german cooperation
DEUTSCHE ZUSAMMENARBEIT

Potential Analysis of Biochar-Systems for Improved Soil and Nutrient Management in Ethiopian Agriculture

REPORT 3

Identification and characterization of two priority areas for a biochar system pilot project in Ethiopia

Potential Analysis of Biochar-Systems for Improved Soil and Nutrient Management in Ethiopian Agriculture

Report 3: Identification and characterization of two priority areas for a biochar system pilot project in Ethiopia

July 2017

Authors:
Tobias Seitz, Sebastian Meyer, and Bruno Glaser

Project Steering Committee:
Andreas Möller - BGR
Anja Volk - BGR
Tefera Solomon - Ministry of Agriculture
Berhanu Belay - Jimma University
Dawit Solomon - Cornell University

BMZ-No.: 2015.3503.8
BGR-No.: 05-2387-05

This project was funded by the German Federal Ministry for Economic Cooperation and Development (BMZ)

german cooperation
DEUTSCHE ZUSAMMENARBEIT

Implemented by

Bundesanstalt für Geowissenschaften und Rohstoffe

Federal Democratic Republic of Ethiopia Ministry of Agriculture

Biochar Europe

Summary

Scientific knowledge, as well as knowledge from practical experiences in Ethiopia have been gathered and evaluated. As a final step, two priority areas have been selected that are best suited for a prospective intervention to establish biochar systems in Ethiopian agriculture. The first priority area is suited for the introduction of small-scale pyrolysis or gasification cookstoves in rural areas. The priority area aligns with the project area of the GIZ - ISFM$^+$ project, since the project offers the ideal conditions to combine biochar with other soil improving technologies, such as composting, manuring, or chemical fertilizers. A spatial analysis of pH and SOC content within the project woredas shows that soils in the woredas in Amhara (apart from the highlands) and especially in Western Oromia would benefit the most from the application of biochar substrate. In this area, coffee residues are the most promising feedstock source. A specific stove-model can not be recommended, yet, but several research groups are working on stove optimization in Ethiopia.

The second priority area comprises the flower growing towns in the South and West of Addis Abeba. The area under rose production in these towns accounts for approx. 1000 ha. This area produces an estimated amount of 100,000 t per year and could supply up to 3000 ha of cropping land with biochar-compost substrate. The amount of rose residues allows for several large-scale pyrolysis units, that produce constantly biochar from rose residues. It is recommended to use only woody rootstocks for biochar production and to compost the green residues that contain more nutrients. Since most flower farms have big cooling stores that have a high energy demand, it is possible to use the process heat from pyrolysis for renewable and sustainable cooling systems working according to the absorption chiller principle.

A risk assessment of biochar systems shows that small-scale gasification cookstoves need to be tested on polycyclic aromatic hydrocarbons (PAHs) formation and the biochar should comply with the European Biochar Certificate (EBC) standards. Whereas rose residues may have a very high chloride content, due to an excessive use of pesticides, what might lead to dioxine formation during pyrolysis. The main climate mitigating effect of biochar systems is based on the reduction of greenhouse gases (GHGs). Since both, coffee residues and rose residues, decompose without any other use, they emit a lot of CO_2 and CH_4. Several factors that may effect the climate mitigating effect of biochar systems are taken into account.

Table of contents

1 Introduction

In two preceding reports, the current state of biochar systems in general and specifically in Ethiopia has been evaluated. The positive effects of biochar systems on soil fertility, crop productivity and climate change that are found in literature (report 1), have also been observed by researchers in Ethiopia (report 2). Potential production technologies, feedstock sources and stakeholders have been identified and evaluated (report 2). In a final step, the results will be filtered and aggregated, in order to identify two areas in Ethiopia that offer the best opportunities for a biochar system pilot project. These "priority areas" are characterized in detail and the positive and negative effects that biochar systems might have in these areas will be evaluated. Priority area I aims at the introduction of a biochar system based on small-scale production units, whereas priority area II deals with large-scale pyrolysis plants. Thus, the third report offers small- and large-scale approaches for future activities. Further on, national strategies and public stakeholders that may affect the implementation of biochar systems in Ethiopia are briefly considered.

The selection of the priority areas has been based on various meetings and interviews with experts from governmental institutions, universities, NGOs and the private sector. The report does not reflect the full range of opportunities that exist in Ethiopia since information was rather limited. However, the report provides the best information available. Thus, it offers different strategies for the implementation of a prospective bilateral cooperation and indicates where local collaborations are likely found.

2 Decision making

Several criteria are important for the choice of a priority area. From our point of view, the most significant ones are:

- other rural development projects
- availability of feedstock
- process heat usage options
- depleted soils with a high potential of improvement
- available infrastructure

Regarding priority area I, "other rural development projects" is considered as the most striking criterion, since biochar systems can only be one part of a successful and sustainable soil management, especially in smallholder farming systems. Other soil improvement practices should already be established in areas where biochar systems are introduced: Farmers should be aware of re-using agricultural residues and they should be trained in composting techniques. Cookers should be adapted to improved cookstoves (ICSs). Rural communities should be experienced in participating in trainings and demonstrations. Biochar systems are not a technique, that is suitable for primary development projects. It can rather enhance existing soil management measures, such as manuring or composting. Furthermore, the "availability of feedstock" and the "presence of depleted soils with a high potential of improvement" are crucial for the successful implementation of a small-scale biochar system.

The choice of priority area II has mainly been based on the criterion "availability of feedstock". A large-scale pyrolysis plant needs a continuous feedstock source, in order to run the plant efficiently. Moreover, heat usage options should be nearby to ensure the profitability. Since large amounts of biomass and biochar need to be transported to and from the pyrolysis plant, a well-developed infrastructure is indispensable as well.

