Department of Geography
University of Zurich

Master Thesis GEO511

Agricultural residues as a resource for sustainable agriculture

Knowledge-based agricultural residue management practises of farmers in south-western Karnataka and the introduction of biochar applications

*«Organic matter application is one of the basic things.
We say organic matter is the life of soil, you know.»* (E14B)

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Submitted by:
Severin-Luca Bellè
Bülachstrasse 1B
8057 Zurich
11-918-034

Supervisor:
Dr. Samuel Abiven
Soil Science and Biogeochemistry
Winterthurerstrasse 190
8057 Zurich

Supervisor and Faculty Member:
Prof. Dr. Norman Backhaus
Human Geography
Winterthurerstrasse 190
8057 Zurich

Cover picture: Residue pile (coconut shells) in the backyard of a farm in Honnegowdanahalli Karnataka (India)

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Summary

Agriculture will unquestionably face tremendous challenges in the 21th century, among them adaptation to climate change, soil degradation, overutilization of agricultural inputs and simultaneously expected enhancement of crop production by almost 70% represent the most vital ones. On top of this, the transformation of agriculture needs to address holistic plant-soil ecosystem approaches that include the perception and practises of the majority of small-scale rural farmers, especially in regions most vulnerable to climate change as the state of Karnataka (India) with more than 50% of the geographical area affected by drought already, and with irrigation and electricity mainly dependent on rainfall (monsoon) patterns. Soils in (semi-arid) tropical regions like Karnataka are highly depleted in soil organic matter due to environmentally favoured high mineralisation rates, but also due to low inputs of organic matter to soils. Sufficient, long-term amounts of soil organic matter are key to durable soil fertility and crop production and need to be improved through sustainable agricultural applications in the near future.

The present master project will interdisciplinary address the challenge of organic matter applications in tropical agro-ecosystems by identifying on the one side the traditional, knowledge-based practises of small-scale farmers in the Berambadi watershed in south-western Karnataka in dealing with agricultural residues and, on the other side by testing the sole and combined effect of three organic soil amendments (compost, vermicompost and biochar) on selected functions of three different soils.

The findings of the study nicely highlight the complexity of identifying tailor-made agricultural, organic residue applications for any farming system when evaluated from both a socio-economic and agro-ecological perspective. From discussions with farmers on the one side it becomes clear that agricultural residues are mostly perceived as an agronomic resource and used for many domestic and agricultural purposes. Asked about expectations and doubts on technologies like vermicomposting or biochar applications, farmers can precisely name desired effects upon socio-economic and plant-soil systems irrespective of farming type, mainly improvements in soil fertility, water and nutrient status of soils and subsequently crop yield. Results from an soil incubation study on the other side overall shows that agricultural residue application exist, which can improve the quality of the studies soil. This largely depends on the soil function intended to be improved, and on the soil type the organic matter is applied to. Surprisingly, it turns out that soils with the lowest quality (i.e. red soils) do not generally profit more from organic matter application than soils with higher fertility (i.e. black soils).

That some of the organic residue applications can address the changes in the soil ecosystems farmers desire, provides scope for successive in-depth field studies, where the effects are evaluated with organic matter coming directly from the agro-ecological context, farmers are living and working in.

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Abbreviations

μg, mg, g, kg, t	microgram(s), milligram(s), gram(s), kilogram(s), ton(s)
mm, cm, m, km, ha	millimetre(s), centimetre(s), metre(s), kilometre(s), hectare(s)
μl, ml, l	microlitre, millilitre, litre
GHG	greenhouse gases
C, CO_2, CH_4, TC, TOC, SOC	carbon, carbon dioxide, methane, total carbon (content in %), total organic carbon, soil organic carbon
N, TN	nitrogen, total nitrogen (content in %)
SOM, OM	soil organic matter, organic matter
WHC	water-holding capacity
NGO	Non-governmental organisation
IFCWS	Indo-French Cell for Water Sciences (Bangalore, Karnataka, India)
IIsc	Indian Institute of Science (Bangalore, Karnataka, India)
UAS	University of Agricultural Sciences, GKVK (Bangalore, Karnataka, India)
FAO	Food and Agriculture Organisation of the United Nations
GT, GTM	Grounded-Theory, Grounded-Theory-Methodology
SEM	standard error of the mean
B1, B2, C1, VC1, VC2	Substrates used in the incubation study: o B1: Coconut shell biochar o B2: Rice husk biochar (University of Agricultural Sciences, Bangalore) o C1: Compost (University of Agricultural Sciences, Bangalore) o VC1: Vermicompost (University of Agricultural Sciences, Bangalore) o VC2: Vermicompost (Karthik Vermicompost & Earthworms Consultant)

1. Introduction

1.1 Agriculture in the 21st century

> *«Three of the biggest challenges of the twenty-first century are the need to nearly double food production by 2050, to adapt and build resilience to a more and more challenging climatic environment, and to simultaneously achieve a substantial reduction in atmospheric greenhouse gas concentrations.»* (Scholz *et al.* 2014, p. 1).

This quote, taken from a World Bank study, highlights the big picture of agricultural challenges in the 21st century. According to the FAO (2009), agriculture has to continue to feed the worlds growing population, especially in developing countries and simultaneously develop these regions, where a majority depends on small-scale farming. **On a global scale**, agricultural production has to be enhanced by almost 70% in the near future in a sustainable and efficient way, as well as it has to be mediated through a focus on the participation of small-scale farming and it has to adapt to the current variations in climate (FAO 2011).

Agriculture has always been an essential part of human life, feeding the worlds growing population since thousands of years (Barrow 2012). Agricultural production has, especially in emerging countries like India, shifted from a local subsistence-oriented production of crops for food consumption to a global food production network that is highly resource-intensive, liberalised and commercialised, thus aimed at producing cash crops for export or feedstock for livestock (Page 2002).

The worldwide intensification of agriculture has contributed to a substantial part of GHG emissions to the atmosphere and to the depletion of native SOC pools (Stavi & Lal 2013; Cardoen *et al.* 2015b). Furthermore, the (mis)use of chemical fertiliser in agricultural production has depleted natural resource pools, contaminated water bodies, polluted and degraded the arable soils as the backbone of agriculture and ultimately increased the dependency of farmers (Barrow 2012; Patil *et al.* 2014; FAO 2011; Schutter & Vanloqueren 2011).

With a share of over 60% of the total land area, **agriculture takes up a primary position in India**. Out of this share, approximately 180 million hectare are used for agricultural production with an intensity far beyond 100% (Cardoen *et al.* 2015a). These lands have been cultivated for thousands of years, contributing to a deep pool of agricultural knowledge and practises that have been central to the livelihoods and culture of many Indian[1] farmers (Patil *et al.* 2014).

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[1] *«Indian»* relating here to any person who is native, descent or inhabiting India (according to Oxford University Press (2017)).

With the introduction of the green revolution in the 1960ies, India's agriculture has speeded up its production and has experienced a tremendous shift, mainly through important contributions from science and technology on the one side, but also trough the neoliberal turn of the government of India on the other (Patil *et al.* 2014; Purushothaman, Patil & Francis 2013). The former have contributed to the introduction of high yielding varieties alongside with chemical fertiliser, which resulted in increased crop yields and food security (Patil *et al.* 2014). The latter liberalised India's agriculture, allowing and promoting global capitalism to invest, which brought many technological and infrastructural improvements for rural areas (Patil *et al.* 2014; Purushothaman, Patil & Francis 2013; Ghosh 2004).

The intensification of agriculture had its price. The production of the newly introduced crop varieties needed a specialised infrastructure from irrigation and plant protection to storage management and market facilities (Patil *et al.* 2014). Only a small agrarian elite was in the position to make use of the advancements, thus contributing to a neoliberal and capitalistic development of Indian agriculture (Patil *et al.* 2014; Purushothaman, Patil & Francis 2013; Lerche 2011). Additionally, the liberalisation of the agrarian market of India in the 1990ies further eroded farmers protection from the world market logic, exposing them to international trade and price politics (Lerche 2011).

In 2010, two third of India's population has been depended on agriculture, making it the most important economic activity in the country (Purushothaman, Patil & Francis 2013). Small-scale farmers who cultivate less than one hectare of land still prevail, accounting for 70% of all farmers owning land (Lerche 2011). Small-scale farmers, however, experienced a shift from the production of traditional, subsistence-oriented crops to commercial, high value and high input crops, demanded by the market. This process has increased their dependency on agricultural inputs like water or chemical fertilisers, and likewise on the market, which determines demand and price. Declining productivity and crop yields of major commercial crops have contributed to a steady decline in annual agricultural growth rates, reaching its minimum around the turn of the millennium at 0.6% (Kumar *et al.* 2006; Lerche 2011). Consequently, rising farmers' distress and indebtedness became apparent (Patil *et al.* 2014).

The agrarian reform has brought not only major socio-economic problems, but also environmental ones. Ground- and surface water contamination and depletion through the overuse of water resources and chemical fertilisers, but also the degradation of both resources soil and plant, are some of the major consequences. The dependency on chemical inputs decreased the application of fresh OM to soil, additionally reducing the fertility of many soils (Ghosh 2004; Barrow 2012; Patil *et al.* 2014).

The **development of agriculture in the state of Karnataka** is widely comparable to the nationwide development. From the total geographical area of the state, approximately two third is currently used for agricultural production. However, the economic value generated by agriculture declined from 28%

in 1995 to 12% in 2011 even if the total cultivated land area did not significantly change since the 1960ies (Patil *et al.* 2014; Purushothaman *et al.* 2013).

The main shift in agriculture since the green revolution crystallises in cropping patterns and intensity of agricultural production. An increasing number of farmers, on all scales considered, have started to produce commercial, cash crops instead of focusing on subsistence-oriented production, including domestic dry-adapted crops (Patil *et al.* 2014; Purushothaman, Patil & Francis 2013; Sarkar *et al.* 2011). Agricultural production has become more dependent on inputs like chemical fertiliser and irrigation, and accordingly more expensive. This in turn made it necessary to produce more cash crops in order to obtain the financial resources to sustain these inputs (Deshpande 2002).

Agriculture is mainly performed under drought conditions and it is heavily influenced by monsoon dynamics, whereas one third of the area is under irrigation (Deshpande 2002; Patil *et al.* 2014). High uncertainties due to climate (drought, precipitation) and price variations (market fluctuation), decreasing growth rates and crop yields, reduced public and institutional interest in agriculture, failure of social (community, family) and state institutions to provide support and information about new farming technologies, farmers' migration and business-give-up due to economic indebtedness and distress and ultimately farmer´ suicides are only some of the most important factors that are shaping agriculture in Karnataka today (Deshpande 2002; Purushothaman, Patil & Francis 2013; Kumar *et al.* 2006).

The intensification of agriculture in Karnataka also had its impacts on both land and water resources, disrupting the natural ecosystems to a large extent. Over 50% of the total agricultural area of the state is currently exposed to soil degradation, making it high time for conservation (Sarkar *et al.* 2011).

1.2 Sustainable agriculture in the 21st century - a conceptualisation

The challenges stated in section 1.1 call for an agriculture that is sustainable in all aspects of ecological, socio-economic and political life (Schutter & Vanloqueren 2011; Barrow 2012; Kumar *et al.* 2006). According to the Committee on Twenty-First Century Systems Agriculture, sustainable agriculture consists of four key elements including supply of food, feed and fibre for human consumption, the strengthening of natural resources and the environment, enhancing economic feasibility of agricultural production and increasing performance of farmers and society in all its aspects. Agricultural sustainability is made up of a complex set of ecological and socio-economic concepts (Commitee on Twenty-First Century Systems Agriculture 2010).

The ecological dimension is linked to the protection of resources that are used in agriculture (soil, plant and water) and the use of on-farm practises to manage agricultural systems. Organic fertilisation ideologies that use biomass as a provider of fresh OM are considered to be of major importance

(Schutter & Vanloqueren 2011). Such applications may include manure, compost and other on-farm fertilisers that can be applied to soils (Commitee on Twenty-First Century Systems Agriculture 2010) and that rely more on traditional, nature- and knowledge-based practises of small-scale farmers and rural communities who use agricultural residues and natural resources, rather than relying only on external, non-renewable inputs (Deshpande 2002; Ghosh 2004; Giovannucci *et al.* 2012; Manjunatha *et al.* 2013; Purushothaman, Patil & Francis 2013). This could finally address the goal to decrease the hazardous effect of agriculture on the environment (Stavi & Lal 2013).

The socio-economic perspective places farmers and their practises at the heart of agriculture. Agriculture can only be sustainable if small-scale farmers can secure their livelihoods through sustained crop yields and simultaneously have access to knowledge and technologies of modern agriculture, which reduces the economic risk of farmers through appropriate income and reduced dependency on external inputs (Kumar *et al.* 2006; FAO 2011; Barrow 2012; Giovannucci *et al.* 2012; Patil *et al.* 2014). Experts from the Sustainable Development in the 21st Century project have ranked rural livelihoods and the role of smallholders first when it comes to agricultural development (Giovannucci *et al.* 2012).

For agriculture to become sustainable, scientists, politicians and farmers have to work together on formulating knowledge and developing tailor-made technologies (Schutter & Vanloqueren 2011). Research and development do not only have to focus on the needs of small-scale farmers and innovations in their traditional knowledge and perceptions, but it has actually come from the context within they secure their livelihood (Giovannucci *et al.* 2012). As many small-scale farmers adopt sustainable farming practises due to limited resources (Kumar *et al.* 2006), these practises could be implemented by more farmers in the near future (Giovannucci *et al.* 2012).

Barrow (2012) and Schutter & Vanloqueren (2011) call in this context for a second and modern green revolution, which, in accordance with the first revolution in the 1960ies, increases agricultural production, but in contrast to the first, the second revolution has to be environmentally friendly and based on the logics of nature. The slogan must be improved agricultural production that generates higher yields through healthier ecosystems, not only increased production (Giovannucci *et al.* 2012). Scholars, many of them Indian, also call for the introduction of sustainable agricultural ideologies (or sometimes organic, ecological agriculture) as being the first priority in **changing the face of India's agriculture** (Misra *et al.* 2003; Kumar *et al.* 2006; Mankasingh *et al.* 2011; Patil *et al.* 2014).

Traditional and sustainable approaches to farming which meet the current challenges of agriculture have been largely neglected by the technocratic agricultural development policies so far (Schutter & Vanloqueren 2011; Sarkar *et al.* 2011). A possible explanation is the perception that organic farming cannot be viable as higher returns and lower material costs are not able to compensate lower income due to reduced crop yields (Sarkar *et al.* 2011).

It is noteworthy, however, that sustainable agrarian initiatives exist. There is a body of national and state policy schemes that try to eradicate the problems associated with the agrarian crisis and support individual farmers (Patil *et al.* 2014).

Karnataka is one of the Indian states most vulnerable to climate change, as 54% of its geographical area is affected by drought already, while irrigation and electricity depend to a large extent on rainfall patterns (Indian Institute of Science 2014). It is predicted that rainfall will increase in many regions of the state, but it will also become more variable and days with rain will become less. The south-western monsoon season, which is of major importance for water availability, will make more regions vulnerable to water stress compared to the past. Climatic variations will also affect agricultural productivity, thus possibly reducing yields of many major crops in Karnataka by up to 38%, but possibly increasing yields for other crops depending on regional variations (Indian Institute of Science 2014). Farmers producing commercial crops might be more affected by climate change than farmers who still engage in the cultivation of traditional crops (Sarkar *et al.* 2011).

The retention of water in soils is one of the biggest challenges that agriculture will face under climate change. Besides, in order to address climate change, agricultural practises have to become more sustainable in many terms, including the reduction of GHG emissions and pollution. Adapting to climate change means strengthening natural ecosystem processes related to soils and water, introducing holistic farming systems and promoting more institutional and organisational support and to further demonstrate recent innovations in farm-management practises to rural farming communities, which are moderately to highly vulnerable to climate change, imminently (Indian Institute of Science 2014).

In Karnataka, the first state-wide policy for the promotion of organic agriculture (Karnataka State Policy on Organic Farming) was set in motion in 2004 and subsequently implemented. In its core, it aims at promoting organic farming and to introducing more integrated farming systems (Siddaraju 2011; Patil *et al.* 2014). The implementation of the state policy has increased the number of small farmers shifting to sustainable agriculture and the state governmental budget for it.

NGOs play an essential role in promoting organic farming in Karnataka, as they transfer knowledge in organic practises like composting, vermicomposting, manure preparation or concepts for soil and water protection (Siddaraju 2011). There is an ongoing trend in Karnataka towards the promotion of alternative agricultural practises (Purushothaman, Patil & Francis 2013) and farmers are innovative when it comes to sustainable agriculture, based on their knowledge of such practises (Siddaraju 2011).

1.3 Agricultural residue applications to (tropical) plant-soil systems - a matter of importance

Organic residues, mainly from households and agriculture, make up almost 50% of all solid residues generated globally, whereas in developing countries they can contribute up to 64% (Lim *et al.* 2016). In India, residue generation from agriculture is estimated to be between 400 million tons up to 800 million tons ever year (Ravindranath *et al.* 2005; Srinivasarao *et al.* 2013; Cardoen *et al.* 2015a).

In agriculture, these residues are an important resource for sustaining production of, especially small-scale, farmers who possess only few resources (FAO 2011; Srinivasarao *et al.* 2014). Around 70% of India's agricultural land is not cultivated with advanced technologies (irrigation, fertiliser), making farming practises based on locally available inputs, such as organic amendments to soils, necessary (Manjunatha *et al.* 2013).

However, from the large quantities of agricultural residues, not enough find their way back to the soil, where it would be urgently needed for reduction of chemical fertiliser use and soil quality improvements (Cardoen *et al.* 2015b). The re/usage of residues has gained worldwide attention in recent years due to various environmental problems related to agricultural production. Many agricultural practises have now been identified unsustainable, depleting the native SOM pool and the soils crucial ecological functions (Doan *et al.* 2015). The overuse of chemical fertiliser, soil degradation, but also problems associated with GHG emissions and odours from residue piles have contributed to both debates and developments in the field of organic residue management (Misra *et al.* 2003; Garg *et al.* 2006).

Recycling of agricultural residues to soils is promising for a sustainable agriculture in the near future as it protects the soil resource, it sequesters significant amounts of C and it improves social systems (Srinivasarao *et al.* 2014). Many physical and biochemical soil parameters can be positively influenced by agricultural residue management through improvements in temperature and moisture conditions, in increasing the SOC pool and in adsorbing major nutrients (Jouquet *et al.* 2010; Srinivasarao *et al.* 2014). Consequently, it has been proved to be beneficial for stimulating crop growth when compared to untreated soils (Tognetti *et al.* 2005; Jouquet *et al.* 2010). In addition, most of the residue applications are assumed to be cost-efficient and environmentally friendly (Lim *et al.* 2016).

By contrast, it would be mistaken to assume that agricultural residues have yet no usage. The importance of the preliminary identification of existing local knowledge and practises of managing these residues by farmers, before considering any alternative utilisation, has been emphasised by scientists (Cardoen *et al.* 2015a) while studies that focus specifically on agricultural practises of residue management are still scarce (Veeresh *et al.* 2011). Additionally, the overuse and mismanagement of decomposing plant biomass can contaminate ground- and surface water pools trough toxic levels of leached nutrients. The production and application of composted plant material can, if not practised in the right way, contribute to GHG emissions to the atmosphere (Barrow 2012; Cardoen *et al.* 2015a).

Among residue management practises, composting, vermicomposting and biochar have been heralded to increase soil fertility and agricultural productivity, while simultaneously reducing the environmental impact of agriculture (Jouquet *et al.* 2011; Ngo *et al.* 2016). Composting and vermicomposting are already perceived as valuable methods of converting organic residues into a soil amendment (Ngo *et al.* 2011; Srinivasarao *et al.* 2014; Lim *et al.* 2016). Whereas the understanding of ecological benefits of such applications is underway, socio-economic aspects are still fighting for their cause to be understood (Jouquet *et al.* 2010).

The production of biochar from agricultural residues could be one strategy for a sustainable agriculture in the future (Barrow 2012). The positive effect of biochar applications on crop yields has been observed to be highest for soils with a low level of SOM and low WHC (Ippolito *et al.* 2012; Abiven *et al.* 2014), which is the case for many soils in the semi-arid tropics of Karnataka. Application of biochar to soils can help managing agricultural residues, increasing the SOM content and subsequently be beneficial to many of the soils' essential functions (Mankasingh *et al.* 2011; Jien & Wang 2013).

Yet ecological aspects of biochar are the subject of recent interest from science and technology and concerns about a framework for feasible implementation of biochar systems for development have been identified (Barrow 2012; Scholz *et al.* 2014). Other scholars call for a more detailed overview over the opportunities to locally produce and apply biochar in specific agro-ecological contexts (Barrow 2012; Abiven *et al.* 2014; Scholz *et al.* 2014).

Tropical regions like southern India are crucial for the world's agricultural production and for the food security of its population. Its soils, however, are highly depleted in SOM, mainly caused by conditions that favour high mineralisation of SOM. Leaching of major macro- and micronutrients, as well as high acidity are other characteristics of soils in the semi-arid tropics (Atkinson *et al.* 2010; Mankasingh *et al.* 2011; Wani *et al.* 2011; Jien & Wang 2013). Environmental conditions can only partially be held responsible for the depletion of agricultural soils in SOM. A main driver behind this process is the decreased input of OM back to soils (Stavi & Lal 2013; Cardoen *et al.* 2015b).

A sufficient, long-term amount of SOM is the precondition for durable soil fertility and sustainable agricultural production, especially in tropical regions, as it regulates many biochemical and physical processes in soils, including major nutrient cycles (Bansal & Kapoor 2000; Lehmann & Rondon 2006; Jouquet *et al.* 2011; Mankasingh *et al.* 2011; Srinivasarao *et al.* 2013, 2014).

Additionally, soils in the semi-arid tropics show a high potential of sequestering C in the long-term, as many of these soils have lost a great part of their C stocks during historical agricultural production. The application of OM could therefore increase the SOC stocks through C storage in a more stable way (Ngo *et al.* 2011; Srinivasarao *et al.* 2014).

In this regard, agricultural production can deliver the necessary fresh OM input itself, mostly in the form of agricultural residues like plant biomass and animal excreta (Bansal & Kapoor 2000) which in turn can be applied to soils through sustainable practises like recycling of crop residues, composting, vermicomposting or biochar (Jien & Wang 2013; Lim *et al.* 2016; Srinivasarao *et al.* 2014). Mixing the organic amendments with the first couple of centimetres of agricultural soils could already be sufficient to substantially increase the fertility of tropical soils (Ngo *et al.* 2011).

1.4 The need for interdisciplinary research - locating the master project

Sections 1.1 to 1.3 formulate the basis for locating the master project in the context of sustainable agriculture in Karnataka. The main issues that frame the project are summarised below:

- In the agrarian context of Karnataka, there is a possible scope for sustainable applications that are accessible to all types of farming systems and that transform the current way of agricultural production. Agricultural residue applications like composting, vermicomposting and biochar represent some of the promising strategies to address this issue.
- It is crucial to preliminarily identify the knowledge-based practises of farmers in dealing with agricultural residues in rural Karnataka, before evaluating any sustainable residue application based on ecological studies.

These two points outline one major conceptual feature of the present master project: **its interdisciplinary approach**. Many scholars have advocated for more interdisciplinary research, especially in fields where different academic specialists are working on, as it is the case in agriculture, (agro)ecology and sustainable development (Barrow 2012; Joseph *et al.* 2015; Kumar *et al.* 2006; Scholz *et al.* 2014). Based on academic recommendations and personal interest, the present master project combines approaches of human geography and soil science. The interdisciplinary approach unfolds as followed:

First, knowledge-based practises and perceptions of Karnataka farmers in different environmental settings in dealing with agricultural residues will be identified. Second, the focus will be placed on specific strategies for using residues as a resource for soil amendment. Third, the possible introduction of vermicompost and biochar as tools for managing agricultural residues and for using it as a soil amendment will be discussed with farmers and experts in order to identify the opportunities for possible applications of those.

A soil incubation experiment will evaluate the effect of three applications (compost, vermicompost and biochar) on the quality of the sampled soils in the case villages according to predefined soil parameters (pH, WHC, TC, TN, microbial activity).

The combination of the two approaches is chosen in order to reveal discrepancies between individual farmers' perceptions and practises in dealing with agricultural residues, and the feasibility of three major agricultural practises for residue management and soil amendment.

The following **research questions** will guide the project during data collection and analysis:

A. What knowledge-based practises of agricultural residue management do farmers in different environmental (climate, soil) and socio-economic settings in south-western Karnataka use?
    a. What perceptions do farmers have about organic residues as an agronomic resource?
    b. What expectations and doubts would farmers have upon the introduction of new residue management techniques (vermicompost and biochar) in their farming system?
B. What impact do different residue management techniques (compost, vermicompost and biochar) have on selected physical and biochemical parameters of the studied soils?

Based on the gained knowledge through a detailed literature review, the following **research hypotheses** have been identified and will be evaluated:

A. Farmers in south-western Karnataka use specific, knowledge-based practises to manage agricultural residues, including traditional charring technologies and other ways of preparing soil amendments like manure or compost.
    a. Farmers in south-western Karnataka perceive agricultural residues as a valuable resource for their farming system.
    b. The introduction of vermicompost and biochar applications to soils could represent a cheap and sustainable technology of managing agricultural residues on a small-scale.
B. The application of vermicompost and biochar to soils significantly increases the quality of the studied soils compared to traditional practises of managing agricultural residues.

Chapter 2 introduces the theoretical concepts that the project refers to. A detailed overview over agricultural residues in the Indian context and over agricultural practises of managing these residues, including biochar applications, will be given. Chapter 3 outlines the decision-making for the research area and its specification. In chapter 4, the methods of data collection and analysis for both the human geography and the soil science part will be handled. Chapter 5 presents the main findings of both parts (interviews and incubation) and tries to connect them with each other (section 5.4). Chapter 6 completes the thesis by concluding on the main findings, by critically reflecting the research process and by highlighting ideas for further research.

2. Agricultural residue applications - theoretical framework

Chapter 2 has the purpose of conceptualising the term agricultural residues, embedding it in the context of agriculture in Karnataka and to introduce some of the most important practises of agricultural residue management (cow dung manure, compost, vermicompost and biochar). Ultimately, section 2.4 aims at revealing the effect size of compost, vermicompost and biochar as a soil amendment in terms of selected agro-ecological factors.

2.1 Agricultural residues - a conceptualisation

There are numerous terms that are used in the literature for what will be called henceforth agricultural residues. In the literature, terms like *agriculture biomass, biomass residues or wastes, agricultural residues* (Cardoen *et al.* 2015a, p. 39) or *organic by-product* (Cardoen *et al.* 2015a, p. 42) are used. Other scholars use the terms *agricultural waste, crop residues, agricultural by-products, agro-residues* or simply *biomass* (Srinivasarao *et al.* 2013, p. 2).

Both papers above mentioned further draw an important differentiation. They differentiate between *biomass* and *surplus biomass* resp. *surplus residues* (Srinivasarao *et al.* 2013, pp. 1–2), the latter referring to the part of the total residues that is left when all the residues used for a specific purpose are excluded (Srinivasarao *et al.* 2013). The differentiation could later be helpful to estimate the amount of residues that are available for soil amendment application and therefore to weigh the opportunity for the introduction of vermicompost or biochar from a resource perspective.

Using the term *agricultural waste* (Veeresh *et al.* 2011, p. 77), the authors' define agricultural residues as any organic material that accumulates during the process of agricultural production and processing. This includes crop residues, forest products and animal manure that are available on-farm (Veeresh *et al.* 2011). It comprises all organic compounds found in biomass, which are mainly carbohydrates, lipids, proteins and cellulose, but also other chemical compounds in smaller quantities (Cardoen *et al.* 2015a). Major agricultural residues that are produced in rural farming are animal manure and crop residues, which account for almost 90% of all residues (Gowda *et al.* 1995). Crop residues mainly comprise of stems, leaves, husk, glumes and stumps (Srinivasarao *et al.* 2014), whereby the largest contribution comes from paddy and wheat (straw), banana, sugarcane, cotton (stalks), maize, potato and sorghum (Jowar), which together account for almost 80% of all produced agricultural residues Indian-wide (Cardoen *et al.* 2015a).

2.2 Agricultural residues - the context of Karnataka (India)

The production of agricultural residues in Karnataka (and many parts of India) for any residue management application can be highly beneficial since agriculture can be practised year round (Cardoen *et* *al.* 2015a). Several scholars estimate the amount of available agricultural residues on different scales, with varying results.

A study conducted in 2005 estimates that around 840 million tons of agricultural residues could incur in Indian agriculture (Ravindranath *et al.* 2005). A more recent study calculates an amount of approximately 436 million tons of residues that could annually incur, whereas the surplus residues account for almost 72% (Srinivasarao *et al.* 2013). The same report, based on other estimations by the Indian government (Ministry of New and Renewable Energy), found that around 500 million tons of residues could accumulate annually, whereby 25-30% of it could be surplus. The report also states that around 34 million tons of residues incur in Karnataka, with a surplus of about 25% (Srinivasarao *et al.* 2013). The most recent study calculates agricultural residues in the magnitude of 600 million tons annually, with surplus of again approximately 25% (Cardoen *et al.* 2015a).

On a smaller scale, a study conducted in one taluk[2] of approx. 690km^2 in Karnataka, estimates a production of agricultural residues of > 1.1 million tons per annum. Over 60% of these residues originate from crop biomass and over 20% from animal excreta (Veeresh *et al.* 2011).

Finally, research carried out in a village in southern Karnataka of around 500 inhabitants that are largely dependent on agriculture, shows that over 2000t of residues, including plant biomass (crop residues and tree) and excreta (animal and human) can be generated annually (Gowda *et al.* 1995).

In contrast to the huge amounts of estimated agricultural residues, it is important to note that many farmers in rural Karnataka lack in the necessary OM, either from crops or livestock, to fully perform sustainable agricultural practises (Purushothaman, Patil & Francis 2013). Some scholars however emphasise that deficits in agricultural residues for farming applications could be offset by implementing more efficient and sustainable residue management practises that can be integrated in traditional agricultural methods (Gowda *et al.* 1995; Cardoen *et al.* 2015a). Farming practises that are considered as inefficient in this regard may be the burning of crop residues or simply leaving residues on open fields to decompose (Gowda *et al.* 1995; Ravindranath *et al.* 2005).

2.3 Farming practises for agricultural residue management and applications to soils

There are many ways of processing agricultural residues for further farming applications, especially to soils, which have been discussed in literature. In the following subsections, practises are introduced that will later be of importance for the soil incubation experiment (see section 4.3, 4.4 and 5.3).

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[2] A taluk is the organisational subunit of a district in Karnataka, which again is the subunit of the state.

2.3.1 Traditional practises of agricultural residue management

There are many knowledge-based farming practises that utilise agricultural residues on-farm and in households, and farmers often see an important, if not vital, resource in these residues (Cardoen *et al.* 2015b). Indigenous farming practises have been essential for thousands of years of agriculture, and farmers have known for long the nutrient-rich character of agricultural residues, making them useful to increase the SOM content of soils and therefore to sustain crop production (Maruthi *et al.* 2008).

A village-based study in Karnataka from 1995 for example found that 77% of the agricultural residues generated in the respective village were used as fuel for heating and cooking, for feeding livestock and for preparing traditional organic fertiliser. Only the remaining 23% of the residues have been left for decomposition or burning in agricultural fields itself, without any intended use (Gowda *et al.* 1995).

Another study done in rural Karnataka identifies a diverse set of traditional practises in managing agricultural residues, based on the input materials (crop residues or animal excreta). Whereas residues from various crops are used for many traditional practises ((vermi)composting, mulching, fodder, fuel, residue burning or construction material), residues from animal excreta have largely been used to prepare cow dung manure (Veeresh *et al.* 2011).

The availability to utilise agricultural residues for organic fertilisation to soils might therefore be constrained by these traditional, alternative practises and rural farming communities might not see the application of residues for soil amendment as their first priority (Srinivasarao *et al.* 2014; Joseph *et al.* 2015). This entails that the identification of traditional farming practises as well as perceptions of residues as an agricultural resource by farmer communities is an essential topic before conceptualising and introducing any alternative residue application for soil amendment from the side of science and technology (Cardoen *et al.* 2015b; Ghosh 2004; Gowda *et al.* 1995; Purushothaman *et al.* 2013).

2.3.2 The preparation of cow dung manure (or farmyard manure)

On-farm manure (Figure 1), consisting of animal waste that originates mainly from cattle breeding is being produced in enormous quantities and it is being used intensively as a traditional agricultural input to the plant-soil systems. It represents a common substitute to chemical fertiliser (Lazcano *et al.* 2008). Furthermore, it is heralded to promote C sequestration, to reduce the use of fossil fuels and to increase various soil functions including physical structure, microbial activity

Figure 1: Traditional way of preparing cow dung manure in a pile (own picture).

and nutrient availability (Commitee on Twenty-First Century Systems Agriculture 2010). For rural India, there even exists an informal exchange market, where farmers share manure according to their needs (Ghosh 2004).

In contrast, the application of raw or processed animal manure may also be hazardous for the plant-soil systems (Ngo *et al.* 2011). Manure enhances not only the status of beneficial nutrients such as N, but also that of nutrients that can be dangerous to agro-ecosystems. It releases environmentally hazardous chemical compounds like heavy metals, pathogens, salts and it can contribute to large losses of nutrients through leaching and emission (Lazcano *et al.* 2008). Application practises are normally knowledge- and labour-intensive (Ghosh 2004; Commitee on Twenty-First Century Systems Agriculture 2010), and the substitution of inorganic fertiliser with manure can affect crop yields and subsequently farmers' incomes (Ghosh 2004).

In many cases, animal manure is processed at least to some degree, normally by mixing it with other organic (plant) residues and by letting it decompose in a setup similar to a pile/heap (Figure 1).

2.3.3 Basics of composting

The concept of composting is straightforward to most of us, as we all produce organic residues and subsequently leave it somewhere. The question is how can one define the process that takes place in agricultural terms. Mediated through microorganisms like bacteria or fungi, composting refers to the decomposition of OM such as agricultural residues, animal manure and food waste. It is a naturally occurring biochemical process that is adapted to conditions controllable for agricultural applications (Misra *et al.* 2003; Commitee on Twenty-First Century Systems Agriculture 2010).

Figure 2: Preparation of compost in drums at UAS, Bangalore (own picture).

There are many composting methods used in agriculture (Figure 2 and 3) that are summarised in academic and institutional literature (a good overview give Misra *et al.* (2003)). At first glance, a distinction between aerobic and anaerobic decomposition of OM can be drawn (Misra *et al.* 2003; Lim *et al.* 2016). These two basic composting processes differentiate in the type of microbes involved and in the final products. While aerobic decomposition produces CO_2 alongside NH_3, water and heat, anaerobic decomposition results in CH_4 and other chemical compounds (Misra *et al.* 2003).

Since aerobic composting is more suitable for agricultural applications (Misra *et al.* 2003) and is more commonly used as a traditional method (Lim *et al.* 2016), the underlying biochemical process shall be briefly illustrated. The pile/heap (Figure 3) forms the core element of the composting process because it determines the temperature and speed of composting and the presence of a certain microbial community. The initial phase of decomposition is characterized by increasing temperature due to the work of mesophilic fungi and bacteria that process the compounds that are chemically most unstable (Misra *et al.* 2003), which refers to the activation phase (Lim *et al.* 2016). When the temperature reaches a certain level, thermophilic fungi and bacteria take over the decomposition and further increase the heat of the pile to a level of approx. 65°C, where pathogens and weed seeds are destroyed (Misra *et al.* 2003) and where intense decomposition occurs (Lazcano *et al.* 2008; Lim *et al.* 2016). This period of composting is called sanitisation (Fornes *et al.* 2012). The phase comes to an end when the temperature starts to decrease even after turning the pile. Now, chemically more stable plant compounds are broken down by a group of mesophilic microbes. In this maturation phase, decomposition proceeds at a slower pace since easily degradable OM is rare (Lazcano *et al.* 2008; Fornes *et al.* 2012; Lim *et al.* 2016). Finally, the completion of the composting process can be identified in stagnating temperature (decline of microbial activity) and in the texture and colour of the material, which turns to brownish-black similar to SOM (Misra *et al.* 2003).

Parameters that influence the quality and duration of composting are pile size, frequency of turning, water content, temperature, pH and nutrient availability (Misra *et al.* 2003; Lim *et al.* 2016). The regulation of these parameters is of particular interest when it comes to emissions of GHGs, which can significantly be reduced by choosing suitable raw materials (C:N-ratio), placement of the compost heap and by monitoring and managing water and air circulation properly (Commitee on Twenty-First Century Systems Agriculture 2010; Lim *et al.* 2016).

Figure 3: Traditional way of preparing compost in a pile (own picture).

Most traditional composting methods (Figure 3) share a long duration (generally more than three months), the building of piles/pits and low labour requirements and as well as handling (Misra *et al.* 2003). However, there are still many differences between them. First, aerobic decomposition is generally faster than anaerobic. Second, different composting methods can be applied in different climate conditions, e.g. there are methods favourable for applications in rainy or dry regions (Misra *et al.* 2003). Third, the diverse methods use different organic inputs for composting. While some only use animal waste, other use a combination of plant biomass, manure, wood and soil in different ratios (Misra *et al*. 2003).

The proposed advantages and disadvantages of using composting as a residue management practise are summarised in Table 1, based on insights from literature. Many of the highlighted benefits and constraints also hold true for the preparation of cow dung manure (see subsection 2.3.2). The term "increase or higher in XY" means that the application of composting increases the parameter XY compared to no treatment (control) or other treatments (e.g. manure or chemical fertiliser).

Table 1: Summary of proposed socio-economic and agro-ecological benefits and constraints of applying composting in farming (own representation).

	Proposed benefits	Proposed constraints
Socio-economic	Low labour and technology requirements[2,8,10] Expenditure reduction through on-farm production[2,8]	Duration[8,10] Threat to human health[4] Labour and knowledge intensive[2,10]
Agro-ecological	Higher amount of plant-available nutrients (Ca, K, Na, P)[2,3,5,9] Increase in TC[2,5,8] Increase in TN (smaller C:N-ratio)[3,5,8,9,10] Increase in cation exchange capacity[8,9,10] Change in pH[5,8,9,10] Reduced nutrient leaching[2,5] Improved soil structure[3,8] Improved WHC and water requirements[2,3] Stimulation of microbial activity[11] Enhanced crop growth/yield[2,11] Control of pathogens and diseases (thermophilic stage)[8,10] Volume reduction of organic waste and conversion into an agronomic resource[8]	Higher amount of bonded nutrients[5,10] Inhibited plant growth[5] Short-term impact due to fast mineralisation[1,7] Contamination of plant-soil systems with pathogens, heavy metals and other pollutants[1,2,8] GHG emissions through volatilisation or leaching[1,2,4,7,8,10] Increase in electrical conductivity (salinity problems)[3,6] Bad odour[10]

References: Barrow (2012)[1]; Commitee on Twenty-First Century Systems Agriculture (2010)[2]; Fornes *et al.* (2012)[3]; Gowda *et al.* (1995)[4]; Jouquet *et al.* (2011)[5]; Lazcano *et al.* (2008)[6]; Lehmann & Rondon (2006)[7]; Lim *et al.* (2016)[8]; Liu *et al.* (2012)[9]; Misra *et al.* (2003)[10]; Tognetti *et al.* (2005)[11]

2.3.4 Vermicomposting - imitating nature for high quality compost

Soil scientists have known for long the importance of earthworms as a means of transforming OM into worm casts, them being the heavy workers behind our healthy arable soils (Bansal & Kapoor 2000; Jouquet *et al.* 2010). This knowledge dates back to as early as the work of Charles Darwin in the 19th century (Aalok *et al.* 2008). Only recently however, earthworms have been identified as a potential converter of various domestic and agricultural residues into applicable organic fertiliser, the vermicompost (Aalok *et al.* 2008; Hu & Liu 2012).

Figure 4: Vermicompost preparation in tanks at UAS, Bangalore (own picture).

Vermicomposting can be done in several setups, including open field in a pit, in tanks or crates (Figure 4), in beds or bins, in piles/heaps and in windrows (Nagavallemma *et al.* 2006; Munroe 2007; Aalok *et al.* 2008).

The process of vermicomposting involves the activities of earthworms, which physically break down biodegradable material through mesophilic, enzymatic reactions and which turn the compost pile on a regular basis, thus allowing for aeration. This subsequently creates favourable ecological conditions for the activities of microbes, which break down the fragmented OM through biochemical reactions, leading to a SOM-like substrate rich in nutrients (Misra *et al.* 2003; Garg *et al.* 2006; Lazcano *et al.* 2008; Fornes *et al.* 2012; Lim *et al.* 2016).

After the initial thermophilic stage of decomposition is passed (approximately two weeks) (Garg *et al.* 2006; Nagavallemma *et al.* 2006), earthworms can be added to the OM at a rate of e.g. five kg earthworm per m^2 of OM (Munroe 2007). Subsequently, the earthworms feed on the material, breaking it down for further decomposition and maturation by microorganisms (Bansal & Kapoor 2000; Garg *et al.* 2006; Lazcano *et al*. 2008). For the final product quality, the pre-composting stage is essential, because vermicomposting itself takes place at lower temperatures and is therefore unable to remove pathogens (Fornes *et al.* 2012). Most earthworm species not only eat the same amount of OM as their body weight per day, but they also reduce the amount of the initial material by up to 50%. To feed the earthworms, basically any agricultural residues including plant biomass and animal manure can be used (Nagavallemma *et al.* 2006). Major species that are suitable for vermicomposting are *Eisenia foetida and Eisenia andrei*, which are native to many parts of the word and therefore able to adapt to various environmental conditions (Munroe 2007; Lim *et al.* 2016).

Figure 5: Vermicompost ready for harvesting (own picture).

The vermicompost can be harvested from the top of the pile around one month later (Misra *et al.* 2003) after having it laid out in smaller piles and after the earthworms having moved to the centre of the pile (Figure 5). The remain part and the earthworms will be available for further use (Nagavallemma *et al.* 2006).

Proposed benefits and constraints of vermicomposting are listed in Table 2 based on selected scientific papers. The term "increase or higher in XY" means that the application of vermicompost increases the parameter XY compared to no treatment (control) or other treatments (e.g. manure, compost, etc.).

Table 2: Summary of proposed socio-economic and agro-ecological benefits and constraints of applying vermicompost in farming (own representation).

	Proposed benefits	Proposed constraints
Socio-economic	Duration[8,9,11] Low labour requirements[9,10] Easy application[15] High awareness and acceptance[14,15] Income generation[10,11]	Labour and knowledge intensive[3,10] High(er) costs[3,10] Space requirements[10,14]
Agro-ecological	Increase in TN (smaller C:N-ratio)[1,4,7,8,12,14] Increase in TC (+ C sequestration)[8,10] Increase in major nutrients (P, K, Ca, Na)[2,4,5,8,9,10,14] Increase in cation exchange capacity[3,8] Increase in WHC or water availability[2,3,5,6] Change in pH[5,7,8] Improved soil quality (porosity, structure)[6,8,11] Stimulation of microbial activity and biodiversity[9,10] Immobilisation of heavy metals and other pollutants[8] Reduction of nutrient mineralisation and leaching (especially ammonium and nitrate)[2,6,10,13] Reduction of electrical conductivity[3,7] Enhanced crop growth/yield[2,6,10,11,14] Volume reduction of organic waste and conversion into an agronomic resource[8,15]	No impact on major nutrients (P, K, Cu)[1,3] No enhanced crop growth/yield[5] Higher leaching of OM and nutrients through watering[3] Limited pathogen and weed control (sometimes possible)[3,8,10,14] Managing needs of earthworms (water, temperature of pile, feedstock pre-treatment, environmental hazards)[3,7,8,10,11] Local earthworm species[5,11] GHG emissions from earthworms[8]

References: Bansal & Kapoor (2000)[1]**;** Doan *et al.* (2015)[2]; Fornes *et al.* (2012)[3]; Garg *et al.* (2006)[4]; Jouquet *et al.* (2010)[5]; Jouquet *et al.* (2011)[6]; Lazcano *et al.* (2008)[7]; Lim *et al.* (2016)[8]; Misra *et al.* (2003)[9]; Munroe (2007)[10]; Nagavallemma *et al.* (2006)[11]; Ngo *et al.* (2011)[12]; Ngo *et al.* (2016)[13]; Tognetti *et al.* (2005)[14]; Veeresh *et al.* (2011)[15]

2.3.5 Biochar application to soils - towards a holistic agricultural residue management?

The idea of what scientists today call biochar had already been used by the Indians of the Amazonas, where soils, commonly known as «*Terra Preta*» (Lehmann & Rondon 2006, p. 517), can be found that show high levels of charred OM and improved soil characteristics compared to adjacent soils (Atkinson *et al.* 2010; Lehmann & Rondon 2006). Recent interest in biochar technology mainly roots in its potential for soil amendment, residue management, C sequestration and enhancing of degraded agricultural land (Barrow 2012; Ippolito *et al.* 2012). Especially the potential of C sequestration and climate mitigation have brought biochar to the centre of interest in science and policy only recently (Barrow 2012). Working Group III of the Intergovernmental Panel on Climate Change (IPCC) has taken up biochar as one possible strategy to mitigate climate change and to enhance agricultural production in their Fifth Assessment Report (AR5) in 2014 (Working Group III 2014).

