of the meta-analysis do not allow for an absolute ranking of techniques regarding soil quality, which means that there is no "best" technique. But the information provided in Figure 21 allows for tailoring a ranking based on desired criteria. An example is shown in Figure 22 for which a relative measure was created: For each technique, the number of parameters of type A and B (see Table 14) was counted, this number is called n. Then, it was counted for how many of those parameters the effect is significant (in either the weighted or unweighted analysis or both) and going in the desired direction. This is called p. The score was then calculated like this : $\text{score} = \frac{p}{n} * 100$. A high score means that a high share of significant positive effects on soil were found for a technique in the meta-analysis and that this technique therefore is suitable for soil conservation in agriculture compared to conventional management. It should be emphasised, however: The suitability score is "born" out of the dataset itself and all parameters are treated as equally relevant. It is an artificial measure to compare results within the framework of this meta-analysis. Other solutions, for example based on absolute number of significant parameters or sample size would be equally valid.

This is also how these results can be applied in practice: The desired direction of effects and relevance of parameters would need to be determined based on soil properties and criteria related to the framework conditions of application. For example, if the soil already has a high pH, techniques found to increase pH would not be given preference. Then, a new (weighted) suitability score for techniques in Figure 21 can be produced. Such a procedure has been suggested for creating soil quality indices in order to decide about management of agroecosystems (Andrews & Carroll 2001). Even though they were thinking of creating an index from scratch, their conclusions also fit to applying the results of this meta-analysis: Scoring functions should be adjusted for local conditions, taking for example soil types into account (id.).

4 Qualitative interviews with Swiss farmers to investigate soil management techniques in context

Chapter abstract

In this section, results of the meta-analysis are embedded in the context of Swiss farming. The two main goals were to find out which other factors besides soil parameters matter when choosing soil cultivation techniques in general and what the effect of the implementation of AP 14-17 is in particular.

Ten in-depth interviews were conducted based on guideline questions with farmers from the Swiss Midlands. Five interviewees operated their farm organically, five used conventional management. Farms had different sizes and different branches and are located in eight different cantons. Interviews were transcribed and coded and codes were further grouped to categories. With the process of coding, pro and contra arguments for the use of different alternative soil cultivation techniques were found as well as explanatory variables involved in the decision process when choosing techniques.

Nine interviewees applied conventional and reduced tillage, while other alternatives as intercropping, biochar application, and controlled traffic farming were not applied or only by few. However, the meta-analysis suggests that reduced tillage has less significant positive effects on soil quality than other alternatives such as biochar application or no tillage. What are the reasons for that discrepancy? First of all, the pro and contra arguments used by interviewees showed that they – as expected – do not stress the same arguments as used in scientific studies, focusing more on “visible” and immediate effects of a technique. Second, several out of 24 factors were found to influence the decision of farmers about techniques, with a minimum set of eight variables that seem to matter to all of the interviewees. These explanatory variables are: Level of knowledge and personal experience (with a particular technique), availability and applicability of that technique, personal concepts, ideals and views of the interviewees, the direct payment system, weed and pest control implications of a technique, conservation of soil as the basis of production in general, physical soil properties and last but not least, profitability and costs associated with techniques.

A closer look at some of the variables of the minimum set revealed that:

- Farmers do not refrain from applying alternative techniques because of lacking interest in soil conservation, but they need more information on alternative techniques in order for them to apply them successfully
- Interviewees see costs of some techniques higher than benefits
- No tillage is mostly not applied because it requires using herbicides and even conventional farmers refrain from no tillage for that reason
- New payments introduced with the implementation of AP 14-17 do not seem to have an effect on decision. In other words, payments intended to motivate farmers to apply soil conserving cultivation techniques fail to meet their purpose. If farmers invest in soil conserving management, it is because of other reasons than direct payments

The interviews suggest that there is unexploited potential to improve soil conservation in Swiss agriculture.

4.1 Methods

Interviewees were selected based on farm size (three categories: <20ha, 20-40ha, >40ha) and management form (two categories: conventional and organic). In total ten farmers from eight different cantons in the Swiss Midlands were interviewed. Interviews were structured based on guideline questions with three different topics: Current soil cultivation on farm, opinion on techniques investigated in the meta-analysis and AP 14-17 reform of the direct payment system. Interviews were recorded and transcribed, including a translation from Swiss German to standard German. Using Atlas.ti, transcripts were coded for pro and contra arguments on techniques and for explanatory factors in decisions on techniques. All codes related to farmers decisions on which technique to apply were assigned to categories of explanatory variables.

4.1.1 Choosing candidates for producer interviews

A sampling scheme based on farm size and management form (organic and conventional) was used. In total ten farmers from eight different cantons throughout the Swiss Midlands were interviewed.

4.1.1.1 Selective criteria for sampling scheme

In a recent qualitative study (Schneider & Rist 2010), 22 producers in Swiss Midland were interviewed on the subject of application of direct drill and no tillage production on their farm. Their sampling strategy was to cover as many different farms as possible, meaning different farm types (main and secondary occupation), different production philosophies (intensive and extensive, organic and conventional production), and different cantonal administrative system (with or without subsidy program). The same approach was used here.

As basic criteria, farms should follow the focus of meta-analysis, meaning grain production in temperate zone. Figure 3 in section 2.2.2 showed that this applies to the Swiss Midlands. Also, since studies conducted under organic and conventional management were used, interviewees should therefore represent both types of management forms. Figure 23 shows size of grain cereal producing farms and their management structure. Most of both, organic and conventional farms have an area between ten and fifty hectares. Smaller farms are more likely to be operated as secondary occupation.

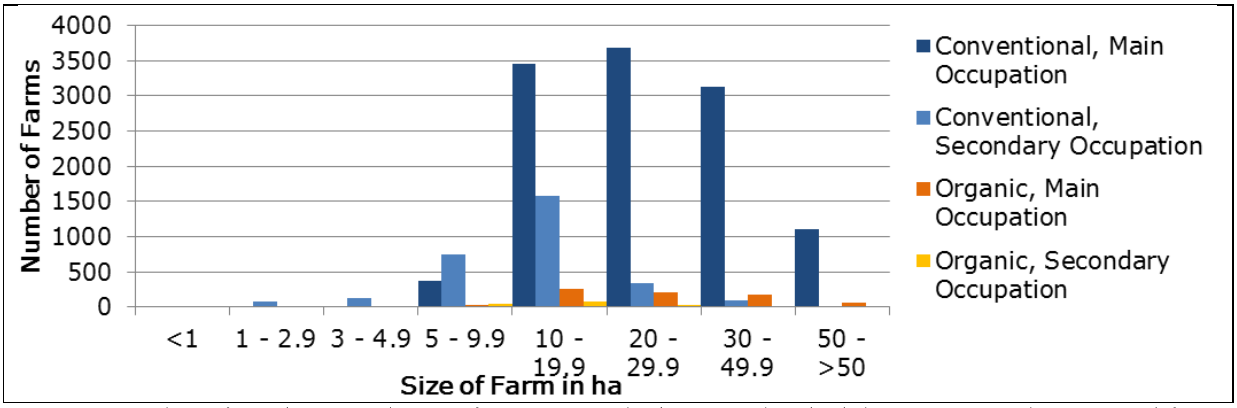


Figure 23 Numbers of mainly grain cultivating farms in Switzerland in 2013 class-divided into organic and conventional farms with farming being either main or secondary occupation of farmers (BFS 2014).

Criteria by Schneider and Rist served as orientation, but because fewer farmers are interviewed, only two criteria are covered: size and management practice (conventional/organic). Size is the main criteria for farm type, whether farms are operated as main or secondary occupation is taken into account, but not as selective criteria. Because there are only a small number of organic farms larger than 50 ha (Figure 23), the threshold is lowered to 40 ha. The proxy for farming philosophy is organic or conventional production system. Also, this is easily available information: For example, organic farmers can be searched for by postcode or place of domicile on the webpage of the certification organisation bio inspecta (Bio.inspecta 2015). Personal information such as age, sex or education of farmers is not used as criteria to facilitate search and to avoid any possibility of personal offence. Also, this would again introduce too much differentiation for too few interviewees. Criteria first of all should help cover the spectrum of cereal producing farms throughout Midlands and are not meant for any comparison between farms. Table 16 gives an overview of selective criteria. Also, I planned to exclude farmers that take part in scientific field trials to avoid bias for certain techniques.

In total, ten farmers from eight cantons were interviewed; more detailed information on interviewees and contacting them is given in Appendix D1 and D2.

Management	**Farm Size (ha)**		
	<20 Conventional	20-40 Conventional	>40 Conventional
	<20 Organic	20-40 Organic	>40 Organic

Table 16 Six different farm types to select interviewees

4.1.1.2 Guideline questions

The type of interviews chosen is semi-structured, in-depth interview, where interviews base on a list of prepared questions but are allowed to "unfold in a conversational manner" (Longhurst 2009). Semi-structured interviews are in the middle of a spectrum from structured interviews with little or no opportunity for respondents to leave the predetermined path to completely unstructured interviews where it is up to respondents to lead conversation (id.). Interviewers guide through a semi-structured interview according to an elaborate list of questions in logical order while giving respondents opportunities to direct conversation (id.). The subsequent sections on choosing participants, defining selective criteria and conducting interviews substantially follow Longhurst's article on in-depth, semi-structured interviews (2009).

Longhurst (2009, p. 581) suggests starting the interview with questions respondents feel comfortable with and keep "more difficult, sensitive, or thought-provoking questions" for the second part. The interview was therefore split in three main parts, which are shown in Table 17. The detailed list of the questions is in Appendix D3.

	Content	**Purpose**
Intro	General questions on the farm	Creating an entry-point to help respondents and me to get used to the interview situation
Part 1	Description of current management on farm	Characterisation of the farm
Part 2	Opinion of the interviewees on techniques investigated in the meta-analysis	Identify factors for decision on techniques besides the soil parameters investigated in the meta-analysis in order to embed the results of the meta-analysis into the context of farming in Switzerland
Part 3	Opinion of the interviewees on influence of direct payment system on farm and farm management	Investigate the initial hypothesis II
End	Questions on management priorities on farm	Assess relevance of soil conservation, closing up

Table 17 Overview of the guideline questions for the interview and their purpose regarding the research question. A list with the questions in detail can be found in Appendix D2

4.1.2 Interview processing

Recorded interviews were transcribed and translated to standard German. In an iterative process, quotes from all transcripts relating to the same concept were assigned a code. Codes were then further grouped into categories. The categories will be discussed in the result section 4.2.

4.1.2.1 Transcribing interviews

Interview processing substantially follows outlines on transcripts and their coding and analysis by Cope (2009). Soon after recording, interviews were transcribed which means that audio-files in Swiss German were typed up and simultaneously translated to standard German. This introduces distortion, because emotions are not so obvious anymore and meaning cannot be conveyed as easily as in spoken language (Cope 2009). Despite introducing additional distortion, translation was important to allow for text and keyword searches that would not be possible in Swiss German transcripts because of different dialects of respondents.

4.1.2.2 Coding transcripts

Transcripts were imported into Atlas.ti, a software package for qualitative data analysis (Atlas.ti 2015). In Atlas.ti, input documents are referred to as "primary documents" and form the basis of analysis by coding (Konopásek 2011). Coding means "a data reduction process of creating categories based either on inherent qualities of the data or on elements predetermined by the researcher to be of particular interest" (Cope 2009, p. 352). Both methods were used: Codes are specifically assigned to answers of guideline questions, but also to patterns in statements not directly related to a question. Assigning codes is a way of conceptualising data, which is the key element of qualitative data analysis (Muckel 2011). Codes represent a concept (id.), so all quotes belonging to the same concept were labelled with the same code. Mostly open codes are used, meaning that codes are overarching keywords rather than actual parts of the quote they are used for (Cope 2009).

The concepts of coding and categorisation (see following section) used here emanate from Grounded Theory, which is sketched briefly in the following box.

Grounded Theory is a theory discovered from systematically collected data in social science and is a concept opposite to theory logically deduced from anterior assumptions (Glaser & Strauss 1998a). The basic idea behind Grounded Theory is that a theory should fit the data, no matter whether they are of qualitative or quantitative nature, and not the other way round (Glaser & Strauss 1998b). Both types of data are suited for both, theory generation and verification (Glaser & Strauss 1998a). However, Glaser and Strauss (id.) were proposing their concept to motivate and guide social scientists to generate theory, denying a primacy of verification. Theory is generated in a permanent process of comparative data analysis (Glaser & Strauss 1998c). Individual conceptual parts of the theory are called categories (id.). Hypothesis of the theory arise from relations between these categories and their properties (id.). They form the framework of a new theory, building the basis for further data sampling and analysis (id.).

Short definition of Grounded Theory

4.1.2.3 Categorisation

Coding was done as an iterative process: Codes were assigned to quotes in the transcripts in a first step; many of them were then merged to what is called in Atlas.ti a "code family". Code families are categories of codes, they are a condensation of codes (Muckel 2011). The iterative coding and grouping of codes is necessary for an efficient analysis (Cope 2009). Categories can only be found during this process, they are not predefined (Muckel 2011). Findings and discussion (section 4.2) rely on categories and codes. Categories (or code families) are listed in the appendix D5, along with an example for coding (D4).

4.1.3 Evaluation of the procedure

This section discusses some issues related to the interviewees that might be conceived as source of bias. For one, this is the fact that almost no women were involved in the interviews and no female farmer was interviewed. For another, this is the fact that one of the interviewees was participating in a scientific study on one of the techniques in question. Also, the process of coding and forming of categories will be commented on.

4.1.3.1 Gender aspects

Female farmers were not interviewed at all (but female partners were sometimes present, see Appendix D1). First of all, because about 95% of farms are managed by men (BLW 2015a), so finding a female farmer is difficult and second, the focus of this work was not to investigate gender. Maybe female farmers would answer the same questions different than male farmers do. Taking female perspectives into account would probably increase the spectrum of answers: After one of the interviews with an organic farmer, his wife told me that other farmers in town are gossiping about them since they changed to organic management, illuminating a social issue about changing farm management that was not address by the farmer during the interview. However, investigating and analysing female in comparison to male perspectives is beyond the scope of my research question.

4.1.3.2 Prepossession

During one of the interviews, I learned that the interviewee made part of his land available for a scientific field trial. Initial misgivings did not hold true, participation in scientific trials do not seem to have any impact on his decisions on soil management. In general, participants are all very interested in different soil management techniques and many have experience with several techniques. This is an advantageous coincidence not planned in the beginning, but which turned out to enrich discussion on techniques a lot. For similar studies with more interviews, experience and knowledge could be taken into account as selective criteria, for example by sending out a questionnaire before choosing interviewees.

4.1.3.3 Process of coding and quality of categories

The discussion of interview findings relies on categories formed during the coding process, so, a few thoughts about the quality of this process seem necessary. According to Muckel (2011), a category (code family) summarising a multitude of codes and even contradicting hypothesis is of high quality. The way to get high quality categories is to constantly search for evidence supporting the category while at the same time looking for contradictions (id.). Are all the categories in this work of high quality? There are two thoughts about this aspect. First, coding requires experience: Muckel (2011) says that she developed a coding style in the course of several research projects; experience I'm certainly lacking since this is my first project of that king. Second, categories are not and do not have to be unalterable, in fact, they remain open during the entire process of theory generation (Muckel 2011). Coding and categorisation are used in this work to generate hypothesis (not an entire new theory, as the theoretical background of these methods may suggest). Creating new hypothesis means to base them in the empirical material (Glaser & Strauss 1998c). This is exactly what has been done during coding and findings presented in the next section all relay on categories and codes derived from interview transcripts. So, even if there are some categories that could be further condensed (which is likely), the quality of findings probably depends more on their strict anchoring in empirical data. In short, categories could certainly be improved but this probably does not affect the quality of derived hypothesis.

4.2 Interview findings and discussion

In this section, interview findings are presented and related to findings of the meta-analysis. In section 4.2.1 interviewees and their farms are described to give an impression of the interview partners. In section 4.2.2, pro and contra arguments from the interviewees on techniques investigated in the meta-analysis are shown and related to the literature. A set of 24 variables explaining the decision of farmers on techniques was found, with eight variables defining a minimum set of variables that presumably applies to all farms in the Swiss Midlands. Section 4.2.4 and section 4.2.5 focus in more detail on two of the variables from the minimum set, costs and direct payments.