3 Policies and regulations

3.1 Regulatory frameworks

In the early 1990s, the Ethiopian Government has introduced the strategy of an Agricultural Development-led Industrialization (ADLI), which emphasizes the importance of the Ethiopian agricultural sector for the country's economic development. ADLI is an evolving strategy that included subsequent development policies and strategies, such as the Sustainable Development and Poverty Reduction Program (SDPRP) and the Plan for Accelerated and Sustainable Development to End Poverty (PASDEP 2005–2010). It forms the strategic basis for the country's development goals in the two Growth and Transformational Plans (GTP I 2010/11 – 2014/15 and GTP II 2015/16 – 2019/20) that aim to make Ethiopia a middle income country by 2020.

The Agriculture Sector Policy and Investment Framework (PIF 2010 – 2020) provides a strategic framework for the prioritization and planning of investment that will serve as an engine for driving Ethiopia's agricultural development. The PIF is a 10-year road map for development that identifies priority areas for investment and estimates the financing needs to be provided by Government and its development partners. Regarding the thematic areas and strategic objectives (SOs) of the PIF (table 1), one can clearly see that biochar systems may contribute essentially to their achievement. It has been demonstrated (report 1, section 5.2) that biochar systems can increase crop yields and thus agricultural productivity (SO1). Large-scale pyrolysis plants may support the energy demand of agricultural processing industries (SO2). The clearly positive effects of

Table 1. The Agriculture Sector Policy and Investment Framework, thematic areas and strategic objectives

Thematic Area	Strategic Objectives (SOs)	
Productivity and Production	SO1	To achieve a sustainable increase in agricultural productivity and production
Rural Commercialisation	SO2	To accelerate agricultural commercialisation and agroindustrial development
Natural Resource Management	SO3	To reduce degradation and improve productivity
Disaster Risk Management and Food Security	SO4	To achieve universal food security and protect vulnerable households from natural disasters

biochar systems on several soil properties (report 1, section 5.1) can counteract the critical soil degradation in Ethiopia (SO3). The combined effect of these improvements will thus result in a better food security (SO4). However, the introduction of biochar systems will require detailed strategies that specify environmental and technological standards for the production of biochar. Moreover, regional guidelines need to be composed, in order to address specific regional issues, especially in terms of feedstock acquisition.

3.2. Public stakeholders

There are numerous public stakeholders that can be involved in the successful implementation of biochar systems in Ethiopia. In the following, we will list those, who are most important in terms of political decision-making, governance and assistance for the introduction of biochar to national agricultural policies.

▶ Ministriy of Agriculture and Natural Resources (MoANR) is responsible for developing policies and strategies, in order to enhance the agricultural productivity and to conserve, develop and sustainably use natural resources. It supervises the regional agricultural bureaus and the national extension system, which can have a key role in overseeing and guiding the dissemination of biochar systems.

▶ Ethiopian Agriculture Transformation Agency (ATA) strives to introduce new technologies and approaches that can address systemic bottlenecks & catalyze transformation of the sector and to play a catalytic role to support partners to effectively execute agreed upon solutions in a coordinated manner. Therefore, it should be one of the main actors for the implementation of biochar systems.

▶ Ministry of Environment, Forestry and Climate Change is in charge of an environmentally friendly and climate-neutral development of the economy. It can promote biochar as a climate-smart technology in national policies and strategies.

▶ Ministry of Water, Irrigation and Energy is responsible for the sustainable energy supply of household and the industrial sector. The introduction of new cookstoves or industrial energy technologies is within its competence.

▶ Research institutions, such as universities and regional agricultural research institutes have to prove the concepts of biochar from a scientific point of view with respect to regional requirements.

▶ The Ethiopian Standard Agency (ESA) can develop national quality standards for biochar, in accordance with the quality standards we presented in report 1 (section 2.1).

4 Priority area I – ISFM+ project area

4.1 Specification of the priority area

Priority area I aligns with the project area of ISFM+ from GIZ. The targeted area for soil fertility improvement technologies comprises a total of 31,802 ha of arable land in 18 woredas[1] in the regional states of Amhara, Oromia and Tigray

[1] "Woreda" is an administrative division in Ethiopia (managed by a local government), equivalent to a district with an average population of 100,000. woredas are composed of a number of Kebele, or neighborhood associations, which are the smallest unit of local government in Ethiopia. Woredas are typically collected together into zones, which form a Kilil (Regional government administration) (woredaNet).

(table 2) (GIZ-ISFM+ Baselinestudy I 2015). Altogether, 72 microwatersheds have been selected as target area. Regarding the agro-ecological zones (AEZ), the ISFM+ woredas in Amhara are mainly classified as highland (2,000-2,500 masl) or midland (1,500-2,000 masl), whereas the woredas in Oromia and Tigray predominantly are classified as midland and lowland (<1,500 masl). The total number of households targeted by ISFM+ is 25,388: in Amhara 7,739 households, in Oromia 5,672 households and in Tigray 11,977 households. In each of the microwatersheds there have already been measures against soil erosion, but few measures against soil degradation. Thus, the potential to improve soil fertility is very high and farmers are already used to other agricultural interventions.

4.2 Implementation strategies

4.2.1 Livelihood

To estimate the chances of a successful implementation of a biochar system, it is reasonable to take a look at the livelihood conditions in the priority area. Biochar systems have a significant effect on several factors that characterize a livelihood zone and, simultaneously, are affected by these factors, themselves. Which crop predominates in an area, or how much livestock one family owns, influences the amount of organic residues

Table 2. Project woredas and targeted micro watershed (MWS) areas (ISFM+ Baseline report I 2015)

Woreda	Total area (ha)	Arable area (ha)	Proportion of irrigated area (%)	Targeted MWS area (ha)	Targeted MWS arable area (ha)
Amhara					
Hulet Eju Enebse	151,563	62,866	26	2,584	1,932
Bibugn	30,972	21,157	26	2,225	756
Sinan	41,372	24,178	31	1,686	1,224
Machakel	79,556	51,480	13	1,715	1,155
Gozamin	119,580	49,152	32	2,610	1,958
Baso Liben	113,284	46,599	14	2,584	1,647
Oromia					
Ambo	83,599	62,167	6	3,940	1,855
Gudeya Bila	84,275	44,666	7	2,894	1,992
Boji Dirmaji	65,662	38,142	3	2,923	1,369
Bedele	114,057	18,090	20	2,503	1,064
Gummay	44,225	14,176	7	2,616	1,393
Sokoru	92,744	33,858	18	2,362	1,369
Tigray					
Adwa	65,531	13,714	na	5,703	3,375
Tahtay Maichew	57,468	17,696	na	4,894	2,844
Raya Azebo	176,308	47,215	10	6,517	1,199
Emba Alaje	76,773	24,677	34	3,820	1,615
Seharti Samre	171,650	45,022	20	4,707	2,491
Dogua Tembien	112,500	19,473	na	5,715	2,565