Furthermore, scholars emphasise the potential of biochar for helping rural farming communities in many parts of the world in terms of improving soil fertility and agricultural productivity (Xu *et al.* 2012; Joseph *et al.* 2015). There are ongoing initiatives in the research and distribution of knowledge as well as the practical application of biochar for farmers in India, e.g. through the Tamil Nadu based NGO Social Change and Development (Social Change and Development 2011: http://www.scad.org.in/what-we-do/farming/soilfertilityproject/, Access: 11.05.2017).

Biochar can be defined as charred OM similar to charcoal. Biochar is gained through the intended heating of OM under the absence (or low levels) of oxygen and under low to moderate temperatures, referred to as thermal decomposition or pyrolysis. The process results in a heterogeneous, carbonaceous material that is rich in aromatic hydrocarbons and other chemically active functional groups, thus reacting with many chemical substances in soils through its reactive surface area (Atkinson *et al.* 2010; Barrow 2012; Galinato *et al.* 2011; Jien & Wang 2013; Lehmann & Rondon 2006).

The production of biochar can be achieved through various setups, including open earth kilns, drum kilns, stoves or more sophisticated steel kon-tiki vessels (Figure 6) (e.g. Schmidt & Taylor (2014); Srinivasarao *et al.* (2013)). The production can be differentiated according to the predominantly occurring process, i.e. pyrolysis (slow, fast or flash), gasification or hydrothermal carbonisation (Scholz *et al.* 2014). The benefit in this context is that simple and low-cost set-ups exist (Joseph *et al.* 2015).

Figure 6: A way to produce biochar with a steel kon-tiki vessel at RiLu Char AG, Schaffhausen (own picture).

The characteristics and quality of the final biochar mainly depend on the initial OM and the conditions during the pyrolysis (Atkinson *et al.* 2010; Barrow 2012). Poultry manure may represent one of the most promising feedstock for biochar production and soil amendment (Jeffery *et al.* 2011; Abiven *et al.* 2014). Temperature conditions affect the pH, nutrient concentrations, C recovery, specific surface area and the porosity of the final product (Atkinson *et al.* 2010; Barrow 2012; Ippolito *et al.* 2012).

Using biochar as a soil amendment reveals a multifaceted set of possible consequences. Biochar alters the soils' pore structure through the introduction of various pore sizes (nano- to macro-pores), which affect the water and air circulation, adsorption and transport processes (mainly of nutrients) and it affects the soils' microbial community (Atkinson *et al.* 2010). Its effect on soil properties and crop growth can vary among crops, soils, climate and biochar applied (Galinato *et al.* 2011; Ippolito *et al.* 2012). Of the many possible factors causing effects on soil quality and crop productivity, pH, WHC and enhanced plant-available nutrient are of major interest (Jeffery *et al.* 2011), whereas the application rate and the particle-size of biochar products might not be of significant importance for soil amendment applications (Jeffery *et al.* 2011; Lehmann & Rondon 2006).

One of the most promising feature of biochar is its potential to sequester large amounts of C. Biochar represents a C sink if it is produced from biomass that takes up C from the atmosphere. Subsequently the charring process converts the easily decomposable C from the biomass into recalcitrant C in biochar (Galinato *et al.* 2011). It is assumed that C in many biochar types is generally environmentally more stable against decomposition than plant C (Ippolito *et al.* 2012). In this regard, the amount of C recovered in biochar compared to the C content in the initial OM is of importance (Jeffery *et al.* 2011). However, C sequestration only occurs above a certain level of C input with the application of biochar, which can be higher than 10 metric t per ha and year for tropical soils (Mankasingh *et al.* 2011).

Section 1.3 outlined some major constraints of OM applications to tropical soils, especially its fast mineralisation under tropical environments. One characteristic of biochar that could help to overcome the limitations of OM applications to tropical soils is: its assumed environmental stability and mean residence time[3] of decades to centuries (Schmidt *et al.* 2011; Abiven *et al.* 2014). This characteristic could indeed be of fundamental interest for agricultural residue applications in tropical regions, but nowadays many scientists see a more rapid mineralisation of biochar in the environment as very likely, too (Schmidt *et al.* 2011; Wang *et al.* 2016). A recent overview over conducted studies about the

[3] Mean residence time or mean life time can be calculated based on the inversion of the decay rate of biochar, which in turn is based on the temporal evolution of C (mainly CO_2) in a biochar sample, and refers to the time in which the biochar is present in a certain C pool in the soil (Lehmann *et al.* 2015).

persistence of biochar found results spanning from a few years to over 5000 years (Lehmann *et al.* 2015).

Proposed benefits and constraints of the biochar technology are listed in Table 3 based on selected scientific papers. The term "increase or higher in XY" means that the application of biochar increases the parameter XY compared to no treatment (control) or other treatments (e.g. manure, compost, etc.).

Table 3: Summary of proposed socio-economic and agro-ecological benefits and constraints of the introduction of biochar applications to farming (own representation).

	Proposed benefits	Proposed constraints
Socio-economic	Low-cost on-farm technologies[1,3,11] Production of useable by-products (biogas)[1] Improved livelihood and income generation[2,9] Dependency reduction on external inputs[3]	Institutional context[3] Access to knowledge and innovation[3] Economic feasibility only under complex socio-economic context[6]
Agro-ecological	Higher quantities of essential nutrients (N, P, K, Ca, Na, ...)[2,9,11] Increase in TC and C sequestration[1,2,3,7,11,13] Improved WHC and water availability[1,2,5,10] Higher cation exchange capacity (+ higher nutrient sorption capacity)[1,2,3,4,5,8,9,10,14] Change in pH[2,4,5,6,8,9] Improved soil quality (rooting depth, porosity, density, aggregates)[2,4,8,11] Stimulation of microbial activity and biodiversity[2,8,9] Environmental stability and effect duration[3,7,9] Enhanced crop growth/yield[1,2] Revitalisation of degraded agricultural land[3] Conversion of various organic waste into an agronomic resource[1,2,3,9,11] Reduction of GHG emissions[2,7,14] Reduction of leaching processes (e.g. nutrients)[2,5,7] Immobilisation of heavy metals and (toxic) pollutants[2,7] Effective for tropical climates[6,9]	Immobilisation and low quantities of plant-available N[2,6,7,9,10,11] Inhibition of crop growth/yield[4,7,10] Uncertainties in production and application[3] High application rates[4,10] Isolated studies under specific ecological conditions only[6] Erosion/leaching of biochar[12]

References: Abiven *et al.* (2014)[1]; Atkinson *et al.* (2010)[2]; Barrow (2012)[3]; Carter *et al.* (2013)[4]; Doan *et al.* (2015)[5]; Galinato *et al.* (2011)[6]; Ippolito *et al.* (2012)[7]; Jien & Wang (2013)[8]; Lehmann & Rondon (2006)[9]; Liu *et al.* (2012)[10]; Mankasingh *et al.* (2011)[11]; Ngo *et al.* (2016)[12]; Srinivasarao *et al.* (2014)[13]; Xu *et al.* (2012)[14]

The production of biochar from harvested residues will require a certain level of knowledge and skill, which is present in many traditional farming systems (Lehmann & Rondon 2006). The production of biochar in a small-scale system would be easily achievable with already existing local techniques such as earthen pits or mounds, and only small adaptations to the charring techniques would have to be made in order to increase the efficiency of C recovery in the biochar product (Lehmann & Rondon 2006). Positive examples of implemented biochar systems exist, as it is the case in the Thai Nguyen region of Vietnam, where local communities use various OM to produce biochar (Joseph *et al.* 2015).

Any implementation of biochar applications on the ground has to be foregone by an evaluation of the environmental and socio-economic context of farmer communities in which it shall be effectuated (Abiven *et al.* 2014; Joseph *et al.* 2015). Socio-economic factors, including the capital and infrastructure to access and finance the biochar technology as well as the skill and knowledge to execute it, are essential for the introduction of a biochar system on farm level (Abiven *et al.* 2014). Any application has to be approached in a participatory way, including the local communities whose livelihoods will be affected and who will be working with the technology (Joseph *et al.* 2015). Ecological factors affecting the successful implementation of biochar applications include the availability of agricultural residues and the presence of soils that benefit from the product (Abiven *et al.* 2014).

Other constraints include the problematic adaption of biochar technologies to specific agro-ecological and socio-economic settings (Abiven *et al.* 2014), the role of traditional agricultural practises for the performance of biochar applications to soils in everyday farming (Jeffery *et al.* 2011), the competition of biochar with domestic and agricultural purposes for agricultural residues (Barrow 2012; Joseph *et al.* 2015) or the mining of natural resources like forests for its production (Mankasingh *et al.* 2011).

2.3.6 Combined agricultural residue applications - overcoming individual limitations

Many scientific publications on composting, vermicomposting and biochar emphasise that the combined application of residue management techniques might be more fruitful than sole applications.

Composting that is followed by vermicomposting could help to eliminate the individual drawbacks of each method, resulting in a broader application potential and a better performance of the process (Lim *et al.* 2016). One major drawback of vermicomposting (Table 2), the control of pathogens and weeds, could be eliminated by inserting a composting phase prior to vermicomposting (Fornes *et al.* 2012).

The same holds true for compost or biochar, as their combined application results in the largest improvements in the plant-soil systems. A study found the greatest positive effect of soil water retention for the combined application of compost and biochar, while also plant-available nutrients and total SOC content increased (Liu *et al.* 2012). The combined application of manure and biochar may reduce the C losses from sole application of manure (Ippolito *et al.* 2012). Especially the limitation of biochar in supplying N could be eradicated by applying a mixture of biochar with other OM (Liu *et al.* 2012).

The combination of vermicompost with biochar is considered to improve the success of individual methods, but the effects of a combined application have not yet been fully understood (Atkinson *et al.* 2010). For example, in a study that compared compost, vermicompost and biochar as soil amendment, the combination of vermicompost and biochar only shows a significant effect on TN and available phosphorus levels, whereas many other soil chemical properties remain unaffected (Doan *et al.* 2015). Another study states that the combination of vermicompost and biochar might reduce the GHG emissions from the activities of earthworms (Ippolito *et al.* 2012).

In a workshop held by one of the few biochar producers in Switzerland, RiLu Char AG in Schaffhausen, the owner emphasises the need to activate any biochar before applying it to agricultural soils. This means that the chemically very reactive biochar can actually be charged by adding OM that contains nutrients and other chemical substances. Otherwise, the biochar would initially absorb a majority of the plant-available nutrients from the soil. This puts forward that the combined application of biochar with other organic amendments might prove most beneficial for agriculture (Patric Rieder (RiLu Char AG), personal communication).

2.4 Effect size of compost, vermicompost and biochar on selected soil parameters

The previous section 2.3 highlights the benefits of compost, vermicompost, biochar and the combination of those on the plant-soil systems on a qualitative basis. In the process of planning fieldwork and preparing the soil incubation experiment, the idea arose that it would be informative to identify the effect size of the treatments on selected parameters of soil quality through a review of scientific data.

2.4.1 Literature search and analysis

The review reveals that up to now and according to the author's search criteria and keywords (Table 4, next page), not enough meta-analyses on either the effect of composting or vermicomposting on the selected soil parameters have been made (only for biochar meta-analysis exist), and that mainly reviews or primary research exist. Keywords used during the search are summarised in Table 4 (next page). This is in line with Ngo *et al.* (2011), who state that only few studies exist on the effects of compost vis-à-vis vermicompost on soil parameters and crop growth. This finally has lead to the abandonment of the idea to conduct a quantitative meta-analysis on the issue.

Instead, primary research data and reviews have been compiled and have been used to calculate possible relative changes of selected soil parameters caused through applying individual or combined residue applications. The findings of this review can be found in subsection 2.4.2 (Table 5 to 8).

Table 4: Keywords used to search for meta-analyses, reviews and primary research studies for the effect of composting, vermicomposting and biochar on selected soil parameters.

Keyword(s) treatments	Keyword(s) type of paper	Keyword(s) soil parameters
Organic inputs, organic fertilisation, organic amendments, organic material, (soil) organic matter Compost, composting, composted material Vermicompost, vermi-composting, earthworm compost, worm cast Biochar, char, charcoal, coal, PyC	Meta-analysis, literature analysis, literature review, effect size analysis, regression analysis, quantitative review	pH C, TC, SOC, carbon, total carbon content, soil carbon, soil carbon stocks N, TN, nitrogen, total nitrogen content, soil nitrogen WHC, water-holding capacity, water retention, soil water, water content, soil moisture (Microbial activity, microbial biomass, microbial community, soil enzyme activity)

2.4.2 Effect size of organic soil amendments on selected soil parameters

All values in Table 5 to 8 in the column *effect size* are relative changes of the soil parameter caused through the treatment in the first column compared to a control treatment (in %) in the study referred to in the last column.

2.4.2.1 pH

Table 5: Relative effect range (% to control) of compost, vermicompost, biochar and the combination of those on pH in selected scientific studies (own representation).

Treatment	Effect size (application rate)	Approach/Design	Reference
Compost	**+5.3%** (20t ha^{-1})	Primary research (Incubation)	Jouquet *et al.* (2011)
Compost	**+2.3%** (20t ha^{-1}, without earthworms) to **+2.8%** (20t ha^{-1}, with earthworms)	Primary research (Mesocosm)	Jouquet *et al.* (2010)
Compost	**+20.8%** (20t ha^{-1})	Primary research (Mesocosm)	Doan *et al.* (2015)
Compost	**+13%** (25t ha^{-1})	Primary research (Pot experiment)	Carter *et al.* (2013)
Compost (average of compost types used in study)	**+10.1%** (30m^3 $ha^{-1)}$)	Primary research (Field study)	Arthur *et al*. (2011)

Compost	**+8.7%** (50g kg soil)	Primary research (Pot experiment)	Trupiano *et al.* (2017)
Vermicompost	**+0.9%** (20t ha^{-1})	Primary research (Incubation)	Jouquet *et al.* (2011)
Vermicompost	**+9.1%** (20t ha^{-1}, without earthworms) to **+7.8%** (20t ha^{-1}, with earthworms)	Primary research (Mesocosm)	Jouquet *et al.* (2010)
Vermicompost	**+22.6%** (20t ha^{-1})	Primary research (Mesocosm)	Doan *et al.* (2015)
Biochar	**+15.9%** (65g kg soil)	Primary research (Pot experiment)	Trupiano *et al.* (2017)
Biochar (wood)	**+17.7%** to **+28.4%**	Primary research (Incubation)	Jien & Wang (2013)
Biochar (rice husk)	**+11.1%** (50g kg soil)	Primary research (Pot experiment)	Carter *et al.* (2013)
Biochar + Compost	**+11.6%** (65g kg soil + 50 g kg soil)	Primary research (Pot experiment)	Trupiano *et al.* (2017)
Biochar (rice husk) + Compost	**+27.9%** (50 g kg soil) & **+40.5%** (150 g kg soil)	Primary research (Pot experiment)	Carter *et al.* (2013)
Biochar (bamboo) + Vermicompost	**+22.6%** (7t ha^{-1} + 20t ha^{-1})	Primary research (Mesocosm)	Doan *et al.* (2015)

2.4.2.2 Water holding capacity

Table 6: Relative effect range (% to control) of compost, vermicompost, biochar and the combination of those on the WHC in selected scientific studies (own representation).

Treatment	Effect size (application rate)	Approach/Design	Reference
Compost	**+0-50%** (depending on application rate and soil type)	Review	Martinez-Blanco *et al.* (2013)
Compost (average of compost types used in study)	**+5%** (30m^3 $ha^{-1)}$)	Primary research (Field study)	Arthur *et al.* (2011)
Compost (average of two measurements in two years)	**+5.4%** (barley, 13-17t ha^{-1}) & **+21.1%** (potato, 13-17t ha^{-1})	Primary research (Field study)	Carter (2007)
Biochar (mesquite wood)	**+100%** (133t ha^{-1}, sandy soil) & **+22.2%** (133t ha^{-1}, clay soil)	Primary research (Column experiment)	Barnes *et al.* (2014)
Biochar (birch wood)	**+11%** (9t ha^{-1})	Primary research (Field study)	Karhu *et al.* (2011)
Biochar (pine wood)	**+5%** (21.6t ha^{-1}) to **+1616.1%** (2160t ha^{-1})	Primary research (Pot experiments)	Yu *et al.* (2013)
Biochar (rice husk)	**+16.7%** to **+62.6%** (depending on application rate)	Primary research (Incubation)	Hseu *et al.* (2014)

2.4.2.3 Total carbon content

Table 7: Relative effect range (% to control) of compost, vermicompost, biochar and the combination of those on the TC content in selected scientific studies (own representation).

Treatment	Effect size (application rate)	Approach/Design	Reference
Compost	**+5.4%** (20t ha^{-1})	Primary research (Incubation)	Jouquet *et al.* (2011)
Compost	**+1180%** (20t ha^{-1}, without earthworms) to **+1720%** (20t ha^{-1}, with earthworms)	Primary research (Mesocosm)	Jouquet *et al.* (2010)
Compost	**+922.6%** (20t ha^{-1})	Primary research (Mesocosm)	Doan *et al.* (2015)
Compost	**+1137%** (20t ha^{-1})	Primary research (Pot experiment)	Ngo *et al.* (2011)
Compost (average of three composts used in study)	**+18.8%** (30m^3 $ha^{-1)}$)	Primary research (Field study)	Arthur *et al.* (2011)
Compost	**+127.3%** (50g kg soil)	Primary research (Pot experiment)	Trupiano *et al.* (2017)
Vermicompost	**+0.5%** (20t ha^{-1})	Primary research (Incubation)	Jouquet *et al.* (2011)
Vermicompost	**+2040%** (20t ha^{-1}, without earthworms) to **+1740%** (20t ha^{-1}, with earthworms)	Primary research (Mesocosm)	Jouquet *et al.* (2010)
Vermicompost	**+874.2%** (20t ha^{-1})	Primary research (Mesocosm)	Doan *et al.* (2015)
Vermicompost	**+1116%** (20t ha^{-1})	Primary research (Pot experiment)	Ngo *et al.* (2011)
Vermicompost	**+51%**	Primary research (Field plot study)	Sujatha & Bhat (2012)
Biochar	**+361.7%** (65g kg soil)	Primary research (Pot experiment)	Trupiano *et al.* (2017)
Biochar (wood)	**+37.9%** to **+42.4%** (change in SOC)	Primary research (Incubation)	Jien & Wang (2013)
Biochar (cassia)	**-8.9%** (3.3t ha^{-1}) to **+117.8%** (6.6t ha^{-1})	Primary research (Plot study)	Mankasingh *et al.* (2011)
Biochar (rice husk)	**+213.1%** (after 1 year) to **+232.8%** (after 2 years)	Primary research (Plot study)	Mankasingh *et al.* (2011)
Biochar + Compost	**+414.8%** (65g kg soil + 50 g kg soil)	Primary research (Pot experiment)	Trupiano *et al.* (2017)
Biochar (bamboo) + Vermicompost	**+900%** (7t ha^{-1} + 20t ha^{-1})	Primary research (Mesocosm)	Doan *et al.* (2015)

2.4.2.4 Total nitrogen content

Table 8: Relative effect range (% to control) of compost, vermicompost, biochar and the combination of those on the TN content in selected scientific studies (own representation).

Treatment	Effect size (application rate)	Approach/Design	Reference
Compost	**+16.7%** (20t ha^{-1})	Primary research (Incubation)	Jouquet *et al.* (2011)
Compost	**+100%** (20t ha^{-1}, without earthworms) to **+133%** (20t ha^{-1}, with earthworms)	Primary research (Mesocosm)	Jouquet *et al.* (2010)
Compost	**+100%** (20t ha^{-1})	Primary research (Mesocosm)	Doan *et al.* (2015)
Compost	**+850%** (20t ha^{-1})	Primary research (Pot experiment)	Ngo *et al.* (2011)
Compost (average of three compost types used in study)	**+29.6%** (30m^3 $ha^{-1)}$)	Primary research (Field study)	Arthur *et al.* (2011)
Compost	**+137.5%** (50g kg soil)	Primary research (Pot experiment)	Trupiano *et al.* (2017)
Vermicompost	**+5.6%** (20t ha^{-1})	Primary research (Incubation)	Jouquet *et al.* (2011)
Vermicompost	**+233%** (20t ha^{-1}, without earthworms) to **+200%** (20t ha^{-1}, with earthworms)	Primary research (Mesocosm)	Jouquet *et al.* (2010)
Vermicompost	**+93.3%** (20t ha^{-1})	Primary research (Mesocosm)	Doan *et al.* (2015)
Vermicompost	**+850%** (20t ha^{-1})	Primary research (Pot experiment)	Ngo *et al.* (2011)
Biochar	**+50%** (65g kg soil)	Primary research (Pot experiment)	Trupiano *et al.* (2017)
Biochar (cassia)	**+41.7%** (3.3t ha^{-1}) to **+83.3%** (6.6t ha^{-1})	Primary research (Plot study)	Mankasingh *et al.* (2011)
Biochar (rice husk)	**+11.1%** (after 1 year) to **+22.2%** (after 2 years)	Primary research (Plot study)	Mankasingh *et al.* (2011)
Biochar + Compost	**+175%** (65g kg soil + 50 g kg soil)	Primary research (Pot experiment)	Trupiano *et al.* (2017)
Biochar (bamboo) + Vermicompost	**+133.3%** (7t ha^{-1} + 20t ha^{-1})	Primary research (Mesocosm)	Doan *et al.* (2015)

3. Research area

3.1 Research area - selection and general description

While discussing the concept of the master thesis, the state of Karnataka (Figure 7), India, as the place to conduct fieldwork was suggested by my supervisor, Dr. Samuel Abiven. Subsequently, in order to identify the final research site, several criteria had to be defined. The selection of appropriate case villages was guided by the following criteria:

- Existing network to field site
- Easy access to field site and case villages
- Occurrence of unequal fertile soils
- Varying climatic conditions (water availability)
- Integration of various crops (and various agricultural residues)

Later on, at the beginning of the fieldwork in October/November and as a result of discussions with several senior scientists of the IFCWS, the Berambadi watershed (11°43'00'' to 11°48'00'' N, 76°31'00'' to 76°40'00'' E) near Gundlupete in Chamarajanagar district in south-western Karnataka (Sekhar *et al.* 2016; Robert *et al.* 2017) was chosen (Figure 7 and 8). The area fulfils the criteria of an existing network since the watershed is part of a long-term research project of the IFCSW, IIsc. Access to the field and to case villages could be ensured through a local field assistant of the IIsc. From Bangalore, the field site can easily be reached in a five to six hour taxi drive. Furthermore, the pre-defined agro-ecological criteria could be met, too (see section 3.2).

Figure 7: Location of research area (Berambadi watershed; rectangle) in Chamarajanagar district (red) in the state of Karnataka (Source: Wikipedia 2010: https://commons.wikimedia.org/wiki/File:Karnataka_Chamarajanagar_locator_map.svg, Access: 11.05.17).

Generally, the research area lies on the eastern side of the Western Ghats mountain range in the Deccan plateau (Figure 8) and borders the states of Kerala (west) and Tamil Nadu (south). In the western part of the Berambadi watershed (west of Maddur/Berambadi), protected forest can be found (Buvaneshwari *et al.* 2017).

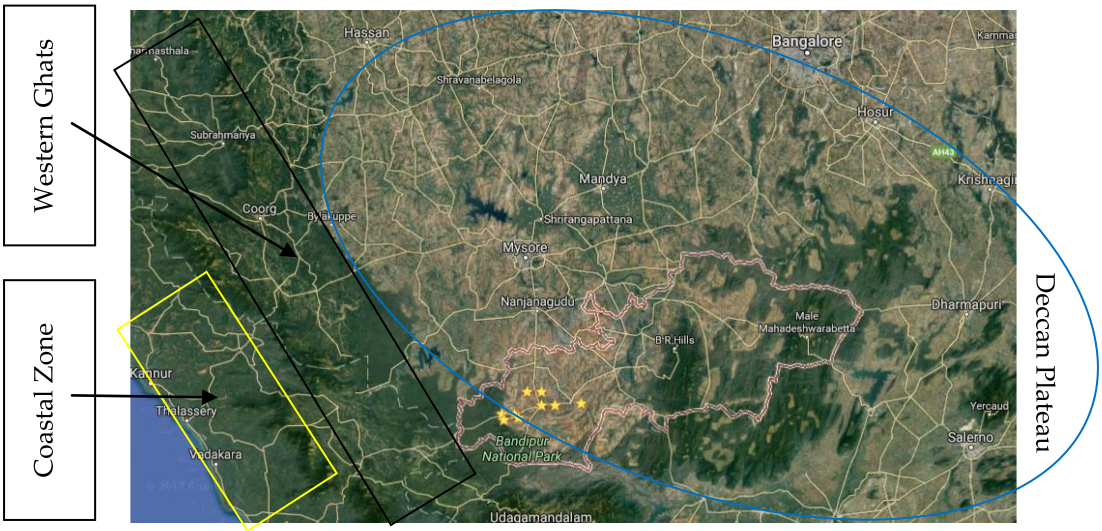

Figure 8: Location of case villages (yellow stars) in Chamarajanagar district (red outline) in south-western Karnataka (Source: Google Maps 2017a: https://www.google.ch/maps/place/Chamarajanagar,+Karnataka,+Indien/@11.9522596,76.5299268,229467m/data=!3m2!1e3!4b1!4m5!3m4!1s0x3baf30e63d48335d:0xbb37da79ef6ef2b3!8m2!3d12.0526441!4d77.2864879, Access: 11.05.2017).

The topography determines the climatic conditions in the area since the Berambadi watershed lies on the lee side of the Western Ghats, which influences rainfall patterns during monsoon seasons (Robert *et al.* 2017). The research area pertains to the climatic zone of the (dry) semi-arid tropics, which covers most of Karnataka except for the coastal region (Srinivasarao *et al.* 2014; Sekhar *et al.* 2016).

3.2 Research area - Gundlupete and Berambadi watershed

For conducting fieldwork, Gundlupete has been chosen as a base since it represents the biggest town in the area (all facilities). From there, a total of 25 interviews were conducted in the Berambadi watershed and four interviews north and east of Gundlupete (see section 8.4).

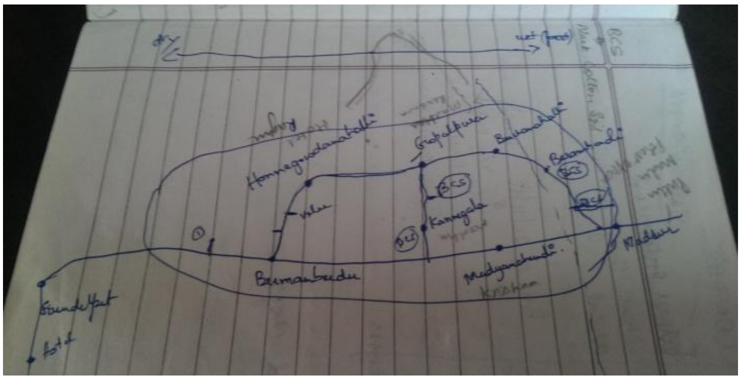
Figure 9: Sketch of the Berambadi watershed by local field assistant (own picture).

The interviews were conducted in villages that were visited together with a local field assistant and where local people already had been met (Figure 9). The local field assistant made sure that the villages included in the sample are either in the west resp. in the east of the Berambadi watershed (and east of Gundlupete) and are either on the hill or near the river bank. This ensures that variations in soil and climatic conditions are taken into account.

A closer look at climatic data (Figure 10) from two villages in the research area shows the differences between the western part of the research area (Berambadi/Maddur) and the eastern part of it (towards Terakanambi). Whereas both meteorological stations represent a tropical sub-humid climate, one can see that the western station (881mm) receives around 250mm more rainfall per year than the eastern station (633mm). This implies that the water availability decreases towards the east (Robert *et al.* 2017), which has major consequences on the irrigation type and cropping patterns of farmers. As for the temperature, it is slightly higher in the eastern part of the research area (+0.7°C), but in both cases lies around 23°C.

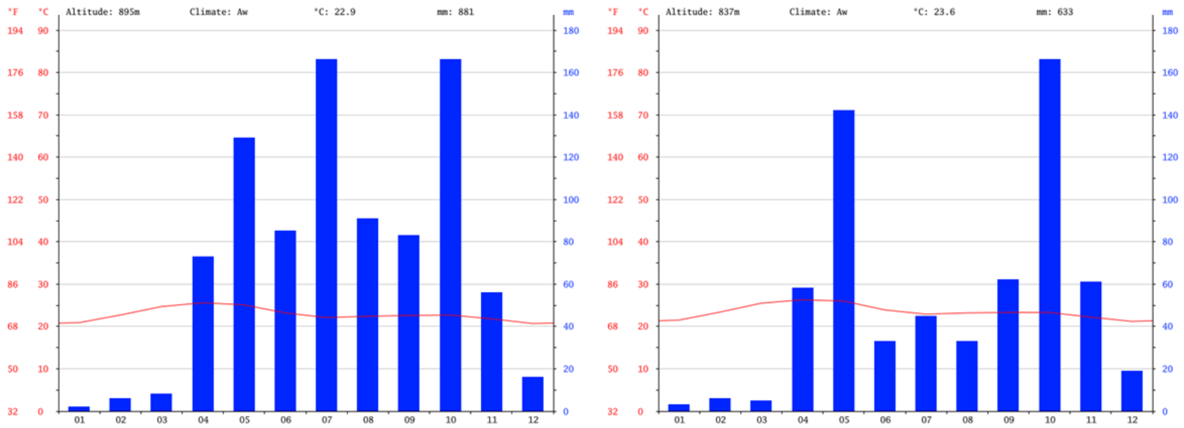

Figure 10: Climate data of Berambadi (left) and Terakanambi (right) (Source: Climate-Data.org / AM Online Projects - Alexander Merkel: https://en.climate-data.org/location/1011896/ (left) and https://de.climate-data.org/location/657544/ (right), Access: 11.05.2017).

At this point, it is important to note that farmers in the research area have been facing severe drought over the last two to three years, and many scientists and farmers said that in 2016, the northeast monsoon (Rabi season, second crop growing season) had completely failed. In this context, water availability has always been a major issue while talking with the farmers, especially rain-fed farmers. This has

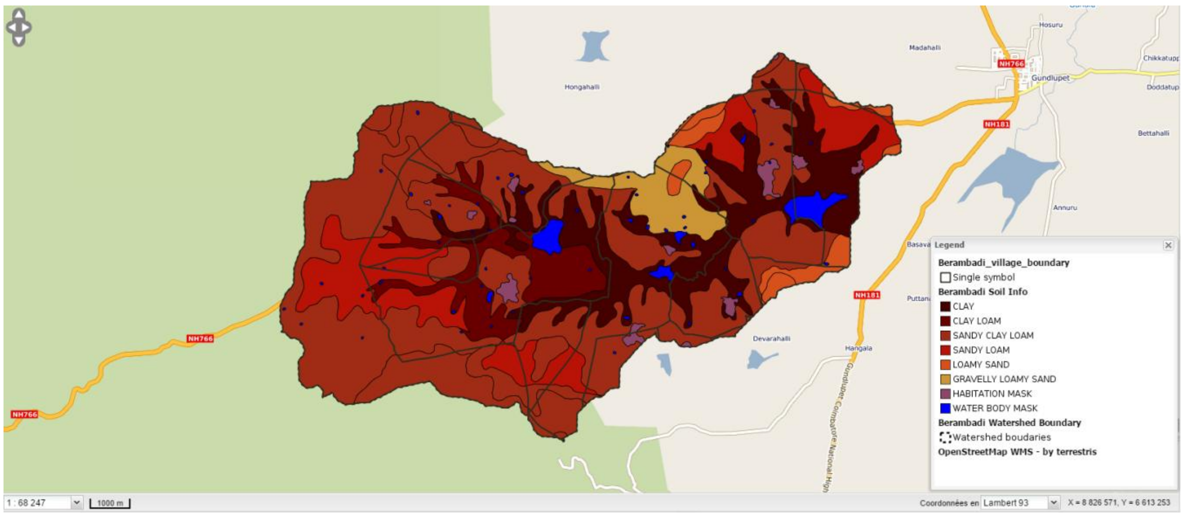

Figure 11: Soil map of the Berambadi watershed with village boundaries (Source: GeoSAS / AICHA - Adaptation of Irrigated agriculture to climate Change 2017: http://geoxxx.agrocampus-ouest.fr/mapfishapp/map/eb33961bf190d21112b2e0b8781660a6?noheader=andlang=en, Access: 11.05.2017).

again influenced the collection of information about agricultural residues since some of the farmers were unable to grow crops in Rabi season and therefore unable to process any residues.

The geology in the southern parts of the Deccan plateau is characterised by granitic gneiss, which forms the basis of the predominantly occurring red soils (Ferralsols and chromic Luvisols) on the hills/hill slopes and the black soils (Vertisol and Vertic intergrades) near the river bank (Barbiéro *et al.* 2007; Buvaneshwari *et al.* 2017). Furthermore, through agricultural practises, Anthroposols can be found in the Berambadi watershed area, where farmers apply river sediments to red soils (Laurent Ruiz (INRA), personal communication). This creates a spatially heterogeneous pattern of soils, illustrated in Figure 11.

The TOC content (%) of soils represent an indicator for the soil fertility status (Figure 12), which seems to be sufficient for most parts of the research area according to Wani *et al.* (2011). Unfortunately, this data is only available on taluk level, and therefore not accurate enough to represent the heterogeneity of the soils in the research area (Figure 11).

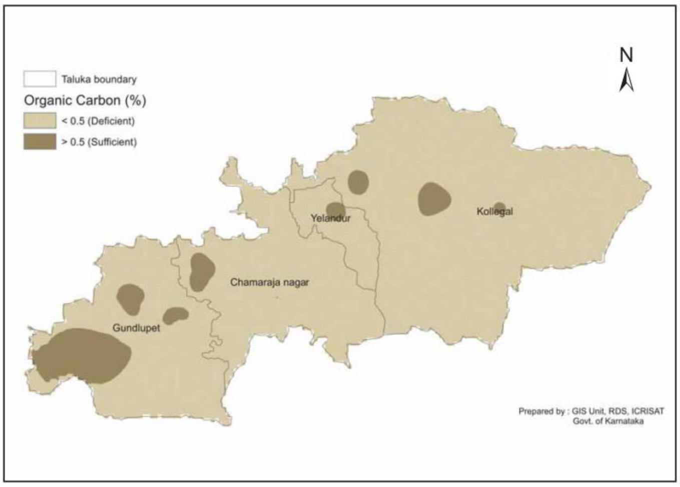

Figure 12: TOC content (in %) for Chamarajanagar district where Berambadi watershed is located (Source: Wani *et al.* 2011).

According to the Chamarajanagar district administration, the total area under cultivation for the period 2014-2015 for Gundlupete taluk accounts for 67'656 ha, which is around 50% of the total geographical area. The rest represents either forest or uncultivated land (Chamarajanagar District Administration 2016). For the Berambadi watershed, the cultivated area is up to 60% of the total area (Buvaneshwari *et al.* 2017). Dictated by the monsoon dynamics, crops are either grown in Kharif season (June to September, south-western monsoon) and/or Rabi season (October to December, north-eastern monsoon), whereas in Summer (January to May), only a limited amount of irrigated plots are under cultivation (Buvaneshwari *et al.* 2017; Robert *et al.* 2017).

Farmers normally either grow perennial (turmeric, sugarcane, banana), annual (Jowar, sunflower, Ragi) or short-term (various vegetables, pulses and grams) crops, mainly dependent on the irrigation type (rain-fed vs. irrigated). A shift to a higher production of irrigated cash crops (e.g. banana and turmeric) can be observed and many farmers start building a bore well or are planning to do so (Sekhar *et al.* 2016; Buvaneshwari *et al.* 2017).

4. Methodology

To address the interdisciplinary research goal, a combination of qualitative methods commonly used in human geography (section 4.1 and 4.2) and methods used in soil science (section 4.3 and 4.4) is applied. The complete set of methods used for data collection and analysis are visualized in Figure 13.

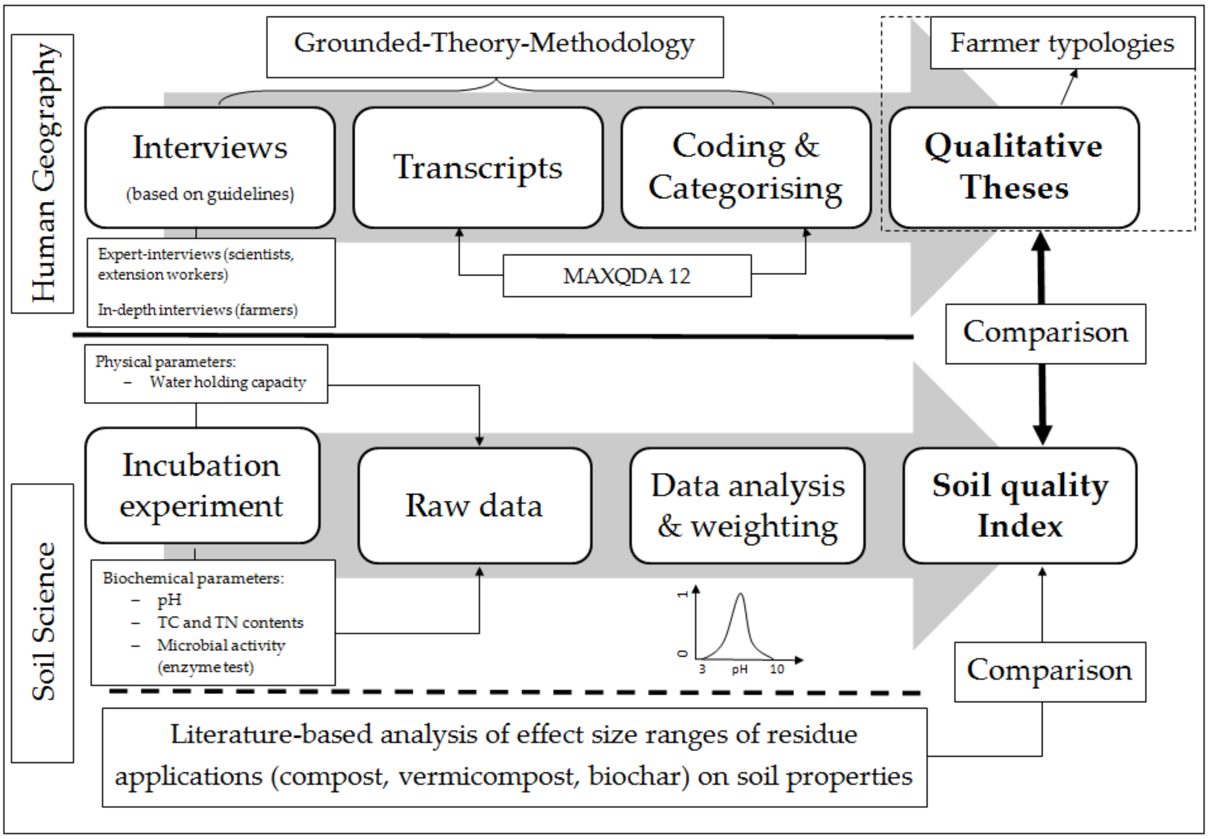

Figure 13: Overview over methods of data collection and analysis (own representation).

4.1 Qualitative methodologies - data collection

Data collection followed the order of: 1) Explorative expert interviews with scientists in and around Bangalore to get an overview over the agrarian context in Karnataka and to gain insights into agricultural residue management practises. These scientists further assisted in organising initial contacts with local scientists and field assistants in the research area. 2) Familiarisation with the area of research, leading discussions with local experts were done (e.g. field assistant, owner of fertiliser shop, etc.) and 3) In order to identify individual agricultural residue management techniques and perceptions of farmers on residues as an agronomic resource, in-depth interviews with farmers were conducted.

Qualitative data collection has not been performed in a linear, but an iterative way, and followed mainly the logic of GT (see subsection 4.1.1 and 4.2.3). For the sake of clarity, the sections on methods of data collection and methods of data analysis are separated. This should not imply that the steps have been conducted separately since the core elements of GT are the parallelisation of data collection and analysis, and the ongoing sampling during data collection (Mey & Mruck 2011; Strübing 2014).

4.1.1 Grounded Theory Methodology - theoretical sampling and saturation

Sampling in qualitative research follows the logic of non-probability, meaning that samples are chosen according to the research purpose, not randomly. This method is especially suitable for in-depth studies, where samples should reflect the variety of features for the studied phenomenon (Ritchie *et al.* 2003). Individual samples are selected based on their symbolic representation of the phenomenon, which is achieved through defining selection criteria that represent the research objective (Ritchie *et al.* 2003). As selected cases in qualitative research are normally detail-rich, only a small number of samples are necessary to reach data saturation. Sample size itself depends on the selected criteria and the heterogeneity of the studied phenomenon (Richtie *et al.* 2003).

Using GT (see subsection 4.2.3) as a methodological framework, sampling has to be theoretical. Theoretical sampling focuses on individual features of a phenomenon in order to work out theoretical categories that can be consolidated by means of a theory about the phenomenon. For exploratory research, where the area of fieldwork is not sufficiently known by the analyst, theoretical sampling can be crucial (Richtie *et al.* 2003). Samples are chosen based on their relevance for research and development of a theory (Ritchie *et al.* 2003; Mey & Mruck 2011). Therefore, it is important to choose the first samples wisely, as they influence further theoretical sampling (Strübing 2014).

Theoretical sampling is strongly linked to the way data is analysed in GT. First, open respectively purposive sampling aims at including a maximum range of cases in the studied population that are relevant for the research goal, which can be done by e.g. using a combination of a chain and a criterion sampling approach, where one case/person after the other is examined (Draucker *et al.* 2007; Patton 1990; Ritchie *et al.* 2003). This is followed by the core theoretical sampling, where samples are chosen according to the emerging categories from the priory performed open coding/sampling (Draucker *et al.* 2007). Sampling here aims at specifically selecting cases that can be compared to each other (Ritchie *et al.* 2003). Typical and extreme cases can be sampled and sampling can be done more systematic or stratified to identify different types of farmers (Draucker *et al.* 2007).