4.2.1 Types of interviewees and farms

The initial sampling scheme was based on farm size and farm management system (organic or conventional). Analysing all interviews revealed that neither farm size nor management practice was among the main drivers in decision on soil management technique. Instead, farmers are grouped by their situation in life. Most of them apply conventional and reduced tillage.

The interviews did not reveal any patterns related to farm size. Also, whether a farm is managed organically or conventionally is rather a consequence of and not an explanation for choices. For example, all organic farmers criticised the use of agrochemicals for weed control under no tillage management. The attitude towards chemical weed control therefore explains their choice of techniques and probably also their choice to become organic farmers.

	Smaller than 20ha	**20 to 40ha**	**Larger than 40ha**
Organic	Promoter [8], Lucerne Cropping and animals	Newcomer [6], Zurich Cropping, off-site	Established [2], Thurgau Cropping and animals
	Established [9], Bern Cropping, processing, animals	Established [10], Bern Cropping, animals, off-site, processing	
Conventional	Promoter [3], Zurich Cropping, off-site	Newcomer [4], Aargau Cropping	Second Advance [7], Vaud Cropping, animals, processing, off-site
		Reconsideration [5], Solothurn Cropping and animals	Second Advance [1], St.Gallen Cropping

Table 18 Overview on farms of interviewees. For each, a classifier, canton of domicile, and income branches as well as management practice and size is given. A detailed explication is given in section

In total ten farmers were interviewed out of eight different cantons in Swiss Midlands, an overview is given in Table 18, grouped according to initial sampling scheme (some more details are given in Appendix D5). The table further shows which classifier the farmer is assigned, which canton he is from and which income sources there are. Classifiers are descriptors characterising the farmers, they are explained in more detail in Table 20. Cropping encloses all crops, also vegetables. "Off-site" means services for others, such as agricultural contract work. Some farms further process produces on farm before selling; referred to as "processing".

The management techniques applied on the interviewees' farms are shown in Table 19. The prevailing techniques are conventional tillage with a mouldboard plough and different forms of reduced tillage. Statistics show that this is also true for all arable land in Switzerland: About two thirds are ploughed and only 5% is not tilled at all, see Figure 24. Biochar was applied once by interviewee 8 in the past, but at the time of interview, none of the farmers was planning to apply it. Controlled traffic farming in a strict sense was not applied by any of the interviewees. Two of them, 1 and 7, were indeed setting up GNSS systems, but not for the main purpose of controlling traffic.

	1	2	3	4	5	6	7	8	9	10	Total
Reduced tillage	yes	yes	no	no	yes	yes	yes	yes	yes	yes	8
Conventional tillage	yes	yes	no	yes	yes	yes	yes	no	yes	yes	8
Intercropping	no	no	no	no	no	no	no	yes	yes	no	2
Relay intercropping	no	no	no	no	no	no	no	yes	no	yes	2
Biochar application	no	no	no	no	no	no	no	yes	no	no	1
No tillage	no	no	yes	no	no	no	no	no	no	no	1
Controlled traffic farming	no	no	no	no	no	no	no	no	no	no	0

Table 19 Overview on application of techniques by interviewees. Column numbers are identification numbers for interviewees as presented in Table 18

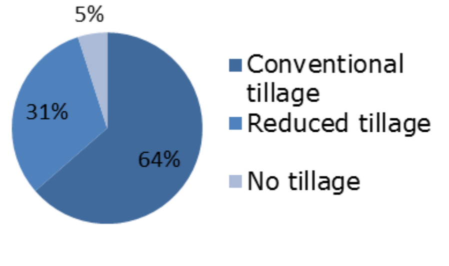


Figure 24 Percentage of arable land in Switzerland by tillage form in 2010 (BFS 2010)

Farms will not be described individually in too much detail because some of them could be identified and anonymity was guaranteed to all interviewees. For characterisation, farmers were classified based on their life situation and their farm management priorities in general. Classification was done after coding and analysing interviews, when personal situation in life was identified as one of the explaining factors for decisions about farm management in general and therefore also about soil management. Table 20 describes in total five classifiers, the previous Table 18 shows which interviewee is assigned to which classifiers.

Newcomer **[4], [6]**	Both interviewees are rather new to farming, but between 40 and 50 years old. They both did not work full time on the farm before they took it over from their retired father or father-in-law. This means that they do not follow a certain strategy but still have to find out what works best. Both of them regularly attend field demonstrations and other training opportunities to acquire information on different management techniques. Their management goals are rather general ideals than tangible concepts. *„What I do is I take further training, I go to field demonstrations and other things I'm interested in. I'm in touch with other farmers in this region, we carpool and discuss. I listen and observe and form my own opinion."* [4]
Established **[2], [9], [10]**	Interviewees in this group manage their farm for at least five years, most of them more than ten years. One interviewee officially took over five years ago but already worked on the farm before. The initial phase of testing and developing a strategy is finished, farm and soil management mostly follow an established rotation and set of techniques. New techniques are tested sometimes, but focus is on improving existing techniques and successful further built up and operation of the farm. One of the farmers will retire in few years and therefore does not want to change his management strategy anymore. *„Right now I think we have only small screws for fine-tuning."* [10]
Second Advance **[1], [7]**	The two farmers in this group were former "established" farmers that recently started to test new techniques, together with their sons that just finished or are about to finish their education and will work full time on the farm. One of them even plans to build up a new branch on farm; both invest a lot into new machinery and in GPS technology. They do not completely change their strategy, but noticeably adjust it. *„We still have a few things to do in soil management. For a year now this is a topic we are actively approaching, my junior and I"* [1].

Reconsideration [5]	There is only one person in this group that is an established farmer but now is reconsidering his management strategy. For one thing, the economic situation of the farm worsened recently, for another thing, he is thinking about how to manage the farm in the future, when he is older and probably without successor. Therefore, he is thinking about major changes on his farm, for example changing to organic production. *„Conventional produce is less and less in demand, it makes you think. Prices are going in one direction only and this is the reason why I started to think about alternatives."* [5]
Promoter [3], [8]	Both farmers in this group are rather young, but could already be part of the established. They both aim at managing their soil with as little inputs and as little negative impacts on soil and environment as possible. Their management strategy is mostly driven by personal conviction and both do advertisement for their technique in some ways. Both are extremely motivated to further develop their technique. *„Since I'm one of the first having this machine, I have the privilege to assist in further developing it. There will be many changes coming up."* [8]

Table 20 Classifiers used to characterise interviewees

It is probably out of coincidence that the two farmers in the "second advance" group both have large farms and manage their farm conventionally, while all of the "established" farmers follow organic management. Also, both farmers in the "promoter" group have clearly less than 20ha. Whether there is a link between those patterns and farm size or not could only be revealed in a quantitative survey.

4.2.2 Pro and contra arguments for techniques according to interviewees

The interviews revealed many arguments for and against techniques that are not directly related to soil quality. These other factors will be investigated in section 4.2.3. For intercropping, biochar application and controlled traffic farming, arguments indicate that some interviewees do not know how to apply them successfully. This means there is unexplored potential for better soil conservation.

4.2.2.1 No tillage

Six respondents judged management forms relaying on minimal and no tillage as beneficial for soil. However, only one of the interviewees actually applies direct seed and also strip tillage. However, for those not applying it, the main reason is the use of herbicides: All of the respondents remarked in some way that minimal or no tillage is not practicable without herbicides today. This is, of course, a knock-out criterion for organic farmers but is also detaining some of the conventional farmers from applying it. There was some disagreement on effect of minimal tillage on weeds: While most participants thought that weeds are favoured, two interviewees brought up the possibility of favouring weeds by bringing weed seeds closer to the soil surface during tillage, facilitating their germination. Erosion control (summarised in the code "increases soil stability and restores structure") was mentioned several times by interviewee 3, but not by other interviewees, even though this is among the important pro arguments found in literature (Loomis & Connor 1992). The arguments used by interviewees seem to differ in two ways from arguments found in scientific literature. For one, the literature contains more arguments on slowly changing and not immediately obvious factors, such as slow warming up of soil (Loomis & Connor 1992), slow N-mineralisation (Frede et al. 1994), or reduced soil erosion (Loomis & Connor

1992). For another, arguments used by farmers relate the technique to farm management in general, while the literature focuses solely on the technique itself, for example, seven interviewees criticise no tillage management to be incompatible with an organic management strategy on farm.

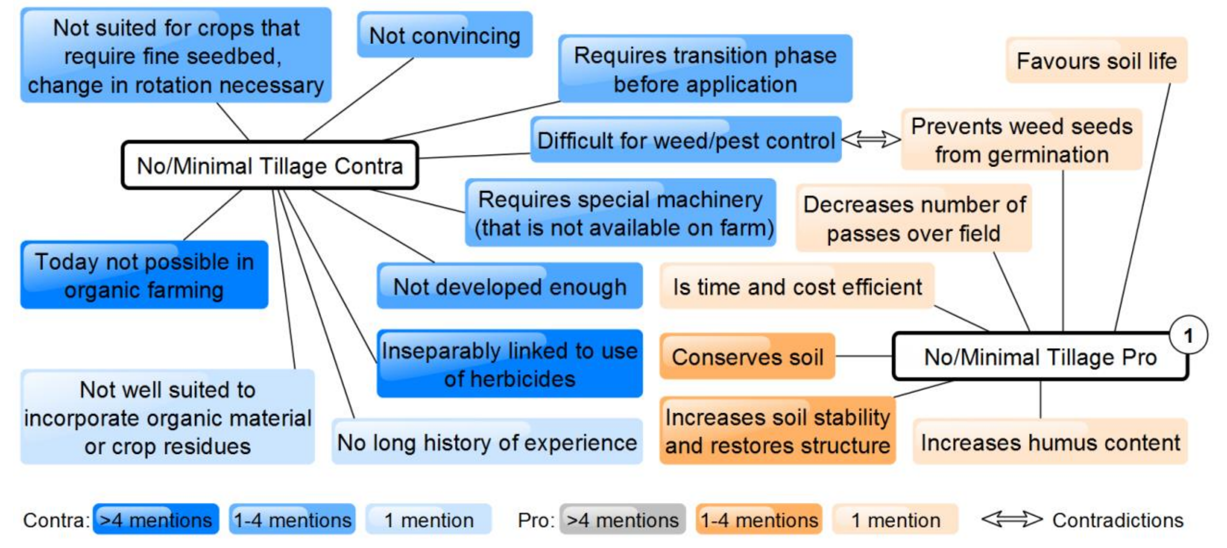


Figure 25 Pro and contra arguments for no or minimal tillage. The number indicates how many of the interviewees apply this technique. Different colours indicate number of interviewees who mentioned a certain argument.

The contradiction related to weed control came up for the other two tillage forms as well: While most interviewees see ploughing as the best way to suppress weeds, interviewee 3 was convinced that any form of tillage brings weed seeds closer to the soil surface where they are more likely to germinate, therefore increasing weed pressure compared to no tillage. A review article following this question found that weed seeds brought close to the surface by tilling indeed are likely to germinate while under no tillage weed seeds always remain close to the surface where they are likely to decay (Chauhan et al. 2006). However, there are many factors besides tillage influencing germination and not all interactions are understood (id.). So, the contradiction rather arises from different combinations of factors resulting in different weed populations than from one position being wrong and the other one right.

Pro and contra arguments for no tillage management have already been investigated with qualitative interviews among Swiss farmers (Schneider & Rist 2010). Arguments in Figure 25 agree well with the findings of Schneider and Rist (2010), with one remarkable difference: They found social and aesthetic aspects such as the opinion of neighbours to be important, underestimated factors in decisions. Such arguments were not brought up by interviewees for or against techniques, but where sometimes mentioned in a more general way; by organic farmers. For example, the girlfriend of an interviewee said: *"If you are in this social fabric of farmers, you get a lot of that at the pub: Swine, such a mess on the field!"* [6].

4.2.2.2 Reduced tillage

Again, erosion control was not mentioned in interviews but is considered to be one of the benefits of the method in the literature (Loomis & Connor 1992). All interviewees except number 4 (who has never applied reduced tillage) mention one or more pro arguments. At the same time, all except number 8 (who does not apply conventional tillage) also mention one or more contra arguments. Also, some of the arguments used contradict each other. This resembles results of the meta-analysis, where some effects contradicted each other and the direction of effects was often not clear (see section 3.2.5.2). A plausible reason for these inconsistencies is the vague definition of reduced tillage, allowing for a number of methods (different machinery, different tillage depth) to fall under the term reduced tillage. The interviewees used a narrower definition by using the term shallow tillage. Loomis and Connor (1992b) count chisel ploughs with a tillage depth of 20cm to the group of reduced tillage methods, while one of the interviewees explicitly says: *"Whether you use a chisel plough to 20cm or you turn the soil [meaning conventional tillage], that is no difference to me"* [3]. The definition used by interviewees corresponds to the direct payments for soil conserving management which are issued for methods with tillage no deeper than 10cm (see Table 9). Using a narrower definition for both meta-analysis and interviews would have probably led to more expressive results.

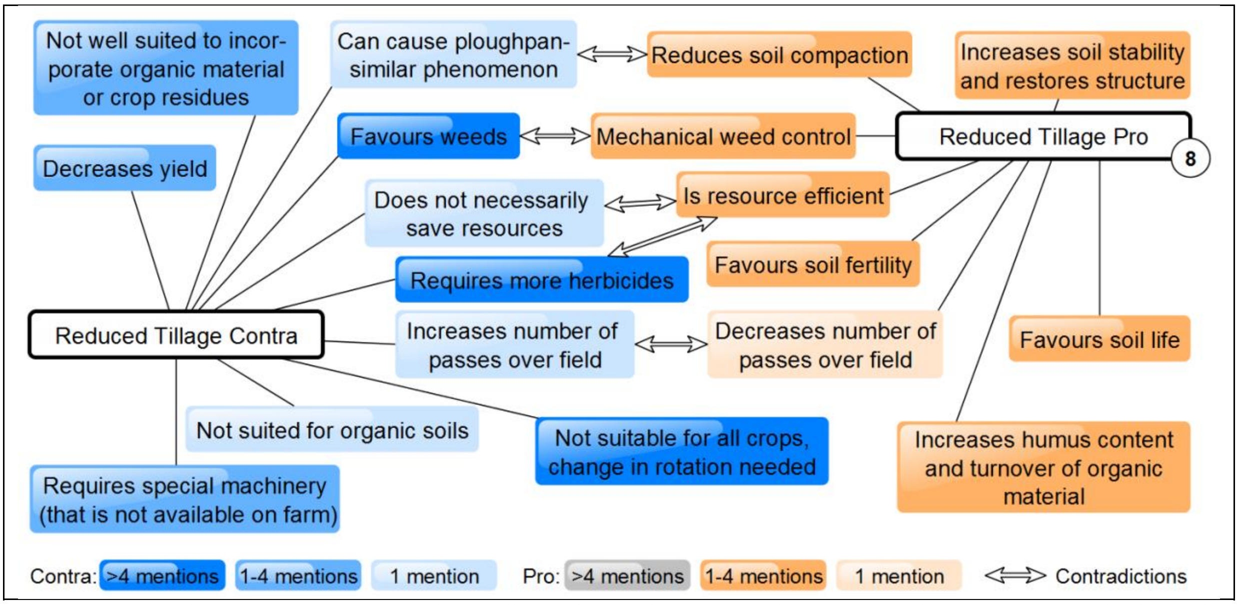


Figure 26 Pro and contra arguments for reduced tillage. The number indicates how many of the interviewees apply this technique. Different colours indicate number of interviewees who mentioned a certain argument.