[2] Wealth is related to the total income of a household. Total income is defined as the sum of a household's annual food income and cash income, converted to calorie equivalents, and expressed in relation to the household's annual calorie requirement (USAID 2011).

considerably. Moreover, families with higher income or families that own more land can try more easily to adopt a new soil improvement strategy than poor families that face insufficient food supply. According to An Atlas of Ethiopian Livelihoods (USAID 2011), the wealthiest[2] farmers live in the target woredas in Oromia, followed by the woredas in Amhara, and the poorest households live in Tigray. This aligns with the observation that in Oromia most farmers grow cash crops (mainly coffee) or crops for sale. Whereas, farmers in Tigray mainly grow crops for their own consumption. Thus, the project woredas in West-Oromia may provide enough residues for biochar production. In higher altitudes in Amhara with more precipitation, farmers mainly grow barley and wheat, whereas in medium altitudes they also grow teff, maize and also pulses, which leads to a higher income, and thus, to more houshold investments. A list of the livelihood zones in the project areas is given in appendix A.

4.2.2 Technology

A central issue for the implementation of a small-scale biochar system is an appropriate stove technology, that is adopted by local cookers. As outlined in report 2 (sections 2.2.1 and 2.2.2), the most promising gasification cookstoves are currently developed by Pro Lehm in cooperation with Awassa University and by Kaffakocher. Both should be considered as potential partners for the introduction of gasification cookstoves. Both projects have pointed out a high potential for injera-baking gasification cookstoves. A single stovemodel can not be recommended at this point.

4.2.3 Feedstock

According to the ISFM$^+$ project manager Steffen Schulz (personal communication) the availability of non-competitive biomass is a key bottleneck in every project area. Therefore, the availability of uncompetitive feedstock is likely to be the limiting factor for the efficiency of a biochar system. Most likely, cookers have to continue to use wood as fuel source and, hence, also as feedstock for biochar production. Using gasification cookstoves, will increase fuel efficiency, and automatically produce biochar as a by-product. This will reduce the amount of fuel wood per household and save labour for collecting wood. In Oromia, where coffee is grown and coffee processing units are nearby. Farmers can take coffee residues as sustainable fuel and feedstock source for biochar production (see report 2, section 3.2).

4.2.4 Integration into ISFM$^+$ technologies

The ISFM$^+$ project has demonstrated and applied several soil improving technologies within their project area. Especially liming strategies can be substituted by or supplemented with biochar. In every project area compost technologies have been introduced. It has been observed that co-composting with biochar will increase the stability of the resulting substrate (Fischer and Glaser 2012) and, thus, the sustainability of the technology. In the ISFM$^+$ Fieldguide Technical Implementation –

Integrated Soil Fertility Management (MoANR 2016), farmers can learn how to make compost and which resources they can use. The bottom left picture in figure 1 indicates that farmers should use the ash residues from cooking, which is the basic step for an integration of biochar into composting strategies. Given the conditions mentioned in report 2 (section 2.3.1) are met, the ISFM⁺ project manager considers biochar as a feasible soil improvement tool for selected target areas.

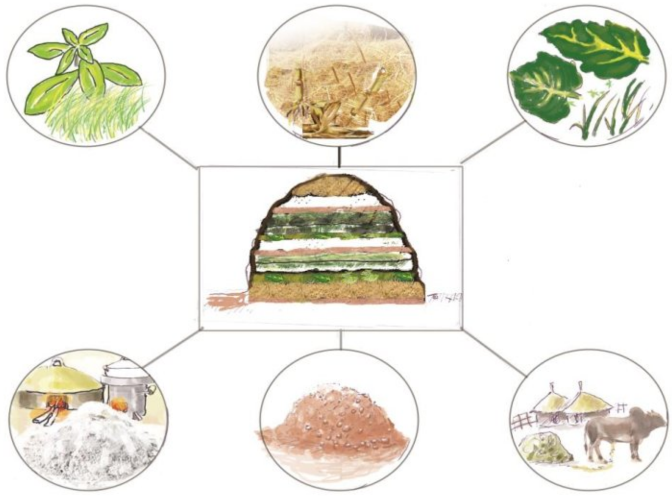


Figure 1. Ingredients to make compost (taken from MoANR 2016)

4.3 Expected soil improving effects

Only limited information is available about the soil conditions in these areas. In the woreda Gozamin in Amhara, there seem to be some Acrisols, that would benefit from the liming effect of biochar (table 3). Other soil types that are found within the project area and that could be improved by biochar substrates are mainly Vertisols and Lixisols. The former mainly occurs in the woredas Ambo and Sokoru in Oromia, the latter mainly in Boji Dirmaji and Bedele, also in Oromia. For Tigray region only soil texture is available. Very sandy soils are found in the woreda Seharti Samre, and very clayey soils occur in the woredas Tahtay Maichew, Raya Azebo, Emba Alaje and Dogua Tembien (GIZ-ISFM⁺ Baselinestudy I 2015). Sandy soils can be improved in terms of water holding capacity and CEC, whereas clayey soils are improved in terms of drainage, aeration and workability.