The sampling process in GT is flexible and ongoing during data collection until sampling is completed with respect to both depth of information as well as breadth of it, referring to theoretical saturation (O'Reilly & Parker 2012). Any new sample would then no longer contribute to new categories or the reframing of existing ones (Draucker *et al.* 2007; Mey & Mruck 2011; Ritchie *et al.* 2003). At this point of research, all categories are explained in their homogeneity in-itself, and in their heterogeneity between each other, as well as in their relation to each other (O'Reilly & Parker 2012). Until this stage is reached, new samples can continuously be added (Ritchie *et al.* 2003), leaving space for adjustments in the sampling strategy (e.g. by adjusting topic guides to emerging concepts). In order to include more samples, the gathered data has to be analysed so that the identified concepts can further be elaborated with new samples (Ritchie *et al.* 2003). Since both diverging and similar concepts should emerge, the sampling has a comparative focus, where samples are chosen based on their similarity or deviation from existing concepts (Draucker *et al.* 2007; Mey & Mruck 2011; Ritchie *et al.* 2003).

Sampling for expert interviews in this case is a combination of chain sampling, criterion sampling and theoretical sampling. Through asking a well-situated person in the field of research, one can access possible interview participants (Patton 1990). This could be achieved through my supervisor, Dr. Samuel Abiven, collecting a list of possible experts in the field of agricultural residue applications and introducing me to local scientists at IIsc, Bangalore. The list contains experts particularly active in fields relevant to the research and is therefore to be considered criterion based, mainly through expertise in compost, vermicompost, biochar or through expertise in the research area itself. To include experts with different knowledge and perception about the research goal, the logic of theoretical sampling was later taken up and further experts were iteratively sampled on site to complement the sampling and to ensure objectivity (Bogner & Menz 2009; Meuser & Nagel 2009). Further experts were generally sampled based on the existing network of already interviewed persons, and on their belief that these experts possess the required expertise.

Since the sampling of experts in the first stage of fieldwork in Bangalore was fruitful and a lot of information about the area of fieldwork could be gathered, it was decided not to conduct further on-site expert interviews with local scientists. Nonetheless, discussions with local experts (field assistant, owner of fertiliser shop, officer of forest department, etc.) provided further information and access to farmer networks in the research area.

The previous explanation about theoretical sampling means that the **sampling has to include as a heterogeneous group of farmers** as possible, without losing depth of information about individual farmer types. As mentioned in chapter 3, initial access to the area of fieldwork could be ensured through a local field assistant of IIsc. Upon arrival, the assistant introduced the author to farmers and school teachers in villages in the Berambadi watershed. Additionally, we were presented to a well-situated farmer (English-speaking) who could help us approaching farmers during data collection.

The initial sampling with help of the field assistant was followed by a theoretical sampling according to GT. In each of the visited villages, a set of interviews was conducted to obtain depth in information about farming, agricultural residue management and openness towards new technologies. To ensure breadth of varying farming practises, farmers and other local people were asked about any farmers practising a specific kind of farming, e.g. organic farming, or producing (vermi)compost or cultivating black or red soils. With this strategy, it was usually no problem to get introduced to more farmers.

As a rule of thumb, in most villages it was enough to conduct three to four interviews to cover the majority of farming types. Generally only a very small number of farmer(s) apply different agricultural practises (especially when it comes to residue management), which could be identified and included in the sampling. The small number of interviews per village was also justified in order to include farmers from villages with different environmental settings.

Sampling was continuously adjusted after completion of the first set of interviews, and after going through these interviews again. The final sample includes a wide range of socio-economic and agro-ecological farmer types (see section 8.3).

4.1.2 Expert interviews

Expert interviews are semi-structured, explorative interviews that assess contextual knowledge of experts, which they mainly hold through their socio-institutional position and that can be shared explicitly (Meuser & Nagel 2008). Experts are constructs based on the ascription that they possess specialized knowledge, which can be distinguished from everyday knowledge (Meuser & Nagel 2008).

Exploratory expert interviews have the purpose of getting an initial overview over the field of research, of getting insights into the research questions, organising field research and making adjustments to topic guides (Bogner & Menz 2009). A total of nine exploratory expert interviews with scientists and private companies were conducted in the first weeks of fieldwork in Bangalore as to get contextual knowledge about agriculture in the state of Karnataka, about agricultural residue management practises of farmers and as to establish the necessary contacts to arrange the following fieldwork.

Systematizing expert interviews have the purpose of accessing specialized knowledge about specific experiences that experts hold through their practise in a particular field (Bogner & Menz 2009), especially focused on the context and everyday practise of agricultural residue management by farmers in the research area. In this regard, a total of five interviews were conducted with a) a scientist who has been working in the research area for many years, b) a NGO that works together with farmers on agricultural residue management (especially vermicomposting) and c) three specialists and producers of vermicompost resp. biochar.

Expert interviews are generally conducted by means of open, topic guide based questions (Meuser & Nagel 2008). This openness enables the researcher to adapt to any specific situation in the interview, whereas the topic guide assures that the main questions of research are covered throughout all interviews (Bogner & Menz 2009). The empirical data from the interviews is comparable as all experts share a common institutional context, i.e. they possess knowledge in the field of research interest, and because all interviews were conducted on the basis of the same topic guide (Meuser & Nagel 2009).

For the **preparation of the topic guide** (see section 8.1) the following had to be considered. The intention was to thematically structure the guide in five parts (I-V) and to use different kinds of questions (main questions, checklist and follow-ups/probes), so that the interview procedure would be consistent and to ensure that the expert's knowledge could be assessed with respect to the research question (Helfferich 2014; Meuser & Nagel 2008). This also means that stimuli were replaced by more specific main questions relating to the research questions. This structuring however did not erase possible flexibility and openness for discussions (Helfferich 2014).

After posing the initial main question, it was the expert who chose the storyline and only additional questions from the checklist or follow-ups were asked if further information was deemed necessary. The division of the topic guide in different question types should also not imply any hierarchical structure, but rather have these questions been used to complement information for thematic parts.

The topic guide was examined in a pre-test with a scientist at the IFCWS at IISc. This person was already familiar with the project and willing to help testing it. Thereafter, important changes to the topic guide and the wording of questions have been made.

4.1.3 In-depth interviews with farmers

In-depth interviews represent a more or less unstructured way of collecting qualitative data. The method combines both structured and flexible elements for conducting interviews (Legard *et al.* 2003).

Any interview is structured to a necessary extent by a topic guide that ensures the coverage of the main topics and contains questions to achieve depth of information. Flexibility in the interview conduction on the other side ensures openness towards the interviewees' perceptions of the research topic so that issues raised by the interviewees can be taken up and explored in more detail. In-depth interviews are interactive and develop towards a conversation between the interviewer (and translator) and the interviewee, but with an underlying purpose (Legard *et al.* 2003).

This method aims at reaching detailed information about a specific phenomenon, including reasons, beliefs and opinions about the research topic, i.e. in this case agricultural residue management practises. To reach that stage, stimuli that open up topics during the interview are followed by more specific questions. Here, the researcher (and translator) has (have) to carefully listen to the interviewee's explanation in order to be able to ask for further depth and to rule out the essentials of the answers as to where one can dig deeper (Legard *et al.* 2003).

Knowledge about the topic under investigation is constructed during the interview, for example when farmers reflect on specific circumstances of their everyday life or when they are asked conceptually about new residue technologies (Legard *et al.* 2003). This means that during an in-depth interview, a shift from the social reality of individual farmers to a more conceptual level of the topic under investigation has to be ensured (Legard *et al*. 2003).

In-depth interviews are characterised by a six stage setup. In a first step, the interviewer (and translator) has (have) to ensure a relaxed atmosphere and that all people present feel comfortable (Legard *et al.* 2003). During fieldwork this was mainly achieved through talking about the project and the researcher's own personality and by accepting any offerings (e.g. tea) from the interviewee.

Second, and crucial for the later quality and fluency of the interview, the research itself as well as the procedure of the interview had to be introduced (Legard *et al.* 2003). Here, the interviewer and translator made sure that the interviewees felt comfortable with the interview and its recording, and that they had understood the structure of the interview, mainly to facilitate a smooth conversation and translation.

Third, before the recorder was turned on and the actual interview started, the interviewees had been asked to share information about their life and farms. This step intended to gather general information about e.g. farm size, soil type, family status and so on and to encourage the interviewees to talk freely (Legard *et al.* 2003).

Fourth, the main part of the interview followed, where the interviewer and translator went through the main dimensions of the research with the interviewee and through issues that had surged during the interview. In this step, it is not only important to cover all dimensions of the research topic, but also to achieve depth (Legard *et al.* 2003). These issues were mainly addressed during fieldwork by: a) iteratively asking the interviewees to specify certain answers or by asking the same questions differently or at different times during the interview, b) taking up information introduced by the interviewee and phrasing following questions according to it, and c) letting the interviewees decide about e.g. what crop or field they wished to talk about.

In a fifth step, the interview was closed by asking the farmers about wanting to add anything that hadn't been covered so far in the discussion. By eventually visiting the field(s) of the interviewees, the conversation was again brought back to an everyday level (Legard *et al.* 2003).

Before leaving the interviewee, generally a post-interview discussion was held to talk about the goals of the research project (Legard *et al.* 2003) and frequently about e.g. farming practises in Switzerland.

The **topic guide** (see section 8.2) was structured according to the previously described stages of the in-depth interview. It functions as a support tool for the interview, yet not as its basis. This means that the thematic blocks and structure of questions remained flexible and could always be phrased according to the interview situation (Helfferich 2014). In general, stimuli were combined with a checklist containing keywords. These helped to keep the important questions in mind, but left enough space to adapt the questions to the narrations of the interviewees (Arthur & Nazroo 2003). The stimuli of course intended to trigger long narrations and explanations by interviewees.

The topic guide was generally designed with the help of the SPSS-principle described in Helfferich (2014). In a first step, as much questions relating to the research questions as possible were collected. These were then tested on their relevance for the research and for generating informative answers. Finally, the questions were sorted according to question type and thematic blocks and then structured in order to get the final topic guide.

The topic guide for the in-depth interviews with farmers was preliminarily discussed with the translator, mainly to see if a layperson understands the questions and their underlying structure. Later on, after having conducted the first set of interviews, adaptations to the topic guide were made continuously as to ensure the comprehensibility of the questions. Likewise, adaptations to the procedure of conducting the interviews were made. For example, part II of the topic guide (see section 8.2) was divided into two stimuli and several keywords on the checklist. Soon after having started the interviews, it appeared to be much easier to just ask the interviewees about how they grow their crops from the land preparation until the harvest. After that narration, questions about more specific information could still be asked. Interviewees normally gave long answers and subsequently provided further information concerning the questions for specification.

The concept of photo elicitation refers to displaying photographs or pictures during an interview (Harper 2002). The photographs can function as a stimuli for the interviewee to start talking or help to form a better understanding of a certain topic during the interview between the interviewee and the interviewer (Helfferich 2014).

After completion of the first interviews, it became clear that the verbal introduction of new technologies like vermicomposting and especially biochar, which most interviewees were unfamiliar with, with only one laminated picture lead more to confusion that it actually served as a helpful introduction. To explain biochar applications more illustratively, a set of six laminated pictures (Figure 14a-f, next page) was chronologically displayed to introduce the biochar concept step-by-step.

Figure 14: Set of pictures used for introduction of biochar concept during fieldwork.

a) Coconut shell (left) and rice husk (right) as input materials for biochar production (Source: GreenPower 2010-2013: http://piroliz.org/clients/articles/2013-04-25-11-36-50/eng/ (left) and Dreamstime 2000-2017: https://www.dreamstime.com/royalty-free-stock-photography-rice-husk-image14609007 (right), Access: 11.05.2017)

b) Biochar production in an oil drum (Source: International Biochar Initiative 2017: http://www.biochar-international.org/carbon_roots_international, Access: 11.05.2017)

c) Biochar visualised as black particles (Source: CarbonZero Project - Switzerland (a): https://www.biochar.info/biochar.biochar-overview.cfml, Access: 11.05.2017)

d) Electron microscope image of biochar (Source: Wittman, M. 2017: https://www.tcia.org/TCIA/Blog_Items/2015/Working_with_Biochar.aspx, Access: 11.05.2017)

e) Effect of biochar on soil fertility (Source: Grissom, Tom (Youtube) 2011: https://www.youtube.com/watch?v=f9MbLOLI600, Access: 11.05.2017)

f) Effect of biochar on plant growth (Source: CarbonZero Project - Switzerland (b): https://www.biochar.info/biochar.biochar-overview.cfml, Access: 11.05.2017)

4.2 Qualitative methodologies - data analysis

During data collection the gathered interview data was preliminarily analysed in order to adjust theoretical sampling. This was performed for a) the expert interviews by ongoing transcription and noting down emerging concepts and b) the in-depth interviews with farmers by listening to the records back in the hotel room at the end of every day. These procedures, however, do not refer to a full method of analysis and were only relevant during data collection.

4.2.1 Documentation of data - transcription

If verbal data, nowadays mainly in the form of audio recordings, is converted into written documents and becomes empirical data, it is called transcription (Höld 2009; Hammersley 2010). Records and transcripts have become standard in social research, since they enable to repeatedly analyse the data and provide more information than written field notes (Hammersley 2010). Transcripts are some sort of constructs created throughout research through the selection and interpretation of what has been said and heard on the record (Höld 2009; Hammersley 2010).

The way transcription is performed later determines data analysis and has therefore to be chosen according to the method of data analysis (Höld 2009). Strict or word-by-word transcription places great importance on every word that has been said, not the overall meaning of a statement and all recorded words are typed out in a text program (Höld 2009; Hammersley 2010). This transcription style was chosen to sustain as much information as possible, partly due to the fact that already during translation in the interviews and later through coding, information is abstracted to a large extent. Transcripts were corrected for orthography, but not for grammar. All interviews were transcribed using the software Express Scribe Transcription Software Pro 5.90 (NCH Software).

Expert interviews are normally not transcribed word-by-word, but focusing on thematically relevant empirical data (Meuser & Nagel 2009). Since in this case most expert interviews were rather short in time, even here all recorded interview material was transcribed.

4.2.2 Analysis of expert interviews

The method for analysing expert interviews as described in Meuser & Nagel (2009, p. 476–477) more or less follows the logic of data analysis under GT. After having transcribed the empirical material, it is paraphrased to reduce its amount. This step was left out since most expert interviews were short in time and therefore no reduction was needed. In a next step, the generated material is coded, whereby codes are assigned that are as close to the original text material as possible.

This is followed by the comparison of codes from individual interviews with others to develop categories, which are still close to the empirical material. Only after this step the categories are conceptualised and abstracted from the empirical material, which is then followed by a theoretical generalisation, relating the categories to each other and thus resulting in typologies or theories (Meuser & Nagel 2009).

Since these procedures are very close to those of GT, all expert interviews were analysed according to theoretical coding under GT (see section 4.2.3). Since expert interviews have rather a explorative character and aim at revealing the big picture of agricultural residue management in Karnataka, the coding was relatively superficial.

4.2.3 Grounded Theory Methodology - analysing in-depth interviews with farmers

Essentially GT is a qualitative-interpretative and comparative-analytical research style, which dates back to the work of Barney Glaser and Anselm Strauss (Strübing 2014). This research style surfaces when it comes to data analysis. The goal of GT is to develop theories based on empirical data, following defined iterative methodological steps (Mey & Mruck 2011). From the empirical data, the goal is to advance theoretical concepts on different levels (codes and categories) that help developing a core category, which then can be framed as a theory (Strübing 2014).

The interpretation and abstraction of empirical material under GT is performed in different steps of theoretical coding (Draucker *et al.* 2007; Mey & Mruck 2011; Strübing 2014). In the present master project mainly the coding process of Strauss and Corbin was utilised to analyse empirical data (Mey & Mruck 2011). The three coding steps described below were executed simultaneously, which follows the iterative logic of GT. Nonetheless, it was mainly open coding at the beginning of data analysis and selective coding at the end (Mey & Mruck 2011).

In a first step, open coding tries to break down the empirical material (e.g. interview transcripts) into small sequences (e.g. words, lines, sentences or paragraphs), which then are conceptualised and assigned with codes that reflect the content of the text material. This is achieved by posing questions about the meaning of sequences to the text. In early stages of data analysis, this is performed very carefully and in much detail, but later only the interesting and important text sequences are coded more closely (Mey & Mruck 2011; Strübing 2014).

For any identified empirical phenomenon, one can assign descriptive-constructed codes or In-vivo codes (e.g. a word from the transcript itself), whereby multiple coding is possible. Codes in qualitative research depict a word or a phrase that representatively stands for a piece of empirical material (Saldana 2009). For this thesis, both constructed and In-vivo codes have been utilised and a coding system rich in detail and hierarchical structure has been chosen, mainly to have a more nuanced analysis of the empirical material. An example of open coding can be found in Figure 15 (next page).

Here, an excerpt of a farmer's answer to a question about expectations on the technology of biochar has been assigned with multiple codes.

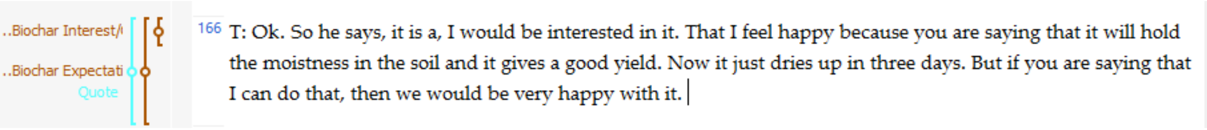

Figure 15: Example of multiple coding with MAXQDA 12 (own representation).

The paragraphs' first sentence has been assigned the code biochar - interest/openness, whereas the remaining three sentences have been assigned to the code biochar - expectations/requirements. For illustration purposes in the result chapter, the paragraph has further been linked with the code quote.

Second, axial coding tries to relate the emerging categories, e.g. visually in a diagram. These categories build on the empirical material that is relevant to the research question and are created through systematic comparison and connection of the preliminarily constructed codes and through their abstraction. The comparison of individual codes to form categories mainly builds on the ideas of homogeneity within a single category and heterogeneity between categories (Strübing 2014). The hierarchical process is summarised under the term categorisation (Flick 2005; Mey & Mruck 2011). In the coding software MAXQDA 12, the process of categorisation can be performed manually by moving individual codes, grouping them and rephrasing codes; or with the tool *creative coding*, where all relevant main codes are listed and can be dragged and dropped to a control page where they can be reorganised, and grouped (Figure 16).

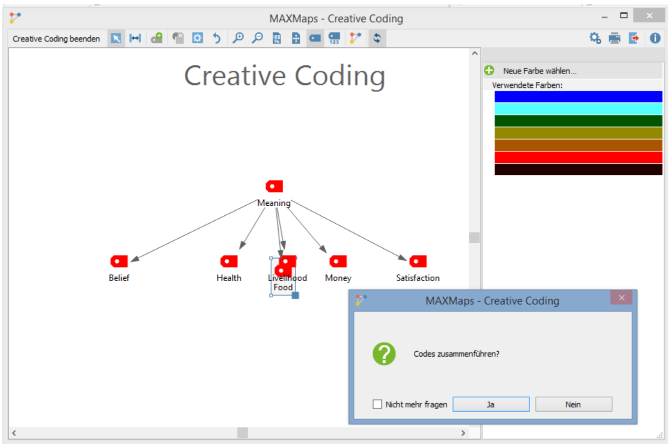

Figure 16: Example of axial coding using the tool creative coding in MAXQDA 12 (own representation).

Third, during selective coding, the core category is chosen and it is defined how categories are related to it. This corresponds to the formulation of an answer or a story to the research question, whereas the network of categories function as an explanation (Flick 2005; Mey & Mruck 2011).

Data analysis under GT comes to an end when theoretical saturation occurs. This means that additional empirical data and their conceptualisation (codes) do not contribute to new insights within the created categories (Mey & Mruck 2011). For a master thesis, it is hardly possible to reach the stage of creating a fundamental theory about a social phenomenon and thus to reach theoretical saturation (mainly due to time and resource availability for collecting empirical material). In this case, after having completed theoretical coding, no theory was developed from the empirical data, but rather theses to explain each subcategory in more detail (summarised in subsection 5.2.6).

All coding operations have been conducted with the help of the software MAXQDA 12 (VERBI GmbH), a tool for qualitative data analysis. This increases the quality of analysis by adding transparency and traceability (Mey & Mruck 2011).

GT was mainly chosen for the thesis as it is a flexible, circular research process that allows adaption of the research focus and tools (Strübing 2014). Coding and categorisation under GT with MAXQDA 12 further helps to compare the results with the analysis of the soil science part since MAXQDA 12 counts and lists all coded text sequences.

4.2.4 Visualisation and analysis of codes and categories - first data assessment

As MAXQDA 12 stores and counts all codes and categories throughout all coded transcripts, it was possible to generate a visualisation in the form of matrixes and maps with the program. This was implemented through the tools MAXMaps (for expert interviews) and the code-matrix-browser (for in-depth interviews) in MAXQDA 12 with the aim of giving a first overview of the results, as well as a first answer to the research questions (see section 5.1 and 5.2). Especially the code-matrix-browser where the frequency of single codes and categories can be plotted against any number of interviews was used frequently.

In a next step, single codes and categories central to the research goal and questions have been closely interpreted and the most striking findings are presented, supported by quotes from the primary data (see subsection 5.2.2 to 5.2.4). To do so, all coded text sequences for each farmer were tabulated in Microsoft Excel and then analysed closely. At this point if need be, single codes were regrouped or recoded based on the initial findings to make the (sub)categories more coherent.

4.2.5 Relating the results to farmer types - second data assessment

After having completed data analysis with GT, the empirical data from the farmer interviews was assessed a second time (see subsection 5.2.5) by relating fundamental parameters of farming (soil and irrigation type, farm size) to the findings of the first data assessment (see subsection 4.2.4 and 5.2.4). The goal of the second data assessment aimed at creating farmer typologies that could be used to highlight different understandings of individual farmers when it comes to new agricultural residue management technologies. Subsequently, the links between farmer types and the findings of GT are statistically tested (IBM SPSS Statistics 21) in order to identify trends between farmer types (see subsection 5.2.5 and section 8.5).

Building typologies means that the object under investigation, i.e. the farmers, are grouped into types that are as homogeneous as possible within a specific type, and as heterogeneous as possible between different types. They are mainly constructed by assigning a set of attributes and their characteristics to each type. The overall grouping process and its result can be labelled typologies (Kluge 2000). To construct farmer types, the relevant attributes and characteristics have to be defined according to the empirical data and the knowledge of the researcher. This was executed by looking at a) the metadata collected during fieldwork, especially the farm size, soil and irrigation type (see section 8.3) and b) the identified categories from GT.

In a second step, sampled farmers had to be assigned to the defined attributes in order create provisional types that can be checked for internal homogeneity and external heterogeneity (Kluge 2000). In order to construct the final types, the previous steps had to be set in relation. Finally, the identified farmer types can be defined in accordance with their attributes and their relations to one and another (Kluge 2000).

4.3 Soil scientific methodologies - data collection

4.3.1 Soil sampling

According to the information given by senior scientists at the IFCWS, there are predominantly three soil types in the Berambadi watershed (see section 3.2). On the basis of that, three representative agricultural fields of farmers cultivating either a red, black resp. mixed red-black (Anthroposols) soil were chosen for sampling. For each soil type, three randomly selected sampling spots were chosen within the farmer's field and soils were collected to a depth of 20cm (agricultural horizon), which mainly derives from the empirical data and specifications for the ploughing deepness.

> *«And then what we plough is only seven to eight inches.»* (F19)

The three samples of each soil type were then thoroughly mixed. The samples were air dried and kept in sampling bags slightly open for oxygen circulation and in the end transported to Switzerland.

4.3.1.1 Characteristics of red soils

The representative red soil was sampled in the village of Gopalpura in the field of interviewee F11. The field is located on a rather steep slope on a hill (Figure 17). The soil shows a surprisingly high pH, but an extremely low WHC at field capacity, and low TC and TN contents (Table 9, next page).

Figure 17: Agricultural field where samples of red soils were taken (own picture).

Table 9: Average values of main soil parameters for the representative red soil before (bare) and after (control) the incubation experiment (n = 3, number in parentheses = SEM).

	Bare (Soil not incubated)	Control (Soil incubated for 70 days at 24°C)
pH	7.5 ± (0.03)	7.1 ± (0.06)
WHC (%)	3.72 ± (0.05)	5.97 ± (0.14)
TC (%)	0.41 ± (0.06)	0.45 ± (0.02)
TN (%)	0.05 ± (0.007)	0.05 ± (0.004)
C/N ratio	8.66 ± (0.02)	8.64 ± (0.21)

4.3.1.2 Characteristics of black soils

The representative black soil was sampled in the village of Gopalpura in the field of interviewee F12. The field is located at the bottom of the valley, directly next to the river bank (Figure 18). The black (cotton) soil shows a similar pH as the red soil, but a higher WHC at field capacity. TC and TN contents are higher than for the red soil, but still rather low (Table 10).

Figure 18: Sampling of black soil (own picture).

Table 10: Average values of main soil parameters for the representative black soil before (bare) and after (control) the incubation experiment (n = 3, number in parentheses = SEM).

	Bare (Soil not incubated)	Control (Soil incubated for 70 days at 24°C)
pH	7.2 ± (0.09)	7.8 ± (0.07)
WHC (%)	16.02 ± (0.39)	16.38 ± (0.70)
TC (%)	1.57 ± (0.03)	1.56 ± (0.03)
TN (%)	0.10 ± (0.002)	0.10 ± (0.001)
C/N ratio	16.03 ± (0.38)	15.90 ± (0.17)

4.3.1.3 Characteristics of Anthroposol

The representative Anthroposol was sampled in the village of Berambadi in the field of interviewee F23 (Figure 19). We were told by the farmer that the native red soil had been mixed with sediments from the river bank to make it browner. The field is located near the forest at the state border to Kerala on the LEE side of the Ghats Mountains. The soil shows the lowest pH of the three soils, intermediate values for WHC and TC content and highest TN contents (Table 11, next page).

Figure 19: Sampling of Anthroposol (own picture).

Table 11: Average values of main soil parameters for the representative Anthroposol before (bare) and after (control) the incubation experiment (n = 3, number in parentheses = SEM).

	Bare (Soil not incubated)	Control (Soil incubated for 70 days at 24°C)
pH	7.3 ± (0.03)	7.0 ± (0.03)
WHC (%)	8.54 ± (0.20)	14.02 ± (0.04)
TC (%)	1.11 ± (0.03)	1.13 ± (0.02)
TN (%)	0.12 ± (0.004)	0.12 ± (0.002)
C/N ratio	9.44 ± (0.08)	9.55 ± (0.06)

4.3.2 Substrates

Substrates were liberally provided by the UAS (C1, VC1, B2), by Jean Riotte (B1) who found a shop producing coconut shell biochar in Bangalore and by Karthik Vermicompost and Earthworm Consultant (VC1), also in Bangalore. Main ecological characteristics of the substrates used in the incubation experiment are summarised in Table 12.

Table 12: Main average ecological characteristics of the substrates used in the incubation experiment (n = 3, number in parentheses = SEM, n.d. = not detected).

	B1	B2	C1	VC1	VC2
pH	9.1 ± (0.03)	7.3 ± (0.03)	6.8 ± (0.03)	7.4 ± (0.07)	6.7 ± (0.03)
WHC (%)	9.27 ± (0.25)	6.27 ± (0.86)	16.70 ± (0.79)	18.66 ± (0.37)	17.28 ± (0.09)
TC (%)	85.73 ± (2.68)	42.66 ± (0.43)	13.04 ± (1.73)	11.30 ± (0.40)	14.28 ± (1.41)
TN (%)	n.d.	0.40 ± (0.16)	1.37 ± (0.13)	1.34 ± (0.06)	1.41 ± (0.11)
C/N ratio	n.d.	138.88 ± (39.95)	9.48 ± (0.08)	8.42 ± (0.09)	10.08 ± (0.33)

4.3.2.1 Compost (C1)

For producing the compost, cow dung and crop residues (dried material, leaves, etc.) are used. The first three weeks of the production process are characterised by high temperature, the pre-decomposition phase. After these three weeks, a microbial community is introduced to the drum-composter (Figure 2). To get high quality compost, regular turning for aeration and monitoring of moisture are maintained (Dr. H.C. Prakasha, UAS, personal communication).

4.3.2.2 Vermicompost (VC1 and VC2)

For producing the vermicompost VC1 (Figure 4), again cow dung and crop residues are used. These materials are pre-decomposed in heaps for three weeks at high temperatures (60-70°C). The material is then filled into long solid tanks, to which the earthworms are introduced (Figure 4). The tank is then covered with a plastic sheet. Every 15 days, the top layer of the vermicompost pile is removed by hand and the earthworms subsequently move down due to the temperature change on the surface. The whole tank is converted into vermicompost within a month (Dr. H.C. Prakasha, UAS, personal communication).

To produce vermicompost VC2, all kinds of organic residues are used (Figure 20). Animal excreta, mainly cow dung, are then added to the plant residues in the ratio 3:1. The organic residues are kept at a moisture level of 60% and turned every five days for the first three to four weeks. After this initial phase, the organic material is filled into a solid tank together with a certain amount of earthworms (Figure 20). The final vermicompost can either be collected regularly from the top every week or in the end by forming a heap on the ground (Karthik Vermicompost 2016, personal communication).

Figure 20: Production of vermicompost at Karthik Vermicompost (own picture).

4.3.2.3 Biochar (B1 and B2)

The coconut shell biochar (B1) has its origin in a small shop in Bangalore, whereas it is produced in the countryside without any mechanisms regarding controlling temperature and other parameters (Jean Riotte (IFCWS), personal communication). For the incubation, the coconut shell biochar is crushed into small pieces by applying a hammer to the big particles (Table 12).

Biochar B2 is produced from rice husk under controlled conditions (no further information, Table 12).

4.3.3 Soil incubation experiment

The effect of individual and combined substrates on five selected properties (pH, WHC, TC, TN, microbial activity) of the three soil types was assessed under controlled conditions by conducting a small incubation experiment. The experiment was static, meaning that no ongoing measurements were conducted, but only at the end of the incubation period of 70 days through destructive sampling.

Soils were left in original shape (not sieved to <2mm) and pre-incubated by adding 15% deionised water of the total mass for eight days.

The amount of dry soil to be incubated was calculated according to the availability of soil material and accounted for 60g (<2500g of soil available for each soil type and 36 samples were needed for each). The equivalent of pre-incubated soil to be used was then calculated based on the humidity of the different soil types and accounted for 79.3g, 69.4g and 76.3g for black soil, red soil and Anthroposol, respectively.

The amount of substrate to be added as a treatment to the soil was calculated based on the approximate application rate of farmers in the Berambadi watershed, which was identified through the empirical material. The interview data shows that around 5-10t/ha of OM is applied. The amount of soil per hectare was approximated by defining 20cm as the agricultural horizon (see subsection 4.3.1), and the bulk density was set to $1.3t/m^3$. Equation 1 depicts this:

Equation (1) $$0.2m*10'000m^2*1.3t/m^3 = 2600t$$

To determine the amount of substrate for the incubation, the application of OM per soil volume has to be simply calculated, as shown in equation 2. An application rate of 10t per ha was used in this case (maximal value of range above).

Equation (2) $$10t/2600t = 0.00385$$

Then, through multiplying the weight of the dry soil to be incubated with the factor calculated in equation 2, the substrate to be incubated is determined (equation 3).

Equation (3) $$60g*0.00385 = 0.23g = \underline{\underline{230mg}}$$

For single treatments, 230mg of substrate was weighed in, for combined treatments (e.g. biochar + compost) equally 115mg of each substrate were weighed in with a precision balance.

Next, the appropriate amount of pre-incubated soil was put into 0.2l plastic cups and the respective substrate was thoroughly mixed into it. The soil was then slightly, manually compressed and two cups were put in 2l glass jars together with a 20ml glass vial filled with deionised water. The jars were put into an incubator (Figure 21) and kept at 24°C, which corresponds to the mean annual air temperature of 23.9°C of Berambadi weather station (see section 3.2). The incubation was prepared according to Abiven *et al.* (2005) and Jien & Wang (2013).

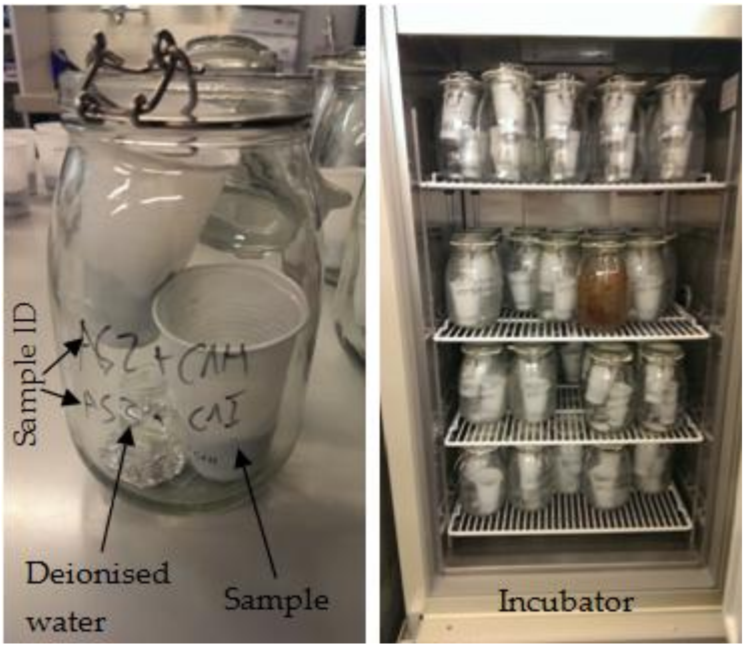

Figure 21: Setup of soil incubation experiment (own picture).

Each treatment was prepared in three replicates, making a total of 108 samples (3 soils, 12 treatments (B1, B2, C1, VC1, VC2, B1&C1, B1&VC1, B1&VC2, B2&C1, B2&VC1, B2&VC2, Control), 3 replicates).

The samples were periodically weighed to track loss of moisture and the 2l jars were regularly opened to renew the oxygen (due to respiration).

4.3.4 Soil measurements

4.3.4.1 Sample preparation

For the measurements of pH, TC and TN contents, subsamples of all replicates were dried for 24 hours in an oven at 60°C to remove any water. The subsamples were then milled to fine earth using a planetary mill (Fretsch pulverisette 5) for 10 minutes and biochar subsamples were milled with a horizontal mill (Retsch MM400) at a speed of 30 turns/s for one minute.

4.3.4.2 pH

The pH was measured by using a Metrohm 692 pH/Ion meter. Milled subsamples of each replicate were prepared by mixing 5.0g of soil with 25ml of deionised water (1:5 soil:water solution). Subsequently, all replicates were stirred for 30 minutes with a magnetic stirrer and left for sedimentation of particles for another 30 minutes. The pH was measured in the soil suspension with a glass electrode (maximal 5 minutes) and values have been recorded with an accuracy of one digit after the comma.

Regarding measurement uncertainties, some considerations have to be made. Deionised water instead of $CaCl_2$ was used, because of the presence of biochar in most of the replicates and its potential interaction with the chemical solution. This, however, has implications on the measured value of the pH, since measurements in water are normally higher than measurements with $CaCl_2$ (caused by fluctuations in electrolyte concentrations in soil suspension, especially around pH 7 where small changes in soil solution cause significant changes in pH) (Minasny *et al.* 2011). Another issue relates to the sedimentation of particles that allows measuring the pH in the soil suspension. Many replicates were rich in clay and therefore sedimentation proceeded rather slowly, and the measurements were performed in a particle-rich suspension (could be addressed by centrifugation of the soil-water solution and/or using not-milled samples).

4.3.4.3 Water holding capacity

The measurement of WHC was conducted at the laboratory of the Soil and Terrestrial Environmental Physics group of the Institute of Terrestrial Ecosystems at the Swiss Federal Institute of Technology (ETH), where the facility of a pF laboratory station exists (ecoTech GmbH, 2015).

Each replicate was weighed by volume into metal rings of 57mm x 11mm (until the metal ring was filled to the upper level) and the material was held by a very fine tissue net (fixed with a rubber band to the metal ring). Weights of each replicate were noted down and subsequently put into a water bath for 24 hours until saturation occurred and the samples were shiny on the top (water sucked up by the soil material from the bottom).

Approx. 22 replicates were put onto the membrane of the suction plate. The machine was set to a suction tension for field capacity at -325 to -335 millibar (= 33kPa or pF 2.5), which is automatically regulated by an attached vacuum pump. Field capacity of any soil correlates to the water content that a soil can hold against gravity in a static equilibrium and represents a major soil characteristic (for plants, the available water content, which is the amount of water between field capacity and the permanent wilting point, is of major importance) (Streck 2012). However, it would have been too much work in the context of the present master thesis to measure WHC at two different tensions.

To determine the equilibrium state of each replicate, replicates were weighed after 24 hours, 36 hours and subsequently again after one, two and three hours to see if there was any difference in weight. Measurements were stopped when only minor changes (<0.5g) would still occur.

All replicates were then put into an oven at 105°C for 24 hours to remove any water in the samples and subsequently weighed. By calculating the weight difference between a replicate at equilibrium and after drying, the volumetric water content could be calculated using the formula in equation 4:

Equation (4) Volumetric water content (%) at pF 2.5 = $\left(\frac{Sample\ equilibrium - Sample\ dry}{Sample\ dry}\right) \times 100$

Possible measurement uncertainties include full saturation of replicates before measurement (water has to diffuse into fine aggregates), interactions between individual replicates on suction plate (water film) and possible weight loss due to frequent weighing of individual samples.

4.3.4.4 Total carbon and nitrogen contents

Total C and N contents (and $d^{13}C$) were measured with an element analyser (coupled to an isotope ratio mass spectrometer) at the Soil Science group of the Department of Geography, University of Zurich (ThermoScientific Flash 2000 (Organic Element Analyiser) and ThermoScientific Delta V Plus (Isotope Ratio Mass Spectrometer)). The basic principle of this machine includes the combustion of the samples with oxygen in a combustion chamber and to subsequently trap and measure CO_2 and N_2.

Samples were prepared by weighing a specific mass of each replicate into tin capsules (5 x 9mm). For all replicates that contain mainly soil (including soil + treatment), 10mg of material was weighed in. For the substrates (vermi)compost (0.8 to 1mg) and biochar (200 to 300µg), smaller amounts were weighed in, mainly based on the expected higher TC content.

4.3.4.5 Microbial activity and diversity

For the purpose of evaluating the magnitude of microbial activity in the studied soils before and after exposition to the different treatments, a more or less automatic semi-quantitative enzymatic test for the identification of 19 enzymes for a soil suspension was chosen. The principle of the test (api® ZYM) from the manufacturer Biomerieux is based on reactions between synthetic substrates on the test strips and the inoculated soil suspension that is uncovered by adding reagents into each of the 20 cupules, which results in colour changes of different intensities depending on the presence of enzymes.

The execution was done by following the steps in the test manual and based on a study that exactly applied the api® ZYM system to soil microorganisms (Martinez *et al.* 2016).

First, the preparation of the dense suspension to be inoculated on the test strips was performed in the following steps:

1) A homogenised mixture of the three replicates of each soil sample (1.0g) was mixed with deionised water in a ratio of 1:1.5 (soil:water) and stored in the fridge until use. Since there had been some issues regarding insufficient volume of the supernatant (maybe some water was trapped in the sediments) and regarding the freshness of the samples, a second test run (only for one soil type, in total 12 samples) was executed with samples of higher weight (2.0g soil : 3.0g water) directly out of the incubator (possible higher microbial activity).

2) Before use, samples were taken out of the fridge and left at room temperature for > 12 hours. Each sample then was stirred for 1 minute with a Vortex-Genie 2 (Scientific Industries) and subsequently left for sedimentation for 10 minutes (Martinez *et al.* 2016).

3) To get rid of the intrinsic colour of the soil samples, all samples were centrifuged for 10 minutes at 4000g to get a clear supernatant (Martinez *et al.* 2016).

After having completed the preparation of the supernatant, the second step included the preparation of the test strips:

4) For each sample, a test strip was put into a plastic incubation box that was preliminarily wetted with 5 ml of deionised water to get a moist atmosphere and that was marked with the corresponding laboratory code for the sample.

5) Into each of the total 20 cupules of the test strips (19 enzymes + 1 control), 65µl of supernatant was added and subsequently put into an incubator for 4 hours at 37°C. In this period, the supernatant reacts with the synthetic substrates at the bottom of each cupule.

Once the incubation was finished, third the reactions were made visible (colour changes) through adding one drop of the chemical reagents ZYM A (Tris-hydroxymethyl-aminomethane + Hydrochloric acid + Sodium lauryl sulphate + water) and ZYM B (Methanol Dimethylsulfoxide -> Fast Blue BB). Test strips were left in the fume cupboard so that toxic reagents could vaporise.

Finally, the test strips were left for 5 minutes and subsequently exposed to intense light (sodium vapour lamps) for 10 seconds to remove any leftovers of the second reagent (Fast Blue BB). Results were recorded by taking pictures of each strip with a conventional smart phone (HTC One, 4 megapixels, 2688x1520 resolution). Since differences in colour intensity between many of the samples were minuscule, the process of assigning intensity values between 0 and 5 as described in the manual and according to Martinez *et al.* (2016) was not performed.

From a general point of view, it has to be mentioned that the purpose of applying the api® ZYM test was to get familiar with this kind of test and to make its quality as good as possible through experimenting with many of the influencing factors (preparation of suspension, exposure to light, measuring intensity). Further possible changes to the test had been proposed by the supervisor Dr. Samuel Abiven (e.g. measuring the intensity of the colours with a spectrometer and comparing it to a standard colour, then quantitatively determine the intensity with a linear model), but were not accomplishable within the scope of the master project.

4.4 Soil science methodologies - data analysis

In order to evaluate the effect of individual and combined treatments on the selected soil properties of the three soil types, different analyses were run and will be introduced in subsection 4.4.1 to 4.4.4.

4.4.1 Statistical analysis

Datasets for all soil parameters (pH, WHC, TC, C/N) for the three soil types were statistically analysed using the software R Studio 1.0.143 (2009-2016).

Before running any statistical test, all datasets had been investigated through looking at the descriptive statistics (means + standard errors of the mean (SEM)) and through testing the homogeneity of variance using the Levene's test for equal variances.

Subsequently, means of each treatment ($n = 3$, level of significance $p < 0.05$) for every parameter and every soil type were compared using a one-way analysis of variance (ANOVA) with the soil parameters as the dependent variables and the treatments as the comparing factor. Under the condition that the analysis of variance was significant ($p < 0.05$), post-hoc tests were conducted in order to identify which treatments (comparing factors) are significantly different at $p < 0.05$.

Post-hoc test were run with the Fisher's least significant difference (LSD), which compares individual groups based on the overall standard deviation (for R script see section 8.6).

Means and SEM of each soil property for all soil types were visualised with Microsoft Office Excel and significant differences between individual treatments from the statistical analysis in R Studio 1.0.143 have been added to the graphs (indicated by letters).

4.4.2 Average effects of organic residue applications on selected soil parameters

In order to evaluate whether the effects of individual or combined treatments on selected soil parameters actually match the observed (effective) effects measured in the soil incubation experiment, absolute average changes due to individual or combined treatments are visualised alongside the effective absolute changes due to the application of these treatments.

An example: To see whether the average effect of applying biochar B1 and compost C1 on the WHC of the control black soil (16.38%) is different from the measured effective effect of applying the combined treatment B1&C1, all absolute changes to the control soil had to be calculated. The WHC of the amended black soil with biochar B1 accounts for 16.05% (-0.33%), and the WHC of the amended soil with compost C1 for 15.63% (-0.75%). The average effect of applying these two treatments would account for ((-0.33%+-0.75%)/2) = -0.54%, and therefore would reduce the WHC of the control soil to 15.84%. In this example, however, the measured effective WHC of the black soil amended with both substrates (B1&C1) accounts for 18.17%.

Values for all soil types and the parameters pH, WHC and TC content have been calculated and visualised with Microsoft Office Excel 2016.

4.4.3 Analysis of microbial activity and diversity results

As stated in subsection 4.3.4.5, the api® ZYM test resulted in rather low differences in the enzymatic activity between single treatments. Therefore, only a qualitative (visual) analysis of the test results will be given in subsection 5.3.2.4 and a few exemplary pictures of the test results will be added.