4.2.2.3 Conventional tillage

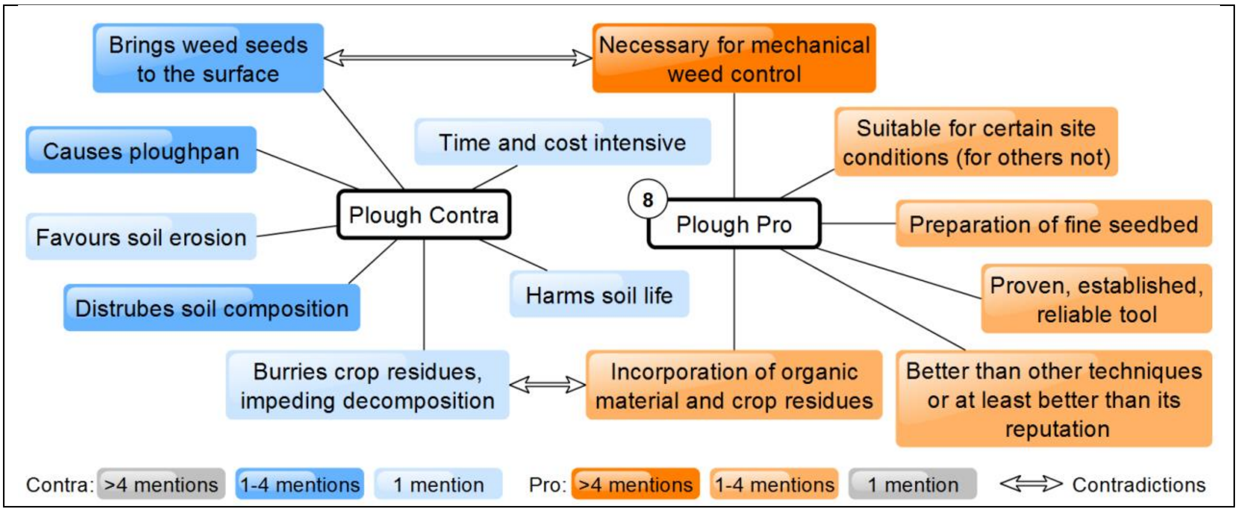


Figure 27 Pro and contra arguments for conventional tillage. The number indicates how many interviewees apply this technique. Different colours indicate number of interviewees who mentioned a certain argument.

The variety of arguments for and against conventional tillage is smaller than for other techniques. The reason for that is that respondents treated some pro arguments for other tillage methods implicitly as contra arguments for ploughing and vice-versa, confirming that conventional tillage is the default. Here, soil erosion has been mentioned by one interviewee.

The contradiction regarding weeds has already been commented on in the section on no tillage. The contradiction regarding incorporation of organic material is probably the result of different burial depth interviewees had in mind: Besides other factors, biologic activity in soils is decreasing with depth (Scheffer & Schachtschabel 2010c), influencing decomposition of plant residues (Scheffer & Schachtschabel 2010f). This could have been verified directly during the interviews by more detailed questions.

The argument that ploughing is better than its reputation implies interviewees are experiencing a negative connotation of ploughing. Two interviewees made this thought explicit: *"The plough is being demonised"* [10]. The reason seems to be the support given to minimal and no tillage practices by the administration via direct payments: *"These are things that gain acceptance, because of the money, I mustn't say it, but direct seed is something sacred for college-men"* [5].

4.2.2.4 Relay intercropping

Pro arguments brought up in interviews agree well with arguments found in scientific literature (see section 2.2.4.5). Interviewees however brought up more negative arguments related to farming practices, for example cost-effectiveness. Four interviewees think that not enough information is available to apply relay intercropping with success. In fact, many of the interactions are not fully understood yet by scientists (Ehrmann & Ritz 2014). More field trials could probably reduce some of that uncertainty.

Seven of the interviewees see positive aspects about relay intercropping, but at the time of interviews, only two were applying it. However, one was testing it and two were planning to try it in the following season. Many arguments for not applying it are somehow related to the fact that undersowing cannot be applied in a way for efforts to pay off. For this technique, there is probably the most agreement between the valuation by interviewees and findings from the meta-analysis: In both, relay intercropping comes off badly, especially regarding yield losses. At least one of the interviewees explicitly considers relay intercropping in spite of possible yield losses: *"Just because it might affect yield negatively is not a reason for me to not do it"* [9].

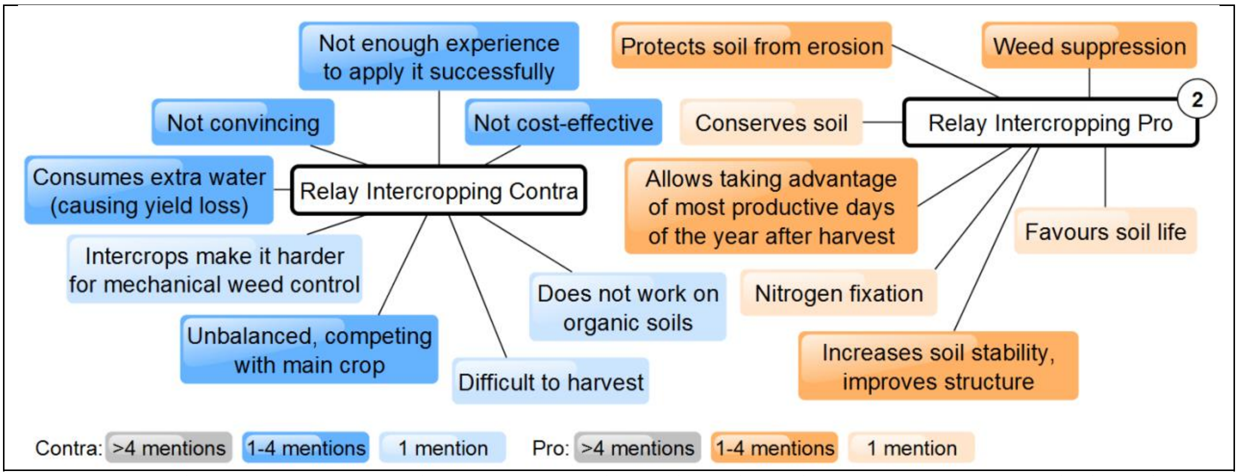


Figure 28 Pro and contra arguments for relay intercropping. The number indicates how many interviewees apply this technique. Different colours indicate number of interviewees who mentioned a certain argument.

4.2.2.5 Intercropping

The judgement is even more obvious for intercropping than for relay intercropping: Only the two respondents who actually practice intercropping see benefits of this technique, while for most of them, efforts are too high compared to expected benefits. Compared to relay intercropping, more economic reasons were alleged: Even if interviewees think they could intercrop with success, they do not see sales potential. Three arguments were used in those cases:

- Does not fit in management strategy: *"Such a blend, we could not even use it, it is not suitable at all for beef cattle fattening"* [7]
- Not suited for all crops: Interviewee 5 produces potatoes and does not see how he could combine potatoes with another crop
- Difficult to sell: When asked about pea-oat intercrops, interviewee 6 said: *"I would do it, if there was a market demand"*

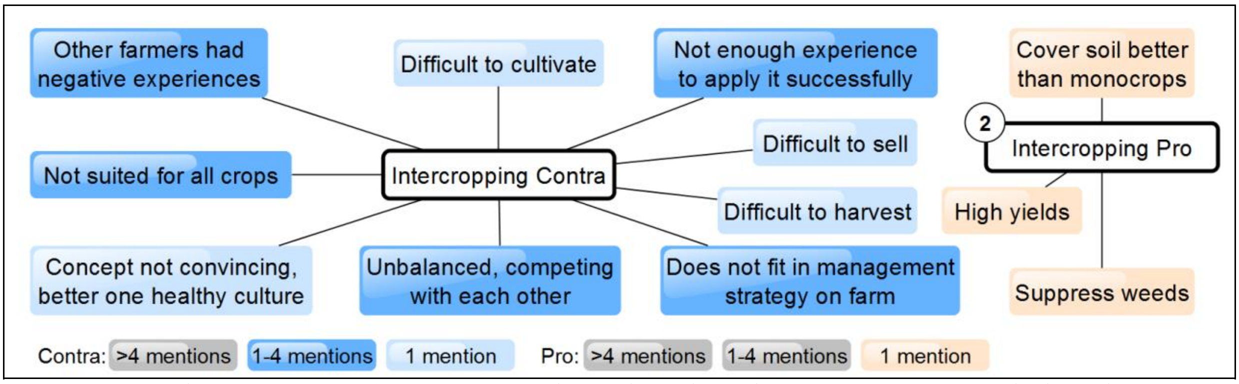


Figure 29 Pro and contra arguments for intercropping. The number indicates how many interviewees apply this technique. Different colours indicate number of interviewees who mentioned a certain argument.

Compared to the literature, most of the negative arguments were brought up in interviews, while only three positive arguments were mentioned. Again, invisible aspects were not mentioned, for example reduction of nutrient leaching (Ehrmann & Ritz 2013) or lower grain protein contents (FiBL 2013).

Another argument that could not be found in the literature is the experience of colleagues. One of the respondents saw a barley-pea intercrop: *"A farmer in our town did that, but so far all you can see are peas, nothing else"* [6]. While this observation did not discourage him from planning a similar intercrop for the next season, others might refrain from such experiments.

Also, personal opinions seem to matter as well: One of the interviewees prefers to focus on one crop, *"better one, but sound"* [10].

Given the results of the meta-analysis, there seems to be a lot of potential for development of intercropping. The yield increase associated with intercropping found in the meta-analysis is the best confirmed of all techniques (significant in both, the analysis of weighted and unweighted data). Also, soil organic carbon is increased. Both are parameters of high importance for the interviewees.

4.2.2.6 Biochar application

Biochar is mostly not applied because respondents do not know it or do not see a need to apply it. Only one of the participants applied it after being won over by a talk of a consultant, and was disappointed: *"He [a consultant] told me this is the only remedy to save the planet. Well, in my opinion, it is not"* [8]. Two of the respondents, 2 and 10, would consider it, if more information and proof of success was available. Since only one person actually applied biochar and did not mention any advantages, the positive arguments listed here do not base on personal experiences of interviewees.

Apparently, not only farmers experience uncertainties related to biochar application, but also scientist. Advocacy for biochar application has been criticised for lacking sufficient scientific basis (A. Mukherjee & Lal 2014).

In spite of those uncertainties, the results of the meta-analysis for biochar application are surprisingly unambiguous: Most parameters were affected in a positive way by biochar application compared to controls, in five cases even significantly compared to other techniques. Measured by positive effects on soil parameters, biochar application was the second best technique after intercropping. As with intercropping, there seems to be some unexplored potential of biochar application in Swiss farming.

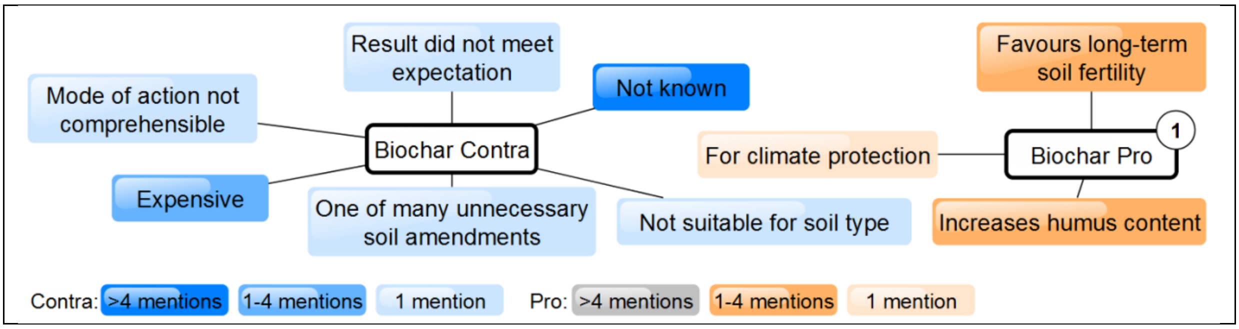


Figure 30 Pro and contra arguments for biochar application. The number indicates how many interviewees have applied this technique. Different colours indicate number of interviewees who mentioned a certain argument.

4.2.2.7 Controlled traffic farming

None of the respondents applies CTF or would even consider it. High costs discourage most small farmers from investing in this technique. Two farmers (1, 7) invested or plan to invest in GNSS technology, because they are interested in high management precision associated with GNSS controlled tractors and not at all because they plan to define fixed tracks. Five interviewees criticised the concept of fixed tracks for being not applicable under Swiss conditions with small fields and small working width of machinery: *"The most common working width is 3m for sowing. We once had a closer look at it [CTF], if you overlay all the tracks you end up with about 50cm that are not wheeled"* [3]. Also, the shape of fields is a problem: *"I think, on really big fields, it might make sense. But here, with small parcel sizes that are not even quadrangular, where you can drive in from only one side, and I even can't turn around because of railway tracks, here, I think, it's just too expensive"* [4].

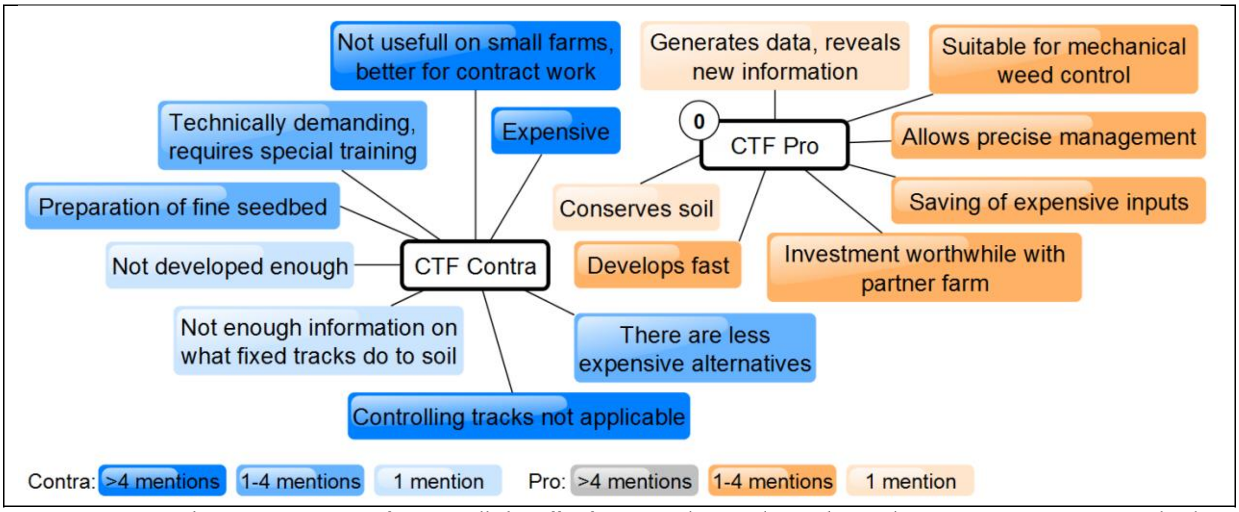


Figure 31 Pro and contra arguments for controlled traffic farming. The number indicates how many interviewees apply this technique. Different colours indicate number of interviewees who mentioned a certain argument.

Comparing arguments of interviewees to the literature suggests that most of them were probably thinking of precision agriculture rather than traffic control. Precision agriculture aims at managing inputs by use of technologies such as GNSS in order to increase cost efficiency, productivity, and environmental gains (Hedley 2015). In the literature, CTF is first of all seen as beneficial for physical soil parameters, especially for reduction of compaction (Gasso et al. 2013), while interviewees stressed advantages related to the use of GNSS steering systems. This does not mean that interviewees do not consider soil compaction to be irrelevant, in fact, five of the interviewees see heavy machines as cause of soil compaction and think machine weight should be reduced in consequence. However, with many passes, even light machines can cause severe compaction and avoiding compaction by CTF rather than just reducing it was found to be the better solution in a review by Chamen et al. (2015).

4.2.2.8 Summary pro and contra arguments

The key findings of the previous sections regarding the research question are the following:

- First, the three techniques intercropping, biochar application and controlled traffic farming that were found to have significant positive effects on soil parameters were least applied among interviewees. Among the main reasons is the lack of information on those techniques. Biochar application and controlled traffic farming are not well known as techniques. Intercropping is known, but interviewees do not know how to apply it successfully. In other words: There is unexploited potential to improve soil conservation by better transfer of information, e.g. by field trials.
- Second, arguments used by interviewees differ from arguments used in scientific studies in two ways: Interviewees used more arguments not related to measurable parameters as used for the meta-analysis; this will be discussed in the following section 4.2.3. Also, if soil parameters were mentioned, then rather the ones with immediate effects, suggesting that the effect of other parameters is either too small to be noticed (effects found to be significant in the meta-analysis do not need to be necessarily relevant) or that it is underestimated.

4.2.3 Explanatory variables for decision about techniques

The decision about applying or not applying a certain soil management technique on farm can be thought of as an equation with the outcome of the decision as result and factors taken into account as explanatory variables. A maximum range of variables was identified from all interviews. For individual interviews, the set of variables is expected to vary and also the weights implicitly attributed to each variable.