Regarding soil acidity, one can clearly see that most acid soils are found in Oromia (appendix B I); whereas soils in Tigray have mostly a pH >6. In Amhara they are rather acidic. Since the use of lime is associated with high costs and difficulties in transportation (Abate et al. 2016), most Ethiopian farmers apply only insufficient amounts of lime to counteract soil acidity (Lemma 2011, Abate et al. 2016). Biochar can be a cheap and easily available alternative to

Table 3. Relative distribution of soil types in some ISFM⁺ project woredas (ISFM⁺ Baseline report I 2015)

Woreda	Nitisol	Cambisol	Acrisol	Vertisol	Andosol	Lixisol	Luvisol	Nitisol high clay
Amhara								
Gozamin	40	50	10	0	0	0	0	0
Oromia								
Ambo	36	0	0	34	29	0	0	0
Gudeya Bila	100	0	0	0	0	0	0	0
Boji Dirmaji	5	0	0	0	0	80	15	0
Bedele	39	0	0	0	0	28	33	0
Gummay	0	0	0	5	0	0	60	35
Sokoru	60	0	0	30	0	0	10	0

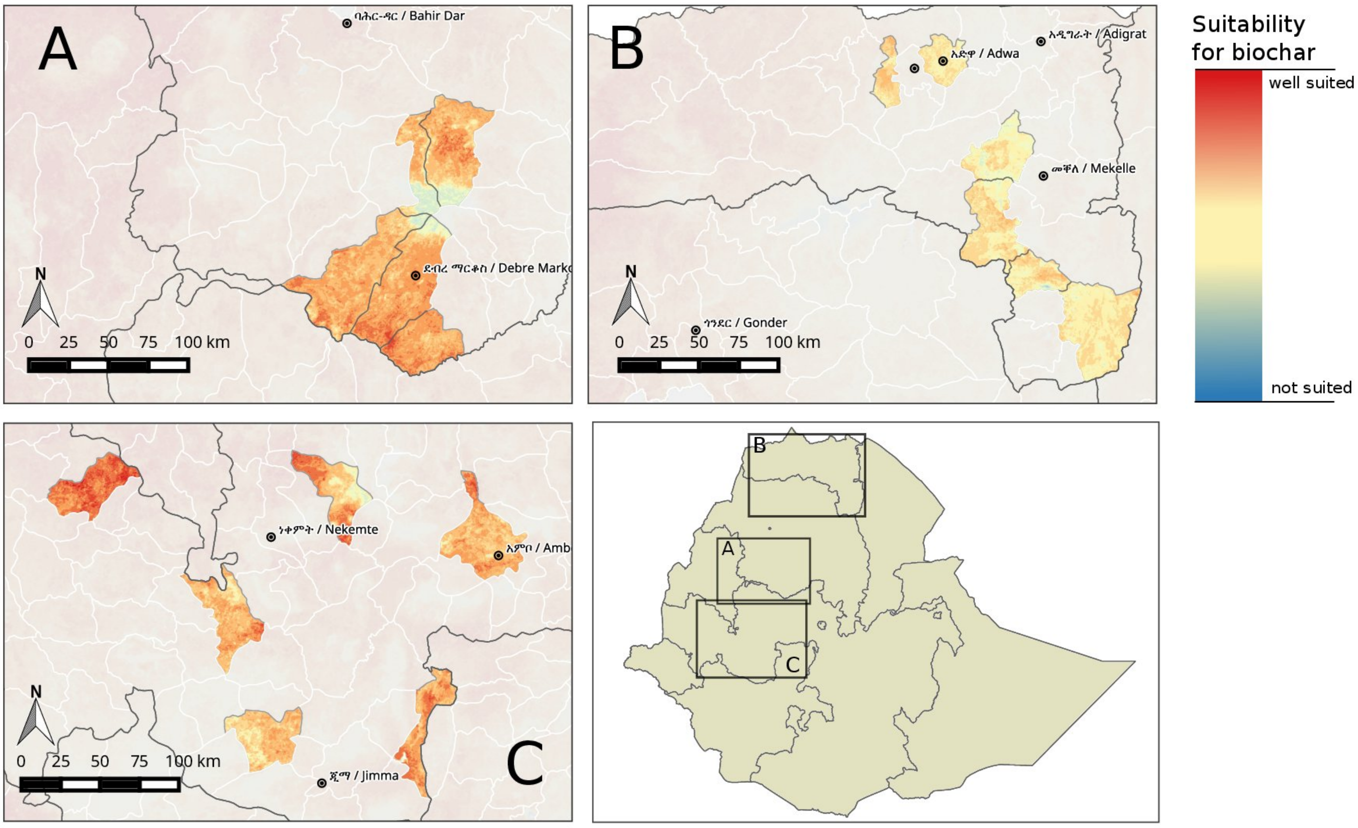


Figure 2. Suitability map for biochar substrate application within ISFM⁺ project woredas, based on soil pH and SOC

lime. It increases the soil pH effectively, as described by Berihun et al. (2017) for farmers around Dilly area (SNNPR). However, acid soils in Oromia are also those soils with the highest organic carbon content (appendix B II) and production rate (section 4.2.1) and, thus, they offer little incentive for farmers to invest in soil improving technologies (see report 2, section 2.2.1). Therefore, we created a suitability map that combines high soil acidity with low SOC, and, thus, shows those areas that are best suited for the application of biochar substrates (figure 2). The map indicates that the project woredas in Tigray are less suited for biochar substrate application than the project woredas in Amhara and Oromia. Especially Boji woreda in Western Oromia seems to provide good conditions for the implementation of biochar systems. However, the map only focuses on two soil properties, whereas the success of the implentation of biochar systems is dependent on many more conditions.