4.4.4 Index of soil quality changes

In order to show the overall effect of individual and combined treatments on the quality of the three soil types, relative changes (in %) of each measured soil parameters to the control soil for each soil type were calculated and then visualised in a radar chart (see subsection 5.3.3). Equation 5 gives an example of how the relative changes were computed:

Equation (5) $$\text{Relative change (\%)} = \left(\frac{Soil\ (Treatment) - Soil\ (Control)}{Soil\ (Control)}\right) \times 100$$

Changes of soil parameters due to the application of treatments compared to the control soil have not been normalised (i.e. changes are assigned to pre-defined categories), as it is normally the case when building an index. The reason behind this decision roots in the fact that changes compared to the control are rather narrow between treatments, and therefore miniscule differences in the effect size of treatments would have a huge impact on the normalised index.

The results from this analysis (see subsection 5.3.3) can further be compared to the literature review on the effect size of compost, vermicompost and biochar (see subsection 2.4.2).

5. Results and discussion

5.1 Agricultural residues as a resource for sustainable agriculture - the expert's view

The aim of section 5.1 is not to present all results from the expert interviews, but rather to highlight the most striking findings that are specifically related to agricultural residue management. A major part of interviewing experts purposed as an entry point to the research area and to gather a better overview and understanding of it, and not to reinvent the wheel about agriculture in Karnataka in the 21st century. Therefore, the focus of this section will mainly lie on the opportunities of introducing new residue management technologies like vermicompost and biochar, and not on farming (methods).

5.1.1 Agricultural residues - perception, availability and application

The majority of experts believe that farmers see a valuable resource in agricultural residues, while only a minority thinks that farmers perceive residues as waste. This is supported by the fact that residue application seems to be common among farmers.

> *«They'll not waste it. It's a resource for them. They know, farmers know.»* (E10B)

Generally, experts see it as a better option to generate agricultural residues on-farm rather than purchasing OM from outside. Whether the availability of residues for the production of organic amendments for farming is sufficient or deficient, is a controversial subject. Some experts link the insufficient production of agricultural residues to the trend of decreasing livestock concentration among farmers.

> *«And with the demand in these materials for the farm usage, the production is not sufficient to meet the actual requirement.»* (E5B)

Many experts advocate that agricultural residue applications (or OM application in general) are key to sustain and improve agricultural production as well as soil fertility and they also claim that the application of residues back to the soil is currently insufficient. Finally, some experts point out the importance of considering the goal and specific socio-economic and ecological context in which applications of residues take place. It is not only a matter of which technology is applied under which condition, but also whether a combination of technologies could make sense.

> *«So it's the same for the substrates. Some of them are more interesting in some environments and absolutely not in others. It depends on the function you're looking for [...].»* (E1B)

5.1.2 Openness of farmers towards new farming technologies (vermicomposting, biochar)

Experts have designated some major factors that might influence farmers' openness towards the introduction of new technologies. First, the cost of implementation is a major concern of farmers, including considerations about possible labour problems. New technologies need to be cost-efficient. Second, farmers' capability resp. patience to wait for the effects to show up has been identified as rather low. Third, experts point out the importance of guidance during the introduction of new technologies, without which the acceptance and persistence of such technologies cannot be guaranteed. When these criteria are fulfilled, experts generally rate the interest of farmers in new technologies high.

> *«I think general what I understand about farming practises in India is that they are open to any suggestions if it has good output and is less in money.»* (E2B)

For **vermicompost**, on the one side, a high awareness of the technology among farmers, extending to the possession of knowledge about scientific methods of preparing it, has been identified by experts. Furthermore, some have detected an increased demand for purchasing the final vermicompost rather than producing it. On the other side, only a small number of farmers have de facto implemented the technology in their farming systems and the occurrence of vermicomposting among farmers is only high when guided projects by e.g. NGOs are running. Low rates of applying vermicomposting could be related to constraints described previously in this subsection.

> *«Vermicomposting, it's a well known thing. Everybody knows it.»* (E3B)

> *«I have seen that very marginally. Mostly in places where there are project from NGOs [...].»* (E9B)

Interest in **biochar applications** has in the last couple of years not only picked up globally (see subsection 2.3.5), but also in India. The development and occurrence of the technology, however, is at its beginnings and successful applications are limited to a handful of (mostly) scientific and internationally organised projects (Srinivasarao *et al.* 2013).

> *«But unfortunately, it is still in the embryonic stage. We have not yet reached the stage of recommending biochar.»* (E4B)

Of the many requirements that experts have rated as crucial for the introduction of biochar, affordable costs, low-tech setups, fast output on crop growth and yield and the spreading of appropriate knowledge to the farm-level are of major importance.

> *«If you say by applying biochar, crop will increase over the next decades and so on. They will not be excited.»* (E13B)

Experts further stress the importance of evaluating the intended goal and associated context in which biochar will be applied and that sole, blind applications of biochar might cause negative feedbacks on agricultural production. Therefore, combined solutions with other residue management applications or commercial fertilisers are emphasised not only by experts in India, but also in discussions on biochar with experts in Switzerland (see subsection 2.3.5).

This mainly refers to the activation or charging of biochar with nutrients in order to neutralise it, before it will be applied to agricultural soils.

> *«So it depends on the situation. Maybe that's not the only solution. That's part of a system that can be improved and then for this part of these resources can be used to produce biochar. But it's not only biochar or nothing.»* (E1B)

In a context like Karnataka, experts have designated a couple of organic residue inputs that could be suitable for farm-level biochar applications, including rice husk, straws of major grains (wheat, maize, Jowar), coconut shell/frond, cotton stalks, bagasse of sugarcane or from horticulture trees. How the different input material will influence the production and quality of biochar and its subsequent application on soil, will have to be evaluated in more detailed scientific studies. Only a few experts so far stress the issue of residue availability for biochar production, which could present a major concern when it comes to the introduction of the technology.

> *«And moreover the availability of residues for producing the biochar is a major issue.»* (E5B)

5.2 Conceptualisation of agricultural residues and their usage for agriculture - the farmer's view

The coding and categorising according to GT results in a hierarchical organisation of all coded empirical material. The main category (farming) can be explained by five subcategories (Figure 22), which in turn further comprise all (sub)codes used to conceptualise the data.

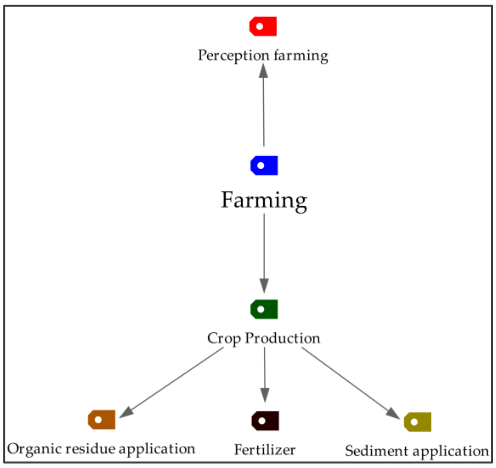

Figure 22: Identified (sub)categories of all empirical material in MAXQDA 12.

A significant part of data analysis reveals findings that are not directly related to the research, but have been helpful during data collection and analysis and to get a better understanding of important dimensions of the research topic, including the subcategories **perception farming, crop production** and **fertiliser**. This is caused by the fact that farming is entangled in many social realities and cannot be considered solely from an agronomic perspective. It does not mean, however that these subcategories are simply ignored in the upcoming interpretation, but they have rather been used to complement the findings about the main subcategory **organic residue application**, whenever necessary.

Based on these introductory remarks, the interpretation and presentation of the findings proceed as follows: First, the most important findings about the perception of farming by farmers, about ways of producing crops and about using fertiliser as an agricultural input, will be highlighted in subsection

5.2.1. Second, farmers' perceptions and knowledge about agricultural residues will briefly be introduced in subsection 5.2.2. Third, the most common knowledge-based agricultural residue management practises will be presented in subsection 5.2.3, which will give first indications about opportunities to introduce innovative residue management applications. Fourth, the opportunity to introduce two of such sustainable residue management applications, namely vermicompost and biochar, will be evaluated from a socio-economic perspective in subsection 5.2.4. Fifth, subsection 5.2.5 aims at identifying farmer types based on selected criteria and at relating these types to the opportunities for new residue technologies. Sixth, subsection 5.2.6 will summarise and discuss the findings.

All findings will be supported through figures generated in MAXQDA 12 (where only farmer interviews are included in which coding for certain phenomena have been made) and through quotes from the primary interview data. Abbreviations in brackets after the quotes indicate which farmer's interview the quote was taken from (for additional information about individual farmers see section 8.3).

5.2.1 General overview over farming in the Berambadi watershed

The subcategory **perception farming** includes findings about farmers perceptions of crucial factors for farming, about the perceived link to the environment, about the meaning of farming and finally about how farmers conceptualise the future of farming (Figure 23, next page). Especially statements about crucial factors and the future of farming may later be of importance when evaluating the opportunity to introduce innovative residue management practises like biochar.

For farmers, the most crucial agronomic factors for farming are **water** (rain), **soil** (fertility) and **livestock** (bullocks/cows), whereas **labourers**, the **market** and **education/experience** are important socio-economic factors (Figure 23). This is in line with perceptions about the link of farming to the environment, where rain (and soil) is most frequently mentioned. All 29 interviewed farmers, irrespective of irrigation type, emphasise the importance of water (rain), making it a major issue that has to be taken into consideration in any farming application to come. Except four farmers for soil (fertility) and three farmers for livestock (bullocks/cows), all other farmers designate the importance of soil and livestock.

Farming can be seen as the main source of earning one's **livelihood** (livelihood, money, food). Furthermore, farmers **believe** in farming, perceive it as something satisfying that is good for health. On the contrary, many farmers also see problems in the current developments of agriculture (Figure 23).

Out of 29 interviewed farmers, 21 wish to receive **help** resp. **education** about farming and new technologies, and 22 farmers wish to grow **alternative/new crops** in the future (Figure 23). These findings already show the openness of farmers towards training in new technologies (e.g. biochar).

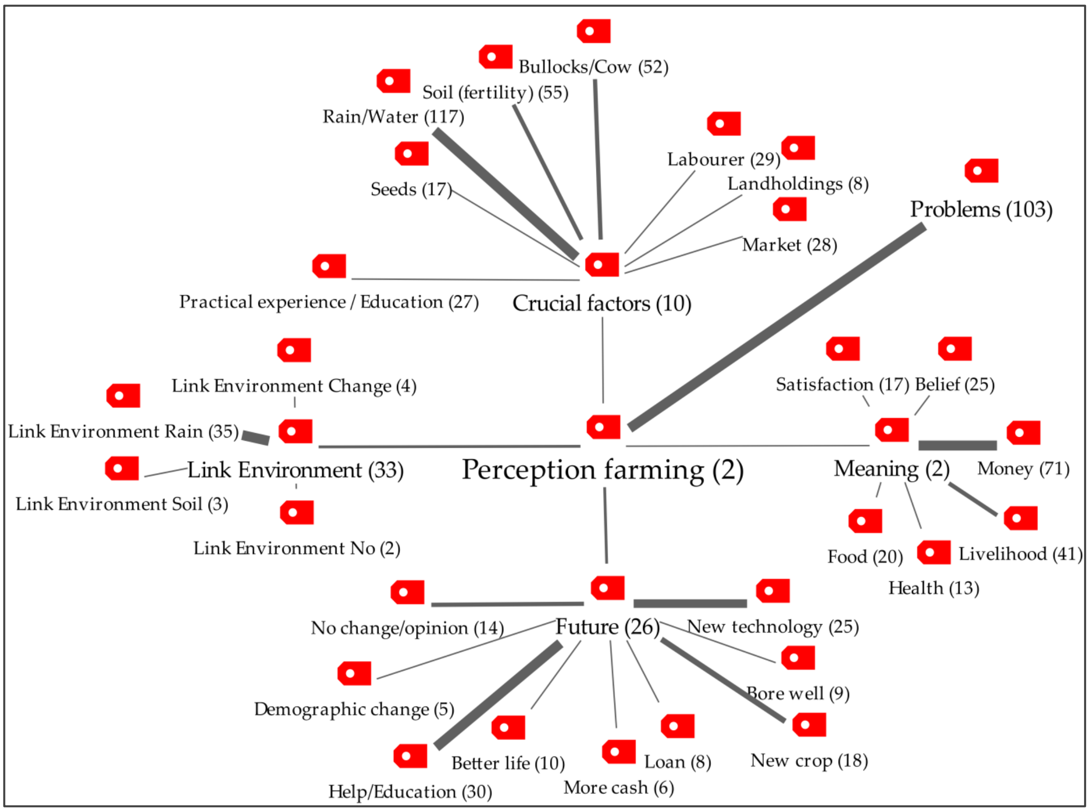

Figure 23: Hierarchical organisation of (sub)codes under the subcategory *perception farming* in MAX-QDA 12 using the code-subcode-segments-model. The thickness of lines correlates to the relative frequency of occurrence of individual codes in relation to the next main code and the number in brackets to their absolute value.

It is self-evident that the subcategory **crop production** comprises many of the farming practises that are used by farmers to cultivate the land and to grow crops (Figure 24, next page). During fieldwork, it was much easier for farmers to talk about crop production, i.e. what they actually **do** to grow their crops, instead of only answering specific questions about agricultural residue management. Figure 24 shows that all known important agricultural operations from the soil cultivation to sowing, weeding and plant growth until the harvest itself are included in this subcategory.

Especially the main code **plant growth/yield** seems to be of major importance for farmers (220 entries in MAXQDA 12), and only one farmer did not address this issue. As we will see later on, the issue of plant growth and yield is a fundamental factor that influences farmers' perception of knowledge-based and new residue management applications.

Under the main code **crops** and based on the thickness of the lines, one can clearly identify **banana, maize, onion, sunflower and turmeric** as the most frequently mentioned crops. The identification of the commonly grown crop varieties is crucial, as it not only determines the availability of residues, but also its suitability for specific residue applications like vermicomposting or biochar.

As introduced previously, farmers designate water (rain) as one of the most fundamental agronomic parameter. In the research area, farmers irrigate their crops either by rain (rain-fed) or by drip (bore well), whereas the trend has currently shifted towards the latter. Whether the **irrigation type** has an influence on farmers' interest in resp. scepticism towards agricultural residue management applications will be evaluated in subsection 5.2.5.

Finally, twelve out of 29 farmers either emphasise the merits of **organic farming** or they designate organic farming as an alternative option to their current agricultural practises. It is debatable whether the increased interest in organic farming would automatically cause a higher openness towards agricultural residue applications like biochar, but it could likely be the case.

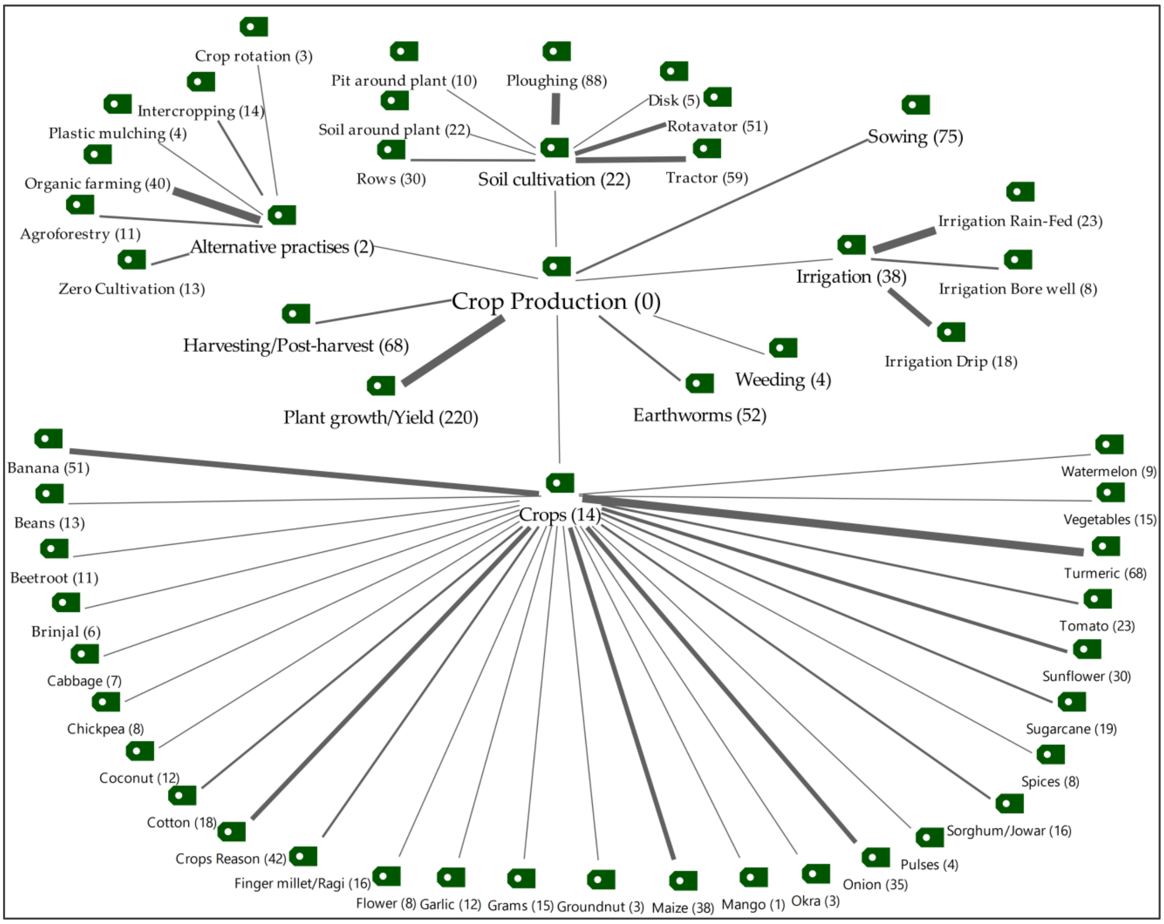

Figure 24: Hierarchical organisation of (sub)codes under the subcategory *crop production* in MAXQDA 12 using the code-subcode-segments-model. The thickness of lines correlates to the relative frequency of occurrence of individual codes in relation to the next main code and the number in brackets to their absolute value.

Interview data referring to the usage of commercial **fertiliser**, whether chemical (chemical fertiliser, pesticide, herbicide and insecticide) or organic (organic nutrients, organic compost, etc.), is subsumed in the subcategory fertiliser (Figure 25, next page) and it has been wilfully separated from any organic residue application to soils. However, application of fertiliser and residues in various forms cannot be completely separated from each other since these two kinds of soil amendments are sometimes used together in the same field. From the 29 interviewed farmers, only one farmer (F20) did not use any fertiliser at the time of fieldwork. Some farmers might have used only organic fertiliser alongside other residue applications (F1, F2, F15), but without a hundred percent guarantee. This is due to the fact that terms like manure, fertiliser and compost were used as synonyms by farmers and might therefore have led to misinterpretation in the empirical data while coding (e.g. manure can refer to fertiliser in general or more specifically to cow dung manure). This holds true not only for the sub-category fertiliser, but also for the interpretation of the core subcategory organic residue application.

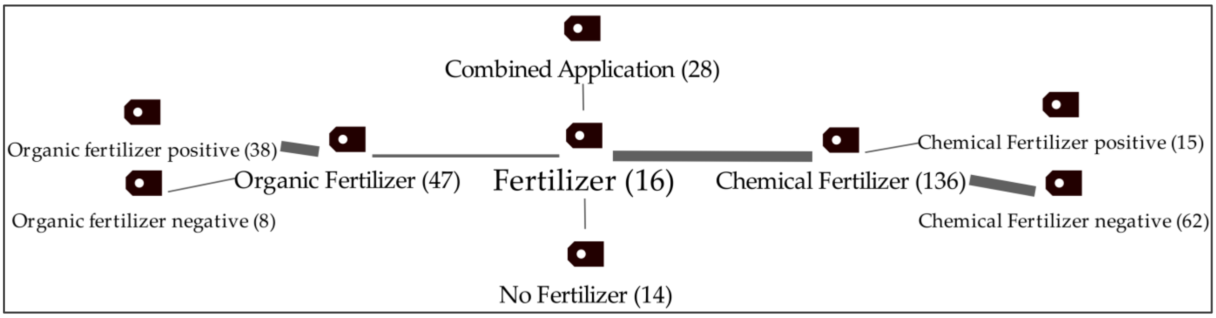

Figure 25: Hierarchical organisation of (sub)codes under the subcategory *fertiliser* in MAXQDA 12 using the code-subcode-segments-model. The thickness of lines correlates to the relative frequency of occurrence of individual codes in relation to the next main code and the number in brackets to their absolute value.

As clearly visible in Figure 25, application of commercial chemical and organic fertiliser is common amongst farmers in the research area, whereby chemical fertilisers are used more regularly. The perception of applying fertilisers to the plant-soil system varies significantly. While chemical fertilisers are more frequently perceived negatively, organic fertilisers enjoy a good reputation.

> *«But if you use the chemical fertilisers, he says the soil becomes hard and it's lost all its nutrient capacity.»* (F21)

These findings, alongside with the increased interest in organic farming, could indicate a possible opportunity for the introduction of residue management applications like vermicompost and biochar.

5.2.2 Farmers' perceptions and knowledge about agricultural residues

As will be shown in the upcoming sections, farmer use specific knowledge-based farming practises to handle agricultural residues. Perceptions of farmers about residues and their knowledge in dealing with these can come from a general conceptualisation of residues or it can be entangled in these specific traditional residue management practises. As both perspectives are important, findings about farmers' perceptions and knowledge on agricultural residues will be presented in two ways. A general summary of the topic will be given in this subsection, whereas specific perceptions and knowledge related to certain agricultural residue applications will be highlighted directly in the corresponding subsections (see subsections 5.2.3.1 to 5.2.3.5).

Out of 13 farmers who have shared their general perception about agricultural residues, five farmers regard it as a **resource** only (F5-F7, F16, F22), whereas the remaining eight farmers consider residues either as a **resource or as a waste**, depending on the context in which residues are analysed (F12, F14, F19, F21, F23, F25, F28, F29). This context can include crop type (e.g. residues of crop A suitable as an input to soils and therefore considered as a resource, whereas residues of crop B considered as a waste), residue application or whether farmers produce organically or conventionally (e.g. for organic farmers, residues are more crucial).

> *«Yes it is good that what we can put into the soil, the remains of the plants. He puts it into the soil.»* (F7)

> *«So he feels that if you remove that it's just a waste. So what can you do with it? So they burn it and put it into the field.»* (F23)

From a general point of view, farmers source their **knowledge** mainly through four channels, including a) tradition (family knowledge) resp. practical experience (21 farmers), b) individuals/gurus[4] (16 farmers), c) the agricultural department (12 farmers) and d) the media, including TV, radio and books/magazines (12 farmers).

5.2.3 Knowledge-based agricultural residue management practises

Subsections 2.3.1 to 2.3.3 introduced selected agricultural practises that use residues to prepare organic soil amendments theoretically. This subsection has the aim of presenting reasons, beliefs and opinions of farmers upon the application of traditional agricultural residue management practises.

5.2.3.1 Composting

Composting represents by far the most prevalent way of using agricultural residues to prepare soil amendments in and around Berambadi watershed. An image present in all villages during fieldwork was heaps of agricultural residues along the roads or in front of farm houses (Figure 1 and 26).

As shown in subsection 2.3.1 and 2.3.2, composting might refer to traditional practises including the preparation of cow dung resp. farmyard manure and simple compost applications, or more knowledge-intensive, scientific practises of composting, although the boundary between them is in reality rather fuzzy. As can be seen, a distinction between the preparation of cow dung manure in particular and composting in general was drawn during analysis. However, since the preparation of cow dung manure represents a way of composting itself, it is likewise integrated in the subsection on composting.

[4] According to Duden, a guru refers to «*a spiritual leader under Hinduism*», but can also represent a leader in any kind of things (Source: Bibliographisches Institut GmbH 2017: http://www.duden.de/rechtschreibung/Guru; Access: 12.05.2017)

«Another kind of composting is cow dung, which he accumulates in one place that you can see.» (F4)

It is evident that drawing this differentiation may have led to overlapping or insecure ascription of empirical data to the individual practises, but based on the data the distinction seems necessary. Hence, this subsection begins with presenting the findings for composting on a general basis, followed by a closer look at the practises of cow dung manure.

From the entire 432 entries about composting, 83 were made for **composting from a general point of view**, especially about the preparation of compost and its effects on the plant-soil system (Figure 26).

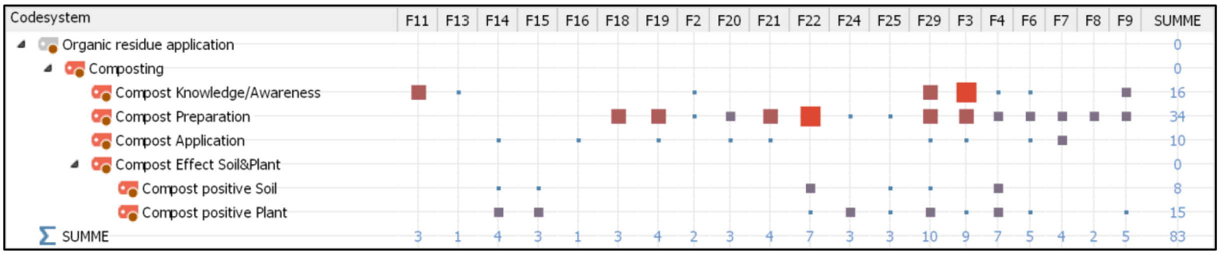

Figure 26: Distribution of coding on *general compost application* in selected interviews. Symbol size correlates to the frequency of occurrence of codes in each interview.

Except for one farmer (F11), all farmers represented in Figure 26 are aware of composting as a way of processing agricultural residues (F11: three entries for awareness, but all are negative). It would however be mistaken to assume that farmers who are not included in Figure 26, aren't aware of composting. As can be seen further below, all interviewed farmers, except for one (F15), shared information about preparing farmyard manure, and therefore know the concept of composting.

Only few farmers designated their origin of knowledge about composting and it generally originates from a) individuals/gurus (F3, F4, F29), b) the media (TV, radio, etc.) (F3, F6) and c) governmental institutions (F6). Knowledge about the preparation of compost includes information about the duration, the set-up and input materials of the process. Specifications of farmers about the duration of the decomposition/degradation of agricultural residues by composting varies from days (F3, F4, F9, F24) over months (F7, F21, F29) to years (F19). Information about the set-up of composting include whether it is done in a pile/heap (F6, F8, F18, F19, F22, F25) or a pit/tank (F4, F7, F9, F21, F22, F24, F29), whether the residues are put in layers (F4, F18, F22, F29), whether it is watered on a regular basis (F3, F20, F21, F29) and whether it is covered by a shed (F3, F22).

«So he learned about the compost from the government offices. They trained him. They tell these people. He also heard about it in the radio. So where he gets the information from. That's how he got to know about the organic compost.» (F6)

«So he collects the leaves of the grass and the other leaves, sticks, straws, everything. And he makes a pit and he puts that in the pit. And then on top of that he puts this banana plantain remains. Whatever he

has. He puts all that also into it. And then pours two litres of water into it. And then let it degrade for some time. And then adds the cow dung on the top [...].» (F29)

Most farmers use for this type of composting crop residues only (F8, F19, F21) or a combination of crop residues and cow dung (F4, F7, F9, F20, F22, F29). One farmer uses a mixture of crop residues and soils (F24) and another farmer (F3) a mixture of cow dung and an organic addition (*Trichoderma,* a fungi). The empirical data further indicates that three farmers might practise anaerobic composting, since they were talking about closing the pile (F7, F21, F24). Instead of preparing compost, two farmers further mentioned the possibility to purchase it from outside (F7, F16).

When it comes to the application of compost, farmers possess knowledge about the timing (F3, F6, F29) and application rate (F20). Some farmers apply compost in combination with other agricultural inputs, e.g. commercial fertiliser or cow dung (F14, F19).

«So he says now the important thing is that you put this when you till the land.» (F3)

The effect of composting on both soils (8 times) and plants (15) is solely rated positively. Composting is considered to increase general soil fertility (F4, F14, F22, F25) and nutrient availability in soils (F14, F15, F25, F29). Furthermore, it increases crop growth and yield (F4, F9, F14, F15, F22, F24, F25, F29), also in the long-term (F15), and it enhances nutrient uptake by plants (F6, F9, F29).

«So it gives a good strength to the soil by giving more nutrients.» (F15)

«And then you get a good yield.» (F22)

Despite many farmers share their knowledge about composting which implies that they are aware of its preparation, still some farmers honestly mention that they have not put it into practise (F2, F7, F9), also due to problems like labour shortage (F7). One farmer further emphasised that a very small percentage of farmers actually apply composting beyond the preparation of cow dung manure (F21).

A specific, knowledge-based practise of preparing a traditional compost in the research area is called **Jeevamrutha** (Figure 27, next page), which is explicitly named by five farmers (F1-F4, F20), among which four of them are from east of Gundlupete. Even if only five farmers address the topic, Jeevamrutha might be much more popular among farmers, as one farmer stated (F2).

The preparation of Jeevamrutha is nicely described by F20 (see quote next page). The mixture can be applied every month after the crop has grown to the size of a nursery plant and it can be applied alongside other residue management practises, e.g. mulching.

«Ten litres of, this is called Jeevamrutha. Ten litres of urine. Ten kg of cow dung. Two kg of black eyed beans or beans powdered. Two kg of Jaggery, which is not generally available in the market. Not that Jaggery, but other black, black Jaggery, which is organically done. And then one fist of soil from the wild growth of the border of your land. So you take all this and mix together.» (F20)

Figure 27: Preparation of Jeevamrutha (own picture).

Advantages of the application of Jeevamrutha are its assumed positive effects on a) soil fertility, especially soil structure (pores), nutrient availability and WHC, b) soil biology, especially the prevalence of earthworms and c) plant growth and yield. Disadvantages include cost of preparation and odour.

«So when he introduces this into the soil, there's a rotation happening because of the worms and the soil. And then they form pores. Because of this, the soil becomes more nutrient and when it becomes more nutrient, it gives a better yield.» (F4)

Cow dung resp. farmyard manure represents the most commonly used residue management application and is a crucial agricultural input for rural farmers in the research area. Nearly all farmers share information about it (except F15) and many see a very common practise in farmyard manure (F2, F18, F24, F29). For a couple of farmers, it is furthermore the only known practise and it is perceived as a necessity for farming (F3, F4, F9, F10, F13, F14, F17, F20, F26, F29). Some farmers possess a general awareness of its preparation (F3, F7, F23, F29), but had not been using it at the time of fieldwork (F23).

The practise of farmyard manure has been used by farmers for many years and it is self-evident that the knowledge about it originates from both experience and tradition (F4, F8, F9, F11-F13, F18, F21, F22, F28).

«So he is saying traditionally that's what they have been doing. He learnt it from his father and his kids learn from him. So it's coming in the family.» (F22)

Figure 28: Common heap method of preparing farmyard manure (own picture).

In the majority of cases, cow dung manure is prepared in (roadside) piles/heaps (F3-F5, F7, F8, F10-F14, F17, F18, F27), as shown in Figure 28, whereas some farmers pile the organic residues up in an earth pit (F6, F16, F21-F24, F28) or in a tank (F29). Only one farmer designates the impossibility to produce cow dung manure (F2). Piles are normally left before application for one year (F5-F7, F10-F12, F14, F17, F23, F24, F27) or at least for six to ten months (F5, F8, F10, F13, F21).

«So he digs a pit, piles up the cow dung and then leaves it for eight to ten months.» (F21)

A few farmers (F10, F22) use pure cow dung when preparing the farmyard manure, while others use additional material, especially water (F4, F6, F29), crop residues and remains of forage (F5, F13, F14, F17, F18, F23, F24, F27, F29) and other wastage (F5, F8, F13).

> *«What he does, is, after two days of the cow dung, they collect it. He puts it into the tank, which has one litre of water. And then they mix the fodder and then Ragi powder. They mix all the things and then that's the mixture, which they give into all the plants. That is the only mixture, which is going as a cow dung manure into the plants.»* (F29)

Some farmers further apply other techniques, e.g. mixing of the cow dung pile (F13, F18), drying the product (F6) or using the soil around the cow dung pile for the fields too (F24). Instead of preparing the cow dung on-farm, farmers purchase the final product outside (F2, F6, F7, F10, F13, F23, F24, F26). Some farmers do so because of insufficient production on their farm (F13, F17, F19, F28). Others share cow dung with other farmers in a local exchange market (F6, F13).

> *«But people who don't have land, but then have cows and the dung, which is there. You can use, you can take it from those people for a price.»* (F6)

Cow dung manure is applied to agricultural fields in the month of March/April before sowing and/or when the crops start sprouting (F3, F9, F12, F19, F21, F23-F29). The common application practise includes the formation of pile(s) in the field or on the roads nearby in order to spread the manure across the field (F3-F8, F11-F14, F16, F17, F19, F21-F24, F28). In many cases, the application of cow dung is followed by a (second) step of soil cultivation, e.g. by ploughing or rotating the soil (F5, F7, F8, F11, F18, F21, F23, F24, F27).

> *«And after one year they get that during the month of March and put it into the field. They make a pile close by so that they can spread it across. Once they spread the cow dung, they use the tractor and then mix it with the soil.»* (F23)

Application rates can vary, but are mostly in the magnitude of tens tons per acre (F6, F10, F16, F17, F19-F21, F29). Some farmers cannot produce enough cow dung manure for all their fields and therefore use a rotation approach between fields (F14, F16) or apply it only to specific crops (F14). Other farmers do not apply any cow dung to their fields (F2, F23). As it is with many other residue applications, also cow dung manure is often applied in combination, e.g. with chemical fertiliser or mulches (F5-F7, F19, F22).

> *«So he says, it's not enough for all the crops that I grow that I can use this. So I don't use it for all the crops. So, but I use it for turmeric and onion and other vegetables, which I grow.»* (F14)

The farmers' perception of the effects of cow dung manure application to the plant-soil system is almost exclusively positive (Figure 29). In contrast to 33 positive entries for plants, only one sceptical entry is recorded. The same can be identified for soils with 27 positive and only 3 negative entries.

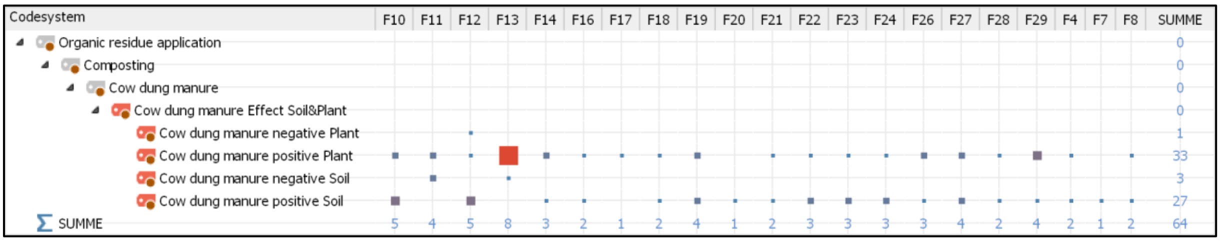

Figure 29: Distribution of coding on the effect of *cow dung manure* on the plant-soil system in selected interviews. Symbol size correlates to the frequency of occurrence of codes in each interview.

Positive effects of farmyard manure on soils include a) a general increase in soil fertility (F7, F8, F10, F12, F14, F20, F21, F23, F24, F29), b) improvements in soil structure and smoothness (F19, F26, F28, F29), c) improved nutrient availability (F10, F12, F18, F27, F28), d) improved moisture content (F4, F21, F22) and e) enhanced earthworm prevalence (F19, F24, F27). The observation that the application of cow dung manure has no significant effect on soils can be rated as neutral (F11, F13).

> *«What happens, is, the soil absorbs all the nutrients from the cow dung and then you get a good strength. The strength of the soil is increased.»* (F12)

Crop production is positively influenced by application of farmyard manure through a) enhanced plant growth and yield (F4, F8, F10-F14, F17, F18, F21-F24, F26-F29), b) absence of pest attacks (F23) and c) smooth growth without any disturbance or harm (F19, F27). Negative effects include the emergence of white worms that eat plant roots (F26) and the delayed effect of cow dung on plant growth (F12). Farmers further agree upon the duration of the effects of cow dung manure, which more or less lies in the magnitude of months (F17) to years (F12, F16, F22, F29).

> *«So when you put this into the soil, you have a good growth for the plant and then there's no problem in the plant. I mean no attacks of any pests or insects. So they don't have to worry about medicines.»* (F23)

> *«It just dries the plant then. Once it starts eating the root.»* (F26)

To conclude on farmyard manure, this residue management practise is further linked to the analysis of reasons behind certain farming practises. Briefly summarised, convenience and belief in cow dung manure might be major reasons for using it in farming (e.g. F4, F11).

> *«So he says, he is using only cow dung and cow urine to protect our country. And for ourselves too.»* (F4)

5.2.3.2 Residue burning (ash)

Already on the first farm visited during fieldwork, the observation could be made that farmers traditionally produce something similar to biochar: ash resp. coal from residue burning (Figure 30). In the course of fieldwork, this observation recurred several times and questions about reasons behind and effects of the practise arose.

Figure 30: Traditional ash/coal production through residue burning in the field of F13 (own picture).

Totally 17 farmers address the topic of residue burning (Figure 31), with sometimes antithetic beliefs in its effect in the plant-soil system.

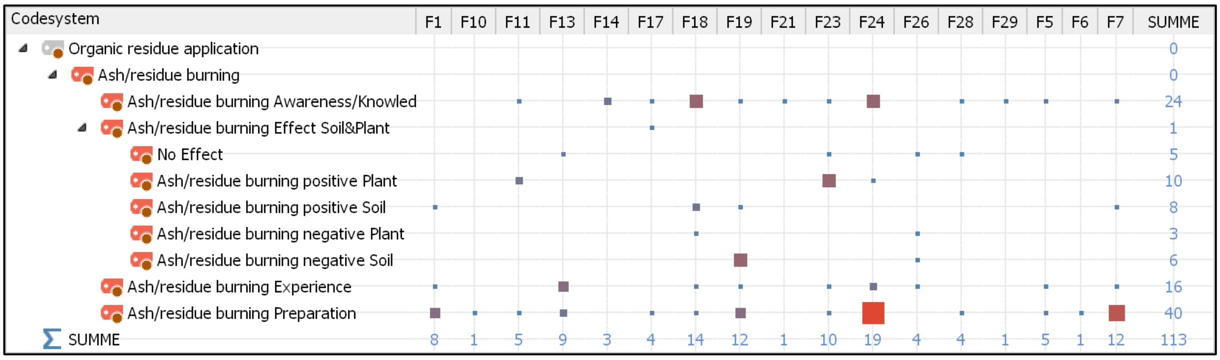

Figure 31: Distribution of coding on *ash/residue burning* in selected interviews. Symbol size correlates to the frequency of occurrence of codes in each interview.

Information about the preparation and application of ash relates to its production and how it is subsequently applied to soils. Generally, the ash is either produced by residue burning in- or outside agricultural fields (F7, F10, F11, F13, F17-F19, F23, F24) or it originates from domestic cooking or from processing agricultural products (e.g. boiling turmeric roots or Jaggery production) (F5, F6, F19, F23, F24, F28). Only one farmer designates the purchase of the product from a private company (F1).

To check which **crop residues are used for burning and subsequent ash application**, the main code ash/residue burning was combined with the code crops with a code-relations-browser matrix in MAXQDA 12 (shows the code co-occurrence). As a result, the following crops could be identified: **banana, beans, coconut, maize, sugarcane, tomato and turmeric**.

Application of ash can be sole (most farmers) or in combination with other organic residue applications, especially compost resp. cow dung manure (F17, F18, F24, F28) or vermicompost (F1). Some farmer burn parts of their agricultural residues, but do not apply it directly to their fields (F13, F18).

> *«But if something is such that it cannot be used into the compost, I mean the manure. That he burns, mixes it with the manure and puts it into the soil.»* (F18)

How the application of ash affects the plant-soil systems was rated 33 times by farmers (Figure 31). The effect on soils was rated positively eight times (F1, F7, (F17), F18) and negatively six times (F19, F26), but mainly F19 militated against it. Positive effects include a) improved WHC (F1, F18), b) increased nutrient availability (F1, F18) and c) improved soil structure (F18). Negative effects refer to the heat generation of burning residues and subsequently the death of earthworms (F19), which also affects plant growth negatively (F18). Two farmers emphasise that it would be helpful to experiment with ash and to observe it over longer timescales (F1, F24).

> «*Because of the water-holding capacity he is using the ash.*» (F1)

> «*But if you burn directly in the field, there is a problem then because earthworms die because of the heat.*» (F19)

Effects on plant growth and yield were assessed positively ten times (F11, F23, F24) and negatively three times (F18, F26). Five farmers further designated ash to have no effect (F13, F19, F23, F26, F28).

> «*And the remains is an ash. Nobody puts that ash back into the soil because if you put that, you'll never get a yield. The plants will never grow well. So nobody uses that.*» (F18)

> «*So they, he's saying, they get a good yield in the place where they have burned and there are no weeds grown there [...].*» (F24)

The main reasons for burning agricultural residues include a) removing surplus residues from the fields (F13, F24), b) no other application with specific residue (e.g. from tomato or beans) possible (F7, F10, F13, F14, F18, F23, F24) and c) perception of it as a waste (F23, F28). It is noteworthy that besides F19 who emphasises the negative effects of residue burning on the plant-soil system, F21 sees residue burning as an old-fashioned, lavish farming practise.

> «*He said if you don't burn it, then it just piles up in the way and then it's not clean in the field. So we have to burn it once it dries because it is not degrade fast.*» (F13)

> «*The others are following the old method still. Some farmers burn it and just leave it and they don't know how to do things. They're burning and wasting it. It is an old method.*» (F21)

5.2.3.3 Green manure or mulching

Green manure resp. mulching is a prime example of a knowledge-based agricultural residue management practise that hadn't been considered much before conducting fieldwork. But as it turns out, mulching plays a fundamental role in managing residues (182 entries) and it is perceived as advantageous for the plant-soil system by almost all farmers (Figure 32, next page).

As shown in Figure 32, except for three farmers (F5, F13, F22), all interviewed farmers are aware of mulching and possess specific knowledge about its preparation, application and effects on the plant-soil system. A few farmers spoke about the origin of knowledge on mulching. It comes either from officials from the agricultural department (F19), from inspiration of other people (F26) or from tradition and experience (F9, F23-F26).

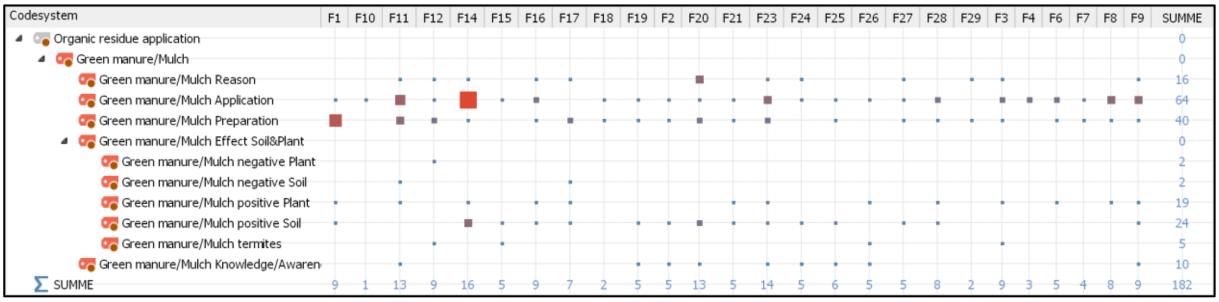

Figure 32: Distribution of coding on *green manure/mulching* in all interviews. Symbol size correlates to the frequency of occurrence of codes in each interview.