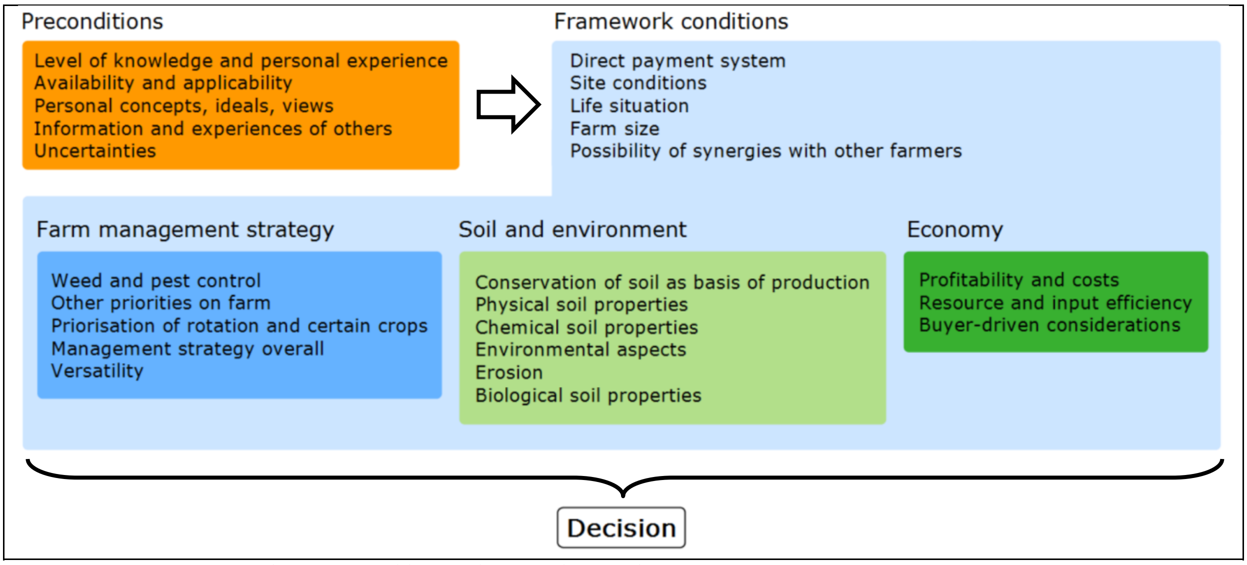


Figure 32 Overview on explanatory variables for decision about techniques

In total 24 variables were found that can be assigned to one of five groups, all of them are shown in Figure 32 and are explained in the following subsections. Each variable is illustrated by a quote as an example for what kinds of answers were attributed to which category. A colour code indicates for how many farmers a variable matters for decision. However, the colour code cannot be used immediately as indicator of priority. Especially variables that were mentioned less often can be nevertheless highly relevant for individual farmers. An overview on which codes were summarised to which variable is given in Appendix D5.

4.2.3.1 Preconditions

Preconditions are shown in Table 21. They can act as disqualifiers: If certain preconditions are not met, applying a new technique is off the table or will not be considered upfront.

All (10)	Level of knowledge and personal experience *"As soon as I know my craft a bit better I think I would try it [intercropping]."* [4]
All (10)	Availability and applicability *"With a bigger chisel it might be possible, but there is no one around here who has one and my tractor would be too weak for it anyways."* [10]
All (10)	Personal concepts, ideals, views *"In my view, soil should be cultivated. Of course, it should be organic production; it would be more ecological, more sustainable."* [8]
5 to 6	Information and experiences of others (1, 3, 5, 6, 8) *"They used to do barley-pea intercrops here, but well, I don't know what they did wrong, but it was always unbalanced."* [3]
less than 5	Uncertainties (3, 4, 7, 10) *"Some say you should use as large tyres as possible, to conserve soil. But with controlled traffic, you should not roll the entire field, well..."* [3]

Table 21 Explanatory variables that are preconditions for decision with example quotes. The colour code indicates for how many of the interviewees the variable matters in decisions.

All (10) | 7 to 9 | 5 to 6 | less than 5

Level of knowledge and personal experience

Six interviewees had negative experiences with intercropping forms, keeping some of them from applying it again. Reversely, positive experiences encourage application: Six interviewees mentioned positive experiences with ploughing; all of them use it regularly. If interviewees think they do not know enough about a technique to apply it successfully, it can keep them from applying it as well. Missing information was an issue for nine interviewees. Two interviewees criticised national scientific institutions for not providing more information on techniques, for example from field trials. Seven interviewees handle the problem of lack of experience by testing techniques themselves. Regarding CTF, it has already been pointed out in section 4.2.2.7 that most interviewees probably had precision farming in mind rather than fixed tracks, which are the essential element of CTF. However, this was only made explicit by one interviewee.

Availability and applicability

For intercropping forms, CTF, no tillage and reduced tillage, interviewees saw problems regarding the availability of these techniques, for example, four interviewees mentioned that machinery for zero tillage farming is not developed enough yet. Also, interviewees do not think that all techniques are equal regarding their applicability: Seven interviewees think that today, zero tillage cannot be applied under organic management. Five of them think that managing soil with fixed tracks (CTF) is not possible in Switzerland. Doubts about applicability were also mentioned related to intercropping forms and reduced tillage.

Personal concepts, ideals, views

Probably the most important precondition is personal perspective of interviewees, even though rarely mentioned explicitly. The example quote in Table 21 shows: Personal opinions impact important strategic decisions such as managing a farm organically, which in turn impact decisions on soil management techniques substantially. Another example is balancing cropped area and ecological compensation area: Three interviewees think that food production is more valuable than set-aside, and two of them indeed invest more into soil conserving management than in set-aside.

Information and experiences of others

Besides own experiences and testing of techniques, information from others, farmers or experts, are taken into account. Regarding techniques, this aspect was relevant for biochar application and intercropping: The interviewee who applied biochar once felt that he was not given good advice by an expert. Three interviewees saw other farmers being unsuccessful with intercrops, keeping two of them from trying it themselves.

Uncertainties

Decisions related to techniques and soil management in general can be impeded by uncertainties. This was, however, only mentioned by four interviewees. Two of them problematised the fact that information on techniques and their effect sometimes contradict.

What is the consequence of these preconditions on the investigated techniques? The reasons given in the interviews for and against application of techniques showed that the techniques found to have positive effects on soil quality in the meta-analysis are the least known among interviewees (see section 4.2.2.8). Techniques that are not well known such as biochar application but also controlling field traffic, are, in consequence, not applied either. This is insofar surprising since none of the techniques is new: For example, a review on controlled traffic farming was already published in 1982 (Morling 1982), no tillage has already been practiced in the fifties of the last century (Link 1954) and intercropping techniques are even much older (Hauggaard-Nielsen et al. 2001). The most recent is biochar application, introduced in Switzerland in 2013 (Klimastiftung Schweiz 2013), which would explain why it is not widely known and applied.

Level of knowledge was found to be an explanatory variable in decision applying to all interviewees; it is assumed that this would remain a relevant factor in a representative survey. This means that techniques as for example CTF are not considered in the first place by many farmers in Switzerland and that in reverse increasing the level of knowledge about alternative techniques would eventually lead to their adoption and ultimately lead to better soil conservation.

4.2.3.2 Framework conditions

Framework conditions are not really variables but rather constants in decisions about techniques, because they enclose all circumstance a farmer faces at the time point of decision that cannot be changed quickly or easily.

Direct payment system

As one of the farmers put it: *"This is the system we're in and that's the way it is. Some are okay with it, others not"* [1]. Many interviewees judged direct payments to have a weak influence on their decisions about management. However, it should not be disregarded that all of the interviewees fulfil requirements of proof of ecological performance in order to be entitled for payments at all, so in fact they all have to adjust their management to it somehow. The extent of this adjustment is controversial among interviewees; opinions are on a range between the following two extreme positions: *"To do anything, just for payments? I don't do that, it goes against the grain for me, I don't take bribes, no"* [8], while interviewee 1 argued from an economic perspective, saying that many farmers until today did not understand that extending ecological compensation areas on unproductive land is more profitable than cropping. Others were less drastic and largely agreeing with the quote in Table 22. In total, nine interviewees said that the implementation of AP

14-17 did not motivate them to change their management strategy profoundly and four explicitly pointed out that new payments for conserving management are not enough for new investments in soil management techniques.

Site conditions

Obviously, techniques have to fit site conditions on a farm. For example, interviewee 5 does not want to apply relay intercropping because he thinks the intercrop would compete with the main crop for water on the sandy soils on his farm.

Life situation

Personal situation in life has already been used for grouping interviewees in section 4.2.1, because it seems to be related to motivation of interviewees to apply or invest in new techniques: *"I'm 47; it won't take that much longer to 65. So I really have to think about: What is worthwhile investing in?"* [6].

Farm size

As mentioned in section 4.2.1, farm size seems to play a minor role in decision, since only few interviewees mentioned it explicitly. Nevertheless it has importance when it comes to large investments in expensive techniques as is the case with GPS technology for controlled traffic farming. When respondents said, their farm is too small to invest in GNSS they often also meant that their investment volume is too small: *"It is too expensive; it makes absolutely no sense on a 20ha farm"* [6].

Possibility of synergies with other farmers

However, even expensive techniques and machinery become affordable if there is a partner nearby to invest with. For those interviewees who have reliable partnerships with other farms, expensive investments become an option, no matter how many hectares they have. *"Somehow we have to create synergies; we do not have any fears of contacts"* [1].

Direct payment system *I don't really mind it [payment program], I do what seems best for my soil, whether I get money for it or not. It is nice if I do get money and if not I do it anyway."* [9]
Site conditions (1, 2, 3, 4, 5, 7, 9, 10) *"From here to the Rhine, we have everything from sandy to organic soils, and all within 500m. It really causes trouble."* [1]
Life situation (1, 2, 3, 4, 5, 6, 8, 10) *"I used to be the kind of person who immediately tried new things after reading about it, but I don't do it anymore. Juvenility is over."* [8]
Farm size (2, 4, 5, 6, 9) *"Well, on our small parcels, this [CTF] is a non-issue. They apply it in eastern Germany, but they have huge farms there."* [5]
Possibility of synergies with other farmers (1, 7, 9) *"We did not buy it by ourselves; we bought the reference station together with a contract worker in our town."* [7]

Table 22 Explanatory variables grouped for being framework conditions with example quotes. The colour code indicates for how many of the interviewees the variable matters in decisions.

All (10) | 7 to 9 | 5 to 6 | less than 5

4.2.3.3 Farm management strategy

Weed and pest control

The opinion of interviewees about forms of weed control impacts decisions and judgements on techniques more than management form (organic or conventional). Not only for organic farmers but also for their conventional colleagues, form of weed control associated with a certain technique was among the most important explanatory variables. No tillage, which was seen by all interviewees to be associated with chemical weed control (see section 4.2.2.1), is out of questions for those interviewees who do not can or want to relay on regular use of herbicides which was the case for nine out of ten interviewees. Misapplication of chemical weed control was problematized by all of them, especially one particular active agent: Seven interviewees explicitly referred to glyphosate. Negative reactions to use of herbicides in general ranged from *"we cannot apply it, for spinach, we have zero-tolerance"* [1] to *"it is a pity what we dump in our soils"* [6] to even more drastic views *"we don't know about long-term effects, or maybe we do, Agent Orange in Vietnam, for example"* [4].

Other priorities on farm

Interviewees that have other branches on farm than cropping have to consider those when allocating resources. For example, four interviewees mentioned animal husbandry; two interviewees see ecological compensation as branch to invest in.

All (10)	Weed and pest control *"I have to say, I think it is disproportional how much herbicide is used instead of a plough. It really makes my hair stand on end."* [2]
7 to 9	Other priorities on farm (1, 2, 3, 4, 5, 7, 8, 10) *"Here, a lot revolves around our animals, this is really time-consuming."* [5]
7 to 9	Prioritisation of rotation and certain crops (1, 2, 3, 5, 6, 7, 8, 9, 10) *"Well, sugar beets are a crop that is traditionally cultivated in this area; they usually did well and nearly brought in the most money."* [6]
7 to 9	Management strategy overall (1, 2, 3, 5, 6, 7, 8, 9, 10) *"No, I don't want to change anything anymore. I don't see any reason why. That might sound a bit, well..., but we are successful, we have good yields, all is fine."* [2]
5 to 6	Versatility (1, 2, 4, 5, 7) *"We plough everything. For one, because we bring manure and recycling fertiliser on our fields and plough is well suited to incorporate it. If you work with plough, you can also fight back pathogens."* [4]

Table 23 Explanatory variables that are related to overall management strategy on farm with example quotes. The colour code indicates for how many of the interviewees the variable matters in decisions.

All (10) 7 to 9 5 to 6 less than 5

Priorisation of rotation and certain crops

Not all crops in rotation are equally important. For some interviewees, new techniques are evaluated by their impact on preferential crops, cash crops, so to speak. So does for example interviewee 6 who is experimenting with sugar beet production under organic management (see quote in Table 23). Six of the respondents judged techniques based on their compatibility with the chosen rotation on farm. Four of them give priority to particular crops: Techniques are considered if they fit that purpose.

Management strategy overall

Actually, all variables in the group farm management strategy could have been tied together into this variable. However, separate variables were formed to differentiate between general references to management strategy (for example concerning organic and conventional management form) and explicitly mentioned aspects such as weed control.

Versatility

For about half of the interviewees a wide application range of a technique matters, techniques should fit all purposes and not restrict them for example to certain crops.

4.2.3.4 Soil and environment

Chemical, physical, and biological soil properties

No obvious difference between organic and conventional farmers was found for most variables, except for variables related to soil and environment. While all interviewees mention in some way the importance of soil conservation (four of them explicitly refer to soil as the basis of production to the next generation), a closer look reveals that many of them actually have physical soil properties in mind, especially soil compaction by heavy machines: Nine of the ten interviewees declared they want to reduce soil compaction. This is not surprising since cause and effect of compaction are readily apparent: *"I compare it to jelly: You can put something light-weight on top and it carries it, but if it's too heavy, it collapses. So does soil."* [3]. Differences show up when taking other soil properties into account: All organic farmers mentioned chemical soil properties and three mentioned biological properties, while only two respectively one of the conventional farmers did so. The reason is implicitly given by the quote on chemical soil properties: Organic farmers have to find ways to bring nitrogen into the soil. One could add: Because they cannot draw on artificial fertiliser. Four of the five organic farmers interviewed put emphasise on humus accumulation: "If you get humus accumulation right, it's a fact, humus is a key to almost everything. Increase and sustain humus content." [10].

All (10)	Conservation of soil as basis of production *"In the end this is our capital, a healthy soil. This is really important to me."* [5]
All (10)	Physical soil properties *"I think soil conservation is important, if I ever buy a bigger tractor, I will pay attention to tyres, to reduce pressure."* [4]
5 to 6	Chemical soil properties (1, 2, 3, 6, 8, 9, 10) *"[About relay intercrops] I think every organic farmer has to deal with legumes, to bring nitrogen into the soil."* [6]
5 to 6	Environmental aspects (1, 3, 4, 6, 9, 10) *"I think we should care more for nature. If I can contribute a small share, I am willing to do so."* [4]
5 to 6	Erosion (1, 3, 4, 6, 8, 9) *"The advantage [of intercrops] is that it covers the soil quicker than sole cropped cereals."* [8]
less than 5	Biological soil properties (5, 6, 8, 9) *"Not to disturb the structure of the soil: This protects earthworms and soil life in general."* [9]

Table 24 Explanatory variables related to soil and environment with example quotes. The colour code indicates for how many of the interviewees the variable matters in decisions.

All (10) | 7 to 9 | 5 to 6 | less than 5

Erosion

While good physical soil properties are a concern to all interviewees, many seem to be less aware of physical soil loss as erosion or degradation by surface sealing. One of the interviewees criticises his neighbours for ignoring it: *"We don't have erosion problems, that's what everybody says here. But in spring I was out there with my camera to document it: Soil has been washed away in tons"* [3]. Erosion was mentioned in total ten times by six interviewees during interviews, while physical soil properties were mentioned by all interviewees, in total more than forty times.

Environmental aspects

Another pattern shows up for the newcomer group (see Table 20). They do not have a consolidated strategy yet but rather guidelines for decisions. There, a broad perspective on environment seems to play an important role. The quote on environmental aspects in the table is from one of the newcomer.