4.4 Model of a biochar system in priority area I

The single elements of a small-scale biochar system that were discussed above can be put into one model of a circular economy (figure 3). The model uses coffee residues as feedstock, as it can be the case in project woredas in Oromia: The coffee residues are taken from coffee processing units and used as fuel in a pyrolysis or gasification cookstove (previous pelletizing might be necessary). Biochar is produced as a by-product of cooking. Subsequently, it should be co-composted with organic household waste

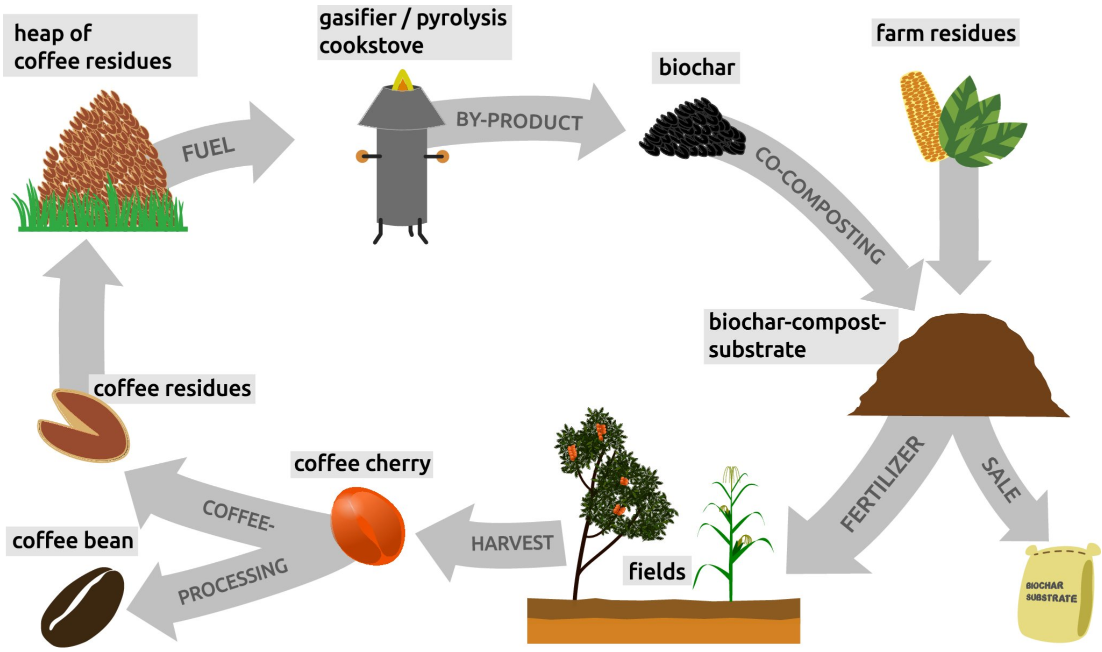


Figure 3. Model of a small-scale biochar system based on coffee residues as feedstock

and farm residues. The resulting biochar-compost-substrate can be applied as fertilizer or lime supplement to the field or sold as soil conditioner. The application of fertile biochar-compost-substrate will increase the crop yields and thus also the amount of coffee and farm residues. Coffee residues accumulate at processing units and can be taken from there.

5 Priority area II – Flower production area of central Oromia

5.1 Specification of the priority area

The second priority area for a prospective biochar project is located in central Oromia. It comprises the flower growing areas in the south and west of Addis Abeba (figure 4), including the major flower growing towns: Holeta, Sebeta, Addis Alem, Menagesha, Debre Zeyit, Koka and Ziway. We mainly focus on rose production farms, since we have no information about the amount of residues from other ornamental flowers, such as *Gypsophila paniculata* or Hypericum. However, their residues may be suited for biochar production, too. In total, the area under production in these towns comprises about 1000 ha of rose cultivation (internal data from Ethiopian Horticulture Development Agency). A detailed description of the allocation of rose farms in the priority area is given in appendix C.

The flower sector in Ethiopia is dominated by international companies from several countries, such as Netherlands, Israel, England, Belgium, India, Germany, and others. The major share of the sector is held by Dutch companies, which have settled their businesses mainly in Ziway. Many Ethiopian farms are found at Sebeta, whereas many Indian farms are at Holeta.

As outlined in Report 2, the annual residue production per ha of rose cultivation accounts

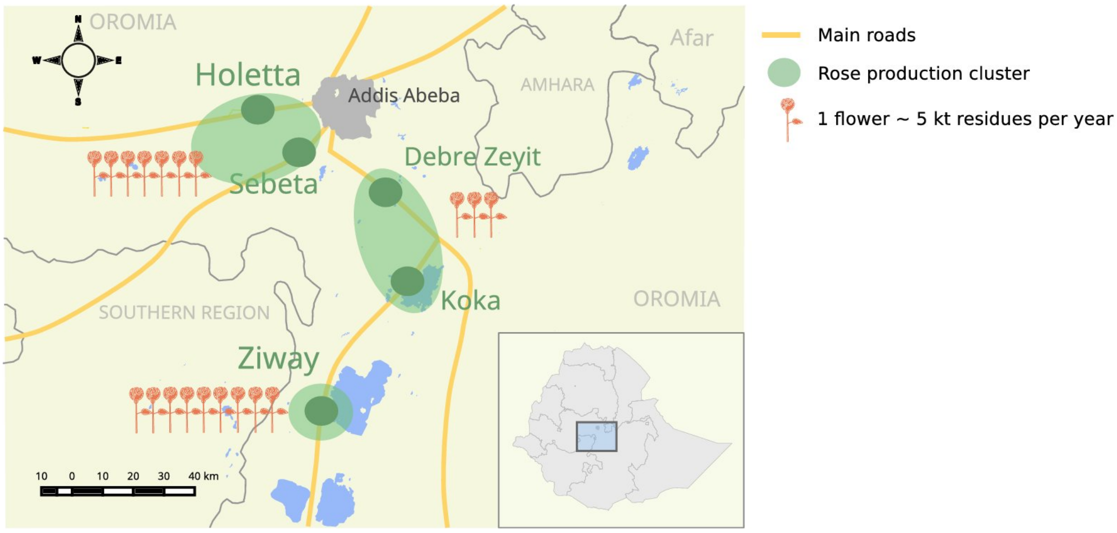


Figure 4. Flower clusters in priority area 2

for at least 100 t, with approx. 20% of woody rootstocks (estimated numbers). This results in an estimated total annual residue production of 100,000 t in the priority area. However, it is recommendable to consider only woody rootstocks as biochar feedstock, since green biomass is nutrient-rich and should rather be composted in order to restore the nutrients contained. Consequently, there are approx. 20,000 t of woody residues available for biochar production, which can be transformed into about 6,000 t of biochar. This amount allows for a large-scale pyrolysis plant as presented in Report 1 (section 3.2).