Preparation of mulches refers to the input material (both crop type and plant part) and specific preparation practises. Crops that are mostly used for mulching are a) weeds/greens (six farmers), b) banana (five farmers), c) sunflower and maize (four farmers) and d) onion, garlic, beetroot and pulses (two farmers each). Other crops mentioned only once include: sugarcane, finger millet, coconut, cotton, groundnut and others. It is self-evident that plant parts used for mulching are those with no use for consumption, i.e. leaves (F6, F9, F12, F25, F28), stems/stocks/sticks (F6, F9, F11, F12, F18, F25) and roots (F3, F11), depending on the crop variety used (Figure 33).

Practises of preparing mulches include a) collecting the residues (F6, F12, F16, F19, F20, F29), b) drying residues before application (F11, F17, F20) and c) letting residues pre-decompose before turning them into the soil (F8, F12, F19, F20).

> *«So now he let it get mushy. I mean when he means mushy, it's degrading and becomes watery.»* (F8)

Figure 33: Example of mulching with fresh and dried banana residues (own picture).

Mulches can be left on the field to decompose (F2, F8, F9, F11, F12, F14) or incorporated into the soil (all farmers except F5, F13, F17, F22) by tractors directly, mainly through rotovators (F1, F7, F9-F11, F14-F16, F18, F20, F21, F23, F25-F27) and tillers (F8, F15, F16).

> *«So all the other plants like the banana and the other things that he grows. Like the corn and other things. He puts it back into the soil by running a tractor the first time and then the rotator.»* (F11)

The vast majority of farmers rate the effect of applying mulches positively. The binarised ratio between positive and negative ratings was identified to be high for both soils (15:2) and plants (13:1). Positive effects of applying mulches for soils include a) a general increase in soil fertility (F2, F9, F14, F19-F21, F24, F25, F28), b) an increase in nutrient availability (F1, F6, F14, F15, F17, F20, F23), c) an improvement in soil structure (F16, F20, F23) and d) a clean field (F14). Negative resp. neutral effects refer to the fact that mulching has no consequence to soil quality (F11, F27) or represents the wrong application for specific residues (F17). Some farmers further consider mulching as a driver behind processes related to soil biota (F3, F12, F15, F26). Termites that are stimulated through mulching are either perceived as destructive for plants (F12) or as beneficial for the plant-soil system (F3, F15, F26), whereas earthworms stimulated through mulching are perceived as beneficial solely (F15). Plant growth enhancement and yield increase are the main beneficial effects of mulch application on plants (F1, F3, F8, F9, F11, F14, F16, F17, F21, F23, F28).

«So you, it becomes, the field also is good to see and it's neat. And also because they'll have more nutrients and will have more energy.» (F14)

«That also I put it back into the field because it gives a good yield as it contains nutrients, which can give nutrients to the soil.» (F17)

The main reasons for practising mulching are a) convenience (easy and cheap) (F3, F9, F23, F27, F29), b) only possible application for residues (F12, F17, F23, F24), c) using every residue and process it (F11, F16, F29) and d) removal of residues in order to clean the fields (F14). Other farmers see in mulching a necessity for organic farming and strongly believe in it (F2, F19, F20), or they see it as more profitable for their farm than selling the crops under certain conditions (F14).

«I use it because it goes back into the soil and I don't have to pluck and then also get the labourers to do this job. Because it's expensive. Then I don't have to pay anything. But if I do this way, it is easier that it's gone back into the soil and I don't have to spend any money.» (F27)

5.2.3.4 Alternative usage of residues

The two most prominent alternative usages of agricultural residues (not for soil amendment) are fuel for domestic and agricultural purposes and forage for animals. Residues are further sold off and given away or used as a construction material (Figure 34).

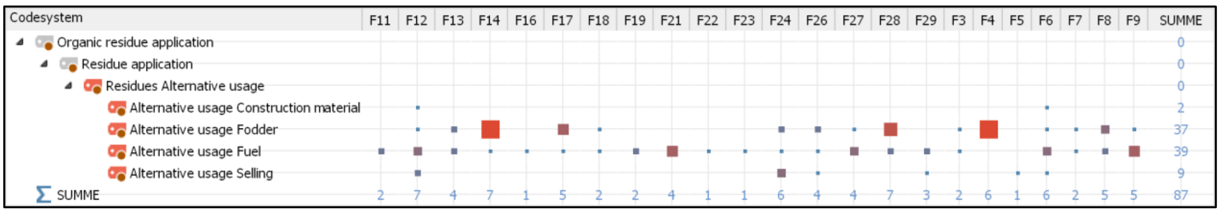

Figure 34: Distribution of coding for *alternative usage of residues* in selected interviews. Symbol size correlates to the frequency of occurrence of codes in each interview.

Agricultural residues are used as fuel in a) 22 cases for processing farm products, especially the turmeric root (F3, F7-F9, F11-F14, F16, F18, F19, F21-F23) and sugarcane stalks (F6), b) twelve cases for domestic cooking purposes (F6, F9, F17, F24, F27, F28) and c) five cases as a general source of fuel (F12, F13, F26, F29). Input material for fuel comes from various residues, especially turmeric (19 times), sunflower (6), cotton (4), sugarcane (3), coconut (2) and Jowar, vegetables and cow dung cake (1).

> *«So he, yes he uses it as a fuel for cooking the turmeric. But sometimes that's not enough. So he uses others like sugarcane or Jowar.»* (F16)


Figure 35: Drying of crop residues for forage in heaps (own picture).

In total, 15 farmers emphasise the importance of crop residues as a **forage** for livestock (Figure 35), whereby five farmers particularly rely on residues as a resource for animal fodder (F4, F8, F14, F17, F28). The crop residues that serve as an input material include: maize (12 times), pulses (8), sorghum and finger millet (3) and beetroot, sugarcane, vegetables and spices (one each). Plant parts mostly used for forage are leaves and stems/stocks/sticks.

> *«So he says, he has grown this Jowar. And horse gram, because that can be a feeding for the cows.»* (F4)

A couple of farmers either sell part of the residues to other people (F5, F6, F12, F24, F29) or give it to people who possess livestock (F12, F26). Two farmers use residues as a construction material (F6, F12).

5.2.3.5 Sediment application

The practise of applying river sediments especially to (sandy) red soils (see section 3.2) does not represent an agricultural residue management application, but could still be of interest due to its link to biochar applications. Although this practise might be much more common in the research area, only five farmers addressed the issue during the interviews (F8, F10, F12, F16, F24). River sediments are applied to agricultural fields because they are perceived to have a positive effect on soil fertility (improvement of soil quality and WHC) and on plant growth and yield.

> *«So he gets the soil from the river bank and puts them into the soil. Actually if you see the soil is very sandy. So when you mix these two soils, when you make a path or I don't know what you call. Make a hole to hold the water. So when you make that, the soil is able to hold the water.»* (F8)

River sediments might be majorly made of small particles like silt and clay and therefore have a higher surface area compared to native soils in the research area, which could explain the perceived positive effects by farmers. This in turn could enhance farmers' interest in biochar applications, since biochar could mimic the function of these river sediments.

5.2.4 Identifying opportunities for the introduction of vermicompost and biochar

5.2.4.1 Availability of agricultural residues for vermicompost and biochar applications

Subsection 5.2.3 has illustrated the traditional practises of dealing with agricultural residues. Before going into detail about the opportunity to introduce new residue management technologies in existing farming systems in the research area, the question about whether farmers actually possess enough residues has to be addressed shortly. Entries specifically about residue availability and residue competition have only been registered sporadically (12 + 2) and by far not in all interviews (Figure 36).

Codesystem	F13	F16	F18	F2	F23	F24	F25	F28	F3	F6	F7	SUMME
Organic residue application												0
Residue application												0
Residue availability												0
Residue availability positive	■		■		■			■	■	■	■	7
Residue availability negative		■	■	■		■	■					5
Residues Competition	■							■				2
SUMME	2	1	2	1	1	1	1	2	1	1	1	14

Figure 36: Distribution of coding on *residue availability* and *residue competition* in selected interviews. Data is binarised, i.e. all dots represent one entry.

The ratio between a sufficient amount of residues and a deficient amount of residues for any residue application is rather narrow and therefore no clear trend whether farmers consider residue availability as sufficient or deficient can be observed (Figure 36). One farmer further is double-minded (F18). Additionally, two farmers emphasise competition between different residue applications (F13, F28), but this may be the case for many farmers since all of them use various traditional management technologies for agricultural residues that could compete with technologies like vermicomposting and biochar.

A generally sufficient availability of residues is stated by four farmers (F7, F13, F18, F28) and a specifically positive availability of residues for new technologies (vermicompost, biochar) by seven farmers (F1-F3, F6, F7, F14, F23).

> *«In case of horticulture crops, so many waste is there. In case of coconut trees.»* (F2)

> *«So he says no he does not require to buy anything from outside. What he grows and waste from the cows what they eat and whatever waste that he starts dumping, it would be enough for his own land.»* (F7)

A general deficiency in residues for any application is named by five farmers (F16, F18, F24, F25, F28) and a deficiency of residues for specific residue applications (vermicompost, biochar) by five farmers (F2, F13, F17, F21, F28; see also paragraphs about expectations/requirements and doubts/fears for vermicompost and biochar in subsections 5.2.4.2 and 5.2.4.3). Reasons for indicating a deficiency in residues stem from a) lack of trees (for biochar production), b) insufficient production of residues from various crops (e.g. pulses, chickpea, vegetables (tomato)), c) competing usages of residues and d) insufficient production of residues for applications to all fields.

«Then farmers what they're doing, they're not having that much of trees in land. So then simply they're going and cutting the forestry. That's the major disadvantage only in biochar.» (F2)

«You don't have any remains from the chickpea and other pulses much.» (F24)

Assumptions about insufficient residue availability for biochar production might be caused by the idea that it has to be applied year after year or that farmers would need specific residues (i.e. trees).

5.2.4.2 Vermicomposting

For vermicomposting, a relatively complex set of coding has been developed in MAXQDA 12 in order to structure and interpret the findings. The complexity roots in the fact that many farmers possess knowledge and experience about the technology, but still haven't tried it on their own, leaving space for discussion about expectations and doubts. Therefore, the analysis begins with identifying awareness and interest in vermicompost among farmers, followed by their experiences in preparing and applying it. The last parts will then focus on expectations/requirements and doubts/fears under the condition that farmers would actually do vermicomposting in their farming system.

As shown in Figure 37, only 14 farmers indicate **interest resp. openness** towards the technology of vermicomposting. The figure, however, has to be taken with a pinch of salt. The interpretation that the remaining 15 farmers are not interested in the technology is dangerous. It might just stem from the fact that most farmers have already been aware of the technology (see below) and have assumed it being clear that they are open towards the technology. As we will see later, many of the farmers not listed in Figure 37, actually talk openly about the residue application.

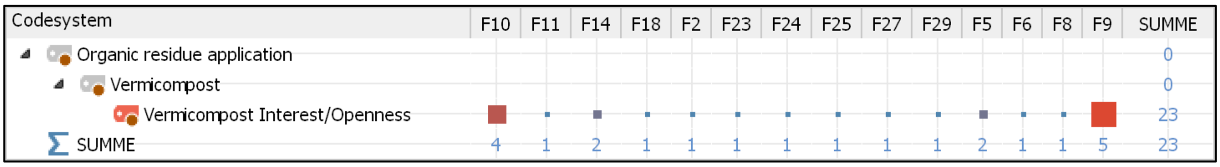

Figure 37: Distribution of coding for *vermicompost - interest/openness* in selected interviews. Symbol size correlates to the frequency of occurrence of codes in each interview.

A few farmers designate vermicompost as a good method on a general basis (F2, F17, F18) and many farmers acknowledge their interest in it (F9, F10, F14, F23, F24, F27). Even more farmers signify their interest in effectively doing vermicomposting now or in the near future (F5-F11, F14, F25, F29).

«He would be interested to do this. Because if you're saying that you can get a good yield with these worms in the field, then he would definitely be interested in that.» (F14)

All interviewed farmers are **aware of vermicomposting** (Figure 38, next page), with one exception. Several farmers were especially keen on talking about vermicomposting (F1, F6, F7, F11, F15, F16, F25, F26, F29).

That two farmers (F4, F20) are missing in Figure 38 does not mean that they are not aware of vermicomposting, but these two farmers militate against the technology.

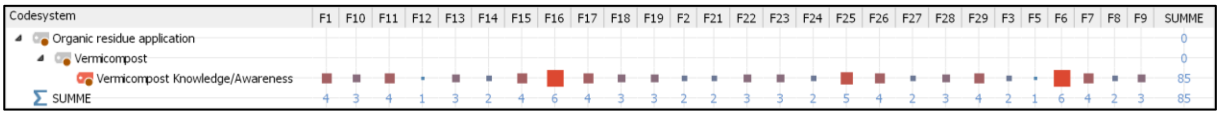

Figure 38: Distribution of coding on *knowledge/awareness of vermicomposting* in selected interviews. Symbol size correlates to the frequency of occurrence of codes in each interview.

A significant number of farmers indicate that they do not possess the necessary knowledge for doing vermicomposting or that they haven't tried it out, albeit they have been aware of the technology (F2, F6-F9, F11, F13-F15, F22-F26, F29).

> *«So he doesn't have any idea, is to how you can actually do it and what, how to go about it.»* (F14)

> *«No he has just seen it in TV. But here the neighbouring places, nobody has used it.»* (F23)

Knowledge of farmers about vermicomposting originates from multiple sources. It can be derived from a) individuals/gurus (F1, F7, F11, F15, F18, F23, F25), b) media, including TV, radio, newspapers and books (F1, F6, F9, F22, F23, F25, F28), c) organisations, including NGOs (F1, F26-F28) and d) governmental institutions, especially agricultural departments and village councils (F6, F7, F10, F12, F16-F18, F21). The farmers' knowledge can include knowledge about the a) preparation and application of vermicompost (Figure 39, next page) and b) effect of vermicompost on the plant-soil system (Figure 40, next page).

> *«So there was a guy from the agricultural department who came here and then tell them to use vermicompost because it's good for the soil. And that's how they know.»* (F16)

Figure 39 (next page) gives an overview on the distribution of **knowledge about the preparation of vermicompost** among the interviewed farmers. Conspicuously, four farmers possess a significant amount of knowledge (F1, F3, F18, F21). This is not surprising since F1 is preparing vermicompost on-farm, F18 had been producing vermicompost on a farm where he had worked as an agricultural labourer and F21 is a village head who has been involved in governmental projects about it.

Farmers' knowledge about the preparation of vermicompost can range from a general understanding of the technology (F5-F7, F14, F15, F17, F19, F25, F28) to the possession of specific information about its implementation (F1, F3, F16, F18, F21, F22, F27, F29), which can include knowledge about the duration, preparation, input material or the set-up.

> *«So he says, he makes a bed of the cow dung first and then he puts the green leaves. And then he puts the worms. And then he sprinkles it with water. Because it has to be cold. Else the worms die. And once this is done, these eat and then you have the compost.»* (F18)

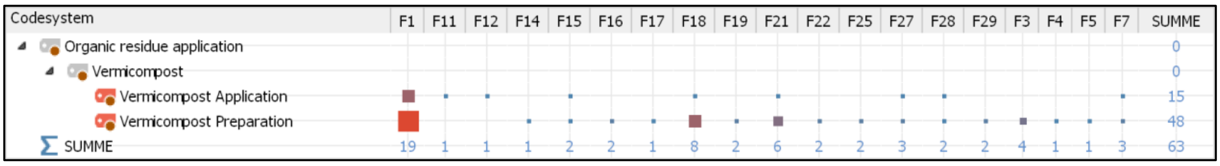

Figure 39: Distribution of coding on the *preparation and application of vermicompost* in selected interviews. Symbol size correlates to the frequency of occurrence of codes in each interview.

Furthermore, a couple of farmers possess **knowledge about the application of vermicompost** (Figure 39) to agricultural land (F1, F7, F11, F12, F15, F18, F21, F27, F28). Here, knowledge about application in general, application rates, combined applications or timing can be mentioned.

«So per acre then you have to put, hectare, you have to put seven and a half tons, is what he says. Is the calculation.» (F7)

«And then they come and put it in the field just before they want to put the seed for something.» (F27)

The following paragraph summarises the experiences of farmers who have used vermicompost in farming and/or who possess knowledge about the **effect of applying vermicompost in agricultural production**. In total 52 entries from 22 farmers were recorded, of which 25 are related to effects on soils and 27 on plants. The ratio between positive and negative entries accounts for 24:1 for soils and 22:5 for plants, which demonstrates that farmers see a great value in vermicomposting (Figure 40).

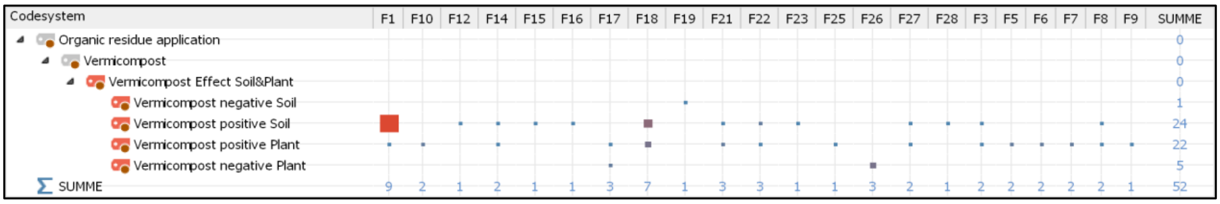

Figure 40: Distribution of coding on the *effect of vermicompost on the plant-soil system* in selected interviews. Symbol size correlates to the frequency of occurrence of codes in each interview.

The majority of farmers regard vermicompost as beneficial for soils (F1, F3, F8, F12, F14-F16, F18, F21-F23, F27, F28), and two farmers even consider it as extraordinary (F1, F18). Important positive changes in the soil ecosystem include a) a general increase in soil fertility (F3, F12, F14, F16, F21-F23, F27, F28), b) an increase in WHC (F1, F3, F18, F22), c) improvements in soil structure (air circulation, root penetration and soil bulking) (F1, F3, F18) and d) improvements in nutrient availability (F1, F15, F18, F22). On contrary, a couple of farmers emphasise that the production of vermicompost and its subsequent application is not necessary since the work of earthworms already present in the soil is sufficient and superior to it (F2, F4, F19, F20, see also below).

«So he says the moistness of the soil is retained because he is using the earthworms. And the earthworms like he said already that it digs and goes in. So the water is sipping into the soil. It does not go. And the earthworm has a sixteen nutrient-giving capacity.» (F1)

«So he says the earthworms, which are there in our soils, is natural from our soil. And it is environmental friendly. I mean, you don't have to put something else. It's sufficient.» (F20)

The same story can be told about the effect on plants. Fundamental positive changes due to the application comprise a) stimulation of plant growth and increase in crop yield (F1, F5-F10, F14, F17, F18, F21, F22, F25, F27), b) increase in nutrient uptake capability (F6, F14, F18) and c) a general perception that vermicomposting represents a superior technology (F3, F6).

«So when it is loose, the roots can absorb the nutrients better and you get a good yield.» (F18)

Four farmers however discussed negative experiences with vermicompost, while three of them (F10, F23, F26) especially emphasise their negative experience (≥3 entries about bad experience). Negative effects of vermicomposting include a) the stimulation of weed growth after application of a commercial vermicompost (F26), b) the necessity to apply it in combination with water due to heat generation (F17), c) the duration as to when the benefits show up (F2, F12) and d) the lack of support and knowledge about the technology (see below). Still, one farmer (F10) did not only point out the disadvantages of vermicomposting, but also designated it as a good tool.

«What he has realised, is, it's not so great. You get a good yield only for three months. After that it does not give you a good yield.» (F12)

«So when there is good rain, then I can use it. Otherwise it's an excess of heat. So then it would eat away my crop. So I can't use it, is what he said.» (F17)

It is noteworthy that during data analysis, a distinction between the effect of vermicomposting as a residue management application and the effect of earthworms from a general point of view was drawn. The latter focused more on the farmers' opinion and beliefs upon the effect of earthworms that are already present in soils. That these two codes were frequently used simultaneously and that they may refer to the same thing should be quite clear, but might still have lead to confusion during data interpretation (e.g. counting the same thing twice). Since 78 entries about earthworms from 20 farmers were registered (Figure 41), it is nevertheless worth noting down some highlighting facts about it.

As shown in Figure 41, most entries were recorded for a general code about earthworms (52) and the fact that earthworms have a positive effect on soils (21). The effect of earthworms on plants can be positive (3) or negative (2), without any clear trend.

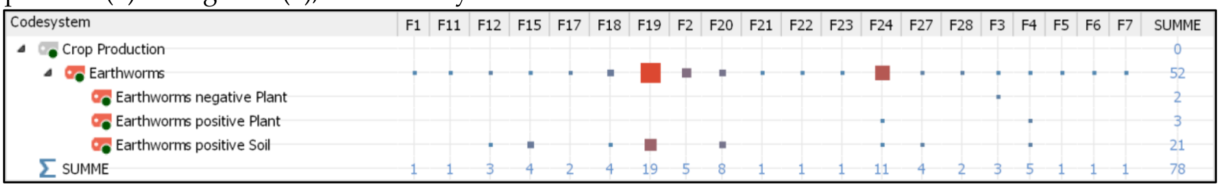

Figure 41: Distribution of coding about *earthworms* in selected interviews. Symbol size correlates to the frequency of occurrence of codes in each interview.

From a general point of view, farmers discussed five major issues about earthworms, including a) the absence of earthworms (F12), b) the death of earthworms due to the application of chemical fertiliser or due to lack of water and therefore heat generation (F1, F15, F19, F23, F28), c) the appearance of earthworms only during rainy season (F24, F28), d) the origin of earthworms (F7, F18) and e) the amenity of earthworms in processing residues from various agricultural residue management applications (e.g. cow dung manure, mulches, compost) (F3, F4, F17, F20, F27).

> *«So when you use this Jeevamrutha, because of the smell of that, the earthworms come up. But if you use the chemicals, then they go down the earth and they never come back. It's done.»* (F20)

Earthworms are reckoned of fundamental importance when it comes to soil fertility. Many farmers believe that earthworms improve soil structure, WHC and nutrient availability (F2, F4, F12, F17-F20, F24, F27).

> *«So when he introduced this into the soil, there's a rotation happening because of the worms and the soil. And then they form pores. Because of this, the soil becomes more nutrient and when it becomes more nutrient, it gives a better yield. Because the plants absorb the water. Because of the holes or the pores, which are formed by the worms. They can, I mean the ground absorbs this water and then it gives back to the plant.»* (F4)

The effect of earthworms on plants can either be positive (increase of growth and yield) (F4, F24) or negative (attack on plants) (F3).

> *«But he tells also the worms, which attack the plants now. So he is giving an example of tomato plant. When it's grown, how the worms come and attack it. So in the night, these worms come and (?) the tomato. And they make sort of holes when the worms start attacking it. It sort of holds the plant, the tomato plant and makes a hole.»* (F3)

The following paragraphs deal with the introduction of vermicompost into existing farming systems and present findings on **farmers' expectations upon it, including their requirements to execute it**. In total, 69 entries from 21 farmers were registered (Figure 42), whereby nine farmers were especially talkative and placed ≥ 4 entries (F5-F8, F10, F12, F13, F23, F28). Eight farmers did not specify any expectations/requirements for the introduction of vermicompost (F1, F3, F4, F19-F21, F24, F29), but this finding could be related to the fact that these farmers possess enough knowledge about the technology already and did therefore not address this issue in more detail.

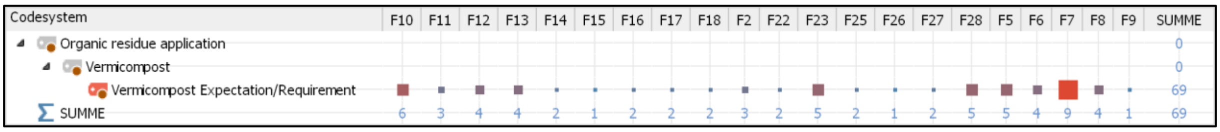

Figure 42: Distribution of coding for *vermicompost - expectation/requirement* in selected interviews. Symbol size correlates to the frequency of occurrence of codes in each interview.

The most fundamental socio-economic expectation designated by many farmers can be summarised under the term guidance (F2, F6, F7, F10-F12, F16, F22, F23, F25, F27, F28), referring to education and information transfer about the technology and the demonstration of its usage. Some farmers further pinpoint a lack of guidance from institutional side and expect more support if they should be able to apply vermicomposting in the long-term (F10, F16, F22, F23).

«They have a communication problem from the officials. Because nobody guided him so that he can do this. And there is a problem in our administrative system and in the Karnataka government that whatever they want to do, is not reaching the farmers. So the implementation is not there. Nobody is there to guide them properly and communicate ideas to them.» (F22)

Second, purchasing the product (final vermicompost or the earthworms) from the market or getting it from an institution (e.g. state/district agricultural department, NGO, etc.) seems to be a viable solution in the eyes of many farmers (F5-F7, F10, F12, F14-F16, F26, F28), whereas only few farmers would prefer to prepare it on their own (F7, F10). Some farmers do not only see a lack of institutional support concerning education, but also when it comes to the supply of organic material (F10, F16).

«So he needs to get it from the shop. You can't do it on your own. You can't create it on your own.» (F5)

A third requirement for farmers is investment capacity, which seems not to be high enough from the farmers' point of view (F5, F8, F13, F18). Other farmers see in vermicomposting a less expensive, good alternative fertilisation application (e.g. F21) and an additional source of income (e.g. F15, F18).

«He feels, he does not have enough money to build a tank for which he requires lot of money.» (F13)

«This is less expensive. More cheap to use it. And from his experience it is good, is what he has felt.» (F21)

Fourth, there are requirements regarding the production tools, including labour requirements (F7, F11, F15, F18) and some farmers wish to try it out first (F7, F10, F11, F13, F16, F17). Another farmer mentioned in this context that vermicomposting represents an easy technology (F2).

«Without adding any chemicals, we can do this separately and see what is the benefit of this.» (F7)

«So he says, he does not have enough facilities to make the vermicompost on his own. So one person has to be constantly available to make the vermicompost.» (F15)

Fifth, minor expectations only mentioned once are a) patience until the technology starts to work (F2) and b) health improvements for humans when organic products like vermicompost are used (F6, F25).

Plant growth and yield are of primary interest for most of the farmers when talking about agro-ecological expectations (F5-F12, F14, F17, F23, F25-F27). Closely linked to this, and also of major relevance, is soil fertility, which should increase through applying vermicompost (F14, F21, F25, F27, F28).

> *«You would get good yield for three years. He is sure of that if you would use earthworms, vermicompost into the soil. He is very sure of that.»* (F8)

> *«So he is saying the soil should become more nutrient and fertile. If that is good, then automatically the plant growth will be good.»* (F27)

Furthermore, there are a few agro-ecological expectations related to the application of vermicompost to the plant-soil system. First, some farmers expect that it can only be applied in combination with (rain-) water (F5, F8, F12, F17). Second, requirements about the application rate need to be in order (F7, F13) and third, it is also a matter of residue availability (see also subsection 5.2.4.1), whether farmers can engage in vermicomposting (F21, F23).

> *«But if he uses this, you need per acre of land at least three tons of vermicompost. He needs to the soil.»* (F7)

Even if the awareness of farmers about vermicomposting is high and even if many of them possess knowledge about its production and application, this does not imply that farmers are without any **doubt** about it (Figure 43). 14 out of 29 farmers made critical considerations, and some are especially sceptic (F2, F4, F11, F20, F28). The spectrum of opinion ranges from having no doubt at all (F7, F28) to categorically doubt it respectively not seeing any need for its application (F4, F19, F20).

> *«There is good benefit. He doesn't have any doubts.»* (F7)

> *«He is saying what we are doing. If I do that, the earthworms are produced in the earth and in my soil itself. Why do I have to do it separately?»* (F20)

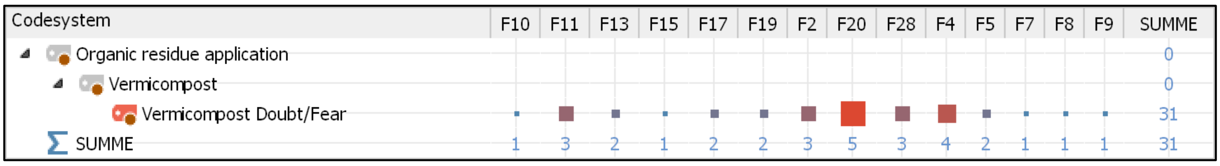

Figure 43: Distribution of coding on *vermicompost - doubt/fear* in selected interviews. Symbol size correlates to the frequency of occurrence of codes in each interview.

Socio-economically, major doubts include the perception of vermicomposting being costly and labour-intensive, which figures as an important constraint for farmers (F2, F8, F11, F19, F20). Other farmers also see a risk in investing in new technologies like vermicomposting (F13, F15). Another socio-economic doubt, which appears less frequently, is the lack of patience in waiting for vermicompost to work (F2, F9, F10). A few farmers further state that it is difficult to produce vermicompost and that it would be easier if they could purchase the final product (F5, F11, F15, see also paragraph about expectations above).

> *«But that one second that's expensive you know? One second that's expensive.»* (F2)

> *«He is saying, yes everybody says it that they'll do it. But it's only one time that they do this. It's not like long run that they do this. He strongly believes that people are doing it only one time and then later they're not doing.»* (F10)

From an agro-ecological perspective, three noteworthy doubts have cropped up. One concern is the fact that not enough vermicompost for all fields could be produced from the residues available (see also subsection 5.2.4.1) (F13, F21). Another fear comes with the belief that vermicompost introduces heat into the plant-soil system and therefore is only applicable in combination with water (F8, F17). A third concern is the survival of earthworms, endangered by several factors (F9, F19, F28).

> *«But now also another point would be now if I have to, if I produce the worms separately and put it into the field. Because I have already chemicals enough in the soil, then there's enough, too much heat in the soil and the earthworms die when I put these into the soil.»* (F19)

5.2.4.3 Biochar applications

The introduction of biochar applications draws conceptual interest from the side of the farmers. All 29 farmers shared at least some ideas about biochar, and most of them showed interest in the technology (Figure 44). Only one farmer (F5) did not specifiy any thoughts about the concept of biochar, but only mentioned lack of awareness.

A couple of farmers had been aware of the production of ash and its subsequent application to soils, with varying beliefs on its effects. Some field observations even go to the point, where the residue burning resulted in some sort of charcoal (see subsection 5.2.3.2 and Figure 30), which may have influenced ideas about biochar and therefore the upcoming analysis.

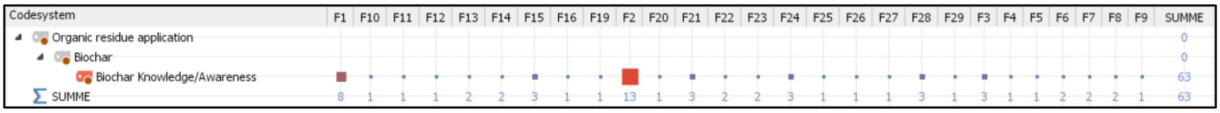

Figure 44: Distribution of coding on *biochar - knowledge/awareness* in all interviews. Symbol size correlates to the frequency of occurrence of codes in each interview.

Figure 44 only tells something about which farmers talked about the **awareness of biochar and possible knowledge of it**, and likewise how many times they did so. It does not tell, however, whether it is positive (farmer do know something about biochar) or negative (farmer do not know biochar). To answer this question, individual codes from the analysis have to be combined in MAXQDA 12. If the code about biochar - knowledge/awareness is correlated with residue application - knowledge/experience - none, referring to lack of knowledge about any residue application, it turns out that these two concepts were used 30 times for identical text sequences. However, this does not mean that all 29 farmers are unaware of the concept of biochar, since the combined occurrence of these two codes can also originate from less than 30 interview transcripts. Therefore, one can look into the list of coding in MAXQDA 12 to pinpoint all text sequences where the two codes show up at the same time. This is the case for 18 farmers (F3-F7, F9-F13, F15, F16, F19, F22, F23, F25, F26, F29). The remaining farmers are either aware or possess knowledge about biochar resp. char/coal (F1, F2, F8, F14, F20, F21, F24, F27, F28), or no entry whatsoever in this context was made (F17, F18). Some farmers are even engaged with the concept of biochar in much detail, and they share their knowledge about it. In some cases during discussion with farmers the concept led to confusion, and it was not clear whether the farmers (e.g. F8, F21, F23, F24, F28) are aware of biochar and actually know about it or whether they were talking about something different (e.g. organic compost).

> *«He has heard about it. He knows that it's pyrolysis. But he thinks, it's like with the ash and then where you form the ash, coal. You burn the coal and then you put it into the soil, because it has a retaining capacity of carbon. And it emits it slowly.»* (F1)

> *«Yes there is not a fertile. Just there is some media. Biochar is medium. It's not a fertile. Just media is that material is kept all the microorganisms to in holding capacity is there. So it will give the plants.»* (F2)

From the experience during fieldwork and from the discussions with farmers in Berambadi watershed it can be concluded that almost all farmers are **open for the concept of biochar and show interest in it** at least to some degree, which is supported by the findings presented in Figure 45. Farmers wanted to hear about the technology and engaged in discussions about it. Figure 45 shows some trends about the interest of farmers in biochar. A few farmers show extraordinary interest in the new technology (F2, F16, F17, F20, F26), while for others no entry about it was made (F5, F11, F18, F21, F23).

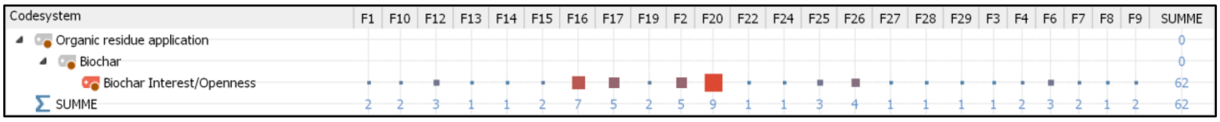

Figure 45: Distribution of coding on *biochar - interest/openness* in selected interviews. Symbol size correlates to the frequency of occurrence of codes in each interviews.

Meanwhile, no coding about interest/openness in biochar in this context cannot be interpreted as no interest in biochar from individual farmers, but rather means that the specific code biochar - interest/openness was not used in a single farmer's transcript. These farmers could still have designated some expectations or doubts about the technology, which would again stand for interest in biochar. Therefore, such obstacles for the analysis originate in the coding style, not in what farmers have said.

As mentioned above, some farmers show extraordinary interest in biochar which sometimes went as far as asking specific questions about its production and application or as far as them taking notes during the introduction on biochar. One exception is F24 who does possess knowledge about char/coal, but does not have any interest in the technology of biochar.

«How come we have not heard about it and nobody has told us about it?» (F15)

«He needs more details. What are the micronutrients, which are there in this?» (F20)

The investigation about farmers' **expectations upon the introduction of biochar applications** in their farming systems and about their **requirements** to prepare it was fruitful. In total, 90 entries were made, and an addition of 27 + 19 entries for the openness to experiment with it or directly doing it respectively (Figure 46). Only two farmers did not designate any expectations (F5, F24).

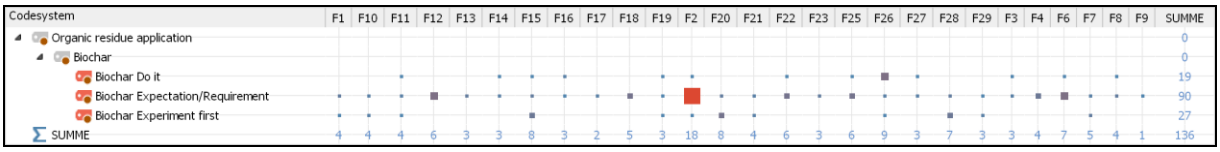

Figure 46: Distribution of coding on *biochar - expectation/requirement*, *biochar - experiment first* and *biochar - do it* in selected interviews. Symbol size correlates to the frequency of occurrence of codes in each interview.

From a socio-economic perspective, five important expectations/requirements, mainly from the production side of biochar, could be identified. First, many farmers name guidance, education and information about the technology of biochar as crucial (F1-F4, F6, F7, F10-F12, F16, F19, F22, F23, F25). Only if farmers get proper instructions from the right people about how to produce and apply biochar, they can use it in a sustainable way. This includes helping them to get practical experience in preparing it (e.g. F6, F7, F10). Another issue associated with education/information is the requirement of many farmers to know how much biochar should be applied to a defined area of land (F12, F13, F16, F19, F20, F26). This information is linked to residue availability and possibility to produce enough quantity of biochar (e.g. labour constraints).

«If they get taught by the right people, they are open to try and use technologies like biochar, the farmer says.» (F12)

«He is saying: Do you have a measurement as to how much is it for one acre that you can put?» (F20)

Second, the production method and the distribution of the right production tools are stressed by some farmers (F15, F16, F18, F25, F29). Specifically, the pyrolysis unit needs to be there (F18, F25, F29) or the energy input to burn the residues (F16).

«So yes I mean, he would need a bucket to burn it and also wastages to make the coal for himself.» (F18)

Third, farmers' answers deviate when it comes to the question if they should be able to produce biochar themselves (F3, F4, F7, F12, F14, F28) or use a biochar product that can be purchased (F4, F6, F9, F15, F22, F28). On the one side, factors that influence the opportunity to prepare biochar on-farm are instruction/information, labour, satisfaction and reduced external dependency. On the other side, some farmers would welcome if a ready-made biochar product would be available on the market, partially because it is stated that it can be difficult to produce biochar on-farm (e.g. F15).

«So he is, it seems interesting for him that you can do it on your own [...]. So that he has not to depend on others, is what seems interesting for him.» (F7)

«So he has I mean what you need, he says no I have to collect all the waste in one place. And I have work with respect to making a pit and then collecting it and then putting it into the device to heat it up and make this. I would have to work. That is what I would need.» (F14)

«So he says it's not easy to do this on our own. It would be easy if somebody is produced it and we can buy it from them.» (F15)

Fourth, farmers stress the importance of their investment capacity which subsequently implies that new technologies like biochar have to be of low cost (F4, F6, F9, F26). Fifth and last, one farmer adds an important issue about the concept of biochar. For the benefits of such new technologies to show up, patience is needed (F2).

«So he feels that it should be low cost. Because it should be available to the farmers.» (F4)

Agro-ecologically, six major expectations/requirements are named by the farmers. The first is not only of outstanding importance when it comes to the application of biochar technology, but can be found for any residue application and it originates in the farmers' desire for a good plant growth and yield. Out of necessity, biochar needs to sustain (or increase) crop yields (F6, F8, F10-F12, F14, F15, F18, F21, F22, F25, F26).

«His expectation is that the farmers adopt this, all of them would expect a good yield. And good growth of the plant. If that is there, that's what the farmer requires. So they would use it.» (F21)

Secondly and closely linked to the first expectation is the requirement that biochar has to improve the soil fertility (F2, F6, F12, F18, F21, F22) and that it should not harm the plant-soil system (F4, F17).

«Ok. So he says, it is a, I would be interested in it. That I feel happy because you are saying that it will hold the moistness in the soil and it gives a good yield. Now it just dries up in three days. But if you are saying that I can do that, then we would be very happy with it.» (F12)

A fundamental third expectation deals with the input material to produce biochar (F2, F6, F13, F17, F18, F20, F28). A few farmers point out the necessity to have trees or horticulture crops (F2, F13, F28) and another farmer emphasises the possible competition for organic residues with other usages (F17). That the input material has to come from locally available material is also mentioned (F2). One farmer only states that he would have enough residues to produce biochar (F6, see also subsection 5.2.4.1).

«So he is saying if you want to make coal, then you have to cut the tree and then make coal.» (F13)

«So the main thing is, he needs wastage because whatever he can burn, he needs that as a feed for the cows.» (F17)

Fourth, farmers expect biochar only to be applicable if there is enough water available (F8, F18, F27), as it is explained further below. Fifth, some farmers designate other effects that they would wish to see upon the introduction of biochar in their farming systems. The reduction of fertiliser input (F20) and weed control (F22) are worth mentioning here. Sixth, the right timing of introducing biochar is addressed once (F23) and also that biochar itself only functions as a medium, not as a fertiliser (F2).

To conclude on farmers expectations/requirements about biochar, there are two significant findings that are worth being presented here. On one side, many farmers express the need to **preliminarily test the effect of biochar** on their plant-soil systems in a small piece of land before applying it, so that they gain practical experience (F1, F2, F7, F10, F11, F15, F19-F21, F26, F28, F29). Only then they can judge for themselves whether biochar is suitable for their lands or not and only after this they can share whether they would do it or not. On the other side, an almost identical number of farmers designate that they would **directly do it**, albeit under certain conditions (F2, F3, F6, F8, F11, F14-F16, F19, F22, F25, F26, F27).

«Maybe three, four months I use the biochar concept also in my land.» (F2)

«So he says if you use it, then they can tell the advantages and the disadvantages of whether it works or no. I mean, they have to try it before they can say. At least for half an acre and then see the advantages.» (F21)

Out of 29 interviewed farmers, 15 farmers express **doubts/fears about the biochar technology** (Figure 47) and three farmers are especially sceptical about the technology (F13, F17, F19).

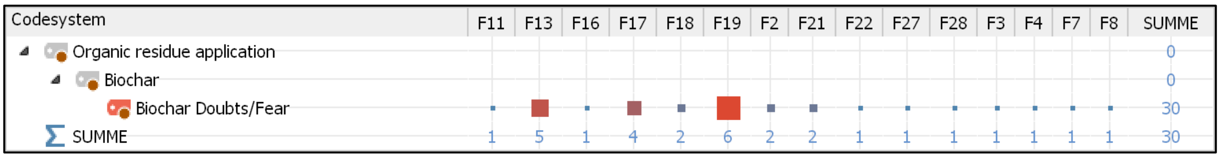

Figure 47: Distribution of coding on *biochar- doubts/fear* in selected interviews. Symbol size correlates to the frequency of occurrence of codes in each interview.

The availability of residues to produce and apply biochar is one major doubt that farmers express (F2, F13, F19, F28). First, they fear that the quantity, which has to be applied, is very high (F13). Second, several farmers precise doubts about the usage of trees (on-farm or from the forest) for the production of biochar (F2, F13, F19), especially from a long-term perspective. Third, competing interests with other usages of agricultural residues are also mentioned (F28).

«Then farmers what they're doing, they're not having that much of trees in land. So then simply they're going and cutting the forestry. That's a major disadvantage only in biochar.» (F2)

Several farmers fear that the application of biochar has negative consequences on soils and subsequently plant growth and yield (F8, F17, F21, F22). This might come from the belief that burning residues to produce biochar in the fields will kill important macro- and microorganisms in the soil (F17, F21) and the belief that burning of OM harms the environment (F21). Another doubt that is related to the previous one, is the belief that biochar can only be applied with enough water, mainly because of the heat that will be introduced by biochar application (F8, F18, F27).

«So his opinion is that he has been given feedback that when you burn this in the soil the sensitive insects or the microorganisms, which are there in the soil, get burned. That does not help the soil.» (F21)

Extra work might be another constraint of a successful implementation of biochar applications (F7, F19), especially when it has to be produced in large quantities (F7). Linked to this, some farmers also state that other agricultural residue management applications (e.g. cow dung manure) are superior to biochar and that there is no need for it (F16, F19). Related to the requirement of education and training about biochar, several farmers also fear that they do not possess the right information/instruction on how to prepare the biochar (F3, F19). Other doubts relate to land tenure (F11) or market mechanisms (F4), whereby it remains unclear what the fears are in detail. The fact that middlemen make more money might refer to the belief that the biochar product has to be purchased.

«So he says, I mean he is scared because when I explained it to him that it has to be burned in this particular temperature, so he says I don't know the temperature. That means if I burned it more, then it's going to be a waste.» (F3)

«So what you're telling me, is that I have extra work that I burn something and add into the soil.» (F19)

Two of the farmers who had been most sceptical towards the introduction of the biochar technology, were more convinced about the concept of biochar after the discussion during the interview (F17, F19), which shows that correct information about the technology is of major importance.

5.2.5 Farmer typologies - opportunity for introducing vermicompost and biochar

As introduced in subsection 4.2.5, the idea of the second data assessment was to create farmer typologies based on fundamental attributes that determine farming in the research area. Since soil and irrigation type, which is mainly dependent on the geographical location of the farm, and farm size have been identified as the most crucial factors for farming, farmers were grouped into types based on these attributes (Figure 48).