4.2.3.5 Economy

Profitability and costs

No surprise at all, aspects of profitability and cost considerations are among the most mentioned variables. Six respondents mentioned increasing profitability as a management goal. How do they value it compared to soil conservation? According to self-declaration of five interviewees, profitability and soil conservation together have highest priority in decisions on farm management: *"The way we understand soil conserving management, it has highest priority together with profitability. I'm convinced that in the long run they are connected anyways."* [10]. Two interviewees pointed out that soil conservation could never be given higher priority than profitability within an agricultural framework, because this would mean: *"Planting trees, leave it and done! Set-aside would be perfect for soil."* [10].

Resource and input efficiency

While profitability and costs refer to direct money flows, resource and input efficiency encloses those aspects of economic efficiency where money is not visible at first sight. One of the conventional farmers for example said about reduced tillage: *"You need much less energy to prepare your field, without using too much diesel for example. You don't even need a big tractor."* [5].

Buyer-driven considerations

Farmers are not completely independent when deciding about techniques or new investments on farm in general. They take the entire chain including buyer and sales markets into account. If a technique seems to be disadvantageous for current important sales relationships, it is not considered anymore, especially from those farmers in vegetable and fruit production. The following quote is part of the answer of one of the conventional vegetable farmers to the question why he does not want to apply minimal tillage. After talking about weed control, crop residues and rotation, he said: *"It is also related to buyers: Do we leave certain markets or not. It is complicated, first, you need to manage to get in and then you need to manage to stay in"* [1].

	Profitability and costs *"This is the goal we followed for the last ten to fifteen years: Least possible harm to soil with highest possible return. With little expense and little machinery."* [3]
	Resource and input efficiency (1, 3, 4, 5, 6, 7, 8, 9, 10) *"[Reduced tillage] is reasonable; you need less energy to prepare your field, without using too much fuel, for example."* [5]
	Buyer-driven considerations (1, 5, 6, 7, 9, 10) *"They told me not to do oat-pea intercrop, because the cereal collection centres can hardly get rid of it."* [6]

Table 25 Explanatory variables belonging to group "economy" with example quotes. The colour code indicates for how many of the interviewees the variable matters in decisions.

All (10) | 7 to 9 | 5 to 6 | less than 5

4.2.3.6 Summary of explanatory variables

As expected in the hypothesis on the research question, soil physical, chemical, and biological parameters matter in decision about soil cultivation techniques, but as three of 24 different variables. The lowest common denominator among all interviewees, meaning the variables that matter to all of them, is shown in Figure 33.

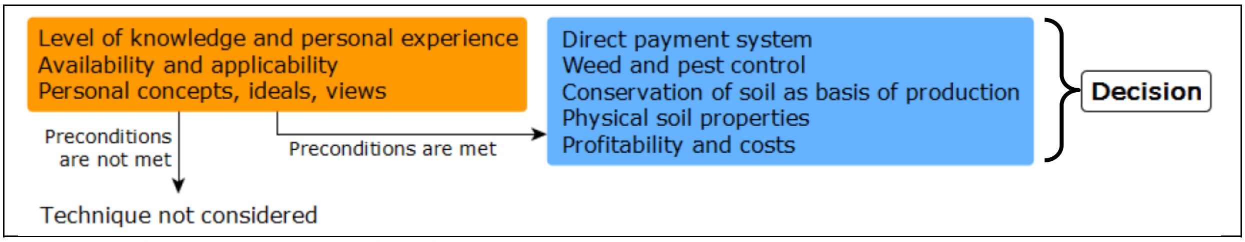


Figure 33 Subset of explanatory variables that matters to all interviewees and can be seen as lowest common denominator or minimum set of variables for decisions. Compare to maximum set in Figure 32. The variables in the orange box on the left act as preconditions, preselecting techniques considered in the decision process.

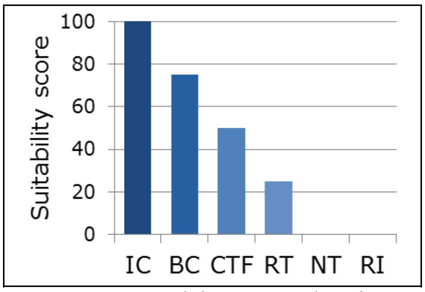


Figure 34 Suitability score based on physical soil parameters and yield, calculation is explained in section 3.2.5.3.

I hypothesise that this minimum set of variables is involved in decisions on techniques of farmers in Switzerland; a representative survey could verify this assumption (Deduction I). Regarding the parameters investigated in the meta-analysis, the minimum set suggests that all farmers put an emphasis on physical parameters and yield, while a smaller group also takes chemical properties into account and even fewer also biological parameters. So, how would a ranking as done in section 3.2.5.3 look like if only physical parameters and yield were taken into account? The result is shown in Figure 34 and is very similar to the ranking shown in Figure 22. Again, the well-known techniques can be found at the low end. Taking only yield into account, the ranking would be IC > BC > CTF ~ RT ~ NT > RI, with CTF, RT, and NT not being significantly different from conventional management. This means that when taking some of the preferences of farmers into account, results of the meta-analysis suggest that intercropping, biochar application, and controlled traffic farming are alternatives to conventional management that have a potential to both fit in farmer's decision criteria and support soil conservation. Reduced tillage has some beneficial effects on physical parameters, but no advantages regarding yield.

4.2.4 Costs of techniques

Costs were found to be an important factor in decisions (see section 4.2.3.6). In fact, acquisition costs for techniques differ substantially: Intercropping and reduced tillage have the lowest acquisition costs among techniques studied in the meta-analysis. Whereas adopting controlled traffic farming or no tillage is expensive. It is likely that costs impede widespread application of these techniques.

While costs were not taken into account in meta-analysis, they were an often-mentioned argument in interviews and Figure 32 showed that they matter in decisions of all interviewees. Therefore, acquisition costs for all investigated techniques plus for strip-tilling as a form of minimal tillage (because this technique was mentioned in interviews) are listed in Table 26.

Prices for machinery were looked up in a list of standard prices in Switzerland (Gazzarin 2015). This does not mean that interviewees actually paid that price: Visiting a few online sales platforms reveals that minimum prices can be clearly below standard prices and nearly all machines are available second-hand. One of the interviewees built his own strip-till machine for 17’000CHF instead of about 30’000CHF for commercially available machines. Also, not all of the interviewees own a full set of machinery necessary to cultivate a field, some of them rent expensive machinery or machines they rarely use: *“For example, we do not own a disc harrow, but if we think it is necessary to use one, we rent it”* [10].

Technique	**Investment cost (CHF)**	**Total cost**	
Conventional Tillage	Plough: 31’000 (4-blade) Powered harrow: 14’000 Sowing machine: 12’500	57’500	(Gazzarin 2015, p. 88)
Reduced Tillage (two variants)	Chisel: 9’100 Sowing machine: 12’500	21’600	(Gazzarin 2015, p. 89)
	Rotary cultivator:15’000 Top mounted sowing machine: 8’000	23’000	[8]
No Tillage	Direct-sowing machine (3m): 71’000	71’000	(Gazzarin 2015, p. 89)
Minimal Tillage	Strip-till machine: 31’000 (6 rows) Sowing machine: 12’500	43’500	(Gazzarin 2015, p. 89)
Biochar	4.5t/ha: 3749	3749/ha plus cost of tillage/ seeding machinery	(Swiss Biochar 2015)
CTF	Reference station: 30‘000 Modification on tractor: 15‘000	45‘000 plus costs of tillage/ seeding machinery	[7], [8]
Relay intercropping	Cover crop sowing machine: ca. 3’000	3’000 plus costs of tillage/seeding machinery	For example (Agropool 2015)

Table 26 Overview of acquisition costs for different techniques. Prices for machinery were derived from a list of standard prices provided by AGRIDEA (usually with 2.5m working width) and from interviews. Intercropping is not shown because machinery is the same as for the tillage forms. The price for biochar was derived like this: The minimum rate in field trials with significant effect on yield was about 4t per hectare (Husk & Major 2010)**. Swiss-biochar indicates prices for units of 4.5t, therefore this amount was assumed as application rate per hectare.**

Table 26 tells only half of the story, of course. Additional costs arising from additional cultivation measures (e.g. chemical or mechanical weed control) or harvest are not taken into account. Also, yield effects were not accounted for. For example, one of the interviewees experienced a severe yield loss under reduced tillage compared to conventional tillage: *“This is simply massive; this is a 1000CHF difference per hectare with otherwise same costs”* [10]. However, the list gives an idea of costs farmers face who want to switch to a new technique. Ranking the costs is not possible, because costs for biochar vary with area. Ranking tillage treatments only results in NT > CT > MT > RT. Of the non-tillage treatments, hurdles are lowest for intercropping (no additional machinery required). The costs for CT are high, but they do not matter so much since all of the interviewees except one already had the required equipment. Comparing those “entry fees” to the ranking of techniques in Figure 34 gives support for intercropping and all tillage-related alternatives to conventional management. All other techniques basically imply extra costs additional to tillage equipment. Decreasing costs for biochar and controlled traffic farming would probably render those alternatives more attractive for farmers. Regarding the research question, the consequence is that even though alternatives could improve soil quality, costs impede their spreading in Switzerland.

4.2.5 Impact of the adoption of AP 14-17

Interviewees mentioned that investments into soil conserving machinery because of new payments (for reduced, minimal and no tillage) are not worth it. This section plays through three scenarios how a farmer could react to the implementation of AP 14.17. They showed that in fact optimising the farm management for other payment categories is far more profitable than investing in new soil conserving machinery.

Direct payment system was another variable found to influence the decisions of all interviewees (see Figure 33). Against initial expectations, resource efficiency payments are only weak motivation to adopt soil conserving management strategies. However, interviews reveal a completely different effect of rearranged direct payments on farm management, encapsulated nicely by one of the interviewees: *"Regarding profitability, you have to do wildflower set-aside, there is no question. [...] Wildflower set-aside is about twice as lucrative as producing cereals."* [1].

The following case study should illustrate this issue in more detail and examines how a farm could react to recent changes in the direct payment system. It should give an idea on the incentives arising from the direct payment system and how different they are: While new payments have been introduced for soil conserving management in 2014, monetary incentives for set-aside are by far larger. The initial situation describes a fictive farm. Direct payments were estimated with an excel tool provided by AGRIDEA (2015), data on contribution margins of crops were taken from the Wirz manual (Albisser 2015). To reduce complexity, some payments and all costs except those of immediate relevance for the example are ignored or assumed to be the same. Also, revenues for all techniques were assumed to be identical (e.g. same contribution margin in all cases), even though interviews provide evidence that this is not the case (e.g. see Figure 26). The purpose of this example is not to do full-cost accounting, but to give an idea of direct payments in tangible terms.

Initial Situation

Farmer Baur conventionally manages a farm with 26ha of arable land, without animal husbandry in Swiss Midlands. The entire farm belongs to the valley zone, a category in the direct payment system that shapes the frame of payments the farm could possibly get. To fulfil minimal requirements of PEP, 7% of total area needs to be ecological compensation area, in this case 1.82ha, rounded up to 2ha for ease of calculation. These two hectares are extensive meadow (EM) which results in biodiversity payment of 1'500 CHF per hectare. Of the remaining 24 ha, 8 ha are artificial pasture (AP), 4 ha are wheat (W), 4 ha are sunflower (SF), 4 ha are barley (B) and 4 ha are potatoes (P). Because the farm is smaller than 60ha, it receives a security of supply payment of 900CHF per hectare for the 24 ha under rotation plus 400CHF per hectare for the 16 ha cropped land plus 700CHF per hectare for sunflowers. It all sums up to about 33'800CHF of payments for the farm, total return is 77'410CHF. Baur thinks that his management so far was too intensive and wants to adjust it to fulfil more than the minimal ecological requirements.

Crop	ha	A	B	C	D	E
AP	4	900	0	0	0	2'059
AP	4	900	0	0	0	2'059
SF	4	900	400	700	0	1'600
P	4	900	400	0	0	9'600
W	4	900	400	0	0	2'300
B	4	900	400	0	0	1'500
EM	2	0	0	0	1500	468
Total	26	21'600	6'400	2'800	3'000	77'410
Sum						111'210

Table 27 Fictive example of a 26 ha farm with security of supply payments (basic payments (A), payments for cropped land (B), payments for particular cultures (C)), biodiversity payments (D), and contribution margins (E).

Strategy 1: Invest in new soil management technique

Bauer decides to stop ploughing except for potatoes. He buys a rotary cultivator with top mounted sowing machine (as interviewee 8 actually did) for 23'000CHF and does mulch tillage for artificial pasture, wheat, barley, and sunflower. He gets an extra resource efficiency payment of 150 CHF per hectare (except for artificial pasture), about 1'800 CHF for the entire 12 ha. This results in an annual payment of about 35'600 CHF and revenues of about 113'010. On the other hand, there are investment costs of 23'000 CHF. In total, this sums up to 90'010 CHF, 21'200 CHF less than in the initial scenario.

Strategy 2: Rent expensive machinery

Bauer decides to reduce tillage even more and apply minimal tillage, but 31'000CHF for strip-till machinery is more than he can afford. He hires a contract worker instead for 150CHF per hectare (which is an amount interviewee 3 actually requests for that type of work) and gets a resource efficiency payment of 200CHF per hectare, resulting in annual payments of 36'200CHF. Total revenue is 113'610CHF; additional costs are 1'800CHF per year. This sums up to 111'810 CHF, 600 CHF more than in the initial scenario.

Strategy 3: Increase share of ecological compensation area

Bauer decides to stick to his soil cultivation with plough and powered harrow on the cropped area but to increase the share of ecological compensation area. He takes 4 ha of barley out of the rotation for set-aside with wildflowers. Biodiversity payments for wildflower set-aside are 3'800 CHF per hectare in the valley zone, resulting in 15'200 CHF. Opportunity cost is a decrease of security of supply payments of 1'300 CHF per hectare, all in all 5'200 CHF. New annual payment is about 43'500 CHF, new revenue is 115'210CHF. This is 4'000 CHF more than in the initial scenario.

It can be derived from this example that (Deduction III, see chapter 5): Own investments in soil conserving techniques by far do not pay off as much as increasing set-aside and investing in other ecological compensation measures. Business as usual with a small part of arable land turned into set-aside is more profitable for farmers than adopting management techniques that conserve soil on the entire farm. So, will there be a substantial increase of set-aside as a consequence of AP 14-17? Maybe, but there are two constraints: First, interviews reveal that farmers have personal motives against increasing set-aside: *"It is nice to see some [wildflowers] along forest margins, but wildflower set-aside by the hectare and then pay more than 3'500CHF for it, this is nothing but rude"* [8]. Second, interviews suggest that set-aside is limited to those areas of low productivity while fertile soils are continued to be used for production: *"11.2% of our land is ecological compensation area. This is more than we would have to, but the reason is that for some soils this is more profitable than growing vegetables, because of their quality."* [1].

However, taking this example and the weak influence of direct payments on decision (see section 4.2.3.2) into account questions the efficiency of payments for soil conserving management. If this applies not only to the ten farmers interviewed here but also to the rest of farmers in the Swiss Midlands, this would mean that the payments for soil conserving management fail to meet their purpose.

4.2.6 Summary of interview results

The most obvious result of the interviews is: Except for reduced tillage, the techniques that were found to have positive effects on soil physical, chemical, and biological properties compared to conventional management are not frequently used by interviewees.

Looking at the minimum set of explanatory variables for choosing techniques gives some answers why this is the case:

- Level of knowledge and personal experience: CTF and BC application are virtually unknown techniques, IC and RI are known but criticised for the scarcity of information on successful application
- Weed and pest control: Many interviewees see a direct and problematic link between no tillage and use of herbicides, at least for organic farmers, this is an exclusion criterion
- Profitability and costs: Interviewees are apprehensive of high costs associated with CTF and BC application and of low yields associated with other alternative techniques
- Direct payments: Even though NT and RT are being rewarded with extra payments, the amount is too small to motivate a complete change of tillage on farm, therefore, on seven farms, reduced tillage is applied alongside with conventional management and only two farms abstain from conventional tillage completely
- Availability and applicability: Especially NT and CTF require new machinery that is not available on farm. Besides, interviewees think that these two techniques are difficult to apply

Other variables in the minimum set are personal views of the interviewees, conservation of soil in general and physical soil properties in particular. Since these were mentioned by all interviewees, it is assumed that they apply to a majority of crop farmers in Switzerland (Deduction I, see chapter 5).