Since there are no data available, which amounts and ratios of biochar, organic nutrient sources and compost are best suited for rose cultivation, a prospective biochar project needs to be backed by continuous scientific evaluation.

Another factor that gives reason to select the flower sector as priority area is the well developed infrastructure in the area and the good connection to the capital Addis Abeba. Thus, it is possible to draw on the capital's market to distribute biochar for other purposes such as a carrier agent for inoculants or as a prepacked potting soil substrate for homegardens.

5.2 Creation of fertile biochar substrate from rose residues

Ideally, biochar from root stocks should be co-composted with the remaining 80% of green residues, in order to create a fertile biochar substrate that can be used on flower farms or sold to farmers (figure 5). Depending on the nutrient content of the compost, additional nutrient sources might be necessary, in order to create nutrient-rich bio-fertilizer substrate. During composting a mass loss of more than 50% of the fresh green material occurs, when applying an aerobic windrow composting method with regular turning (Tiquia et al. 2002, Tirado and Michel 2010, Verma et al. 2014). Agegnehu et al. (2015) recommend a ratio of 1:5 biochar: compost on a dry matter (DM) basis, to create a fertile biochar-compost-mix. In their study they applied 12 t per ha of biochar-

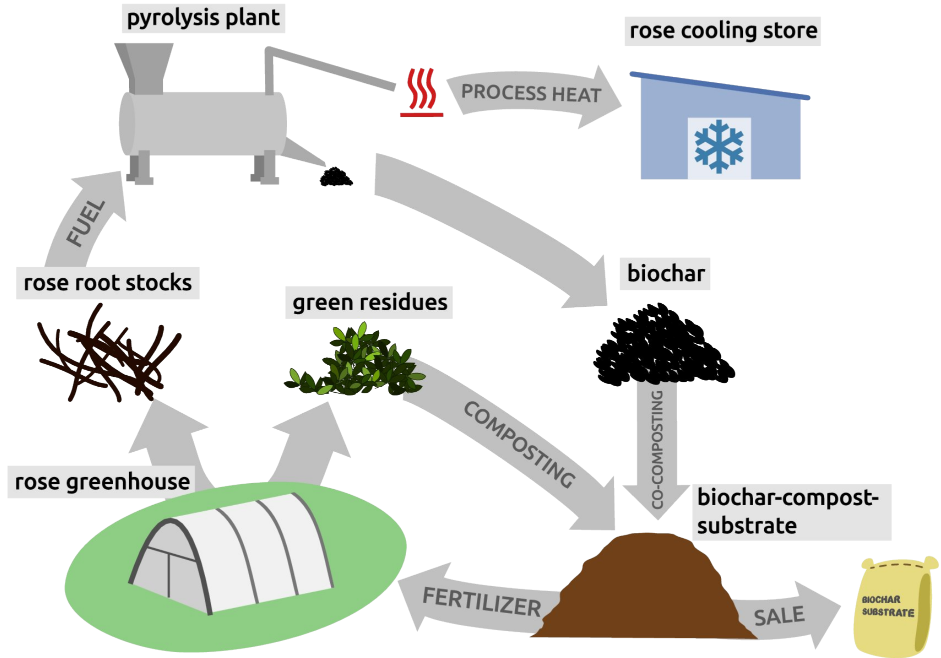


Figure 5. Model of a large-scale biochar system based on flower residues.

compost substrate to barley. Consequently, 6,000 t of biochar can be mixed with 30,000 t (DM) of compost which would suffice for 3,000 ha of cropping land. For rose production in greenhouses, however, it is recommendable to apply much more substrate, since the optimum soil organic matter content is about 10% (Handbook for Modern Greenhouse Rose Cultivation 2001).

5.3 Effects of biochar on soil quality

There are several reasons why the use of biochar substrates is very recommendable within rose farms. Apart from the possibility of using it as a growing media for hydroponic systems (Dumroese et al. 2011, Tian et al. 2012, Northup 2013, Steiner und Harttung 2014, Fascella 2015, Dispenza et al. 2016), biochar substrates can improve the soil quality for rose cultivation and decrease negative environmental impacts. Even though roses can grow in a variety of different soils, there are some characteristics that are preferred for rose cultivation (Handbook for Greenhouse Rose Production in Ethiopia, 2011):

1) homogeneous, stable structure
2) high permeability
3) no disturbing layers in soil profile
4) good drainage and constant groundwater level

As outlined in Report 1 (section 5), biochar can have positive effects according to these preferences. An important factor for high permeability is a low bulk density of the soil. The bulk density of biochar substrates depends highly on the feedstock and the pyrolysis conditions (Downie et al. 2009). Byrne and Nagle (1997) have shown that there is a linear relationship between the bulk density of wood biochars (BD_{BC}) and the bulk densities of their feedstock (BD_{FS}):

$BD_{BC} = 0.8176\ BD_{FS}$

Accordingly, the biochar investigated by Dispenza et al. (2016), which derived from several different wood residues (*Abies alba*, *Larix decidua*, *Picea excelsa*, *Pinus nigra*, *Pinus sylvestris*) had a bulk density of 0.64 g cm^{-3} and, thus, it is averagely lower than the bulk density of most soils but higher than the bulk density of peat substrate (0.32 g cm^{-3}), which is the common growing media for hydroponic rose cultivation. However, the bulk density of biochar would decrease considerably when it is crushed.

According to Moncada (2001), flower growers around lake Naivasha (Kenya) averagely use 69 kg per ha and year of active ingredients from pesticides; for comparison, vegetable growers only used 19 kg. In the cropping season 1999 – 2000, Kenyan Rose farmers used a total of 36 different peesticides (appendix D). Even if secure data are missing for Ethiopia, one can assume that the amounts are comparable to that in Kenya. For that reason Kassa (2017) stresses the hazardous effect that excessive pesticide use can have on soils, ground and surface water, fauna and flora in Ethiopia. Especially insecticides are intensively used in rose cultivation and are very toxic for humans and aquatic organisms (Hengsdijk and Jansen 2006).