The final typology resulted to be rather complex and, more importantly, difficult to use as a tool to analyse the findings from subsection 5.2.4. This analysis step would have provided insights into farming systems that could be most suitable for tailor-made OM applications like biochar. One major problem is the fact that many farmers can be assigned to several types, even when using a differentiated typology (Figure 48), which is mainly due to the presence of more than one soil type for many farmers. The precondition of creating types that are as homogeneous as possible within the type and as heterogeneous as possible in relation to other types could hardly be reached in this context.

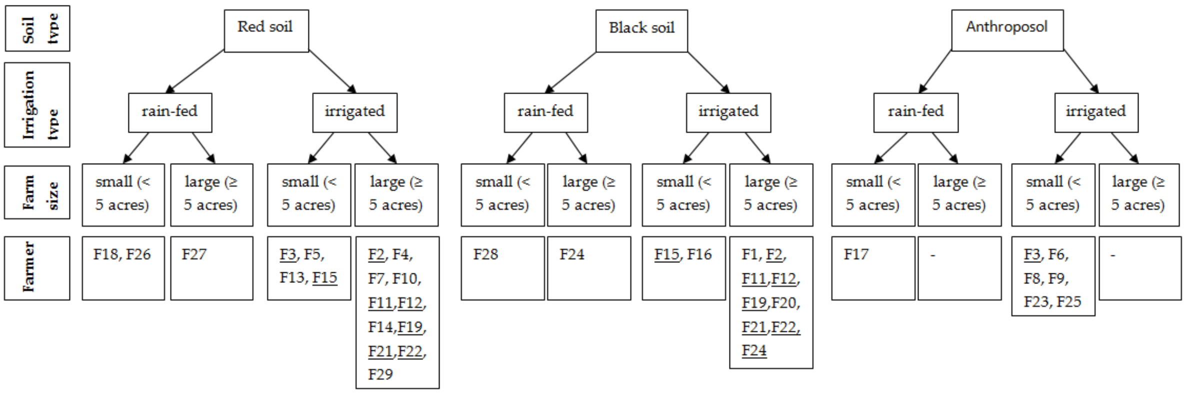

Figure 48: Assigning individual farmers (F + number) to farmer types based on pre-defined criteria. Underlined farmers occur in more than one type.

Another issue associated with the differentiated typology used, is the relatively large number of types (12). However, this resulted in types with no assigned farmer or in types with a relatively small number of farmers assigned (Figure 48). One possible strategy to overcome this in the future would be a reoriented sampling that aims at including enough farmers for each type (which then of course makes the validity of interpretations higher), which though was not possible for this master project.

A cluster analysis, a statistical tool to arrange observed phenomena into groups, was also experimented with. As it turns out, there is an excellent study conducted by French and Indian scientists, which addresses exactly this issue of creating farmer typologies in the Berambadi watershed (Robert *et al.* 2017). Since the study includes way more criteria and a much larger sample size to identify farmer types, it wouldn't have been sensible not to use these findings to analyse the results of subsection 5.2.4. For further analysis in this thesis, only the criteria farm size and irrigation are considered.

In the contemplated study, three farmers types have been identified, including a) large-scale farmers who normally possess more than 2 ha of land and who use bore well(s) for irrigation (will now be referred to as farmer type A), b) small-scale farmers who possess less than 2 ha of land and who fully depend on rain (farmer type B) and c) small-scale farmers who possess less than 2 ha of land, but who do possess a bore well that might be in operation or not (farmer type C) (Robert *et al.* 2017).

Using the typology of Robert *et al.* (2017), interviewed farmers are assigned to the three farmer types (Table 13). From the 29 interviewed farmers, only two did not fit in one of the types (indicated in italic in Table 13). F24 is assigned to famer type A since he has more than 2 ha of land, and uses both bore well as well as rain for irrigation. F27 is fully dependent on rain, and possesses 6 acres of land, but since irrigation is crucial, F27 is assigned to farmer type B.

Table 13: Classification of farmers according to farmer types described in Robert *et al.* (2017) (own representation).

	Criteria	Farmers
Farmer type A	Large (≥ 5 acres) + irrigated (bore well)	F1, F2, F4, F7, F10-F12, F14, F19-F22, F29 *F24 (large, but bore well and rain-fed)*
Farmer type B	Small (< 5 acres) + rain-fed	F17, F18, F26, F28 *F27 (large + rain-fed)*
Farmer type C	Small (< 5 acres) + irrigated (bore well)	F3, F5, F6, F8, F9, F13, F15, F16, F23, F25

Based on the farmer types in Table 13, trends in interests and scepticism in new residue technologies (vermicompost and biochar) are statistically tested, using the coding from GT as input material (see subsection 8.5.4) and IBM SPSS Statistics 21 as a statistical analysis tool. Since soil type has been identified as crucial, a second statistical analysis of farmers, grouped by soil type (red soil, black soil, Anthroposol, mixed soil (more than one soil type)), is also conducted with the same input material.

Before an actual statistical test was performed, the input data had been inspected closely by preparing the descriptive statistics (see subsection 8.5.1) and by building scatter plots (Figure 49, next page) for each treatment and for the two subdivisions of farmers. Figure 49 depicts the relationship between interest and scepticism of individual farmers (single dots) as well as farmer groups (colour). Unfortunately, no identifiable first trends can be observed from these scatter plots, as farmer types as well as farmers based on soil types are scattered heterogeneously.

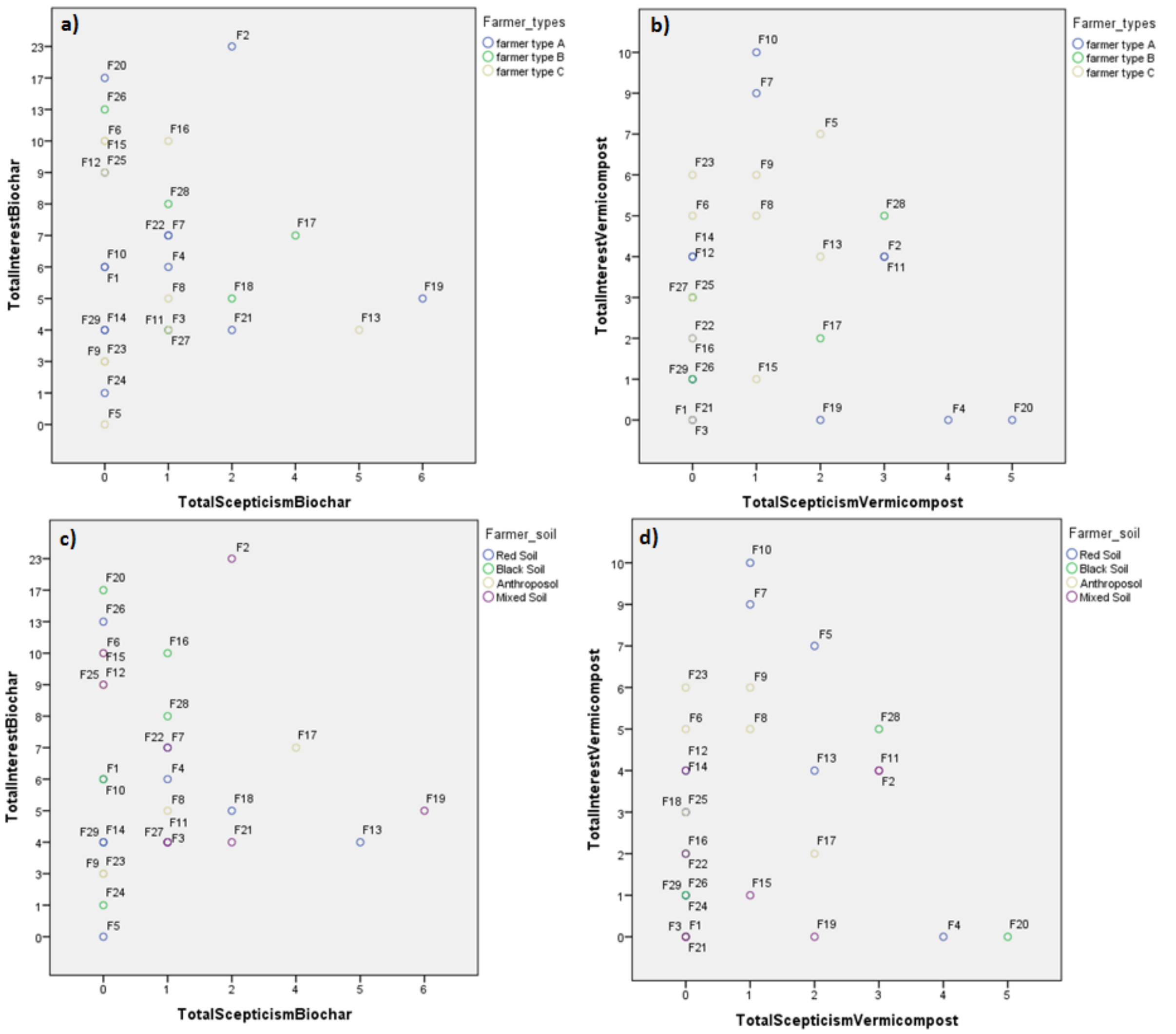

Figure 49: Interest in new residue technologies (biochar and vermicompost) on y-axis plotted against scepticism in new residue technologies (x-axis). Scatter plot a) and b) summarise the relationship according to farmer types and scatter plot c) and d) according to soil types of farmers. Labels (F + number) represent individual farmers.

Mean interest in biochar is highest for farmer type B (7.4), followed by farmer type A (7.36) and farmer type C (5.8). Interestingly, also the mean scepticism is highest for farmer type B (1.6), followed by farmer type A (1.0) and farmer type C (0.80). For vermicomposting, mean interest is highest for farmer type C (3.90) and lower for farmer types A and B (2.79 resp. 2.80). Mean scepticism is highest for farmer type A (1.36), followed by farmer type B (1.0) and farmer type C (0.70) (see subsection 8.5.1).

Mean interest in biochar is highest for farmers with black soils (8.40) and with more than one soil type (8.25), followed by farmers with Anthroposols (6.17) and with red soils (5.30). Mean scepticism is highest for farmers with more than one soil type (1.63), followed by farmers with red soil (1.0), farmers with Anthroposols (0.63) and farmers with black soils (0.40). Mean interest for vermicomposting on the contrary is highest for farmers with Anthroposols (4.5) and with red soils (4.2), followed by farmers with more than one soil type (1.88) and farmers with black soils (1.60). Farmers with black soils show the highest mean scepticism (1.60), followed by farmers with mixed soils (1.13), farmers with red soils (1.0) and farmers with Anthroposols (0.67) (see subsection 8.5.1).

To see whether statistically significant differences in interest and scepticism about new residue technologies among different farmer types exist, a statistical test based on the level of measurement and normal distribution of data was chosen. Since the level of measurement is only ordinal (relative magnitudes based on coding and not on numerical values with fixed interval) and the variables about scepticism in biochar and vermicompost are not distributed normally (see subsection 8.5.2), a non-parametric t-test (Kruskal-Wallis) for more than two independent samples (but with low sample size n) had to be run in IBM SPSS Statistics 21.

Unfortunately, neither for the farmer nor the soil types statistically significant differences in mean interest and scepticism for biochar and vermicompost could be recorded with the t-test (see subsection 8.5.3). All significance levels are higher than the level of inspection. Reasons for this rather disappointing result could originate in low sample size, rather small samples in individual groups and a wide range in the values of each variable (see section 8.5). Therefore, no further Post-Hoc-test for identifying the origin in significant differences between farmer types was conducted.

5.2.6 Synthesis and discussion of findings

Agricultural residues are **perceived** as an agronomic resource depending on the type of plant(s), the system of farming and the type(s) of residue application(s) farmers' use. The finding that farmers perceive residues as an input material for several agricultural and domestic usages rather than a waste, is in line with findings from other scientific studies (Gowda *et al.* 1995; Cardoen *et al.* 2015a, 2015b).

No clear trend whether farmers **possess enough residues or not** for all agricultural operations on-farm could be drawn from the farmer interview data. Findings from expert interviews however indicate a decreasing number of livestock (and subsequently cow dung manure). Furthermore, according to Purushothaman, Patil & Francis (2013), a decrease in the production of agricultural residues for most farms might cause problems for on-farm soil amendments in the future.

Composting, especially the preparation of farmyard manure, represents the most common way of preparing soil amendments from agricultural residues (e.g. Maruthi *et al.* 2008), but other important **knowledge-based residue practises** like mulching or residue burning (ash) exist. Alternative usages of agricultural residues are mainly fodder for livestock and fuel for cooking and processing crop products (Gowda *et al.* 1995). The significant set of traditional residue management practises and their (mostly) positive perception by farmers could reduce the availability of residues for innovative residue management practises like biochar applications.

All farmers but one in the research area are aware of **vermicomposting**, but only few have actually applied it in their farming system, which is in line with another study conducted in Karnataka where 80% of farmers were aware of vermicomposting, but only approx. 20% were actually using it (Veeresh *et al.* 2011). Farmers' perceptions about vermicomposting can range from negative experiences to its specific positive effects on the plant-soil system. Expectations for its introduction can include guidance/training, investment capacity, increased soil fertility and plant growth, which is in line with case studies from interviewed experts of NGOs and e.g. Nagavallemma *et al.* (2006).

Interest in **biochar** in India has not only picked up in science (e.g. Srinivasarao *et al*. (2013)) and public (e.g. the popular book of Reddy (2014)) recently, but the concept has also drawn much interest from the side of farmers in the Berambadi watershed. Some farmers have already engaged in the concept of biochar and possess significant knowledge about it, while others would be interested in experimenting with it or would even apply it in a piece of their land if they would be guided properly. Expected effects of applying biochar to soils might be strongly influenced by perceptions of traditional practises of residue burning and ash application to soils and by opinions about the input material to produce biochar, i.e. the perception that only farmers with significant amounts of trees could engage in biochar production. However, the occurrence of residue burning for soil amendment or processing agricultural products (e.g. turmeric or sugarcane) could also represent a potential for biochar applications whereby these traditional practises could be slightly adjusted in order to produce biochar for small-scale farming without it posing a threat for other usages of agricultural residues (Reddy 2014; Scholz *et al.* 2014; Joseph *et al.* 2015).

From the list of possible **input materials for biochar applications** in the expert interviews (see subsection 5.1.2) and from the literature, the following agricultural residues might be of interest for small-scale biochar applications in and around Berambadi watershed:

- Coconut: Observations during fieldwork indicate that most interviewed farmers in the research area possess coconut trees and some store the dried coconut shells on-farm (picture on cover page). A few farmers even designate coconut shells to be a possible input material for biochar. That biochar could be produced from coconut shells, has been proven by the company of expert E8B and the small store where the biochar (B1) for the incubation experiment came from. In addition, scientific studies have already evaluated the feasibility of coconut shells for biochar production (e.g. Lee *et al.* 2013; Sukartono *et al.* 2011).

- Turmeric: Residues of turmeric are used by many farmers as a fuel to boil the turmeric root, which results in the production of ash/char (see subsection 5.2.3.2). The open-ground burning of turmeric might be convertible into the production of biochar with the introduction of a low-tech set-up like kilns or vessels.

- Bagasse of sugarcane: Sugarcane is not that prevalent among the interviewed farmers in the Berambadi watershed (five farmers), but scientists have proven that its bagasse could be a viable input material for biochar production (Inyang *et al.* 2010; Carrier *et al.* 2012; Lee *et al.* 2013).
- Straws of major grains (maize, Jowar, Ragi, etc.): Many farmers cultivate at least one major grain variety and the crop residues could be an input material for biochar production, especially for maize (Martinsen *et al.* 2014; Wang *et al.* 2015). However, exactly these grain residues function as a major input for feedstock of animals and therefore competing usages could likely arise.
- Banana: Residues of banana plantains are often used for mulching, but the availability of (dried) residues could be high enough in order to use part of it for biochar production (Figure 33). Whether banana residues are suitable for biochar production remains unclear and only few studies have assessed this to date (e.g. Karim *et al.* 2015).

Frequently named agro-ecological expectations of farmers in the research area about biochar, namely the increase in both soil fertility and crop yields, might be met by biochar applications, as scientists expect a more significant effect of the technology in regions with prevailing water scarcity and weathered, poor soils (Abiven *et al.* 2014; Lehmann & Rondon 2006), like in south-western Karnataka.

5.3 Compost, vermicompost and biochar as organic residue applications for soil amendment

This section has the aim of presenting the identified effects of individual and combined application of OM on selected properties of the three chosen soils. In a first step (subsection 5.3.1), a general discussion of the results will be held. Second, the theoretically expected and effectively measured effect size of treatments on soil parameters will be compared to each other (subsection 5.3.2). Third, in subsection 5.3.3, a holistic comparison of relative changes of each treatment on soil parameters will be illustrated. Finally, a brief discussion of the results of the microbial activity assessment will also be provided.

5.3.1 General overview over effects of agricultural residue applications on selected soil parameters

To give an overview over measured changes in soil parameters due to individual and combined organic residue applications, a concise graph for each parameter (pH, WHC, TC and C/N ratio) that includes all three soils was created and will be discussed in the following subsections.

5.3.1.1 pH

Initial pH of all three control soils are in the neutral range and account for 7.8 (black soil), 7.1 (red soil) and 7.0 (Anthroposol), meaning that carbonates are still present in all three soil types (Kretzschmar 2010). Especially the high pH of the highly weathered red soil (7.1) is surprising, also compared to values of tropical Ferralsols or similar soil types from the literature (Agegnehu *et al.* 2015b; FAO 2014; Blume 2010). The plausible explanation for this unexpected outcome lies in the fact that farmer F11, where the red soil was sampled, applies ash from burned residues to his fields, which probably causes a liming effect and therefore increases the pH of the corresponding soil. The measured pH of the black soil (resp. Vertisol) is similar to values found in the literature (Ghosh *et al.* 2010; Pal 2017; Hati *et al.* 2007). As clearly visible in Figure 50 (next page), pH values between the three soil types are significantly different according to one-way analysis of variance ($F = 432.9$, $p < 0.001$), as well as between treatments overall ($F = 4.3$, $p < 0.001$).

Changes in pH due to OM application (Figure 50, next page) are positive for the black soil (+0.1 to +0.4) except with two treatments (-0.1 for VC1 and B1&VC1), negative for the red soil (-0.03 to -0.4) except for biochar applications (+0.1 for B1 and B2) and always positive for the Anthroposol (+0.06 to +0.5). The magnitude of pH changes (see also subsection 5.3.3) is at the lower end of values found in literature (see subsection 2.4.2.1). There are significant differences between treatments for the black soil ($F = 2.8$, $p = 0.016$), the red soil ($F = 2.7$, $p = 0.020$) and the Anthroposol ($F = 13.0$, $p < 0.001$).

For the **black soil**, all combinations of biochar B2 with either compost or one of the two vermicompost are significantly higher than the control, whereas all other treatments are not significantly different from the control at $p = 0.05$ (Figure 50, next page). The treatments B2&VC1 (8.2), B2&C1 (8.1) and B2&VC2 (8.07) show the highest pH, whereas the treatments VC1 and B1&VC1 show the lowest (7.7

resp. 7.67). Significant effects when biochar is applied in combination with (vermi)compost are found in many studies (e.g. Doan *et al.* 2015; Trupiano *et al.* 2017), and this implies that the OM application could improve the buffer capacity of soils (Jouquet *et al.* 2011). That treatments which include VC1 decrease the pH of the control soil (significantly compared to some other treatments) is surprising, since VC1 shows the highest pH of the three (vermi)composts (but also the largest standard error). These findings contradict results from other studies, where significant enhancements in pH after applying e.g. compost or vermicompost are found in soils (e.g. Ghosh *et al.* 2010; Jouquet *et al.* 2011).

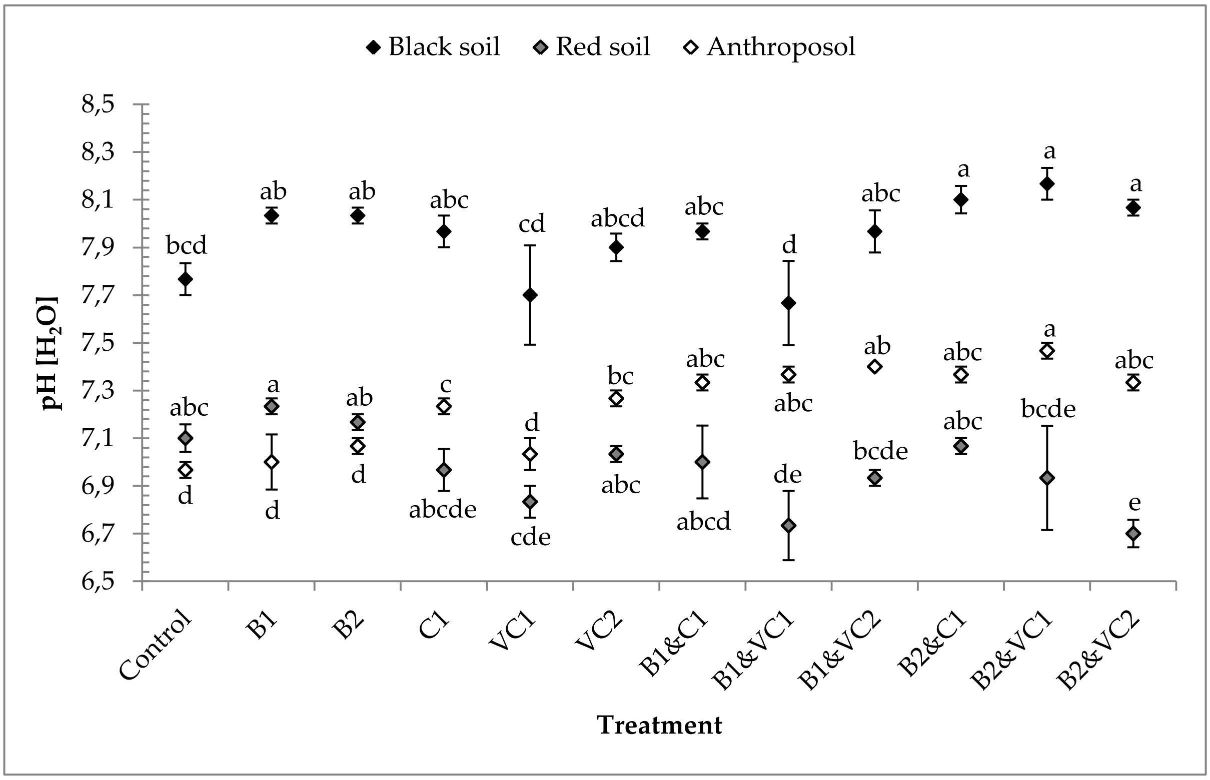

Figure 50: pH of the three studied soils before (control) and after treated with OM (B1, B2, C1, VC1, VC2, B1&C1, B1&VC1, B1&VC2, B2&C1, B2&VC1, B2&VC2) after the incubation experiment (n = 3, error bars = ± SEM). Bars with the same letters are not significantly different at p = 0.05.

Significant differences to the control **red soil** only occur with two treatments (B1&VC1 and B2&VC2), whereas all other treatments are not significantly different from the control at p = 0.05 (Figure 50). Interestingly, only the biochar treatments (B1 and B2) increase the pH of the control red soil to 7.23 (B1) resp. 7.16 (B2). Combinations of biochar and vermicompost (B1&VC1 and B2&VC2) reduce the pH the most to 6.7, and all treatments involving (vermi)compost decrease the pH compared to the control (even if not significantly, Figure 50). In contrast to these results, the study of Agegnehu *et al.* (2015b) found that compost and biochar alone or in combination slightly increase the pH of a Ferralsol, but the authors also did not find significant differences. This is in line with another study that identified the effect of biochar and compost alone or in combination on a sandy soil (Carter *et al.* 2013). An increase in pH due to sole application of biochar was found, but without significance, which supports the findings described above. On the contrary, through combining biochar and compost, the authors found a significant increase in pH as compared to the untreated soil (Carter *et al.* 2013).

For the **Anthroposol**, all combined treatments show significant differences in pH to the control soil and to most single treatments (except C1 and VC2), and most treatments combining biochar and vermicompost show a higher pH after the incubation experiment than any other combination, as for example B2&VC1 with 7.5 (Figure 50). All treatments show a higher pH when compared to the control soil (6.97), even though not all are significantly different (B1, B2, VC1).

Overall, results of the pH measurements are only partially in line with scientific literature. Whereas in most scientific studies, almost all (single or combined) organic treatments show significantly higher pH values compared to the control soil (e.g. Doan *et al.* 2015; Ghosh *et al.* 2010; Trupiano *et al.* 2017), and in some cases also significant differences between single or combined application of (vermi)compost and biochar occur (e.g. Trupiano *et al.* 2017), in the present study this could only be observed for some treatments and likewise not for all soils. For example, from the six combinations of biochar and compost, only three (B1&C1 (Anthroposol) and B2&C1 (Black soil and Anthroposol)) are statistically different from the corresponding control soil, and this finding would be in line with Carter *et al.* (2013). The reason why a combination of biochar and (vermi)compost theoretically leads to a significant increase of pH may lie in the introduction of permanent surface charge through biochar, and variable surface through OM (Kretzschmar 2010), which would increase the soil's buffer capacity.

It is surprising that sole biochar addition had no significant effect on soil pH in any case, which contradicts findings of a large meta-analysis (Biederman & Stanley Harpole 2013). However, the authors of this paper emphasise that the effect of biochar on pH is influenced by both the pH of the studied soils and the biochar properties (Biederman & Stanley Harpole 2013), which might have influenced the variability of the results in the present study. Especially in acidic soils biochar amendments could proof highly beneficial, but since the soils in the present study are all in the neutral range, no clear effect could be observed (Biederman & Stanley Harpole 2013). The present results therefore are nothing surprising, and other studies could not find any significant differences in pH after biochar application (Cely *et al.* 2014). One major mechanism that could induce rising pH is the biochar's liming potential, which is influenced by the carbonate content, the pH and the base cation concentration, while all of these factors determine the amount of protons that can be buffered (van Zwieten *et al.* 2010; Chintala *et al.* 2014).

Changes in soil pH due to (vermi)compost application may be caused through mineralisation of OM or due to release of organic acids and other chemical compounds through microbial activity (Hargreaves *et al.* 2008; Lazcano *et al.* 2008; Lim *et al.* 2015). However, a decrease in pH due to the release of acids might already have happened during (vermi)composting, and this together with the TC content of the (vermin)compost substrates could explain the rather high pH of the (vermi)compost-amended soils. The TC content of the substrates used in this study indicates that there are still minerals (calcareous) in them, which may buffer the acidity of the (vermi)composts in the amended soils.

5.3.1.2 Water holding capacity

WHC of control soils highest for the black soil (16.38%), intermediate for the Anthroposol (14.02%) and lowest for the red soil (5.97%) (Figure 51, next page). The measured WHC for the black soil and the Anthroposol are in line with a study conducted in the research area, but for the red soil, the measured WHC is much lower (Barbiéro *et al.* 2007). However, since Ferralsols are characterised by a very low WHC, the values may still be plausible (FAO 2014). One-way analysis of variance shows significant differences in WHC between soils ($F = 1384.9$, $p < 0.001$) and treatments ($F = 3.5$, $p < 0.001$).

Most treatments decrease the WHC of the black soil (-0.15 to -1.4%), except for the combined application of biochar and compost (B1&C1 (+1.78%) and B2&C1 (+2.52%)) and the combination of biochar and vermicompost (B2&VC2 (+0.51%)). All treatments decrease the WHC of the Anthroposol from -0.5 up to -3.8%. For the red soil, treatments including coconut shell biochar (B1) increase the WHC of the control soil (B1, B1&C1, B1&VC1, B1&VC2) in a range of +0.1 to +0.6%, and all other treatments decrease the WHC up to -1.06% (Figure 51, next page). While the mostly negative changes of WHC are contradictory to the findings of the literature review, the few positive (relative) changes are in the range of other studies (see subsection 2.4.2.2 and 5.3.3). Differences between treatments are slightly significant for the black soil ($F = 2.4$, $p = 0.038$), and significant for the red soil ($F = 14.6$, $p < 0.001$) and the Anthroposol ($F = 7.2$, $p < 0.001$).

Figure 51 (next page) shows that only one treatment, where biochar is combined with compost (18.9%, B2&C1), significantly raises the WHC compared to the control **black soil** (16.38%) and to almost all other treatments (except to B1&C1 and B2&VC2). Treatment B1&C1 (18.17%) indeed shows the second highest WHC, but it is not significantly higher than the control and some other treatments (B2&C1, B2&VC2, B2&VC1, B1). All sole treatments decrease the WHC of the black soil (not significantly). The lowest WHC can be found with treatment B1&VC1 (14.98%), which gives a variation of almost 4%.

Similar to the black soil, treatment B1&C1 (6.57%) shows the highest WHC in the case of the **red soil** and significantly increases its WHC as compared to the control and all other treatments except B1&VC1 (6.26%). Interestingly, B1&VC1 now ranks second (lowest WHC for the black soil) and enhances the WHC of the red soil significantly when compared to some of the other treatments, but not to the control. Except for B1 (not different from the control), all single treatments significantly decrease the WHC as compared to the control (Figure 51, next page). Treatments including coconut shell biochar (B1) normally increase WHC, whereas treatments with rice husk biochar (B2) decrease it (and concerning treatments with B1 or B2, almost all are significantly different at p = 0.05). The highest decline of -1.06% is assigned to the treatment B2&VC2, and is significantly different from the control.

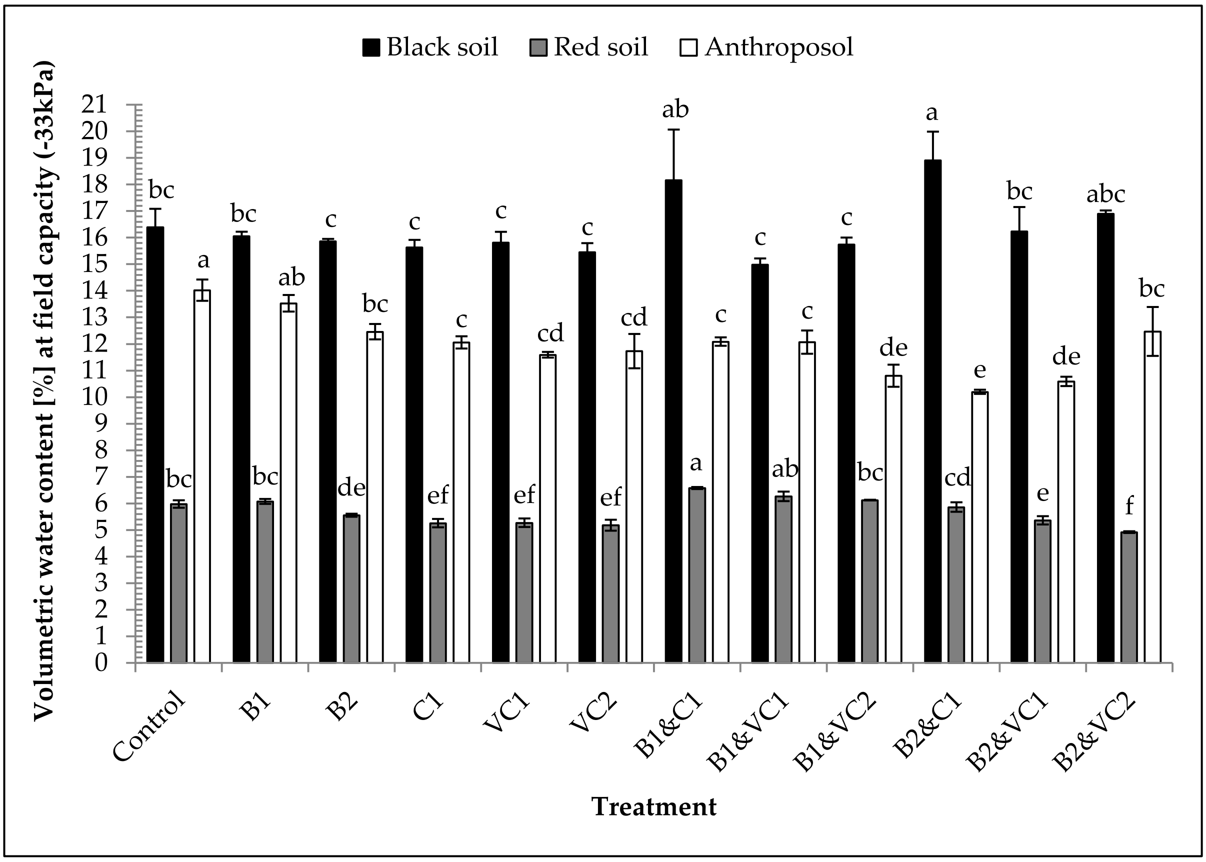

Figure 51: Volumetric water content (%) of the three studied soils before (control) and after treated with OM (B1, B2, C1, VC1, VC2, B1&C1, B1&VC1, B1&VC2, B2&C1, B2&VC1, B2&VC2) after the incubation experiment (n = 3, error bars = ± SEM). Bars with the same letters are not significantly different at p = 0.05.

The interaction of the treatments with the **Anthroposol** reveals a completely different picture (Figure 51). The control soil (14.02%) not only has the highest WHC, but also are the differences to all soils amended with OM actually significant except for the coconut shell biochar (B1). The range from the control to the amended soil (B2&C1) with the lowest WHC (10.19%) accounts for almost 4%, which is a relative change of almost -30%.

Changes in WHC of soils treated with OM are mainly attributed to changes in soil structure (aggregation) and porosity (specific surface area), and through changes in the SOC content (Carter 2007; Basso *et al.* 2013; Ouyang *et al.* 2013; Barnes *et al.* 2014; De Melo Carvalho *et al.* 2014; Hseu *et al.* 2014). On this basis it could be hypothesised that especially the red soil (low initial WHC, low TC content, poor soil structure (sandy, clay with low activity (FAO 2014)) should positively react to OM application.

Many scientific studies found enhanced WHC of soils amended with OM (see also subsection 2.4.2.2). Barnes *et al.* (2014) for example verified the above hypothesis and showed that the application of biochar increases the WHC (at field capacity) of a sandy soil by twofold, and the one of a clay soil by 20%. Also, Basso *et al.* (2013) found an increased WHC of a sandy (loam) soil after adding biochar. The findings represented in Figure 51 however contradict to the results from the literature. Only the sole application of coconut shell biochar (B1) increases the WHC of the red soil, but the effect is not statistically significant. All other biochar-amended soils (biochar only) show a reduced WHC as compared to the corresponding control soils, while for the rice husk biochar (B2) the decrease is even significant for the red soil and the Anthroposol. This stands again in contrast to a study of Hseu *et al.* (2014) who found a significantly higher WHC of a degraded tropical soil rich in silt and clay, which was amended with rice husk biochar. In the present study, rice husk biochar induced relative changes to the control in the order of -3.2% (black soil) up to -11.1% (Anthroposol), the latter a significant change.

Furthermore, scientific literature suggests an enhancement of WHC when biochar is applied in combination with either compost (e.g. Agegnehu *et al.* (2015b)) or vermicompost (e.g. Doan *et al.* (2015)), even if not always significantly different to the control soils. Figure 51 shows that this effect can only be observed in six out of 18 cases in the present study and only for the black (B1&C1, B2&C1, B2&VC2) and the red (B1&C1, B1&VC1, B1&VC2) soil. Out of the mentioned, only in two cases the effect is actually significant (see above).

The observation that sole biochar application almost exclusively and biochar application in combination with (vermi)compost most of the time reduces WHC of soils, may be linked to initial hydrophobic behaviour of biochar surfaces. This characteristic may disappear in the long term when biochar surfaces are exposed to oxidation (e.g. through water or air), which reduces the prevalence of hydrophobic functional groups (Basso *et al.* 2013; Das & Sarmah 2015). However, if this process takes more time than the present incubation study (±70 days), it may diminish the application potential for farmers in the research area since many farmers grow short-term crops (i.e. of three months duration).

Carter (2007) and Hargreaves *et al.* (2008) identify higher water contents for soils amended with compost, and suggest that the effect is strongly influenced by changes in the SOC content, which is induced by adding OM. Even if the TC contents of all compost-amended soils increase (Figure 52, next page), the WHC is always lower compared to the control soils when compost is applied alone (Figure 51). Only when compost is combined with biochar, WHC increases in 50% of the cases. The reason for these contrasting results might stem from the lower C contents of the compost used in the present study, which may also hold true for the vermicompost. Observations from Doan *et al.* (2015) that vermicompost application results in higher WHC compared to compost cannot be identified in the data (Figure 51) since all sole applications of (vermi)compost for all soils are statistically not different from each other.

Finally, the relationship of soils with a high initial WHC showing smaller changes after OM application and vice versa is also not supported by the findings in the present study since the black soil with the highest initial WHC also shows its highest (absolute) positive increase (Barnes *et al.* 2014). Another reason for the rather low changes in WHC after OM application may be the usage of realistic application rates of 10t OM ha^{-1}, instead of higher rates used in other studies (e.g. Barnes *et al.* (2014) used 133t biochar ha^{-1} or Doan *et al.* (2015) 20t OM ha^{-1}).

5.3.1.3 Total carbon content

With a TC content of 1.56%, the black soil contains more C than the Anthroposol (1.13%) and the red soil (0.45%), for which the latter might show the highest reaction to the addition of C through OM application. Comparable to the TC content of the studied black soil, Jha *et al.* (2014) found TC contents for a Vertisol in central India between 1.06 to 2.00%. Jouquet *et al.* (2015) measured a TC content of a Ferralsol near the research area of 3.70%, which is much higher than the measurements in this study.

Unfortunately, the statistical analysis only indicates significant differences in TC content between soils ($F = 966.35$, $p < 0.001$) and small differences for treatments ($F = 2.01$, $p = 0.0395$) for all soils, but not if the analysis of variance is run for each soil type individually (black soil: $F = 1.796$, $p = 0.112$; red soil: $F = 0.975$, $p = 0.493$ and Anthroposol: $F = 1.777$, $p = 0.116$). Therefore, it is of no avail to run a post-hoc test and to indicate significant differences in Figure 52. No matter, the range between individual treatments for the three soil types will briefly be discussed.

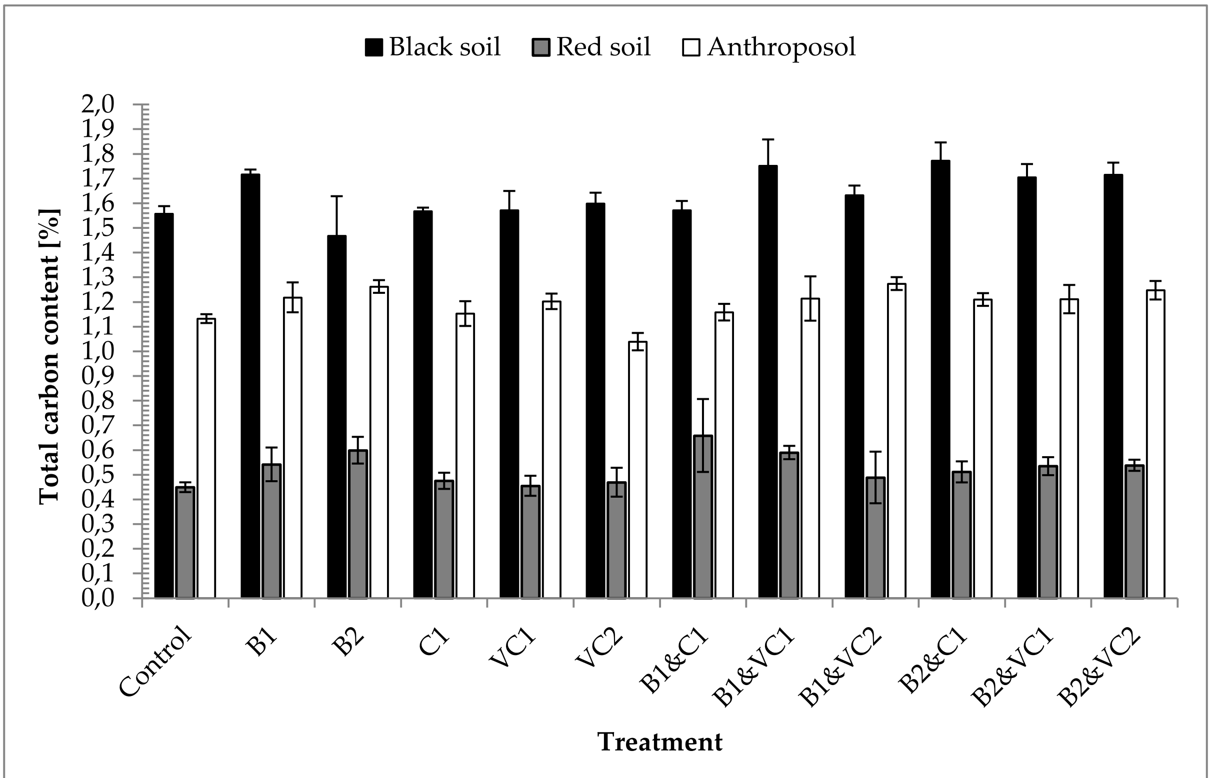

Figure 52: Total carbon content (%) of the three studied soils before (control) and after treated with OM (B1, B2, C1, VC1, VC2, B1&C1, B1&VC1, B1&VC2, B2&C1, B2&VC1, B2&VC2) after the incubation experiment (n = 3, error bars = ± SEM).

For the **black soil**, treatment B2&C1 shows the highest TC content (1.77%) and the rice husk biochar treatment (B2) the lowest (1.47%), though with a relatively high standard error (Figure 52). Treatments with the presence of biochar generally result in a slightly higher TC content than treatments without biochar, except for B1&C1 and B2. The fact that the rice husk biochar (B2) shows a lower TC content than the control soil (1.56%) is attributable to a relatively low TC value for one of the three replicates (1.15%), whereas the other two are in the range of biochar B1 (around 1.7%). This might have been caused through weighing in an inhomogeneous subsample into the tin capsules before analysis.

The TC content is lowest for the control **red soil** (0.45%) and almost identical for compost- (C1) and vermicompost- (V1 and VC2) amended soils (0.45, 0.47 and 0.47% respectively). TC contents of sole application of biochar or in combination with (vermi)composts are slightly higher, whereby the highest content is found with B1&C1 (0.66%). As expected, the relative change of TC for the red soil as compared to the control soil is overall higher than it is for the other two soil types and can account for up to 47% (B1&C1).

A similar picture gives the **Anthroposol**, where one vermicompost treatment (VC2) and the control soil show the lowest TC contents (1.04 resp. 1.13%) while a combination of biochar and vermicompost (B1&VC2) accounts for the highest content (1.27%).

The C content (TC or more frequently SOC) is widely used as an indicator of the SOM content of soils and therefore of soil quality (Agegnehu *et al.* 2015b). Increasing the amount of C in soils through OM application is perceived to be highly beneficial for the plant soil systems (Jouquet *et al.* 2011). Rate and characteristic of added C through OM application represent the main drivers in changes of the TC contents in soils (Wuest & Gollany 2013). Higher application rates of OM with higher C content may lead to (significantly) higher TC contents of amended soils (Liu *et al.* 2012).

For biochar, several mechanisms can lead to an increase of the TC content of amended soils. It is evident that the high TC content of biochar results in higher TC contents of amended soils (Agegnehu *et al.* 2015a). Furthermore, it is known that biochar on one side contains a lot of relatively stable C compounds, but on the other also environmentally relatively labile ones that are taken up by soil microorganisms (Biederman & Stanley Harpole 2013), which again would lead to an increase in the TC (resp. SOC) content of amended soils. Referring to scientific results in this matter, it is generally found that the application of biochar significantly increases the TC content of amended soils. Hseu *et al.* (2014) for example applied rice husk biochar to a loamy clay soil and found significantly higher C contents when compared to the control soil, and Mankasingh *et al.* (2011) found an increase of TC by twofold after the application of cassia biochar (6.6t ha^{-1}) to a lateritic soil. In this master project, the highest absolute change in TC content for sole biochar application accounts for only +0.16%, while this change is not significantly different from the control (Figure 52). This is in line with the study of Jien & Wang (2013), where the application of biochar to a very acidic soil did not result in significant changes of SOC. However, changes induced through sole biochar application in relation to the control can account for up to 33% in case of the red soil amended with rice husk biochar and this would be in the order of values found in literature (see subsection 2.4.2.3).