At least the problem of lacking information could be overcome by increasing the knowledge transfer from science into practical application. I hypothesise that right now, this transfer is not working efficiently (Deduction II, see chapter 5), since most of the techniques are not new.

5 Synthesis

In this section, findings of chapter 3 and 4 are taken up again to highlight some hypotheses that can be derived from those chapters and to answer the research question. Some important observations are listed in the following:

- The results of the meta-analysis do not allow a comprehensive ranking of techniques, because a lot of needed information could not be found in the publications of field trials. As it has been criticised by Fisher (2014), incomplete reporting on field trials are impeding implementation of a truly evidence-based agriculture.
- All of the investigated techniques had significant positive effects on soil quality, except for relay intercropping. This is partially confirming the initial hypothesis I which expected all alternatives to improve soil quality compared to conventional cultivation
- Some alternatives to conventional management are not well known among interviewees. The reason is not a lacking awareness of environmental problems among interviewees. They all saw a need for more soil conservation, but economic and other constraints and lack of information is retaining them from applying alternatives. In total, 24 variables were found that play a role when farmers decide about adopting a technique.
- Even though interviewees reacted in some way to the implementation of AP 14-17, none of them altered soil management in consequence. Those who adopted alternative techniques had other motivations to do so. The initial hypothesis II is rejected for the group of interviewees and it is assumed that other crop farmers did not abandon conventional management either.

The research question can be answered in the following way:

- Biochar application, no tillage, reduced tillage, controlled traffic farming and intercropping could all improve soil conservation in the Swiss Midlands. There is no best technique that fits everywhere, but a site-specific ranking can be derived from the meta-analysis that takes the various explaining variables found in the interviews into account.
- The impact of AP 14-17 on soil management is probably much lower than hypothesised in the beginning. Soil conservation in Swiss arable farming is driven by the explaining variables presented rather than AP 14-17.

The results of the meta-analysis and the interviews brought me to the following deductions, meaning hypotheses derived from both the meta-analysis and the interviews that could be further investigated, for example in surveys.

Deduction I: There is a minimum set of eight explanatory variables driving decisions about soil management in Swiss arable farming (see section 4.2.3.6).

Knowing these explanatory variables could help to promote alternatives.

Deduction II: The transfer of scientific findings into practical application is not working efficiently (see section 4.2.6).

The alternative techniques are not new; most of them are being researched for a while already. But nevertheless, biochar application and controlled traffic farming were hardly known, and both intercropping variants were known but interviewees refrained from them because of lack of experience/expert guidance (among other reasons). In order to exploit the full potential of alternative techniques, transfer of knowledge has to be improved, for example via agricultural research institutes.

Deduction III: AP 14-17 favours a coexistence of conventional soil cultivation with set-aside and other ecological compensation measures (see section 4.2.5).

Even though the last reform of the direct payment system introduced new payments for no, minimal, and reduced tillage, interviews do not suggest that this initiated a paradigm shift in soil management. Payments are too small to compensate for costs of techniques, while payments for compensation areas encourage set-aside. However, this is not improving soil conservation on cropped land. AP 14-17 has been implemented in the last year, so upcoming land use statistics could show whether or not this hypothesis is true. If so, then the payment system should be adjusted to truly promote soil conserving management on arable land.

6 Literature

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Appendix A: Publications used in meta-analysis

A1: Literature search

Publications were searched for in ScienceDirect (Elsevier 2015), Web of Science (Thomson Reuters 2015) and Google Scholar (Google 2011) with keywords presented in the following list:

Technique	**Keywords**
No tillage	No tillage, no till, mulch tillage, direct seed, direct sowing, direct drilling, conventional tillage
Reduced tillage	Reduced tillage, mulch tillage, minimal tillage, chisel, conventional tillage
CTF	Controlled traffic farming, random traffic, fixed tracks, precision farming, GPS + farming
Biochar	Biochar
Relay intercropping	Intercropping, mixed stands, mixed cropping, multi cropping, strip cropping, row intercropping, relay intercropping, relay strip cultivation, relay sowing, undersowing
Intercropping	
Specifiers to restrict search	Temperate, soil, biological soil properties, physical soil properties, chemical soil properties, field, farming, agriculture

Keywords used for literature search. Specifiers mean keywords that were combined with keywords for all techniques

Intercropping and relay intercropping were searched for with the same keywords because they share many common keywords. Results were ranked by relevance. Search for a keyword combination was stopped after fifty consecutive non-relevant results. It was then further restricted to years starting from 2010 to give preference to more recent results. This is especially important for studies on biochar where no trials published before 2010 could be found. Taking the development of conventional and organic management paradigms in Switzerland into account (see section 2.2.1), only studies published after 1980 were used. ScienceDirect (Elsevier 2015) and Web of Science (Thomson Reuters 2015) show by which other publications an article is cited, this option was made use of as well. Search language was English.

It was not possible to estimate a priori how many studies could be used later on for data extraction. The goal was to have about 10 studies for each technique to extract data from with information on all three types of parameters, physical, chemical, and biological. Therefore, about 30 studies were searched for in the first round, speculating that at least one third could be used for analysis later. Overall, 37% of the publications found by keyword search could be used for meta-analysis.

A2: Data extraction

The following list explains extraction were studies did not hand data on a silver platter (e.g. in a table):

- If data of several consecutive years were measured, but data not shown in paper, then the year with the most complete dataset was used, e.g. (Dickson & Campbell 1990) measured yield for four years, but data of penetration resistance and macroporosity is shown for the third year only. Therefore, only data of the third year was used.
- If data of several consecutive years were indicated, a mean value and standard deviation for all years was calculated according to a study on controlled traffic farming by Wang et al. (2009).
- If data was shown in graphical and not numerical form, DigitizeIt (Bormann 2014), a commercial digitalisation software, was used to extract numerical values.
- If important metadata were missing, they were completed, see Appendix B3

- Units were converted if necessary. Conversion does not affect values except for conversion of soil organic matter contents to soil organic carbon contents. The conventional factor of 1.724 was used which has been criticised for being too low (Pribyl 2010).
- If only one generalised parameter value was reported instead of individual values for treatment and controls, the value was not used for meta-analysis. Figure 10 shows in how many cases a certain parameter was measured and how this number splits into cases with individual measurements of treatments and control and cases with only one value for both.

Also, a remark on biochar application studies is necessary: Up to date, not many field studies exist and biochar with different properties were used in these studies (Jeffery et al. 2011). To get as many data as possible, studies used here are not differentiated according to properties of the biochar, introducing some uncertainty in favour of a larger dataset.

A3: List of authors and IDs assigned to data in dataset

Each individual field trial was assigned an identification number (ID). This means that publications with data for several trials got several IDs, while results from several publications but originating from the same trial got the same ID. Where publications contained information on several trials, additional information is given in brackets.

ID	Authors
1	Angers et al. 1993b; Angers et al. 1993a
2	Ekenler & Tabatabai 2003a (Iowa)
3	Anken et al. 2004
4	Bergstrom et al. 2000
5	Chen et al. 2014
6	Dick 1984 (E-Ohio)
7	Dick 1984 (W-Ohio)
8	Doran 1987 (Kentucky 1981)
9	Doran 1987 (Illinois 1981)
10	Doran 1987 (Minnesota 1981)
11	Doran 1987 (Nebraska 1 1981)
12	Doran 1987 (Nebraska 2 1981)
13	Doran 1987 (Nebraska 3 1981)
14	Ekenler & Tabatabai 2003b (Wisconsin)
15	Havlin et al. 1990
16	Havlin et al. 1990
17	Haynes 1999
18	Haynes & Knight 1989
19	Haynes & Knight 1989
20	Licht & Al-Kaisi 2005
21	Licht & Al-Kaisi 2005
22	Lipiec et al. 2006
23	Lupwayi et al. 1998; Lupwayi et al. 1999
24	Monreal & Bergstrom 2000 (Rockwood)
25	Stewart & Vyn 1994
26	Van Eerd et al. 2014; McGonigle et al. 1999 (1991 Trial)
27	Berner et al. 2008

28 Deng & Tabatabai 1996
29 Feiza et al. 2014
30 Kováč et al. 2005
31 van Groenigen et al. 2010
32 Velykis & Satkus 2012
33 Bai et al. 2009
34 Głąb & Kulig 2008
35 Kahlon et al. 2013
36 Kalmár et al. 2013
37 Masciandaro et al. 2004
38 Rasmussen & Rohde 1989 (11 kg N)
39 Rasmussen & Rohde 1989 (16.5 kg N)
40 Rasmussen & Rohde 1989 (22 kg N)
41 Rasmussen & Rohde 1989 (28 kg N)
42 Rasmussen & Rohde 1989 (39 kg N)
43 Tammeorg et al. 2014b (Umbrisol, 2011)
44 Tammeorg et al. 2014b (Umbrisol, 2012)
45 Arlauskienė et al. 2011 (Dotnuva)
46 Arlauskienė et al. 2011 (Joniskelis)
47 Arlauskienė et al. 2011 (Perloja)
48 Hauggaard-Nielsen et al. 2003
49 Jannoura et al. 2014
50 Musa et al. 2010
51 Neugschwandtner & Kaul 2014
52 Oljaca et al. 2012
53 Podgórska-lesiak & Sobkowicz 2013
54 Sawyer et al. 2010 (Mason City)
55 Sawyer et al. 2010 (Floyd)
56 Sawyer et al. 2010 (Grundy)
57 Sawyer et al. 2010 (Butler)
58 Van Eerd et al. 2014 (1995 Trial)
59 Chan et al. 1980 (Oat)
60 Breland 1995
61 Carof et al. 2007
62 Carter & Kunelius 1993
63 Chan et al. 1980
64 Hiltbrunner et al. 2007 (Zürich)
65 Hiltbrunner et al. 2007(Luzern)
66 Ilnicki & Enache 1992
67 Løes et al. 2011 (Apelsvoll)
68 Løes et al. 2011 (Kise)
69 Reinbott et al. 1987
70 White & Scott 1991
71 Domene et al. 2014; Güereña et al. 2013
72 Du et al. 2014; Zhang et al. 2014

73 Hu et al. 2014
74 Husk & Major 2010
75 Jones et al. 2012
76 Karer et al. 2013; Prommer et al. 2014 (Traismauer)
77 Karer et al. 2013 (Kaindorf)
78 Liang et al. 2014
79 Liu et al. 2012
80 Mukherjee et al. 2014
81 Nelissen et al. 2015
82 Rogovska et al. 2014
83 Sun et al. 2013; Sun et al. 2014
84 Weyers & Spokas 2014
85 Zhang et al. 2012
86 Anken et al. 2012
87 Bai et al. 2008
88 Dickson & Campbell 1990
89 Wang et al. 2009
90 Monreal & Bergstrom 2000 (Clinton)
91 Tammeorg et al. 2014a (first year)
92 Tammeorg et al. 2014a (second year)
93 Tammeorg et al. 2014a (third year)
94 Felber et al. 2014
95 Hammond et al. 2013 (East Lothian, first year)
96 Hammond et al. 2013(East Lothian, second year)
97 Hammond et al. 2013 (East Lothian, third year)
98 Hammond et al. 2013 (East Lothian II)
99 Hammond et al. 2013 (Kingdom of Five)
100 Hammond et al. 2013 (Midlothian)
101 Oleszczuk et al. 2014
102 Quilliam et al. 2012
103 Liu et al. 2014 (second year)
104 Liu et al. 2014 (fourth year)
105 Liu et al. 2014 (fifth year)
106 Neumann et al. 2007
107 Eskandari & Ghanbari 2010
108 Doran 1987 (Kentucky 1980)
109 Doran 1987 (Illinois 1980)
110 Doran 1987 (Minnesota 1980)
111 Doran 1987 (Nebraska 1 1980)
112 Doran 1987 (Nebraska 2 1980)
113 Doran 1987 (Nebraska 3 1980)

A4: List of publications used for meta-analysis

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Appendix B: Meta-analysis procedures

B1: Dataset

Both the raw input dataset and the merged dataset for analysis can be found in digital form on the CD that is attached to the back cover.

B2: Merging the dataset

The list of IDs was shown in Appendix A. Values of one or more parameters from the same trial and the same soil horizon are called "set" and ended up as one line in the data input file. If a study analysed data from several soil horizons along the same profile, all the sets along that profile are treated as one "case". Sets of same cases were merged by weighing values by sampling horizon thickness. For example, if SOC was 2% from 0 to 5 and 0.5% from 5 to 20 cm, this would correspond to one case with two sets in the input file. Merging all the sets in the case results in: $\frac{2\% \cdot 5cm + 0.5\% \cdot 15cm}{20cm} = 0.875\%$. So, in the merged dataset this case would have a SOC content of 0.875% SOC for a maximum sampling depth of 20cm.

B3: Meta-data

The following list shows which meta-data has been extracted along with parameter values and how missing data was handled.

Name	Attribute	If data missing in study:
Author	First author of study	(was never missing)
ID	Internal identification number for trials (one study can have more than one ID)	(assigned during extraction)
Set	Number for set of data for one sampling horizon	(assigned during extraction)
Case	Number for all sets from same soil profile	(assigned during extraction)
Year	Year of publication	Only one case, year was estimated from sampling year
Region	Administrative unit study site belonged to, highest unit was considered, e.g. State in USA or Canton in Switzerland	Looked up in Wikipedia and google maps based on information on study site
Country	Country study site was in	(was never missing)
Northing/ Easting	Coordinates of study site	Extracted from google maps based on information on study site
Temp	Mean annual temperature at study site	Extracted from climate-data.org (AmbiWeb 2015) for town nearby
Prec	Mean annual precipitation at study site	Extracted from climate-data.org (AmbiWeb 2015) for town nearby (same as for temperature)
Trial	Type of field trial	No estimates if not indicated
Rep/df	Number of replicates and degrees of freedom	(was never missing)
Area	Total trial area involved	No estimates if not indicated
Dur	Duration of field study	No estimates if not indicated
Span	Number of measurement years covered by one data point	Assumed to be one year

Use	Previous use of field site	No estimates of not indicated
Con/ET	Tillage form in control/experimental treatment	Estimate case-wise based on trial description
CTD/ETD	Tillage depth in control/experimental treatment	No estimates if not indicated
CTM/ETM	Machinery used for tillage in control/experimental treatment	Where tillage was described as “conventional”, mouldboard plough was assumed
CN/EN	Nitrogen fertiliser application rate (kgha-1a-1) in control/experimental treatment	No estimates if not indicated
CM/EM	Mulch application in control/experimental treatment in ordinal scale	No estimates if not indicated
UB/LB/HT	Upper and lower boundary of sampling horizon and horizon thickness	No estimates if not indicated
MaxD	Maximum sampling depth	10cm assumed
Sspec	Soil qualifier according to WRB	Estimated from soil classification if possible
Soil	Soil type according to WRB	Not estimated if completely missing. Soil types from other classifications were transferred to WRB based on comparison charts (CALS 2015; Juma 2015; Legros 2007)
Wet	Binary variable indicating wet/moist soils	Was derived from soil type and qualifier (Gleysoil and qualifier gleyic were classified as wet)
Tex	Texture class according to US Soil Taxonomy triangle	Determined from clay, silt and sand content by online soil texture calculator (NRCS 2015)
Cl	Clay content	Average value for texture class used (different thresholds for clay, silt and sand between classification systems were ignored. Majority of studies did not provide this information)
Si	Silt content	
Sa	Sand content	
Meth	Medium for pH measurement	No estimates if not indicated
Crop	Crop planted in field trial	No estimates if not indicated
Crng	Cropping style, rotation or monoculture	No estimates if not indicated
IC	Intercrop (if intercropping was applied)	No estimates if not indicated
Tech	Technique applied in experimental treatment	No estimates if not indicated
EBC	Amount of biochar applied in experimental treatment	No estimates if not indicated
Details	Additional comments on trial	-
Herb	Herbicide application, binary (yes or no)	No estimates if not indicated

B4: Estimating missing pooled standard deviations

In many studies results were presented with standard error of the mean (SEM) or least significant difference (LSD). Deriving standard deviations of each value individually is not possible for those measures, instead, pooled standard deviation can be calculated (Saville & Rowarth 2008, p. 76):

$$SEM = \frac{SD_p}{\sqrt{n}} \Leftrightarrow SD_p = SEM\,\sqrt{n}$$

With n being the number of replicates used in a study.