Biochar is a well known tool to immobilize hazardous chemicals in soils and thus prevent them from contaminating the environment. The review of Khorram et al. (2016) outlines that the high organic carbon content, the high specific surface area (SSA) and its porous structure are the main determinants of the adsorption capacity of most biochars. Alongside a higher adsorption capacity compared to un-amended soils, biochar-amended soils reduce the amount of leached chemicals and their bioavailability to soil organisms considerably (Khorram et al. 2016). This is of special interest in regions where roses are cultivated next to sensitive water bodies that are also used by local inhabitants for washing and recreational purposes, e.g. in Ziway.

5.4 Heat usage for cooling stores

Large scale pyrolysis systems co-produce significant amounts of thermal energy during the carbonization process. As described in report 1 (section 3.2), between 100 kWth and 1.000 kWth of excess heat power are provided by commercial pyrolysis units. Although energy is in general a precious resource in Ethiopia, it is not easy to find consumers for thermal heat in the flower clusters of the country. The flower cluster have intentionally been established in regions of the country with very warm and stable climate. There is however a high cooling demand in the flower sector to store the roses close to the production site before transport (Reggentin 2016). For this reason, options to convert heat energy to cooling energy are described below.

The heat of pyrolysis systems can be used in either adsorption (1) or absorption (2) cooling systems to provide cooling energy:

1) In adsorption cooling system, the refrigerant (e.g. water) is adsorbed to the surface of solid adsorbers such as silica gel or zeolite (Kim and Ferreira 2008).

2) In absorption cooling system, the refrigerant (e.g. water) is absorbed (taken up) by liquids such as a lithium bromide salt solution (Srikhirin et. al. 2001). The operation principle of absorption cooling cycle of lithium bromide

refrigerators is illustrated in Box 1.

The following preconditions have to be met to convert heat energy from a pyrolysis unit into cooling energy for a rose storage:

▶ Minimum temperature level of the heat source: Absorption cooling system need a higher heat temperature level to power the process (above 85 °C) than adsorption cooling systems (above 60 °C). For comparison: The exhaust gas temperature of pyrolysis systems has several hundred degrees and thus is high enough to power both types of cooling systems.

▶ Temperature level demand of the rose storage: For the storage of roses close to the production site, temperature of about 5 °C are required (Reggentin 2016). Since the cooling water provided by adsorption cooling systems typically cannot reach temperatures below 6 °C, only absorption cooling systems are suitable for this task (Schwarz 2013). Absorption cooling system using a lithium bromide salt solution as absorber can provide cooling temperature of about 5 °C. To provide even lower cooling temperature, (diffusion) absorption cooling systems using e.g. ammonia as refrigerant are needed.

▶ Cooling power supply for the rose storage: Adsorption cooling system units typically provide less cooling power (1 kW to 250 kW) than absorption cooling system units (10 kW to more than 1000 kW) (Schwarz 2013). The energy demand of the indicated cooling unit can be met by pyrolysis units of appropriate size.

One example of an absorption refrigerator manufacturer is the Austrian Company Pink GmbH that provides ammonia and lithium bromide absorption cooling systems with max. 100 kW cooling power (and even larger refrigerator systems together with cooperation partners) (Pink GmbH 2017).

5.5 Current state of biochar systems in priority area II

Yet, there is no operation running that produces biochar from flower residues. However, Soil and More Ethiopia already uses rose residues as source for commercial compost production and plans to establish a biochar system on the basis of non-compostable root stocks (see Report 2, section 2.3.2). In

Box 1. The absorption cooling cycle of lithium bromide refrigerators (Srikhirin et. al. 2001)

1. **Evaporation:** A liquid refrigerant (water) evaporates in a low partial pressure environment in a first chamber of the refrigerator. Because of the low partial pressure, the temperature needed for this evaporation is low. For the evaporation process, energy is needed. Thus, energy (heat) from a second, separate cooling water cycle is extracted. Thereby, the water in this second cooling water cycle is chilled down. This chilled water is used to cool down a rose storage.
2. **Absorption:** The water vapor is absorbed by a concentrated lithium bromide salt solution within the first chamber of the refrigerator.
3. **Regeneration:** The water-saturated lithium bromide salt solution is heated (with the heat of the pyrolysis unit) in the second chamber of the refrigerator, causing the water to evaporate out of the water-diluted lithium bromide solution. The hot water vapor passes through a heat exchanger, transferring its heat outside the system (such as to surrounding ambient-temperature air), and condenses. The condensed water and the concentrated lithium bromide salt solution are recycled to the first chamber of the refrigerator.

collaboration with the British company Carbon Gold, they plan to set up a test-pyrolysis plant and to make first trials on their demonstration farm. Another important actor close to the priority area is the Wondo Genet College of Forestry and Natural Resources, where a project was launched in March 2017 to establish biochar and compost systems from different feedstocks. Therefore, the College might be a suitable institution to evaluate biochar activities in the flower sector from a scientific point of view.

6 Risk assessment for the implementation of biochar systems

6.1 Soil protection

Biochar pollution prevention starts with the feedstock selection. Only feedstock with low heavy metal contents and preferably with low organic pollutants levels should be used for biochar production, even if large pyrolysis plants are able to eliminate organic pollutants in the feedstock (see below). Special care has to be taken if co-current flow gasifiers shall be used for biochar production. To check whether the described conditions have been fulfilled, a representative sample of the final biochar product should be analyzed and compared to the stringent quality criteria of the European Biochar Certificate (EBC).

The following soil protections risks have to be addressed in the priority areas:

Priority area I: In case the selected biochar cook-stoves are based on a gasification process (such as the PRO Lehm gasifier stove (report 1, section 3.3) or the gasifier stoves developed by Kaskad-E GmbH (Guthapfel and Gutzwiller 2016), the technology should only be applied if the biochar samples fulfill the conditions of the EBC biochar standard (especially regarding the PAH limit).

Priority area II: Based on an internal analysis report by Soil & More, the chlorine content in the dry rose residue compost is in the range of 520-820 mg kg^{-1}. The chlorine content in the root stocks has to be analyzed to determine whether this feedstock can be pyrolysed without the risk of dioxine formation.