In the case of combined applications of biochar and (vermi)compost, Doan *et al.* (2015) found significantly higher TC contents of soils amended with biochar, compost, vermicompost or a combination of biochar and vermicompost compared to the control soil, but neither significant differences between compost and vermicompost treatments nor whether vermicompost is applied alone or with biochar. In another study, sole compost application did not significantly increase TC content, whereas its combination with biochar led only to an increase when 20t biochar ha^{-1} were applied, but not with an application rate of 10t biochar ha^{1} (which corresponds to the application rate in the present study) (Liu *et al.* 2012). Agegnehu *et al.* (2015b) show that the application of biochar and compost alone significantly increases TC content of a tropical Ferralsol, and that the combination of the two OM results in the highest C content (even if not different from sole applications). It is difficult to observe a trend in the data visualised in Figure 52 due to the high variability, but it can generally be stated that combined applications of biochar and (vermi)compost normally lead to higher TC contents of amended soils in comparison to the sole application of (vermi)compost, but not compared to biochar application alone (for all three soil types).

Several studies identified increased TC contents in compost- resp. vermicompost-amended soils (Arthur *et al.* 2011; Jouquet *et al.* 2011). The substrates (C1, VC1, VC2) used in this study led to an increase in the TC content, but it was normally miniscule (Figure 52). In one case (Anthroposol amended with vermicompost VC2), a reduction in the TC content is measured, which might have been caused through high decomposition of SOM. Changes in TC of soils amended with (vermi)compost may be a direct result of the C content of the applied OM, and this might again explain the small changes in TC detected in this study, as the TC contents of the substrates (11 to 14%) are relatively low compared to the ones used in other scientific work (e.g. Arthur *et al.* 2011; Doan *et al.* 2015; Jouquet *et al.* 2011).

Finally, Agegnehu *et al.* (2015a) for example also link the increase of TC content of amended soils to processes related to the decomposition (mineralisation) of SOM, which may be insignificant in the short-term incubation study so that no clear interpretation about the relationship between amount of added C and the increase/decrease of TC content can be made. Other processes that influence C dynamics after OM addition may include leaching of dissolved C, formation of soil aggregates or interaction with the clay fraction of the amended soils (e.g. Ngo *et al.* 2011; Ngo *et al.* 2016).

5.3.1.4 C/N ratio

Since TN contents of all three soils (black soil: 0.1%, red soil: 0.05%, Anthroposol: 0.12%) are miniscule, it seems more reasonable to express the amount of TN in comparison to TC, which is possible through the C/N ratio. In accordance with the TC content (subsection 5.3.1.3), the C/N ratio is highest for the black soil (15.9), intermediate for the Anthroposol (9.55) and lowest for the red soil (8.64). The statistical analysis suggests significant differences in the C/N ratio for soils (F = 639.6, p < 0.001) and treatments (F = 8.9, p < 0.001) for the whole dataset.

From a general point of view, OM applications increase the C/N ratio in comparison to the control soil (probably due to the high C/N ratio of biochar) for all soil types, except when compost (C1) or vermicompost (VC1, VC2) are applied solely (Figure 53).

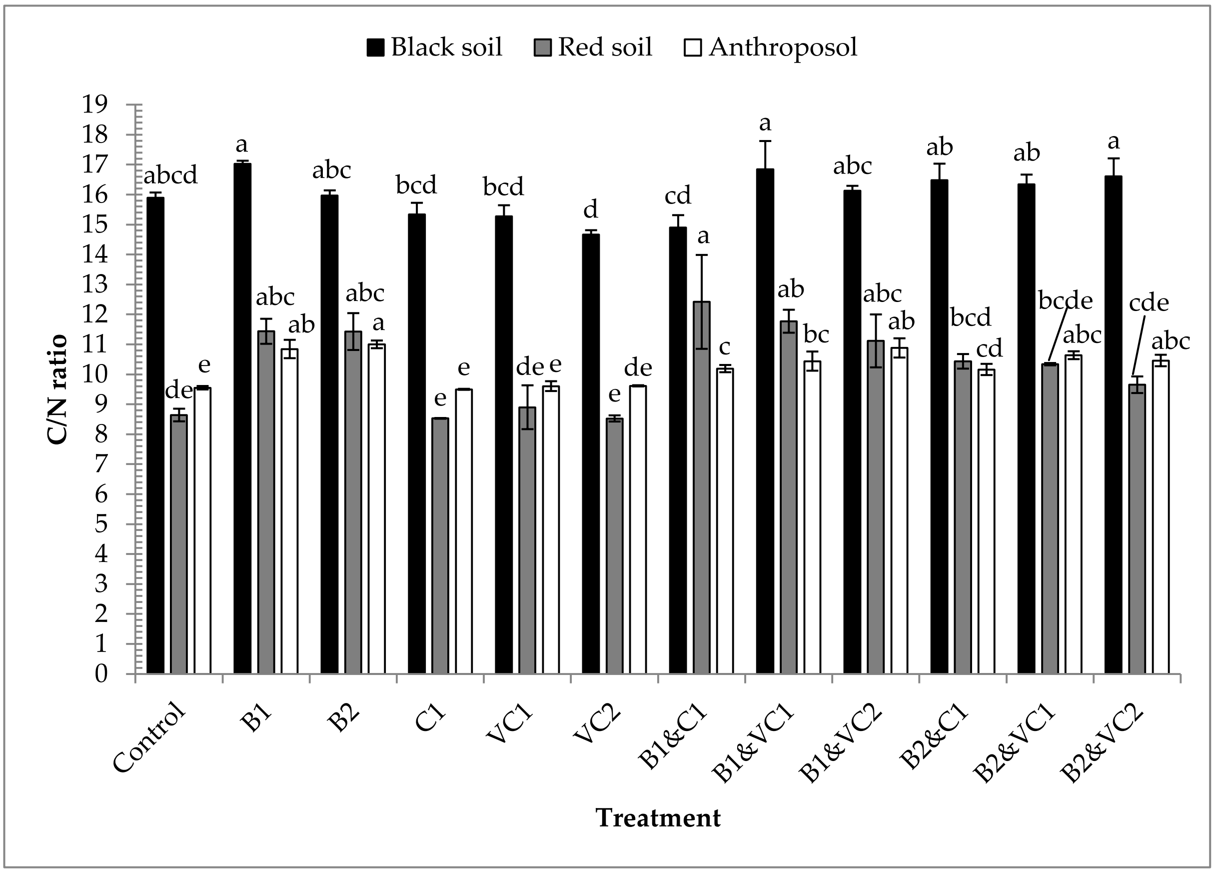

Figure 53: C/N ratio of the three studied soils before (control) and after treated with OM (B1, B2, C1, VC1, VC2, B1&C1, B1&VC1, B1&VC2, B2&C1, B2&VC1, B2&VC2) after the incubation experiment (n = 3, error bars = ± SEM). Bars with the same letters are not significantly different at p = 0.05.

Significant differences between treatments exist for the **black soil** (F = 3.173, p = 0.009), but no OM application significantly increases resp. decreases the C/N ratio compared to the control soil (Figure 53). The application of coconut shell biochar (B1) obviously (high C content) results in the highest C/N ratio (17.03), whereas the application of vermicompost (VC2) results in the lowest (14.66), and the difference is significant at p = 0.05. Treatments that combine biochar and (vermi)compost normally result in higher C/N ratios, except for treatment B1&C1, which shows a significantly lower C/N ratio compared to most other combined treatments (except for B1&VC2, Figure 53).

Stronger differences between treatments can be found for the **red soil** ($F = 4.98$, $p < 0.001$), and there are organic treatments significantly enhancing the C/N ratio compared to the control soil (B1&C1, B1&VC1, B1, B2, B1&VC2), especially when biochar B1 is present alone or in combinations (Figure 53). The highest C/N ratio results from the combination of coconut shell biochar (B1) and compost (C1) and accounts for 12.42. Bare application of compost or vermicompost shows no significant difference to the control soil, and leads to a lower C/N ratio in the end (e.g. C1 or VC2 with 8.53 each).

Finally, also the C/N ratio of the **Anthroposol** changes significantly when OM is applied to the plant-soil systems ($F = 8.6$, $p < 0.001$). While sole compost (C1) or vermicompost (VC1 and VC2) treatments have no significant effect on the control soil and lead to the lowest C/N ratios (e.g. 9.5 for C1), all treatments with either solely biochar or biochar in combination witch (vermi)compost result in significantly higher C/N ratios compared to the control soil and to most single treatments of (vermi)compost (except B2&C1 is not different from VC2 at $p = 0.05$), as shown in Figure 53.

The C/N ratio is an accurate indicator of soil quality since it provides insight into the C and N cycle dynamics of soils. Based on the C/N ratio (of both added OM and amended soils), conclusions about the N mineralisation resp. immobilisation status (major nutrient for plant growth) can be drawn, as well as an evaluation of the C sequestration potential (Abiven *et al.* 2005; Ge *et al.* 2013; Brümmer 2010). The C/N ratio further indicates the stage of SOM decomposition, and with this process advancing, the C/N ratio normally becomes narrower (towards 6 to 10) due to the mineralisation of organic C to inorganic CO_2, meaning that relatively N is accumulated (Stahr 2012). While adding OM with wide C/N ratios (e.g. biochar) may result in lower SOM decomposition and subsequently to N immobilisation (Clough *et al.* 2013; Brümmer 2010), OM with narrow C/N ratios lead to increased decomposition of SOM and therefore possibly to less C sequestration (Ge *et al.* 2013).

In this regard it is important to preliminarily look at the C/N ratios of the OM used in the study (see subsection 4.3.2). Biochar obviously shows a very wide C/N ratio (e.g. 138.9 for B2), whereas the (vermi)composts show a C/N ratio around ± 9.5, indicating an advanced humification for all (vermi)composts. This stands in contrast to the assumption that vermicompost is normally more stabilised than compost (Ngo *et al.* 2011). Furthermore, the C/N ratios of the (vermi)composts are comparable to the C/N ratio of the SOM of the Anthroposol and red soil, whereas the C/N ratio of the black soil is higher, indicating that less SOM is already mineralised.

Proceeding to changes of the C/N ratio of amended soils, Liu *et al.* (2012) for example found increased C/N ratios for soils amended with biochar and compost (significant only at an application rate of 20t biochar ha^{-1}), and a slight decrease in the C/N ratio when compost is applied alone (not significant). Steiner *et al.* (2007) showed that sole application of biochar increases the C/N ratio significantly, which has been confirmed by the study of van Zwieten *et al.* (2010). A study looking into the effect of compost and vermicompost on degraded tropical soils found lower C/N ratios (average of two horizons) compared to the control soil for compost, but almost no change for vermicompost (Jouquet *et al.* 2011). In contrast, Uz & Tavali (2014) found decreased C/N ratios for vermicompost-amended soils, and that the changes are dependent on the application rate. These findings in scientific literature are broadly confirmed by the results presented before (Figure 53). While biochar alone or in combination with (vermi)compost always increases the C/N ratio compared to the corresponding control soils, compost and vermicompost have the opposite effect and normally decrease the C/N ratio (not significantly).

Now, it has to be emphasised that increasing the C/N ratio is not per se a bad thing and decreasing it is similarly neither per se a good thing since the dynamics of C and N cycles are way more complex. Clough *et al.* (2013) for example reviewed the effect of biochar application on soil N cycle and concluded that biochar application can, even if the C/N ratio is increased (which indicates N immobilisation), have positive effects on N availability through its reactive properties, i.e. through adsorption of ammonium and nitrate, and by enhancing N mineralisation. This is in line with primary research where reduced leaching of ammonium and nitrate is observed after the application of not only biochar, but also (vermi)compost (Doan *et al.* 2015).

5.3.2 Individual versus combined agricultural residue applications

In the following subsections, the expected average effects of individual treatments will be compared to the effectively measured effects of combined organic residue applications after the incubation experiment for each soil type and parameter (procedure see subsection 4.4.2). This comparison may give an indication if single or combined treatments are more effectively changing the studied soil functions.

5.3.2.1 pH

As discussed in subsection 5.3.1.1, pH generally increases for the black soil and Anthroposol, and it declines for the red soil when OM is applied (Figure 50). The question remains whether the expected average effect of two individual treatments on the pH is lower or higher than the corresponding treatment that effectively combines these two individual treatments (Figure 54, next page).

The results are surprisingly different for each soil type. Whereas for the **black soil**, the average effect of biochar B1 and either compost (C1) or vermicompost (VC1 and VC2) are higher or identical to the measured combined effect of the treatments, exactly the opposite happens with biochar B2 and the (vermi)composts, where the measured effective changes in pH of a combined application are higher than the average effect of single treatments (Figure 54a).

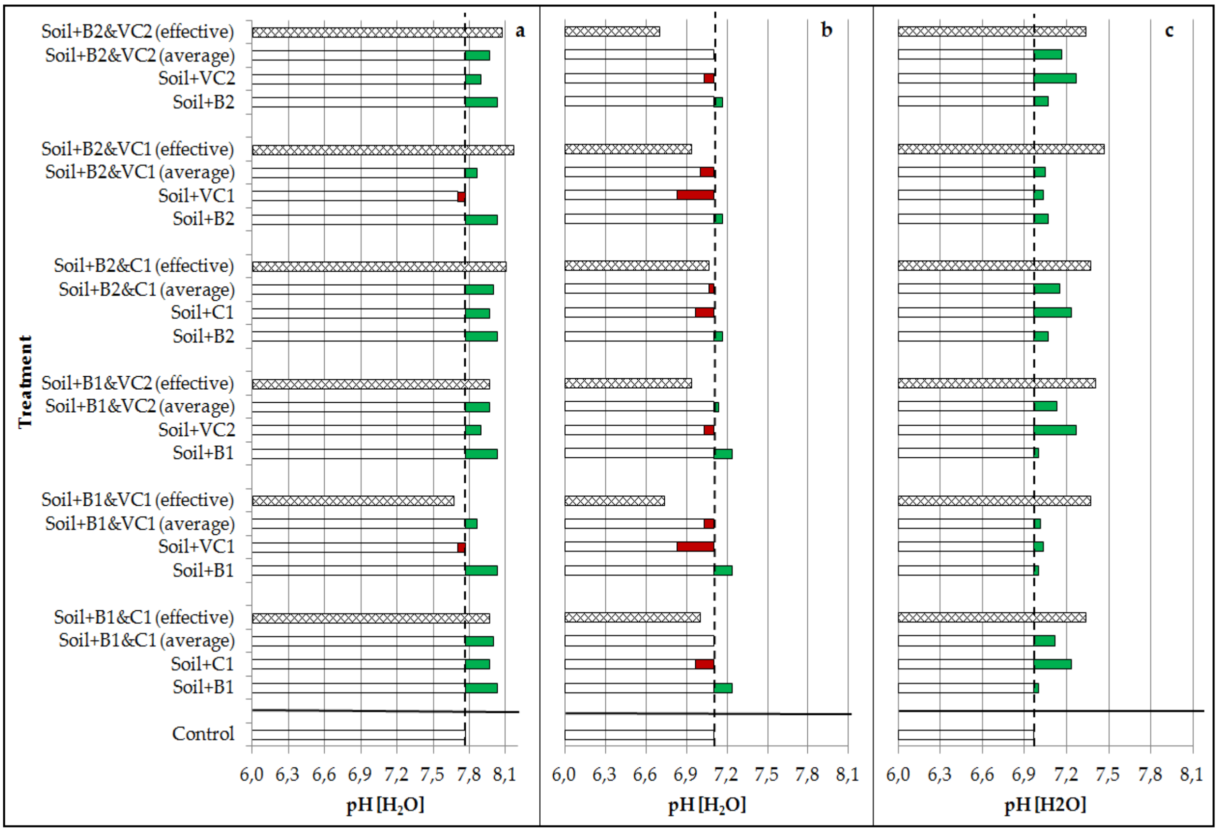

Figure 54: Expected positive (green bars) and negative (red bars) average changes of pH due to combined residue application in comparison to effectively measured changes in pH due to these treatments (dashed bars) for **a) black soil**, **b) red soil** and **c) Anthroposol**. Dotted black lines indicate pH level of the control soil.

Consequently, it would make more sense to apply biochar B2 together with (vermi)compost (B2&C1, B2&VC1 and B2&VC2) instead of applying either B2 or C1, VC1 resp. VC2 alone (Figure 54a). However, only the difference to the sole application of VC1 is significant (Figure 50). In contrast, applying biochar B1 alone is more effective than its combination with C1 (not significantly) resp. VC1 (significantly) or VC2 (not significantly), since the combination of e.g. B1&VC1 shows an even lower pH than the control soil (Figure 54a).

In case of the **red soil**, all expected average changes of pH compared to the control soil, when single treatments are combined, are higher than the measured changes in pH due to the combination of treatments (Figure 54b). This can clearly be spotted in Figure 54b, since the dashed bars (effective pH of combined treatments) are always smaller than the coloured (white) bars (average pH change of application of two individual treatments on the red soil) and the dotted black line (control soil). In comparison to the combined treatments, it would always be better to apply biochar alone, and this suggestion is significant for B1 compared to B1&VC1 and B1&VC2, and for B2 compared to B2&VC2.

In case of B2&VC2, it would also be significantly better to apply VC2 alone even if it reduces the pH to the control soil slightly, yet not significantly.

For the **Anthroposol**, the theoretically calculated average changes in pH of all combinations of individual treatments underestimate the effective changes in pH due to the combined application of the treatments (Figure 54c). This implies that the combined treatments have a higher positive effect on the pH of the control soil compared to single treatments, even though all sole treatments increase the pH of the control soil.

5.3.2.2 Water holding capacity

Strikingly, almost all single treatments (except biochar B1 for the red soil) lead to a drop of WHC compared to the control soils and subsequently expected average effects of combining individual treatments also show negative changes compared to the control soils (Figure 55). However, there are some combined treatments where in effect a positive change of WHC compared to single treatments and the control soils could be identified.

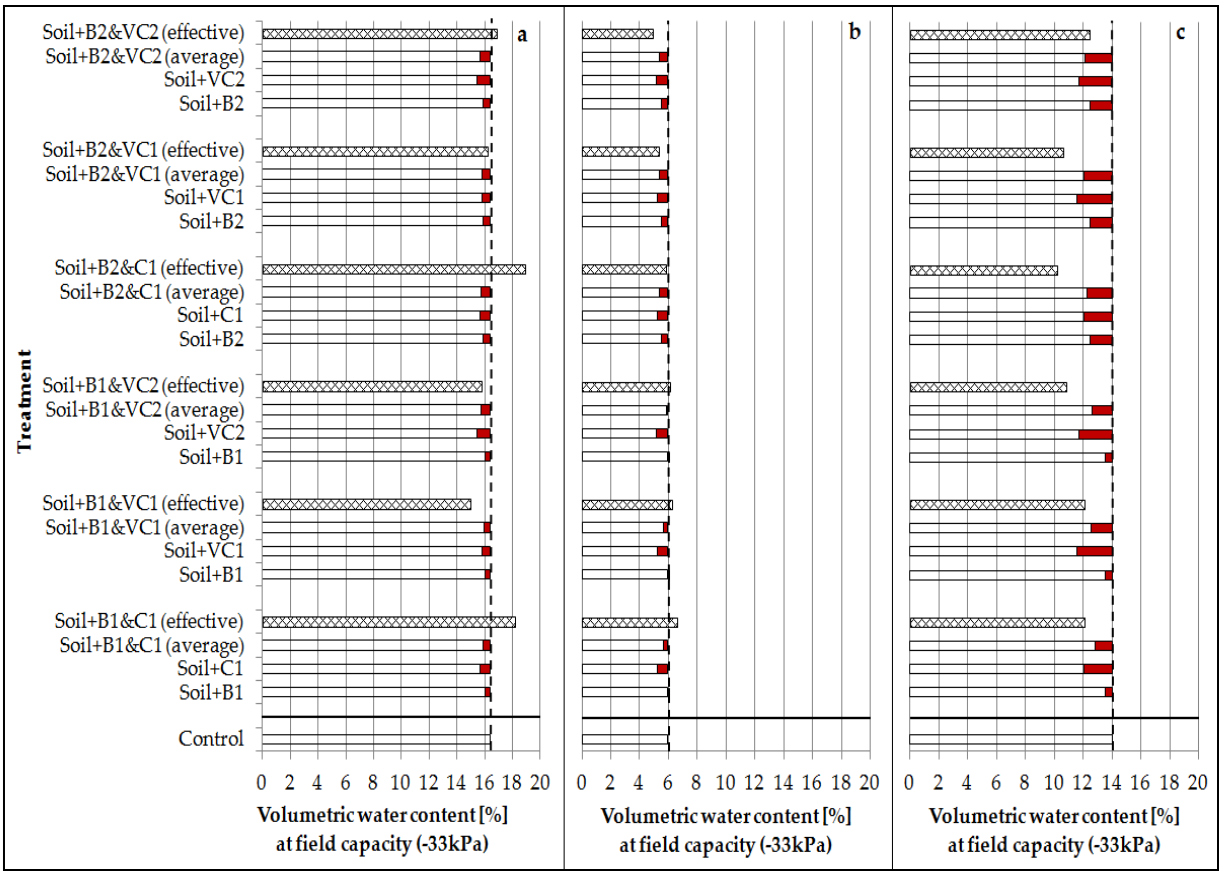

Figure 55: Expected positive (green bars) and negative (red bars) average changes of WHC due to combined residue application in comparison to effectively measured changes in WHC due to these treatments (dashed bars) for a) black soil, b) red soil and c) Anthroposol. Dotted black lines indicate WHC level of the control soil.

Figure 55a indicates that the combined treatments B1&C1, B2&C1, B2&VC1 and B2&VC2 lead to a higher WHC of the **black soil** than the average of the corresponding individual treatments, and that the treatments B1&C1, B2&C1 and B2&VC2 also show a higher WHC in comparison to the control soil. The effect of the combination of coconut shell biochar and compost (B1&C1) is furthermore significantly different from the sole compost, but not from sole biochar application (Figure 51). For B2&C1, the combination is significantly different when compared to both single treatments and therefore should be preferred. Combining rice husk biochar and vermicompost VC2 cannot be seen as significantly better than sole application. In case of the other combined treatments B1&VC1 and B1&VC2, the theoretical average WHC of the combinations of individual treatments is higher (not significantly), and therefore biochar B1 or vermicompost VC1 are better applied alone (Figure 55a).

Application of biochar B1 in combination with either compost (C1) or vermicompost (VC1, VC2) leads to a higher WHC compared to the control **red soil**, and these treatments show an even higher WHC compared to the expected average WHC of the corresponding individual treatments (Figure 55b). For B1&C1, the combination is significantly differing from the individual substrates (Figure 51). The combinations B1&VC1 and B1&VC2 are significantly different to the corresponding sole vermicompost treatments, but not to biochar B1 (Figure 51). Treatment B2&C1 performs better than its corresponding single treatments, but leads to a lower WHC compared to the control soil. For B2&VC1 and B2&VC2, the effective WHC of the combinations is lower than the expected average WHC of the individual treatments, and therefore applying biochar or vermicompost alone (except for VC1), would be better.

For the **Anthroposol** (Figure 55c), the expected average WHC of almost all combinations of single treatments (except the combination B2 with VC2) is higher than the effectively measured WHC of the corresponding combined treatments, and therefore sole application of treatments is mostly more viable. However, no OM application shows positive effects compared to the control soil.

For improving the WHC of the studied soils, it is therefore always better to use combined applications of biochar and (vermi)compost rather than individual treatments (discussion see subsection 5.3.1.2).

5.3.2.3 TC content

It is straightforward that all measured combinations of substrates for all three soil types increase the TC content in comparison to the corresponding control soils (Figure 56, next page). However, in some cases, the corresponding individual treatments could be a preferable alternative to the combined applications (even if not statistically significant due to large variations in the data). The three (vermi)compost treatments have, when applied alone, only very miniscule effects on the TC content of the three studied soils (explanation see subsection 5.3.1.3) and in case of the Anthroposol, vermicompost VC2 results even in a negative feedback. That the application of rice husk biochar B2 to the black soil leads to a drop of its TC content has also been explained previously (see subsection 5.3.1.3).

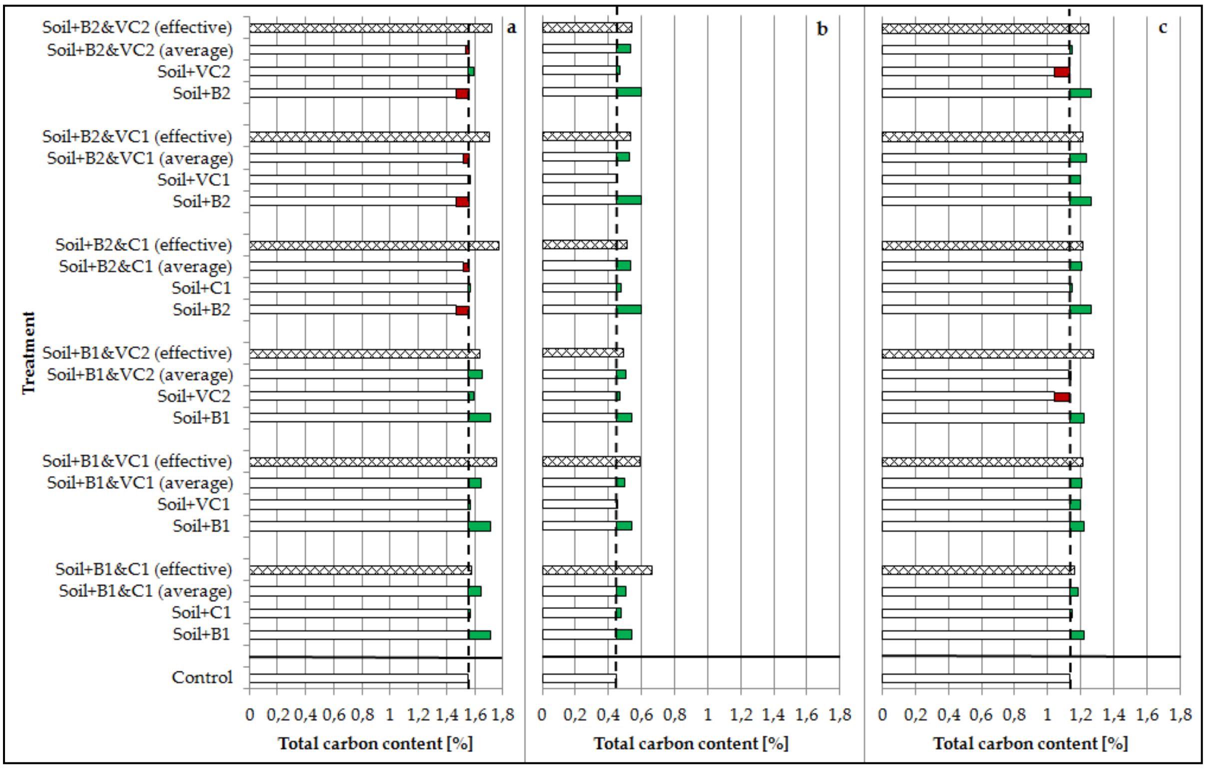

Figure 56: Expected positive (green bars) and negative (red bars) average changes of TC content due to combined residue application in comparison to effectively measured changes in TC content due to these treatments (dashed bars) for a) **black soil**, b) **red soil** and c) **Anthroposol**. Dotted black lines indicate TC content level of the control soil.

In case of the **black soil** (Figure 56a), it may be more viable to apply coconut biochar B1 alone instead of combining it with (vermi)compost, but also the combined applications lead to an acceptable result.

For the **red soil** and in case of rice husk biochar (B2), it would make more sense to apply it alone if the only goal of the OM application is to maximally increase the SOM level of the control red soil (Figure 56b). In case of coconut shell biochar (B1), it can either be applied alone or in combination.

Figure 56c shows that sole application of both biochar types results in higher TC contents of the **Anthroposol** than when combining it with other substrates (except for the combination of coconut shell biochar and vermicompost VC2), and therefore these could be preferably chosen as an OM input.

5.3.2.4 Microbial activity and diversity

As introduced in subsections 4.3.4.5 and 4.4.3, the results of the enzymatic test for the determination of microbial activity/diversity (api®ZYM) were only recorded, but have not been further processed (e.g. into a Shannon diversity index (H')) and will therefore only be assessed briefly on a qualitative basis.

Generally it can be said that the enzymatic test was successfully implemented on the basis of the manufactures' manual and the procedure described in Martinez *et al.* (2016). This is supported by the discovery of strong enzymatic activities in the compost (C1) and vermicompost (VC1, VC2) treatments (Figure 57c-e, next page), and even intensity differences are visible (light vs. more intense violet).

Strong reactions for the enzymes 2 (alkaline phosphatase), 3 (esterase C4), 4 (esterase lipase C8), 6 (leucine arylamidase), 7 (valine arylamidase), 11 (acid phosphatase), 12 (naphthol-AS-BI-phosphohydrolase), 17 (β-glucosidase) and 18 (N-acetyl-β-glucosaminidase) can be clearly observed.

However, it was not possible to run the test for the two biochar types (Figure 57a-b) since it is rather challenging to separate biochar particles (very low density) from water. This evidently explains the strong black colour in Figure 57b, which is not a reaction caused by the enzymatic test.

Figure 57: Results of the enzymatic test (api®ZYM) for a) biochar B1, b) biochar B2, c) compost C1, d) vermicompost VC1 and e) vermicompost VC2.

From this, it could be expected that the application of the compost and vermicompost treatments, showing a relatively high enzymatic activity, to the three studied soils, would change the microbial activity and functional diversity as compared to the control soils.

As visualised in Figure 58, the differences in enzymatic activity for the control black soil (Figure 58a) and black soils treated with compost C1 (Figure 58b), vermicompost VC2 (Figure 58c) or biochar and compost B2&C1 (Figure 58d) are all infinitesimal. For example, when comparing the activity of enzyme Nr. 12 (Figure 58, black rectangle) between the control soil (Figure 58a) and the amended soils (Figure 58b-d), no clear difference can be observed.

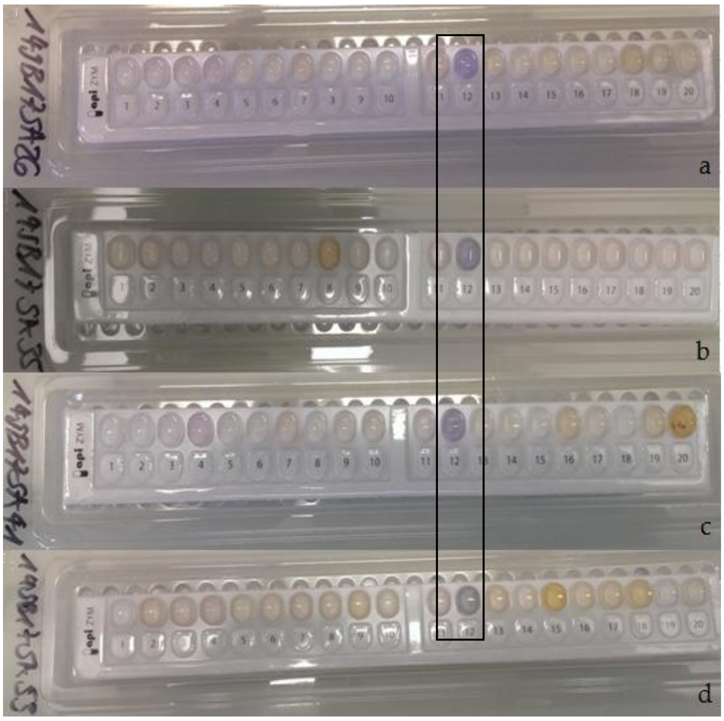

Figure 58: Results of the enzymatic test (api®ZYM) for a) the control black soil and selected organic treatments (b = compost C1, c = vermicompost VC2 and d = biochar and compost B2&C1). The black rectangle encloses en exemplary enzyme (Nr. 12).

It would be mistaken, however, to equate the small differences with an interpretation that no differences in enzymatic activities exist. In Figure 58 one can for example see that the activity of enzyme 4 is slightly higher for the vermicompost VC2 treatment (Figure 58c) when compared to the control soil (Figure 58a).

Assessments of enzymatic activities for soil studies using the api®ZYM kit have only been conducted recently, yet successfully (e.g. Boluda *et al.* 2014; Martinez *et al.* 2016). Furthermore, Trupiano *et al.* (2017) demonstrate that the api®ZYM test can be successfully applied to identify differences in enzymatic activities for soils amended with biochar, compost or a combination of those, and that depending on the studied enzymes, different treatments enhance the activity of soil microbes in different magnitudes (Trupiano *et al.* 2017).

5.3.3 Soil quality index - comparing the aggregated (relative) effects of individual organic residue applications on soils

The idea behind summarising the relative effects of organic treatments on selected agro-ecological parameters for each soil in a radar graph is to come up with a visual assessment showing which treatments performed best overall and for each soil type.

Relative changes of four soil parameters induced through the application of sole or combined organic treatments compared to the corresponding control **black soil** are summarised in Figure 59. At a first glance, it is evident that the combined treatments generally perform better than any sole application of either biochar, and especially compost or vermicompost. Also, it is clearly visible that depending on the soil parameter to be improved, some treatments perform better than others.

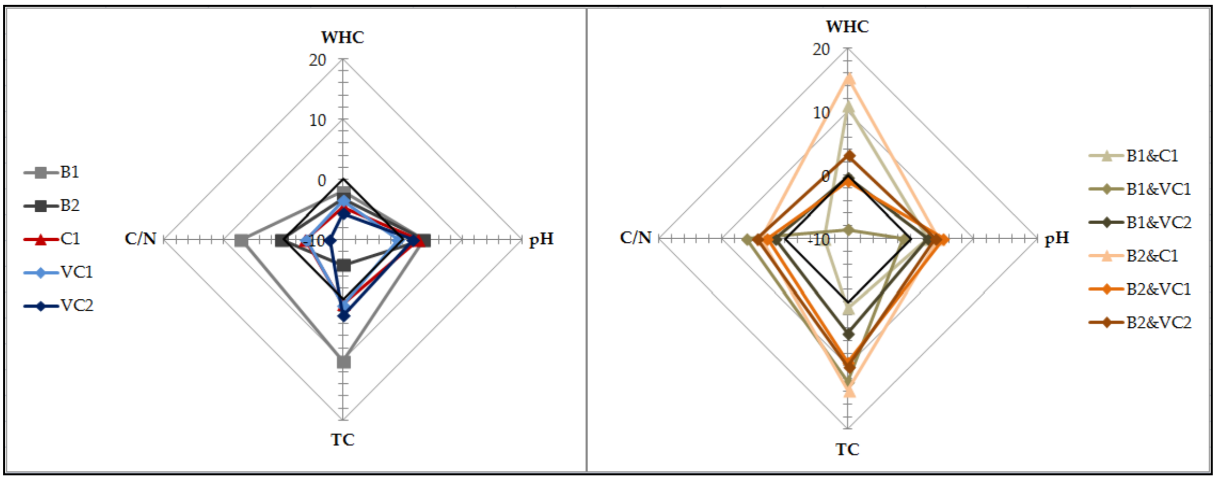

Figure 59: Relative changes (in % to control soil) of four parameters (WHC, pH, TC, C/N) for the black soil due to sole application (left) and combined applications (right) of OM. The solid black line indicates level zero.

When all parameters are assessed, the combination of **coconut shell biochar and compost (B1&C1) and rice husk biochar and compost (B2&C1)** most efficiently increase soil quality of the black soil, whereby the former increases WHC (+11%) and at the same time reduces the C/N ratio (-6%). If water is the major criteria, only three treatments are a possibility (B1&C1, B2&C1, B2&VC2), and B2&C1 shows the highest relative increase (+15%). For improving major nutrient cycles (i.e. reducing the C/N ratio), four treatments are possibly of interest (C1, VC1, VC2, B1&C1), but as stated in subsection 5.3.1.4, an increase in C/N is not simply a negative effect and therefore other treatments may also be possible. VC2 leads to the strongest decrease in the C/N ratio (-7.8%). For both parameters pH and TC, almost all treatments lead to an increase compared to the control soil (except VC1 and B1&VC1 for pH), and the relative changes mostly account for less than 10%.

In case of the **red soil**, it is expected that the application of OM has a majorly positive impact on soil properties. As it is clearly visible in Figure 60, this holds true in a positive way for TC and C/N, and on the contrary in a (mostly) negative way for WHC and pH. Surprisingly, almost all treatments somehow show the same overall pattern, only with different magnitudes (and a few expectations). While for the combined treatments, the combination of coconut shell biochar (B1) with (vermi)composts seems to be more effective than combinations of rice husk biochar (B2) with the (vermi)composts, one can clearly see that both biochars (B1 and B2) are performing better than (vermi)compost when only sole treatments are applied.

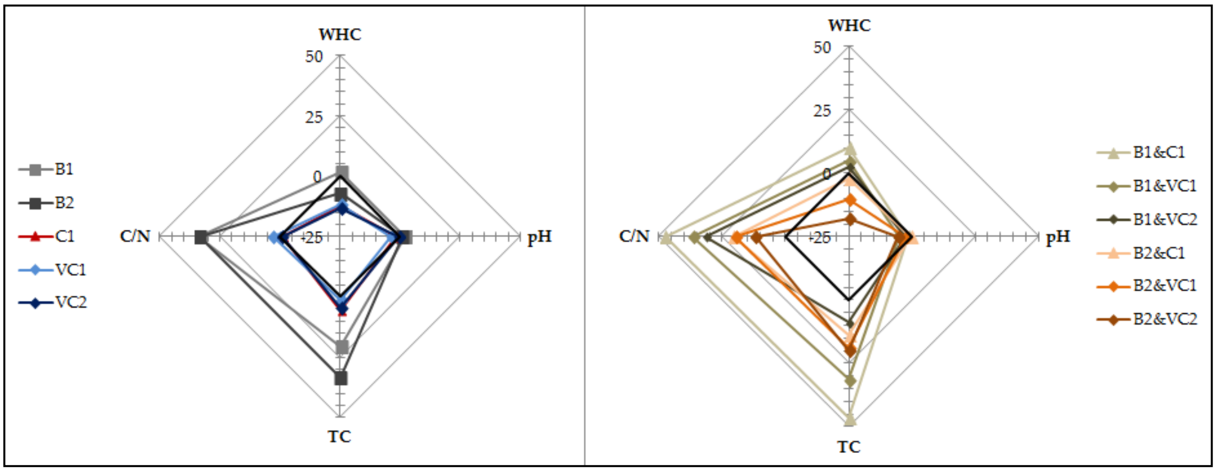

Figure 60: Relative changes (in % to control soil) of four parameters (WHC, pH, TC, C/N) for the red soil due to sole application (left) and combined applications (right) of OM. The solid black line indicates level zero.

For improving the water status of the red soil, treatments including coconut shell biochar (B1, B1&C1, B1&VC1 and B1&VC2) represent the best option (+10% with B1&C1), whereas for pH only the two biochar (B1 and B2) relatively improve the corresponding level of the control soil (but only max. +2%).

For improving the TC content of the control red soil, most combined treatments, especially coconut shell biochar and compost (B1&C1), work as well as applying biochar (B1 and B2) alone (between +8.8 to +46.7%). The same holds true for the C/N ratio, if the goal is its increase. If the C/N ratio should be reduced, sole applications of N-rich OM like compost and vermicompost (VC2) are a better option (Figure 60), but the relative decrease compared to the control soil accounts for less than 1%. Since water is a major, if not the most fundamental, criteria, overall **biochar B1 or its combination with compost (B1&C1)** may be the best solution for an agricultural residue practise for the red soil.

Figure 61 depicts the relative changes of the studied soil parameters compared to an untreated **Anthroposol.** Similar to the red soil discussed above, all treatments somehow follow a comparable pattern for all four parameters, only with varying extent. In this case however, it is very difficult to pick out any treatment that is superior to any other since for example all treatments decrease the WHC compared to the control soil, in some cases up to almost -30% (B2&C1). All treatments enhance the pH compared to the control (+7.2% at most), and all combined treatments lead to a higher relative increase than single treatments, but the differences are rather small.

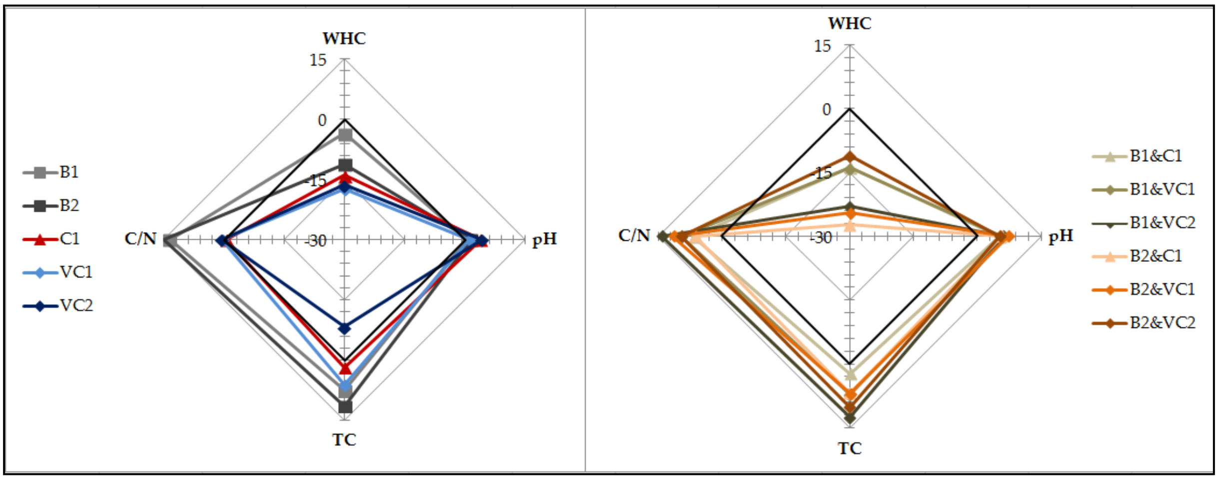

Figure 61: Relative changes (in % to control soil) of four parameters (WHC, pH, TC, C/N) for the Anthroposol due to sole application (left) and combined applications (right) of OM. The solid black line indicates level zero.

For the Anthroposol, only the compost treatment (C1) decreases the C/N ratio (-0.5%), whereas all other treatments lead to a higher C/N ratio (but for the two vermicompost, the increase is insignificant). Applying vermicompost VC2 alone decreases the TC content, while in combination with both biochar types, it increases it the most by up to +12.5% (Figure 61).

Finally, zooming out and evaluating the effects of agricultural residue applications on the three soil types based on the insights from section 5.3, the following (surprising) conclusions can be drawn:

- In contrast to the expectation that the red soil with the poorest soil quality (i.e. lowest WHC, TC) would show the strongest positive reactions to OM application, it is the black soil which generally profits more from OM application, except if the enhancement of the SOM level (TC content) is assessed alone. In case of relative changes of TC content hence, the red soil shows the highest positive changes of the three soils.
- Depending on the soil parameter(s) to be improved, different agricultural residue applications perform better than others, which makes it difficult to designate one superior OM input for one specific soil type or even in general. However, the combination of biochar (coconut shell) and compost may be the generally most suitable treatment identified in this study.