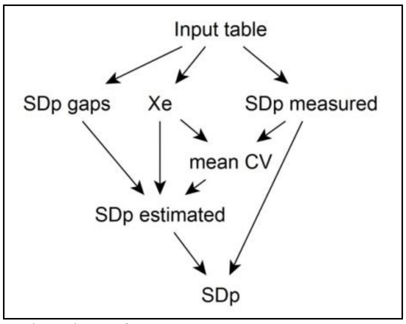
$LSD = SEM\sqrt{2}\ t \Leftrightarrow SD_p = \frac{\text{LSD}\sqrt{n}}{\sqrt{2}\,t}$

With t being the t-value and n being the number of replicates used. T-values depend on degree of freedom and level of significance. The studies included in this work usually replicated their experimental plots two to four times and used a level of significance of 1%, 5% or 10%. Table for t-values was taken from Backhaus et al. (2011, p. 566).

Where individual standard deviations per value were reported, pooled standard deviation was calculated as follows in order to have all deviations in the same, comparable form:

$SD_p = \sqrt{\frac{(n_e-1)S_e^2+(n_c-1)S_c^2}{(n_e+n_c-2)}}$

with Se and Sc being standard deviations of experimental and control group respectively (Borenstein, Larry V Hedges, et al. 2009a, p. 22).



Flowchart for processing steps to estimate missing pooled standard deviation values. Xe are soil parameter values of experimental plots, mean CV is mean coefficient of variance.

In a number of cases, no precision measure was explicitly reported along with results, see Figure 13 in section 3.1.5.1. Were several results were presented with an indicator for significant difference, the smallest difference between significant results was assumed to be the least significant difference. With this assumption, true LSD can be overestimated, but never underestimated. Where no indication at all was available, SDp was estimated with the procedure explained in the following and shown in the flowchart on the left. From the input data file, known SDp and parameter values of experimental treatments were used to calculate mean coefficient of variance (CV) per parameter (Saville & Rowarth 2008, p. 76):

$\text{CV} = \frac{SD_p}{X_e} * 100$

Gaps in the original SDp file were then filled by multiplying parameter values by mean CV. A text file was created with existing and estimated SDp and used as input in subsequent calculations. It is important to note that Hedges and colleagues (1999) did not suggest estimating missing standard deviations, but rather assume that true standard deviations are known. Therefore, unweighted data are analysed and estimates of weighted means are used for discussion of those results only.

B5: Calculating weighted mean log response ratios

The following equations show how the weights and the weighted means were calculated. All of them were taken directly from Hedges et al. (1999).

The variation of sample log response ratios has two components: The first component is within-experiment variation v, calculated from pooled standard deviation (SDp) and number of replicates (n) and values (X) from experiment (e) and control (c) groups:

$v = {SD_p}^2(\frac{1}{n_e X_e^2} + \frac{1}{n_c X_c^2})$

With n being the number of replicates. The second component is between-experiment variation $\hat{\sigma}^2$.

Both are then used to calculate the weights u_i:

$u_i = \frac{1}{v_i + \hat{\sigma}^2}$

The weighted mean of logarithmic response ratios (L) per parameter is then calculated as:

$\bar{L} = \frac{\sum_{i=1}^{k} u_i L_i}{\sum_{i=1}^{k} u_i}$ (k is the number of logarithmic response ratios (L) per parameter)

Also, the standard error of the weighted mean is calculated.

B6: Calculating F-test

Within-group variance for the anova was derived from the standard error in the following way:

$$var = \frac{1}{n-1} \sum_i (x_i - \bar{x})^2 = SD^2$$

With xi being an individual value in the group, x bar being the group mean, n being the number of individual values in the group and SDp being the standard deviation (Stahel 2008a, p. 19).

To calculate standard deviation from standard error, the same formula as in B4 for pooled standard deviation was used (Saville & Rowarth 2008, p. 76):

$$SD = SE(\bar{L})\ n$$

Critical values for the F-test were looked up in a table (Filliben & Heckert 2013).

B7: Analysis of unweighted response ratios

Test for normal distribution and transformation

Quantile-plots were produced to check for normal distribution: Response ratios were not normally distributed. Response ratios were therefore transformed by natural logarithm and square root to reach normal distribution. For data on yield, microbial biomass, and infiltration capacity, a square root transformation was applied. For bulk density, qCO2, and water stable aggregates, no transformation was necessary and for all other data, natural logarithm was used for transformation. Besides visual inspection of the qq-plots, a Shapiro Wilks test for normal distribution (R Core Team 2015c) was run before and after transformation to verify that p values actually increased as a result of transformation.

Regression

A regression is a method to identify statistical relationships between the target (or dependant) variable and one or several input (or independent) variables (Stahel 2008b). Regression models give hints for causal connections, not proofs (id). The regressions therefore are used here to investigate if relationships between techniques and soil parameters still persist when taking other factors (the collected meta-data such as precipitation for example) into account. According to Crawley (2007), a maximum model was built and simplified until all coefficients were significant. Dummy variables were used for nominal variables (Stahel 2008b).

Interpretation of statistical tests: P Value

"A p value is an estimate of the probability that a particular result, or a result more extreme than the result observed, could have occurred by chance, if the null hypothesis were true. In short, the p value is a measure of the credibility of the null hypothesis." (Crawley 2007a, p. 282). In a statistical test, the null hypothesis is rejected, if the p value is below a predefined significance level, usually 5%. (Stahel 2008c, p. 188). The null hypothesis is the model to be examined (id). In contrast, there is the alternative hypothesis as a plausible second option to the model (id.). However, the p value should not be the only measure considered: "effect size and sample sizes are equally important in drawing conclusions" (Crawley 2007a, p. 282). In large samples, minor differences can easily found to be significant, while important differences in small samples can be overlooked (Stahel 2008c, p. 221).

Appendix C: Processing and analysis in R

The R code for data processing and analysis can be found in digital from on the CD that is attached to the back cover.

C1: Output unweighted response ratios

	SOC	pH	TN	MB	Y	BR	UA	AcPA	AlPA	PA	qCO2	SWC	BD	PR	MP	TP
BC	1.42	1.04	1.07	1.57	1.06	1.08	1.55	1.2	1.35	0.96	0.96	1.12	0.93	0.87	1.02	1.02
CTF	1.32	NA	1	NA	1.05	NA	NA	NA	NA	NA	NA	NA	0.95	1.13	1.93	1.15
IC	1.16	NA	NA	1.02	1.16	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NT	1.12	0.99	1.12	2.05	0.92	6.82	1.79	1.28	1.49	1.33	0.57	0.97	1.05	1.46	0.76	0.83
RI	0.97	NA	0.86	NA	0.92	NA	NA	NA	NA	NA	NA	NA	0.95	NA	NA	NA
RT	1.13	0.99	1.04	1.14	0.95	NA	1.38	NA	NA	NA	NA	0.99	1	1.6	0.93	1.06

Means of unweighted response ratios

C2: Output weighted response ratios

	SOC	pH	TN	MB	Y	BR	UA	AcPA	AlPA	PA	qCO2	SWC	BD	PR	MP	TP
BC	2.08	1.06	1.08	1.43	1.10	1.07	1.36	1.18	1.05	0.96	0.92	1.12	0.92	0.84	0.68	NA
CTF	1.32	NA	NA	NA	1.04	NA	NA	NA	NA	NA	NA	NA	0.95	0.93	1.90	1.14
IC	1.16	NA	NA	1.02	1.12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NT	1.06	0.99	1.10	1.40	0.96	4.64	1.22	1.22	1.48	1.02	0.32	0.97	1.04	0.94	0.73	NA
RI	0.97	NA	0.84	NA	0.96	NA	NA	NA	NA	NA	NA	NA	0.96	NA	NA	NA
RT	1.08	0.99	1.03	1.14	1.01	NA	1.36	NA	NA	NA	NA	0.99	0.99	NA	0.93	1.05

Means of weighted response ratios

C3: Output percentage

The following table is the output of the function "Percent", shown in the R code. It expresses the effect of techniques as a percent deviation of the control. The values were derived from converting unweighted response ratios to percentages.

	SOC	pH	TN	MB	Y	BR	UA	AcPA	AlPA	PA	qCO2	SWC	BD	PR	MP	TP
BC	42.4	3.6	6.8	57.2	6.3	7.8	54.9	19.7	34.8	-4.4	-3.7	12.0	-6.7	-13.3	1.9	2.1
CTF	32.0	NA	-0.3	NA	4.8	NA	NA	NA	NA	NA	NA	NA	-4.6	12.8	93.4	14.6
IC	15.7	NA	NA	1.6	15.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NT	12.1	-1.2	12.3	105.3	-7.9	582.1	78.5	28.3	49.2	33.1	-43.1	-2.6	4.7	45.9	-23.7	-17.0
RI	-3.4	NA	-14.4	NA	-8.3	NA	NA	NA	NA	NA	NA	NA	-5.4	NA	NA	NA
RT	13.2	-1.3	3.6	13.8	-4.8	NA	38.3	NA	NA	NA	NA	-1.2	-0.5	59.6	-6.7	5.5

Effect of techniques expressed as percentage relative to controls. Calculated from the mean of unweighted response ratios.

Appendix D: Interviews and coding

D1: Finding interviewees

The methods used are called "recruiting on site" and "cold calling"(Longhurst 2009, p. 580), a detailed overview is given in the table below. Other possible methods are advertisement in medias or sending out questionnaires (id.), which are probably less suited for the small number of interviews used here. If finding interviewees turned out to be more difficult, agricultural institutions such as schools or certification organisations would have been contacted.

3	Selected based on canton out of customer file of a salesperson for farm machinery
3	Contact information via third party (three different people)
2	Personally contacted during field demonstration of different tillage machinery, one of them was demonstrating a

	machine
1	Looked up in online database of certification organisation for organic farmers, contact information from directories
1	Contact information handed out by certification organisation after informing interviewee in advance

Ways of contacting interviewees. Different ways are shown in the right column, number of interviewees found that way is given in the left column.

Except for one person contacted during the field demonstration, all contacted farmers agreed to give an interview. During all contacts before the interview, I explained the project in general and overarching topics of interview. I did not give detailed information on individual questions and techniques to prevent interviewees from preparing for the interviews. Not all interviews were scheduled with participants directly: In five cases, I was talking to their wives first (because they happened to pick up the phone); in two cases I did not even personally talk to the interviewee until the interview actually took place.

Interview language was Swiss German, because this is the language my interviewees and I are most familiar with using agricultural terms. Interviews all took place on respondents' farms or homes.

Six interviews were planned, one in each category of the sampling scheme. In total ten interviews were conducted in the end, because the first few interviews revealed that experience of interviewees matters. Some of the organic farmers I had interviewed changed to organic farming only a few years ago. Therefore, I was particularly looking for interviewees with longer experience in organic farming and kept searching for interviewees even after completing the scheme. For my last interview, I contacted bio inspecta, a certification organisation for organic farms, to explicitly ask for a farmer with about ten years of experience.

All of the participants are male, except for one interview I did with a couple where the female partner is not working on farm, but doing mechanical weed control in her spare time. In one case, the farm is managed by the interviewee alone, in all other cases, female partners at least live on the farm; some of them are also working on farm according to interviewees. I never explicitly asked to talk to a male person, but also did not explicitly ask for the female partner to be present. When I contacted interviewees, I usually presented myself and my project first. If the person on the phone happened to be the female partner, they always suggested scheduling an interview with their husbands, the person in charge for soil management. I implicitly left it up to participants to decide who takes part in the interview. Female partners were sometimes present and asked questions to me, but did actively participate in the interview.

D2: Guideline questions

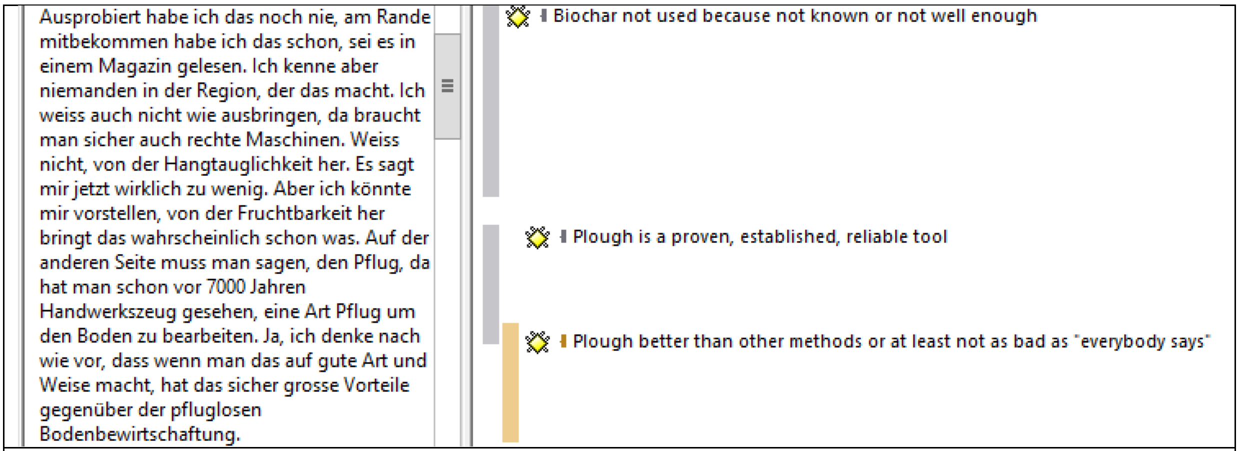
Part	**Question**	**Min**
General information about the farm, current management strategy	Since when do you manage this farm and in which form (organic, conventional), is it yours? How many hectares does it have? (*Sid wänn häsch du dä Betrieb und i welere Form (bio, konventionell), ghört er dir/öi? Wie vil Hektare hät er?*)	3
	Could you tell me about your soil and crop management practices on farm? What do you cultivate and how? Which soil management techniques do you use? (*Chasch du mier e chli über dini Bodebearbeitigs- und Ahbaumethode verzelle? Was bausch ah und wie? Weli Ahbaumethode bruchsch für das?*)	10
	Did you change farming method since you took over the farm or do you plan changes for the future? Which changes and why? (*Hätts sit de Betribsübernahm Veränderige im Acherbau gä oder plansch sonig fürd Zuekunft? Weli sind das und werum häsch die gmacht/wetsch die mache?*)	5

Advantages and disadvantages of techniques	I have put some of the techniques under discussion right now on this list. I will go through this list and I would like you to tell me: - Have you ever heard of that method or do you apply it yourself? Would you consider it? *(Häsch vo dem scho mal ghört oder machsch das scho? Wär das es Thema für dich?)* - Which advantages and disadvantages does this technique have from your perspective? *(Weli Vor- und Nachteil gsesch oder gsächtisch für de Betrieb?)*	15
Influence of direct payment system	Since changes to the direct payment system were made last year, cantons can initiate their own programs. Do you participate in such programs, what are your experiences? *(Sit de Umstellige im Direktzahligssystem letscht Jahr chönd d Kantön ja ihri eigene Förderprogramm mache. Machsch det mit, was sind d'Erfahrige?)* How do direct payments and cantonal subsidy programs influence your decision on land management? (*Was für en Iifluss händ Diräktzahlige und die Förderprogramm uf dini Entscheidige im Acherbau?*)	5
	What is the influence of cantonal programs and the direct payment system in general on your farm and decisions in soil management? *(Was für en Iifluss händ die Programm und d'Direktzahlige im Allgemeine uf de Betrieb und Entscheidige im Acherbau?)*	5
	Did changes in the direct payment system lead to any adjustments or changes in strategy in soil management? *(Häsch uf Grund vo de Veränderige im Direktzahligssystem irgendwelchi Veränderige im Acherbau gmacht oder d'Strategie aapasst?)*	10
Management priorities	Now if you take your entire farm into account (with all branches), if you had to prioritise: How important is conserving soil management to you? *(Wenn du dier jetzt nomal de ganz Betrieb vor Auge füersch und müesstisch e Prioritätelischte mache: Wie wichtig isch da de bodeschonendi Ahbau für dich?)*	5
	Which wishes or goals do you have for the future of your farm? *(Was für Wünsch oder Zil häsch du fürd Zukunft vom Betrieb?)*	2

If necessary, the question was rephrased, but techniques were not explained during the interview. Guideline questions are shown in table 2, in English and Swiss German. The exact wording was not identical in all interviews. Before starting the interview there was a short introduction about me and topic of my thesis. Also, respondents were encouraged to interrupt the interview at any time to ask questions. Scheduled duration of interview was one hour in order to be able to cover all relevant questions, but also to not encroach on participants' time. Most interviews actually took about one hour, except for some participants that voluntarily prolonged it.