5.4 Interdisciplinary evaluation of opportunities for organic residue applications

Coming back to the findings of the discussions with farmers (see subsection 5.2.3 and 5.2.4), three fundamental agro-ecological changes upon the introduction of agricultural residue applications (either compost, vermicompost, biochar or any combination of those) are emphasised by farmers:

1. Improvement in water status of the studied soils
2. Improvement in nutrient status of soils and nutrient availability for plant growth
3. Improvement in soil fertility on a general basis

To assess whether these qualitative expectations of farmers can be addressed through the studied OM applications, the expectations 1 to 3 are compared to the following measured soil parameters (relative changes of corresponding soil parameter to control soil, for classification see section 8.7):

1. Water-holding capacity (WHC)
2. Carbon to nitrogen ratio (C/N)
3. Soil organic matter content and acidity (TC and pH)

The result of the interdisciplinary assessment is summarised in Table 14 (next page). Surprisingly, even if water has been a (the) central topic in discussion with farmers during fieldwork, it is not designated as the major criteria by many farmers during the interviews itself (less than 50% of farmers). However, it is believed that water is of great importance and therefore it may be the most difficult criteria to address with OM applications in the Berambadi watershed, especially so for the Anthroposol (only negatively rated responses to OM applications). For the black and red soil, at least some of the combinations of biochar and (vermi)compost are rated positively and may therefore help to improve the water status of the corresponding soils (Table 14, next page).

Finding agricultural residue applications that improve nutrient availability and general soil fertility is on the other side, at least following the approach and findings of the present study, a bit easier since all soils show either positive or even very positive responses to some of the OM applications (Table 14, next page). However, how exactly soils and, more importantly, plants will react to changes in SOM content and soil pH needs to be evaluated in more detailed, long-term field studies (i.e. a decrease in C/N ratio does not directly lead to an increase in nutrient availability and subsequently in crop yield).

Finally, it is again worth emphasising that a suitable agricultural residue application depends on many factors, including the environmental (climate, soil) and socio-economic (agricultural practises, crops, etc.) context it is applied in, as well as the soil function intended to be improved (Figure 59-61).

Table 14: Comparison of rated farmers' importance and soil response to effects of OM applications on the studied soil functions (++ = very important resp. improved, + = important resp. improved, ± = indifferent resp. no effect, - = unimportant resp. deteriorated, -- = very unimportant resp. deteriorated). For classification, see section 8.7.

	Farmers importance	Criteria	Soil response to OM	
Black soil	+	**Water status (WHC)**	Biochar (B1 / B2):	- / -
			Compost (C1):	-
			Vermicompost (VC1 / VC2):	- / -
			Biochar + Compost (B1&C1 / B2&C1):	++ / ++
			Biochar + Vermicompost (B1&VC / B2&VC):	- / +
	++	**Nutrients (C/N)**	Biochar (B1 / B2):	± / +
			Compost (C1):	+
			Vermicompost (VC1 / VC2):	+/ ++
			Biochar + Compost (B1&C1 / B2&C1):	++ / +
			Biochar + Vermicompost (B1&VC / B2&VC):	+ / +
	++	**Soil fertility (TC & pH)**	Biochar (B1 / B2):	++ / ±*
			Compost (C1):	+
			Vermicompost (VC1 / VC2):	± / +
			Biochar + Compost (B1&C1 / B2&C1):	+ / ++
			Biochar + Vermicompost (B1&VC / B2&VC):	+ / ++
Red soil	+	**Water status (WHC)**	Biochar (B1 / B2):	+ / -
			Compost (C1):	--
			Vermicompost (VC1 / VC2):	-- / --
			Biochar + Compost (B1&C1 / B2&C1):	++ / -
			Biochar + Vermicompost (B1&VC / B2&VC):	+ / --
	++	**Nutrients (C/N)**	Biochar (B1 / B2):	± / ±
			Compost (C1):	+
			Vermicompost (VC1 / VC2):	+ / +
			Biochar + Compost (B1&C1 / B2&C1):	± / ±
			Biochar + Vermicompost (B1&VC / B2&VC):	± / ±
	++	**Soil fertility (TC & pH)**	Biochar (B1 / B2):	++ / ++
			Compost (C1):	±
			Vermicompost (VC1 / VC2):	± / ±
			Biochar + Compost (B1&C1 / B2&C1):	± / ±
			Biochar + Vermicompost (B1&VC / B2&VC):	± / ±
Anthroposol	±	**Water status (WHC)**	Biochar (B1 / B2):	- / --
			Compost (C1):	--
			Vermicompost (VC1 / VC2):	-- / --
			Biochar + Compost (B1&C1 / B2&C1):	-- / --
			Biochar + Vermicompost (B1&VC / B2&VC):	-- / --
	+	**Nutrients (C/N)**	Biochar (B1 / B2):	± / ±
			Compost (C1):	+
			Vermicompost (VC1 / VC2):	+ / +
			Biochar + Compost (B1&C1 / B2&C1):	± / ±
			Biochar + Vermicompost (B1&VC / B2&VC):	± / ±
	++	**Soil fertility (TC & pH)**	Biochar (B1 / B2):	+ / ++
			Compost (C1):	+
			Vermicompost (VC1 / VC2):	+ / ±
			Biochar + Compost (B1&C1 / B2&C1):	+ / ++
			Biochar + Vermicompost (B1&VC / B2&VC):	++ / ++

6. Conclusion

6.1 Concluding remarks

The present project clearly highlights the complexity of identifying tailor-made agricultural residue applications for any farming system, when evaluated from both a socio-economic and an agro-ecological point of view.

On the one side, farmers in the research area possess specific knowledge and perceptions about the usage and benefits of applying organic residues to the soil. These residues have traditionally been used for many domestic and agricultural purposes, which will greatly influence the acceptance and successful implementation of technologies like vermicompost or biochar. Furthermore, many of the farmers can designate clear expectations and doubts about the introduction of recent innovations like the mentioned. That most farmers, irrespective of their farming system (farm size, soil type, irrigation type, etc.), show high interest in vermicompost and biochar and that they can designate desired effects of their application to the plant-soil system (i.e. increase in soil fertility (mainly water and nutrient status) and increase in plant growth), provides scope for successive in-depth field studies where the identified effects of agricultural residue applications found in the laboratory could be further evaluated directly in farmers' fields.

On the other side, however, the soil incubation experiment reveals that it is a very difficult task to improve soil quality as a whole through simply applying any of the soil amendments. Each organic residue application (alone or combined) induces specific changes to individual soil properties for each soil, and summarising the effects of one treatment on all soil properties (and furthermore to all soils) does not generally lead to the identification of one treatment outmatching all others. It is evident that improvements in soil properties through the application of OM depend on many factors, including climatic conditions, initial soil type, applied OM (i.e. C/N ratio, chemical composition), application rate and also agricultural practises. That the present project implements a «realistic» approach towards the application rate of OM (meaning that a rate which farmers actually apply in the research area has been chosen and OM that is actually produced in the field has been selected), may have led to low changes and strong variations in the results. However, the dataset of this project indicates that soil amendments combining biochar and (vermi)compost generally perform better than treatments without biochar, which of course creates space for improvements of traditional agricultural residue practises of farmers in the Berambadi watershed since presently mostly sole application of compost (or chemical fertilisers) is practised.

On this basis, organic residue application systems, especially those including biochar, need to be developed together with farmers for the specific context within which it shall be applied, and with field studies to directly assess the effects on social and natural systems on a in the long term. This again calls forth more interdisciplinary, long-term field studies in which agricultural residues are evaluated within a holistic approach, addressing socio-economic and agronomic questions (Jouquet *et al.* 2010; Joseph *et al.* 2015).

> *«So it's the same for the substrates. Some of them are more interesting in some environments and absolutely not in others. It depends on the function you're looking for [...].»*

6.2 Critical reflection of research design, fieldwork and applied methods

Since it was the first time for the author to plan and conduct a scientific project of this scope, some final considerations about the feasibility of the research design and about the usefulness of the applied methods shall be noted.

Concerning the research design, it can be concluded that the defined research questions and goals could be addressed in the time frame of the project and based on the selected methods of data collection and analysis. However, during the entire project, many tasks needed to be reorganised and adjusted in order to be able to move on to the following tasks. Fieldwork, for example, had not only been stopped after the research area was broadly covered, but also due to various challenges regarding accommodation, financial issues and others. The initial plan of conducting the incubation experiment at IFCWS in Bangalore had also to be dismissed since the author had not been familiar with the methodology and since the time frame for measurements had been too short. Only then the decision was made to bring the samples to Switzerland and to conduct the experiment at the University of Zurich.

The time spent on conducting expert interviews was rather long in comparison to the information that could be gained out of it. A substantial part of empirical data from the expert interviews refers to more or less known information about farming in Karnataka, which can be traced back to inadequate questions in the topic guide (resp. the questions were too general) and is of course not attributable to the experts' answers. Adjustments to the topic guide were made after the pre-test and the first set of interviews, and subsequently more information directly related to the research questions could be collected. Meeting experts still helped to get along in the research area, to gather helpful information and to plan fieldwork to a great extent.

Conducting in-depth interviews with farmers turned out to be a challenging, but effective tool to grasp their social reality and information related to the research goal. Challenges included the right choice of where the interview takes place, the regulation of the interviews, translation and other present people, asking conceptual questions about new technologies and the gathering of too much contextual information not directly related to the research question. These challenges were more or less offset by the space that an in-depth interview leaves for the interviewee to freely talk, and by the structure, enabled by the topic guide, in order to cover relevant aspects of the research.

Using GT as a methodological framework was viable in many aspects, but not in all of them. While the flexible, iterative logic of it proved to be very helpful during the collection of data, the simultaneous conduction of data collection and analysis could not be fully achieved. Collected empirical data had not been continuously coded during fieldwork due to time constraints, and it was only analysed by listening to the records. On this basis, a different qualitative methodology like qualitative content analysis according to Mayring could have been an alternative since it features a more linear progression (Mayring 2014).

Coding and categorising under GT was helpful to conceptualise and reduce the amount of empirical material into structured, condensed findings, but since this was performed only by the author himself (and not as per usual in groups) it could also have led to misunderstandings and misinterpretations of interview data. Coding was not as open as desired, and had been influenced by the author's knowledge gained during fieldwork.

Finally, it is worth **reflecting on the benefits and constraints of the interdisciplinary project** at hand. On the one side, the conduction of interdisciplinary work reveals some challenges. It is evident that conforming to two diverging scientific disciplines and both of their quality criteria goes hand in hand with a reduction of the complexity of individual parts of a project and therefore might cause loss of nuanced information. In this master project, for example, the sample size of farmers was limited to 30 and the incubation to only measure some basic parameters that can be used to give a general indication of the feasibility of individual treatments, but detailed analysis of e.g. soil dynamics could not be addressed. It provides scope for discussion whether this fact should be deemed a weakness or whether it is actually part of the research goal to remain on a broader scientific basis.

On the other side, the project underlines the need for more interdisciplinary work, especially in fields like agriculture. For innovative scientific technologies, as for example biochar, to penetrate to the grassroots level, there is not only a need for a clear understanding of its effects on the environment, but also of how these technologies are perceived by farmer communities and what their needs are, which in turn puts forward a combination of quantitative methods of natural science and qualitative methods of social science. Since many research projects focus on either one of the two aspects, more scientific studies have to take up on an interdisciplinary focus in the near future (Barrow 2012; Joseph *et al.* 2015). It is evident that such an approach involves multiple interests from the side of the researcher, multiple skills in scientific methodology and a high workload, but the additional benefit of understanding a holistic system cannot be denied.

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8. Annexe

8.1 Topic guide - expert interviews

Topic guide for expert interviews

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1. Introduction

Meet up with interviewee, get seated and create a relaxed atmosphere through initial exchange. Thank the interviewee for his/her interest in the project and for taking time for the interview.

2. Presentation of master project topic

Before starting the interview, a short introduction of the interviewer and of the topic and the aim of the master thesis will be given.

- Master student of Geography of the University of Zurich conducting his thesis
- Interest in innovative and sustainable small-scale farming applications
- Master thesis looks at knowledge-based practises of agricultural residue management and the perception of residues as an agronomic resource by farmers
- Comparison of various agricultural residue management applications identified by a literature review (compost, vermicompost, biochar) with both qualitative and quantitative inquiry

Furthermore, a short introduction to the procedure of the interview and its goal will be highlighted.

- Interview divided in thematic blocs (agrarian situation, farming, agricultural residue management, environmental condition)
- Overview over agrarian situation in Karnataka

Thereafter, the interviewee is asked to pose any question regarding the purpose or procedure of the interview or the research(er).

3. Agreement

Emphasise that the information gathered in the interview will be treated objectively and anonymous, so that no information is retraceable to any interviewee.

Subsequently, ask for permission of recording the interview with a voice recorder or digital device (and if necessary explain the intention of recording).

4. Interviewee's profile

Gender ______________

Age _________________

Education ____

____

Relation to agriculture ____

____

Motivation for participation ____

____

____

5. Interview specification

Interview Nr. _________

Interviewer _________

Date ______________

Duration __________

Interview situation (interaction, relationship, difficult situations, etc.) ________________________

____

____

____

____

6. Topic guide

Main question(s)	Check-list for additional/detailed information - only ask if not mentioned Memos - questions can be phrased according to situation	Follow-up and Probes

Part I - Agriculture in Karnataka		
What is the importance of agriculture in Karnataka (and India)?	• Economic perspective (workforce, rural employment, etc.) • Social perspective (for society or farmers) • **Current Problems and Solutions**	• Is there anything to add from a ... perspective? • Could you please specify this? • What do you mean by that? • Is there anything more to tell about...? • What is your opinion on this topic? • What would be the best solution for this...?
How does agricultural production looks like in the state of Karnataka?	• Agricultural inputs (fertiliser, machinery, small-scale applications) • Geographical distribution (agro-ecological zones, climate)	
Part II - Farming / Farmers (focus on farming practises in general)		
How does farming look like? What do farmers do in general?	• Traditional, knowledge-based and small-scale farming practises • Practises for soil cultivation / land management and soil fertilisation	• Can you tell me a bit more about ... practises? • How did it come to it?

Part III - Agricultural residue management		
How do farmers use plant material or animal excreta (residues) on their farms?	• Usage versus non-usage (reasons for not using it) • Traditional versus new technologies • Compost (input material, method of composting, suitability for local context) • Vermicomposting (awareness of method, production) • Biochar applications (existence, pros & cons, material)	• According to your expertise, what is the best management practise? • Why do you favour a certain management practise (reasons)? • Can you tell me more about this method? • Can you explain that to me in more detail? • How did it come to it?
What do farmers think about these organic materials / residues?	• Various point of views (waste, resource) • Usage (heating, animal fodder, for fields) • Importance for their livelihood	
What are suitable farming practises when it comes to agricultural residue management?	• Under various environmental and socio-economic contexts (e.g. knowledge, soil fertility) • Sustainability of management practises (application rate, impact, duration of effects) • Openness to new technologies (expectations, fears, education)	
Part IV - Environmental context of agriculture		
What impact does the local climate have upon agriculture in the different agro-ecological zones?	• Adaption of agricultural practises • Suitable farming practises to manage organic material •	• What method is most useful according to your opinion / expertise? • Why?
What impact do various levels of soil fertility have upon agriculture?	• Adaption of agricultural practises of soil cultivation/amendment • Agricultural residue management practise for soil amendment	
Part V - Conclusion		
Is there anything important you would like to add?	• Check list	• Anything else to add? • Did you miss key dimensions?

7. Note

This final topic guide slightly deviates from the first draft due to changes during data collection. The major changes were done after the pre-test, minor changes or rephrasing of questions after individual interviews if necessary. The content addressed by question however was kept.

8.2 Topic guide - farmer interviews

Topic guide for farmer interviews

1. Introduction

Meet up with interviewee, get seated and create a relaxed atmosphere through initial exchange. Get introduced through the translator. Thank the interviewee for his/her interest in the project and for taking time for the interview.

2. Presentation of master project topic

Before starting the interview, a short introduction of the interviewer and of the topic and the aim of the master thesis will be given.

- Student of Geography of the University of Zurich conducting his master thesis
- Interest in innovative and sustainable small-scale farming applications
- Master thesis looks at knowledge-based practises of agricultural residue management and the perception of residues as a socio-economic resource by farmers within agriculture
- Comparison of various agricultural residue management applications identified by a literature review (compost, vermicompost, biochar) with both qualitative and quantitative inquiry

Furthermore, a short introduction to the procedure of the interview and its goal will be highlighted.

- Interview divided in thematic blocs (perception of agriculture, farming, agricultural residue management practises and residues as a resource, openness to new technologies)
- Translator will translate questions and answers after the interviewer/interviewee has finished talking
- Overview over farming practises of interviewed farmers, their perception and practises related to organic material (residues) and openness towards new technologies (vermicomposting and biochar)

Thereafter, the interviewee is asked to pose any question regarding the purpose or procedure of the interview or the research(er).

3. Agreement

Emphasise that the information gathered in the interview will be treated objectively and anonymous, so that no information is retraceable to any interviewee.

Subsequently, ask for permission of recording the interview with a voice recorder or digital device (and if necessary explain the intention of recording).

4. Interviewee's profile

Gender ______________

Age ________________

Profession and education ____

____

Family status ____

Information on farm (size, topography) ____________________________________

____

Information on agricultural production (soil, crop, irrigation) ______________________

____

____

____

____

Motivation for participation ____

____

5. Interview specification

Interview Nr. ________

Interviewer ________

Date ______________

Duration __________

Location of interview (house, field, village, etc.) ______________________________

Interview situation (interaction, relationship, difficult situations, etc.) ________________

____

____

____

____

6. Topic guide

Main question(s) / **Stimulus**	**Check-list for additional/detailed information -** only ask if not mentioned **Memos -** questions can be phrased according to situation	**Specializing questions / explanations**	**Follow-up and Probes**
Concluding question: Is there anything important you want to add to the ... part on ... ?			

Part I - Importance of agriculture			
What are you thinking about practicing farming?	• For yourself (identification), your family or community • For the environment/nature, for tradition and culture • Future of farm	• What is most important for you about farming? • Do you want to change anything on your farm / your farming practises?	• Why is this so? • Can you tell me more about that? • And... ? • How did it came to this?
Is there anything important you want to add to the first part on your vision of agriculture?			

Part II - Farming (focus on agricultural production and practises)			
Crop	• Reason for choice (climate, soil, tradition and knowledge)	• Why do you cultivate this crop on your land?	• Anything else you cultivate? • Can you tell me your decision behind it? • How did it come to this?
	• Inputs in farming (fertiliser, pesticide, machinery)	• Are you using a lot of external inputs?	
		• Would you use organic material instead of external inputs?	• Why is this so? Why not?
	• Productivity per area, yields of crops	• Could you imagine using organic farming practises to increase yields?	• If so, can you explain it to me in more detail?
Can you explain me how you grow the crop XY from the preparation of the land until the harvest?	• Socio-cultural perspective (tradition, knowledge and education)	• Where did you learn this practise?	• Can you explain me how these practises work in more detail? • How did it come to this?
	• Socio-economic perspective (value, feasibility)	• Why do you use this practise (value)?	
	• Environmental perspective (soil quality, crop yields)	• What effects do the farming practises have upon your fields and soils? • What on crop productivity?	• Can you give me examples of effects? • Can you explain me this in more detail?
Practises	• Harvest (method, loss of organic material)	• Do you lose a lot of material during harvest?	• If so, can you explain me why?
Is there anything important you want to add to the second part on your farming / agricultural practises ?			

Part III - Agricultural residues as a resource for sustainable agriculture (focus on usage/management practises of agricultural residues on-farm)			
How do you use plant material and animal excreta (residues)?	• Usage versus non-usage • Farming practises (leaving it on field, animal fodder, composting, burning) • Alternative usage (fuel, construction material, etc.) • Material as a resource	• If you don't use the material, what are you doing with it? • What for? • Do you think organic material is a resource for you?	• Can you give me an example? • Can you explain why you are not using it? • Can you give specific examples of management practises? • How did it come to this?
Do you use the organic material (plants, excreta) for soils? *(specifically looking at applications to soils and for fertilisation of crops)*	• Material (input material, mixture) • Method of preparing organic material (crop residue burning, composting, vermicomposting, etc.) • Reason for practises	• What material do you use for soils? • How do you apply it to soils? • What is the reason behind putting XY to the soil?	• How did it come to this? • Can you explain it to me in more detail?
Do you use cow dung manure or composting? *(as a traditional way of using organic materials on-farm)*	• Material (plants, animal excreta (urine, dung)) • Practises (mixing, decomposition process, application) • Knowledge and education • Experience • Benefits and constraints	• How do you prepare your compost? • Can you show me? • From where did you learn about composting? • Have you done it for long? • Do you see changes after you have applied compost to your fields (soil, plant)?	• Can you explain me in detail how you do it? • What do you do next? • Can you give me an example?
Is there anything important you want to add to the third part on practises of agricultural residue management and application to soils?			

<table>
<tr><th colspan="4">Part IV - New farming technologies (focus on openness towards vermicomposting and biochar applications)</th></tr>
<tr><td colspan="4">Introduction:
Start with asking if they have ever heard of vermicomposting respectively biochar as an agricultural practise.
• If so: Ask for more detail on the story (practises, context) before continuing with the questions below
• If not: Continue with the introduction of the essentials of vermicomposting and biochar (use the laminated pictures to illustrate the technologies)
    ○ Subsequently start with the questions below after the introduction</td></tr>
<tr><td>What do you think about vermicomposting?
Would you use it on your farm?</td><td>General benefits and considerations
• Socio-cultural perspective (knowledge transfer, prestige)
• Socio-economic perspective (crop productivity, returns, expected losses)
• Environmental perspective (soil health, waste management)

(At this point: Name some benefits like education, increase in soil fertility and yield, knowledge transfer, easy application)
• Openness toward technologies (hopes and fears)</td><td>• What benefits do you wish to have from such practises? When would you apply it?

• What are your considerations / doubts?</td><td>• Can you give me an example?
• Can you specify this?
• How did it come to that?</td></tr>
<tr><td>What do you think about biochar?
Would you use it on your farm?</td><td>General benefits and considerations
• Socio-cultural perspective (knowledge transfer, prestige)
• Socio-economic perspective (crop productivity, returns, expected losses)
• Environmental perspective (soil health, waste management)

(At this point: Name some benefits like education, increase in soil fertility and yield, knowledge transfer, easy application)
• Openness towards technologies (hopes and fears)</td><td>• What benefits do you wish to have from such practises?
• When would you apply it?

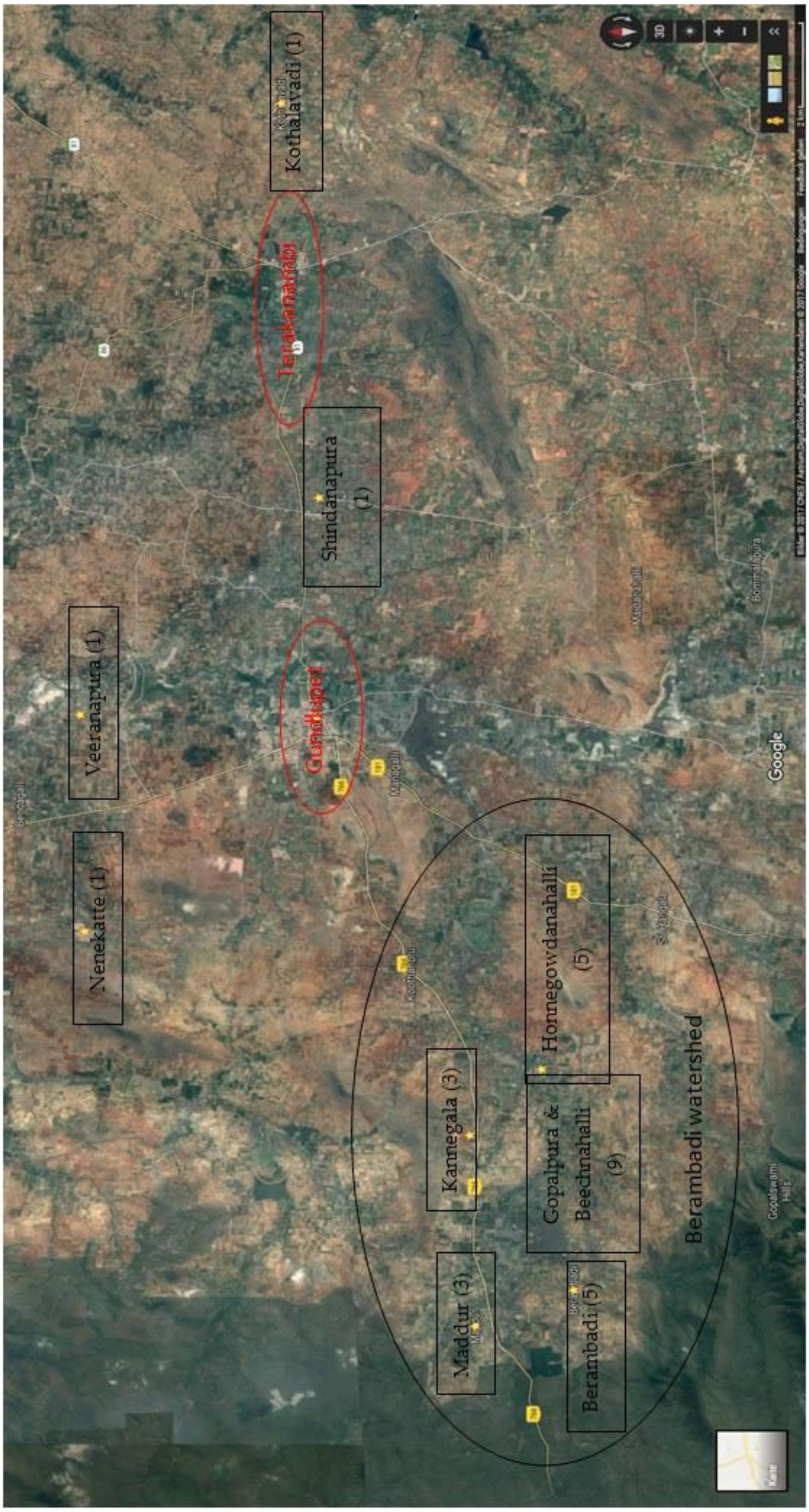
• What are your considerations / doubts?</td><td>• Can you give me an example?
• Can you specify this?</td></tr>
<tr><td colspan="4">Is there anything important you want to add to the fourth part on the expectations of the introduction of new agricultural technologies?</td></tr>
<tr><th colspan="4">Part V - Conclusion</th></tr>
<tr><td colspan="4">• Is there anything you want to add that has not been discussed yet? Any topics you want to raise you think are important?</td></tr>
</table>

8.3 List of farmers

Farmer	Gender	Age	Education	Family status	Farm size	Soil type	Irrigation type	Main crop(s)
F1	male	32	9th grade	4	5 acres	Black soil (clay)	3 Bore wells (500-1000ft)	Sugarcane, turmeric, vegetables, rice, greens
F2	male	33	Master Business Administration	6	24 acres	Black soil and red soil (sandy)	3 Bore wells + drip	Vegetables, horticulture
F3	male	53	6th grade	4	4.5 acres	Red soil and Anthroposol	Bore well (dry) + drip	Banana, turmeric, sugarcane, coconut, silk
F4	male	30	12th grade	4	8 acres	Red soil	Bore well	Jowar, chilli, groundnuts, horse gram
F5	male	59	5th grade	7	3 acres	Red soil	Bore well (dry)	Sunflower, groundnuts, horse gram
F6	male	48	12th grade + Agri-culture course	4	4 acres	Anthroposol	Bore well	Jowar, sunflower, Ragi, ground-nut, grams
F7	male	43	-	8	5 acres	Red soil	Bore well	Banana, turmeric, cabbage
F8	male	45	-	3	2 acres	Anthroposol	Bore well (360-480ft)	Turmeric, sunflower, maize, chilli, watermelon, onion, tomato
F9	male	32	10th grade	5	< 1 acre (24 gundals)	Anthroposol	Bore well (120ft) + drip	Turmeric, maize, sunflower, to-mato, potato, chilli, red gram, onion garlic
F10	male	38	9th grade	8	5 + 9 acres	Red soil (sandy)	Bore well (400-600ft)	Cabbage, beetroot, tomato
F11	male	35	-	8	9 acres	Red soil and black soil	Bore well	Turmeric, sunflower, Jowar, ba-nana, onion
F12	male	36	7th grade	8	12 acres	Black soil and red soil	5 Bore wells (dry)	Turmeric, sugarcane, beetroot, garlic, beans
F13	male	65	-	3	4 acres	Red soil (sandy)	Bore well	Turmeric, sugarcane, maize, chilli, beetroot, tomato

Farmer	Gender	Age	Education	Family status	Farm size	Soil type	Irrigation type	Main crop(s)
F14	male	22	10th grade	5	10 acres	Red soil (sandy)	2 Bore wells	Maize, sunflower, turmeric, garlic, onion, vegetables
F15	male	38	12th grade + Agriculture course	4	4 acres	Black soil and (red soil)	Bore well + drip	Turmeric, sugarcane, banana, onion, garlic, beetroot
F16	male	27	Bsc Mechanical engineering	2	3 acres	Black soil	Bore well + drip	Turmeric, beetroot, cabbage, onion, garlic
F17	male	42	Bsc Arts	4	1 acre	Anthroposol	Rain-fed	Sunflower, Ragi, maize, pulses
F18	male	35	-	4	2 acres	Red soil	Rain-fed	Sunflower, maize, chickpea, black eyed beans
F19	male	47	10th grade	3	12 acres	Black soil and red soil	Bore well + drip	Turmeric, banana, watermelon, onion, garlic, tomato, beetroot
F20	male	55	12th grade	6	4.5 + 2.5 acres	Black soil	Bore well + drip	Banana, watermelon, potato
F21	male	50	10th grade	4	10 acres	Black soil and sandy soil	Bore well + drip	Turmeric, banana, onion, tomato, beans
F22	male	34	Bsc Arts	18	9 acres	Black soil and red soil	Bore well	Turmeric, banana, beetroot, tomato
F23	male	48	9th grade	4	4 acres	Anthroposol	Bore well + drip	Turmeric, banana, watermelon, garlic, onion
F24	male	36	10th grade	9	10 acres	Black soil	Rain-fed + (bore well)	Maize, pulses, black eyed beans, chickpea
F25	male	52	8th grade	4	4.5 acres	Brown soil	Bore well + drip	Banana, watermelon, turmeric, tomato, chilli, garlic, onion
F26	male	50	-	4	< 1 acre (35 gundals)	Sandy soil	Rain-fed	Maize, sunflower, horse gram, flowers
F27	male	35	7th grade	4	6 acres	Red soil (sandy)	Rain-fed	Maize, cotton, Ragi, pulses, flowers
F28	male	39	Bsc Arts	4	2 acres	Black soil	Rain-fed	Ragi, cotton, flowers
F29	male	26	-	4	39 acres	Red soil	7 Bore wells	Banana, flowers, vegetables (onion, tomato, beetroot, cabbage, carrot), beans, chilli

8.4 Overview over case villages



Location of villages (yellow stars) and indication of number of interviews (Source: Google Maps 2017b: https://www.google.ch/maps/place/Gundlupete,+Karnataka+571111,+Indien/@11.7907882,76.7076629,35114m/data=!3m1!1e3!4m5!3m4!1s0x3baf4c538512c97d:0x6096fa1a8f30df47!8m2!3d11.8083459!4d76.6927259; Access 11.05.2.2017, own adaptation).

8.5 Statistics of famer typology analysis

8.5.1 Descriptive statistics

Descriptive Statistics

Farmer_types		N	Range	Minimum	Maximum	Mean		Std. Deviation	Variance	Skewness		Kurtosis	
		Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
farmer type A	TotalInterestBiochar	14	22	1	23	7.36	1.550	5.799	33.632	1.979	.597	3.810	1.154
	TotalScepticismBiochar	14	6	0	6	1.00	.432	1.617	2.615	2.546	.597	7.502	1.154
	TotalInterestVermicompost	14	10	0	10	2.79	.884	3.309	10.951	1.245	.597	.783	1.154
	TotalScepticismVermicompost	14	5	0	5	1.36	.464	1.737	3.016	.999	.597	-.298	1.154
	Valid N (listwise)	14											
farmer type B	TotalInterestBiochar	5	9	4	13	7.40	1.568	3.507	12.300	1.185	.913	1.505	2.000
	TotalScepticismBiochar	5	4	0	4	1.60	.678	1.517	2.300	1.118	.913	1.456	2.000
	TotalInterestVermicompost	5	4	1	5	2.80	.663	1.483	2.200	.552	.913	.868	2.000
	TotalScepticismVermicompost	5	3	0	3	1.00	.632	1.414	2.000	.884	.913	-1.750	2.000
	Valid N (listwise)	5											
farmer type C	TotalInterestBiochar	10	10	0	10	5.80	1.153	3.645	13.289	.011	.687	-1.479	1.334
	TotalScepticismBiochar	10	5	0	5	.80	.490	1.549	2.400	2.654	.687	7.545	1.334
	TotalInterestVermicompost	10	7	0	7	3.90	.737	2.331	5.433	-.442	.687	-1.013	1.334
	TotalScepticismVermicompost	10	2	0	2	.70	.260	.823	.678	.687	.687	-1.043	1.334
	Valid N (listwise)	10											

Descriptive statistics of interest and scepticism in new residue technologies (biochar and vermicompost) by farmer types (SPSS Statistics 21 output, own representation).

Descriptive Statistics

Farmer_soil		N	Range	Minimum	Maximum	Mean		Std. Deviation	Variance	Skewness		Kurtosis	
		Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Red Soil	TotalInterestBiochar	10	13	0	13	5.30	1.044	3.302	10.900	1.175	.687	3.605	1.334
	TotalScepticismBiochar	10	5	0	5	1.00	.494	1.563	2.444	2.180	.687	5.231	1.334
	TotalInterestVermicompost	10	10	0	10	4.20	1.083	3.425	11.733	.638	.687	-.774	1.334
	TotalScepticismVermicompost	10	4	0	4	1.00	.422	1.333	1.778	1.406	.687	1.738	1.334
	Valid N (listwise)	10											
Black Soil	TotalInterestBiochar	5	16	1	17	8.40	2.619	5.857	34.300	.458	.913	1.040	2.000
	TotalScepticismBiochar	5	1	0	1	.40	.245	.548	.300	.609	.913	-3.333	2.000
	TotalInterestVermicompost	5	5	0	5	1.60	.927	2.074	4.300	1.447	.913	1.931	2.000
	TotalScepticismVermicompost	5	5	0	5	1.60	1.030	2.302	5.300	1.016	.913	-1.007	2.000
	Valid N (listwise)	5											
Anthroposol	TotalInterestBiochar	6	7	3	10	6.17	1.222	2.994	8.967	.163	.845	-2.038	1.741
	TotalScepticismBiochar	6	4	0	4	.83	.654	1.602	2.567	2.148	.845	4.640	1.741
	TotalInterestVermicompost	6	4	2	6	4.50	.671	1.643	2.700	-.811	.845	-1.029	1.741
	TotalScepticismVermicompost	6	2	0	2	.67	.333	.816	.667	.857	.845	-.300	1.741
	Valid N (listwise)	6											
Mixed Soil	TotalInterestBiochar	8	19	4	23	8.25	2.266	6.409	41.071	2.134	.752	4.945	1.481
	TotalScepticismBiochar	8	6	0	6	1.63	.680	1.923	3.696	1.998	.752	4.655	1.481
	TotalInterestVermicompost	8	4	0	4	1.88	.666	1.885	3.554	.237	.752	-2.216	1.481
	TotalScepticismVermicompost	8	3	0	3	1.13	.479	1.356	1.839	.623	.752	-1.686	1.481
	Valid N (listwise)	8											

Descriptive statistics of interest and scepticism in new residue technologies (biochar and vermicompost) of farmers grouped by soil types (SPSS Statistics 21 output, own representation).

8.5.2 Test on normal distribution

Statistical test to see whether the variables interest and scepticism in biochar and vermicompost are distributed normally or not at level of significance $\alpha = 0.05$.

One-Sample Kolmogorov-Smirnov Test

		Total Interest Biochar	Total Scepticism Biochar	Total Interest Vermicompost	Total Scepticism Vermicompost
N		29	29	29	29
Normal Parameters[a,b]	Mean	6.83	1.03	3.17	1.07
	Std. Deviation	4.714	1.546	2.726	1.412
Most Extreme Differences	Absolute	.175	.302	.132	.293
	Positive	.175	.302	.132	.293
	Negative	-.139	-.252	-.122	-.225
Kolmogorov-Smirnov Z		.943	1.626	.711	1.576
Asymp. Sig. (2-tailed)		.336	.010	.693	.014

a. Test distribution is Normal.

b. Calculated from data.

8.5.3 Test statistics of non-parametric t-test (Kruskal-Wallis)

The significance of test statistics was set to exact since two out of the three groups contain less than nine individual samples. For two variables, no exact significance could be calculated, but the asymp. significance. Grouping variables were either farmer types A, B and C or the soil types of farmers.

Test statistics of non-parametrical t-test for differences in interest and scepticism about biochar and vermicompost between farmer types (SPSS Statistics 21 output, own representation).

Test Statistics[a,b]

	Total Interest Biochar	Total Scepticism Biochar	Total Interest Vermicompost	Total Scepticism Vermicompost
Chi-Square	.819	2.280	2.381	.426
df	2	2	2	2
Asymp. Sig.	.664	.320	.304	.808
Exact Sig.	.677	.340	.314	.824
Point Probability	.000	.000	.000	.001

a. Kruskal Wallis Test
b. Grouping Variable: Farmer_types

Test statistics of non-parametrical t-test for differences in interest and scepticism about biochar and vermicompost between soil types of farmers (SPSS Statistics 21 output, own representation).

Test Statistics[a,b,c]

	Total Interest Biochar	Total Scepticism Biochar	Total Interest Vermicompost	Total Scepticism Vermicompost
Chi-Square	2.065	3.145	6.910	.246
df	3	3	3	3
Asymp. Sig.	.559	.370	.075	.970
Exact Sig.		.382		.973
Point Probability		.000		.000

a. Kruskal Wallis Test
b. Grouping Variable: Farmer_soil
c. Some or all exact significances cannot be computed because there is insufficient memory.

8.5.4 Procedure of generating input data for statistical test

Example of calculating the farmers' interest in biochar using the coding from MAXQDA 12 (own representation).

Farmer	Do it	Expectation/Requirement	Experiment first	Interest/Openness	Total Interest
F2	1	16	1	5	23

The codes *«biochar-do it»*, *«biochar-expectation/requirement»*, *«biochar-experiment first»* and *«biochar-interest/openness»* are used as indicators for farmers' interest in biochar, whereas the code *«biochar-doubts/fear»* function as an indicator of scepticism. The codes *«vermicomposting-expectation/requirement»* and *«vermicomposting-interest/openness»* are used as indicators for interest in vermicomposting and the code *«vermicomposting-doubt/fear»* for scepticism about it. Subsequently, all coding are counted for each farmer (example in table above). In order to relate the coding on biochar and vermicompost described above to individual farmer types resp. individual soil types of farmers, these variables are recoded in SPSS Statistics 21 into variable groups 1, 2, and 3 resp. 4, 5, 6 and 7.

8.6 R script for statistical analysis of soil data

```r
#Water Holding capacity

#Load data for WHC

WHC<- read.csv("F:/Master-Thesis/Soil_incubation/Data_analysis/R_analysis/CSV/WHC_R.csv", header = TRUE , sep = ";")
WHC
attach(WHC)
plot(Water~Soil)

x<-leveneTest(Water~Soil*Treatment)
summary(x)

a<-aov(Water~Soil*Treatment)
summary (a)

#Subset of each soil type

#Black soil
dat<-subset(WHC, Soil=="Black")
dat
attach(dat)
plot (Water~Treatment)

#ANOVA
a<-aov(Water~Treatment)
summary (a)

#Post hoc (LSD.test, SNK.test, duncan.test)
b<-LSD.test(a, "Treatment")
b

#Red soil
dat<-subset(WHC, Soil=="Red")
dat
attach(dat)
plot (Water~Treatment)

#ANOVA
a<-aov(Water~Treatment)
summary (a)

b<-LSD.test(a, "Treatment")
b

#Anthroposol
dat<-subset(WHC, Soil=="Ant")
dat
attach(dat)
plot (Water~Treatment)

#ANOVA
a<-aov(Water~Treatment)
summary (a)

b<-LSD.test(a, "Treatment")
b

```

R script for statistical analysis (exemplary for WHC, but same script used for other parameters), liberally provided by my supervisor Samuel Abiven.

8.7 Classification of ratings for farmers' importance and soil response to effects of OM applications on soil functions of the studied soils

Rating for soil response to OM (relative change to control) for **water status** (WHC):

++	> +10%
+	+1.01 to +10%
+/-	+1 to -1%
-	-1.01 to -10%
--	< -10%

Rating for soil response to OM (relative change to control) for **nutrients** (C/N):

++	< -5% (actually functions as a fertiliser)
+	+5 to -5%
+/-	> +5% (high C/N ratio is not per se bad for soil quality, since e.g. biochar (introducing high C/N ratio) helps to improve many other soil functions and therefore no negative ranking is assigned)

Rating for soil response to OM (relative change to control) for **soil fertility** (pH & TC):

++	Both parameters positive (> +5%)
	One parameter > +10% AND the other parameter positive (> 0%)
+	Both parameters positive (+1 to +5%)
	One parameter between +1.01 to +10% AND the other parameter positive (> 0%)
+/-	Both parameters either positive or negative AND between -1 to +1%
	One parameter positive AND the other parameter negative
-	Both parameters negative (-1.01 to -5%)
	One parameter between -1.01 to -10% AND the other parameter negative (< 0%)
--	Both parameters negative (< -5%)
	One parameter < -10% AND the other parameter negative (< 0%)

Note 1: For biochar (B1 and B2) and vermicompost (VC1 and VC2), the two corresponding combined treatments were grouped to one (i.e. B1&VC1 + B1&VC2 = B1&VC and B2&VC1 + B2&VC2 = B2&VC) and then classified/rated.

Note 2: For the rating of the soil fertility (pH & TC) for the biochar (B2) amended black soil, the result is ± because the TC shows a negative response. This, however, is caused through an extreme value of one replicate, and therefore the soil fertility for this treatment may also be rated with + or ++ (in Table 14 indicated with an asterisk).

Ratings for **farmers' importance** of selected soil functions:

++ Very important criteria, has to be improved (mentioned by ≥ 50% of farmers)

\+ Important criteria, should be improved (mentioned by 33.33% to 49.99% of farmers)

+/- Indifferent (mentioned by < 33.33% of farmers)

Procedure: For each of the three criteria (water status, nutrients and soil fertility) and each soil type separately, all farmers who designated the criteria as important for any of the agricultural residue applications (compost (cow dung manure), vermicompost and biochar) are recorded (from subsection 5.2.3 and 5.2.4). To normalise the rating (since the three soil types do not contain the same number of farmers), the number of farmers of one soil type who designated the criteria are divided through the number of all farmers of one soil type (Note: some farmers cultivate more than one soil type and therefore are recorded for both soil types).

Black soil (in total 12 farmers):

1. Water status: F1, F12, F21, F22 (4 out of 12 = 33.33%)
2. Nutrients: F1, F12, F15, F21, F22, F28 (6 out of 12 = 50%)
3. Soil fertility: F2, F12, F16, F19, F20, F21, F22, F24, F28 (9 out of 12 = 75%)

Red soil (in total 18 farmers):

1. Water status: F3, F4, F12, F18, F21, F22 (6 out of 18 = 33.33%)
2. Nutrients: F10, F12, F14, F15, F18, F21, F22, F27, F29 (9 out of 18 = 50%)
3. Soil fertility: F2, F3, F4, F7, F10, F12, F14, F18, F19, F21, F22, F26, F27, F29 (14 out of 18 = 77.8%)

Anthroposol (in total 7 farmers):

1. Water status: F3, F8 (2 out of 7 = 28.6%)
2. Nutrients: F6, F9, F25 (3 out of 7 = 42.9%)
3. Soil fertility: F3, F6, F8, F23, F25 (5 out of 7 = 71.4%)

8.8 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.

Severin-Luca Bellè