D3: Coding examples

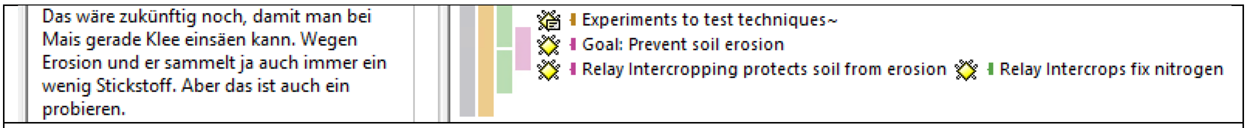
Coding of pro and contra arguments



Coding of pro und contra arguments [4]

The question preceding this extract was about biochar. Eventhough soil fertility is brought up as a pro argument, this is not taken into account when assigning codes, because it is considered a mere assumption since the interviewee himself says that he is not familiar with this method. He moves on to other methods that were subject earlier in the interview. The last part of the answer is attributed to the code “plough better than other methods or at least not as bad as ‘everybody says’” for one because there is a direct comparison to another method, for another because he uses the term “nach wie vor”, meaning “still”. This implies that he consideres ploughing a good technique in spite of other arguments that are not mentioned here.

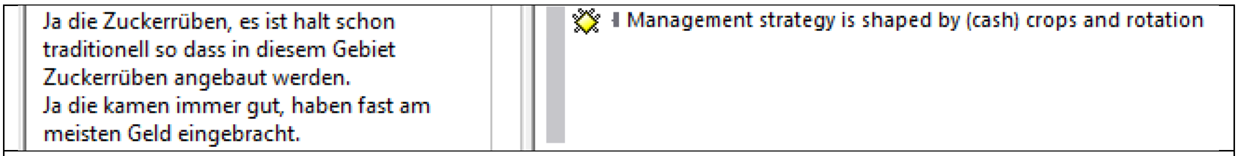
Same quote, several codes



Same quote multiple coded [6]

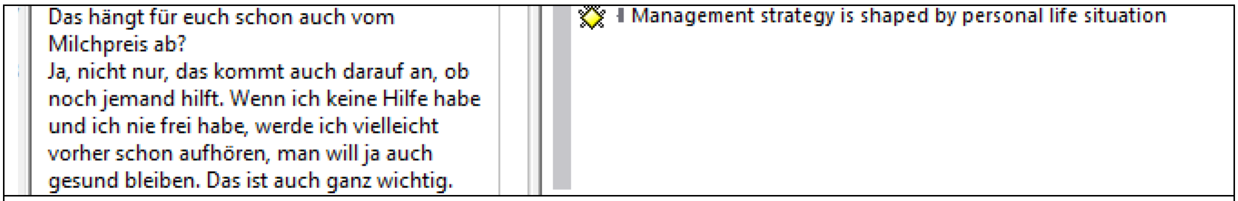
In this passage, the interviewee is talking about relay intercropping. The example shows how different codes were assigned to the same quote, because it containts several layers of information. He mentions several pro arguments, revealing one of his management goals (preventing soil erosion) and his strategy of testing new techniques at the same time.

Coding of desicions



Coding of explanatory variables [6]

In this passage, the interviewee talks about his decision to produce sugar beets. The context is that in the previous years, sugar beet has been a cash crop on the farm, so it will be part of the rotation in the future as well.



Coding of explanatory variables [5]

D4: List of explanatory variables and codes

The following list contains all codes concerning decisions on soil management techniques and the explanatory variable they are assigned to. In the first row of each variable, a short description of criteria for attributing a code to a variable is given. The column “quotes” indicates how many individual quotes are summarised to one code (several quotes can be from the same interviewee).

Group	Variable	Code	Quotes
Preconditions	Level of knowledge and personal experi-	*Codes for quotes, where interviewees mention skills, personal experiences, and level of information*	
		Biochar not used because not known or not well enough	10
		CTF requires special training, technically demanding	4
		Deep tillage sometimes necessary	2
		Conducts experiments to test techniques	19

		Intercrops are unbalanced	3
		Management strategy is shaped by outcome of experiments	4
		Mode of action of biochar not comprehensible	1
		No/Minimal tillage requires careful transition phase to build up structure	2
		Not enough information on intercropping to apply it	3
		Not enough information on what fixed tracks do to soil to apply CTF	1
		Not enough information or experience to apply relay intercropping	6
		Plough is a proven, established, reliable tool	3
		Plough is indispensable (for some crops/situations)	4
		Reduced tillage cannot replace plough	1
		Reduced tillage is valuable alternative to ploughing, "it works"	4
		Relay intercropping is not convincing	2
		Relay intercrops are unbalanced	3
		Plough better than other methods or at least not as bad as "everybody says" (moved from personal view)	9
	Availability and applicability	*Codes for quotes where interviewees talk about their (physical) access to techniques and their impression about how "ready-to-use" a technique is*	
		CTF develops fast	2
		CTF no enough developed yet	1
		CTF requires (stable) access to reference signal	1
		CTF sensu stricto is difficult or not applicable in Swiss farming	9
		Information on (new) technique found abroad, not in CH	8
		Intercropping is not developed enough	1
		Intercrops are difficult to cultivate	1
		Intercrops are difficult to harvest	1
		No/Minimal tillage requires special machinery (that is not available on farm)	2
		No/Minimal tillage machinery not developed enough	4
		No/Minimal tillage today not possible in organic production	10
		Not everything available on market that is needed for production	2
		Reduce tillage requires special machinery (that is not available on farm)	3
		Relay intercropping not developed enough	1
		Relay intercrops are difficult to harvest	1
		Shallow tillage is technically demanding	3
	Personal concepts, ideals, views	*All quotes where interviewees reveal personal opinions about how the farm should be managed and about techniques. These opinions do not arise from personal experiences with techniques*	
		(Ecological) production is better than ecological compensation	3
		Adjustments because of the money and not because of conviction is insincere	6
		Biochar is yet another unnecessary fancy soil amendment	1
		Goal: independence of direct payments	4

		Intercrops are not convincing, better focus on one healthy culture	1
		Management strategy is shaped by personal conviction and experiences in life	8
		No/Minimal tillage has no long history of experience	1
		No/Minimal tillage not convincing concept	3
		Soil management is fun/interesting	2
		Use of agrochemicals does not mean farm management is unecological (moved from weed/pest control)	1
	Information and experience of others	*All quotes on the fact that interviewees learned about a technique from someone else*	
		Biochar was falsely advertised as universal remedy	1
		Extension for strategy	2
		Other farmers had negative experiences with intercrops	3
	Uncertainties	*All quotes in which interviewees express uncertainties possibly impeding decisions*	
		Behaviour of agricultural administrative institutions causes uncertainty	4
		Changes in DP system are not predictable, shaped by political interest groups and cause planning uncertainties	2
		Contradictory information on techniques causes uncertainties	4
		Planning uncertainties for leased land	1
Framework conditions	Direct payment system	*Quotes on the effect of the direct payment system and participation in ecological compensation programs*	
		Adjustment to DP system is necessary to increase income	5
		Adjustments because of new DP system were considered but discarded (DP too little)	3
		Changes in DP system caused some adjustments, but not enough for new investments in soil management	6
		Change in DP system had little or no impact on management strategy	6
		DP is welcome extra money (can be a pro argument in decision)	3
		DP leads to adjustments in management where those were easily feasible	6
		Management strategy is shaped by DP system	1
		Management strategy will be adjusted as reaction to changes in DP system	2
		No/Minimal tillage did gain currency because of DP system change	5
		Participation in programs only if "it fits"	13
	Site conditions	*Quotes that declare a dependency of techniques from site conditions*	
		Biochar not suitable for organic soils	1
		Management strategy is shaped by site conditions	14
		No/Minimal tillage does not work on poorly structured soil	1
		Physical soil conservation depends on soil type	2
		Plough is suitable for certain site conditions (and for others not)	6
		Reduced tillage not suited for organic soils	1
		Relay intercropping does not work under too wet climate	1

		Relay intercropping does not work on organic soils	2
		Site conditions and rotation require use of more than one technique	13
	Life situation	*All quotes where interviewees talk about personal and family issues that impact farm management in some way*	
		Future of farm not sure	2
		Management strategy is shaped by personal life situation	11
	Far m	CTF not useful on small farms/better for contract work	5
	Possibility of synergies with other farm-	*Quotes about teaming up with other farmers for large investments*	
		CTF system is affordable with partner	2
		Investment into biochar should be done with other farmers	1
Farm management strategy	Weed and pest control	*All quotes related to chemical and mechanical weed and pest control*	
		(Mechanical) weed control is challenging under reduced tillage	4
		Chemical weed control is dangerous or not investigated enough	2
		Chemical weed control is less expensive than mechanical weed control	2
		CTF suited for mechanical weed control	2
		Goal: avoid/reduce chemical weed control	14
		Intercrops suppress weeds	1
		No/Minimal tillage difficult for weed/pest control	4
		No/Minimal tillage inseparably linked to use of herbicides	10
		No/Minimal tillage prevents weed seeds from germination	1
		No/Minimal tillage should not get extra DP because of herbicide application	1
		Plough favours weeds	2
		Plough is good/necessary for mechanical weed/pest control	11
		Reduced tillage for mechanical weed control	2
		Reduced tillage favours weeds	5
		Reduced tillage requires a lot of herbicides	5
		Relay intercropping makes it harder to apply mechanical weed control	1
		Relay intercrops suppress wees	4
	Other priorities on farm	*Quotes on priorities other than cropping and soil management on farm*	
		Current challenge is balancing workload for all employees	2
		DP mostly impacted other branches on farm than soil management	3
		Ecological compensation programs are lucrative (even more than some crops)	14
		Ecological compensation is a branch on farm	2
		Future changes will concern animal husbandry	2
		Goal: Extend land tenure	2
		Goal: Improve/increase ecological compensation areas	5

		Management strategy is shaped by animal husbandry	1
		Changes in the past concerned animal husbandry	2
	Priorisation of rotation and certain crops	*All quotes that reveal that priorities are given to certain crops or that management and techniques are adjusted to a rotation*	
		Intercropping not suited for all crops	3
		Management strategy is shaped by (cash) crops and rotation	4
		No/Minimal tillage not suited for crops that require fine seedbed, change in rotation necessary	8
		Plough is necessary to prepare fine seedbed	2
		Reduced tillage after certain crops	3
		Reduced tillage not suitable for all crops, change in rotation necessary	5
		Relay intercropping suitable for certain crops	2
		Rotation requires use of more than one technique	3
	Management strategy overall	*All quotes where interviewees talk about their management strategy in general*	
		Intercropping does not fit in management strategy on farm	5
		Management strategy that has been defined will not be changed soon	3
		Management strategy has been defined some time ago	2
		Management strategy is shaped by production form (conventional or organic)	4
		Management strategy was defined for the long term and is not adjusted because of changes in the DP system	4
		Past changes involved new machinery, not new techniques	2
		Soil management strategy was successful so far, will not be changed soon	4
	Versatility	*All quotes that are related to the opinion that a technique should fit more than one purpose or adaptable for several tasks*	
		CTF generates data and reveals new information on soil/management	1
		No/Minimal tillage does not allow incorporation of plant residues	1
		Plough to bring organic material/crop residues into soil	6
		Reduced tillage not well suited to incorporate organic material	3
Soil and environment	Conservation of soil as basis of production	*All quotes that reveal general concerns about soil quality*	
		Deep tillage is bad practice	1
		Goal: further develop soil management system for better soil protection	5
		Goal: minimise negative management impacts on soil	7
		Goal: shallow tillage when possible	1
		Goal: soil conserving management	1
		No/Minimal tillage conserves soil	3
		Reduced tillage conserves soil	2
		Reduced tillage favours soil fertility	3
		Relay intercropping allows taking advantages of most productive period in growing season	4

		Relay intercropping conserves soil	1
		Rotation is changed for soil conservation reasons	1
		Soil protection is important because healthy soil is the capital of the farm	4
		Yield decrease is taken into account for soil (and environment) conserving management	5
	Physical soil properties	*All quotes specifically related to physical soil properties*	
		Too much machine weight on soil is bad practice	10
		Distribute weight for better trafficability	5
		Goal: good soil structure	2
		Goal: prevent compaction by less power, weight, and passes of machines on the field	14
		No/Minimal tillage increases soil stability and structure	3
		Plough causes plough-pan	2
		Reduced tillage can cause plough-pan similar phenomenon	1
		Reduced tillage increases soil stability/restores structure	2
		Reduced tillage reduces soil compaction	2
		Relay intercropping increases soil stability and structure	2
	Chemical soil properties	*All quotes specifically related to chemical soil properties*	
		Biochar favours (long-term) soil fertility	4
		Biochar increases humus content	4
		Goal: increase humus content	5
		No/Minimal tillage increases humus content	1
		Reduced tillage increases humus content and turnover of organic material	2
		Relay intercrops fix nitrogen	3
	Biological soil properties	*All quotes specifically related to biological soil properties (often, farmers refer to soil fauna, especially earthworms)*	
		Goal: promote soil life	2
		No/Minimal tillage favours soil life	1
		Plough harms soil life	1
		Reduced tillage favours soil life	3
		Relay intercropping favours soil life	1
	Environmental aspects	*All quotes where interviewees mention environmental aspects other than soil conservation*	
		Biochar for climate protection	2
		CTF is environment-friendly	1
		Goal: protection of environment in general	5
		Goal: let nature do the work	6
		Impact of chemical weed control on environmental processes not known well enough	2
		Soil protection is part of overall goal of environment protection	1

	Erosion	*All quotes related to qualitative and quantitative aspects of soil erosion*	
		Insufficient erosion prevention is bad practice	2
		Goal: prevent surface sealing	2
		Goal: prevent soil erosion	1
		Intercrops cover soil better than monocrops	1
		Plough favours soil erosion	1
		Relay intercropping protects soil from erosion	4
Economy	Profitability and costs	*All quotes on profitability in general or related to techniques that are output-oriented*	
		Biochar application: results did not meet expectation	1
		Biochar is expensive	2
		CTF for high precision (e.g. saves inputs)	3
		CTF is expensive (for what it does)	11
		Goal: added value	3
		Goal: high profitability	14
		Intercrops have high yields	1
		Organic production is more in demand/more lucrative than conventional	2
		Reduced tillage decreases yield	4
		Relay intercropping is not cost-effective	3
		Soil protection and profitability are equally important, both highly relevant	6
		There are less expensive alternatives to CTF	4
	Resource and input efficiency	*Quotes on monetary and non-monetary inputs*	
		Use of too many and too much inputs is bad practice	4
		CTF help saving expensive inputs	3
		Goal: resource efficiency	2
		No/Minimal tillage decreases number of passes over field	1
		No/Minimal tillage is time and cost efficient	3
		Plough is time and cost intensive	1
		Reduced tillage decreases number of passes over field	1
		Reduced tillage does not necessarily save resources	2
		Reduced tillage increases number of passes over field	1
		Reduced tillage is resource efficient	4
		Relay intercropping consumes extra water (causing less yield)	3
	Buyer-driven	*Quotes addressing sales markets*	
		Goal: good position in market	3
		Intercropping not suited for contracted vegetable production	1

		Intercrops are difficult to sell on the market	1
		Management strategy is shaped by sales markets	8
		Market situation is more important for decisions than direct payments	2
		No/Minimal tillage requires change in production that buyer would not accept	2
		Stable partnership with buyer for certain crops	3

D5: List of interviewees

Interviewee	Date of interview	Canton	Interviewee
1	June 03 2015	St.Gallen	Manager
2	June 05 20125	Thurgau	Manager
3	June 08 2015	Zurich	Manager
4	June 07 2015	Aargau	Manager
5	June 01 2015	Solothurn	Manager
6	May 24 2015	Zurich	Manager and girlfriend
7	June 01 2015	Vaud	Manager and two sons
8	May 23 2015	Lucerne	Manager
9	June 23 2015	Bern	Manager
10	June 27 2015	Bern	Manager

Personal declaration: I hereby declare that the submitted thesis is the result of my own, independent work. All external sources are explicitly acknowledged in the thesis.