Due to the high temperatures in the combustion chamber of large pyrolysis plants, organic pollutants potentially contained in the biomass feedstock (e.g. pesticide residues) are generally broken down and combusted. This safeguard misses in small-scale cookstoves. For that reason, the content of organic pollutants of local feedstock sources that may serve as fuel in gasifier cookstoves, such as coffee residues, should be analyzed.

6.2 Climate mitigation

To assess the climate impact of biochar systems, it is necessary to take into account the emissions and removal of greenhouse gases (in the given context, the greenhouse gases CO_2, CH_4 and N_2O are most relevant), as well as the changes in the soil albedo. The climate impact of the introduction of biochar systems cannot be determined without assessing the status quo with regard to biomass feedstock use, energy supply and agricultural production.

Box 2. Positive (green) and negative (red) climate impacts of a small-scale biochar system in priority area 1 and strategies to counteract the negative impacts (grey)

+	1) Reduction of the CO_2 - and CH_4 emissions of the outdoor residue storage 2) Replacement of fuel-wood use for cooking (reduction of connected GHG emissions) 3) Sequestration of carbon contained in the biochar produced from the coffee residues after biochar application to the soil 4) Reduction of the GHG emissions caused by the production of nitrogen fertilizer (since biochar can increase the nitrogen usage efficiency (Agegnehu et. al. 2016b)) 5) Reduction of the soil N_2O emissions (see Kammann et al 2012)
–	1) GHG emissions caused by the feedstock provision 2) GHG emissions caused by the manufacturing of the cook-stoves 3) GHG emissions caused by the biochar production 4) GHG emission caused by the biochar transport to the field and the biochar application 5) Albedo impact of biochar application (Meyer et. al. 2012) 6) Emission of ultrafine carbon aerosols (Maienza et al. 2017)
~	1) Usage of modern cook-stoves that burn the majority of the pyrolysis / gasification gases (they contain inter alia CH_4) 2) Local usage of the biochar, usage of low-energy intensive transport and application means 3) Continuous vegetation cover on the biochar-amended plots (to reduce the albedo impact) 4) Co-composting, pelletizing, moistening or mixing of biochar with moist substrates before application to minimize aerosol emissions 5) Incorporation into the soil

The following climate protections risks have to be addressed in the priority areas:

Priority area I: Not utilized coffee production residues are mostly stored on heaps outdoors. The aerobic and anaerobic decomposition of the coffee residue heaps and resulting CO_2- and CH_4-emissions represent the current status quo of this feedstock use.

The positive and negative impacts of a biochar system based on small scale gasifier cookstoves using coffee residues as feedstock are shown in box 2.

Priority area II: In the composting facility of the company Soil & More at Ziway, rose root stocks are sorted out of the rose plant residues before composting. The root stocks are stored on heaps and are currently not utilized. A slow (mainly aerobic) decomposition of the rose stock heap and resulting CO_2-emissions represent the current status quo of this feedstock use. It should also be noted that the majority of the roses produced in Ethiopia is being exported. Due to a long range transport and cooling demand, cut flowers cause average emissions of 11,5 kg CO_2 kg^{-1} (Grabolle et al. 2007).

The positive and negative effects of a large scale pyrolysis plant using rose root stocks as feedstock are shown in box 3.

The calculation of comprehensive climate impact balances (CIBs) for the two recommended biochars systems in Ethiopia is out of the scope of this report. However, the CIB for a large-scale biochar system based on wheat straw as feedstock, presented in Meyer et al. 2012 (figure 6), gives a first indication for the order of magnitude of the climate impact of biochar systems as specified for priority area II.

The ordinate of the figure shows the amount of CO_2-equivalent-emissions (positive values) and savings (negative values) per tonne of feedstock (dry mass). The biomass provision causes the most emissions , followed by the albedo impact of biochar applied to the field. The GHG emissions caused by the manufacturing of the pyrolysis plant and the GHG emissions caused by the biochar transport to the farm and the biochar application have a marginal impact on the climate. The major CO_2- savings of this biochar system is the balance of the biogenic CO_2-emissions (during pyrolysis) and the CO_2-sequestration (via biochar). In this context, it should be noted that biomass produced with short rotation periods (e.g. wheat straw, coffee husks or rose residues) generally has a more favorable impact on the climate than biomass produced with long rotation periods (e.g. wood). The replacement of the status quo energy use (natural gas based heat provision in the example

Box 3. Positive (green) and negative (red) climate impacts of a large-scale biochar system in priority area 2 and strategies to counteract the negative impacts (grey)

+

1) Reduction of the CO_2 - (and CH_4-)emissions of the current outdoor root stock storage
2) Replacement of the status quo energy supply for cooling purposes. The reduction of GHG emissions depends on the type of status quo energy supply: large reductions, if the energy is provided by diesel generators, whereas the replacement of hydro-power will result in marginal (or no) emission savings.
3) Sequestration of carbon contained in the biochar produced from the root stocks after biochar application to the soil
4) Reduction of the GHG emissions caused by the production of nitrogen fertilizer (since biochar can increase the nitrogen usage efficiency (Agegnehu et. al. 2016b))
5) Reduction of the soil N_2O emissions (see Kammann et al 2012)

–

1) GHG emissions caused by the feedstock provision
2) GHG emissions caused by the manufacturing of the pyrolysis plant
3) GHG emissions caused by the biochar production
4) GHG emission caused by the biochar transport to the farms and the biochar application
5) Albedo impact of biochar application (Meyer et. al. 2012)
6) Emission of ultrafine carbon aerosols (Maienza et al. 2017)

~

1) Usage of modern large scale pyrolysis systems that burn all pyrolysis gases (they contain inter alia CH_4)
2) Local usage of the biochar, usage of low-energy intensive transport and application means
3) Continuous vegetation cover on the biochar-amended plots (to reduce the albedo impact)
4) Co-composting, pelletizing, moistening or mixing of biochar with moist substrates before application to minimize aerosol emissions
5) Incorporation into the soil

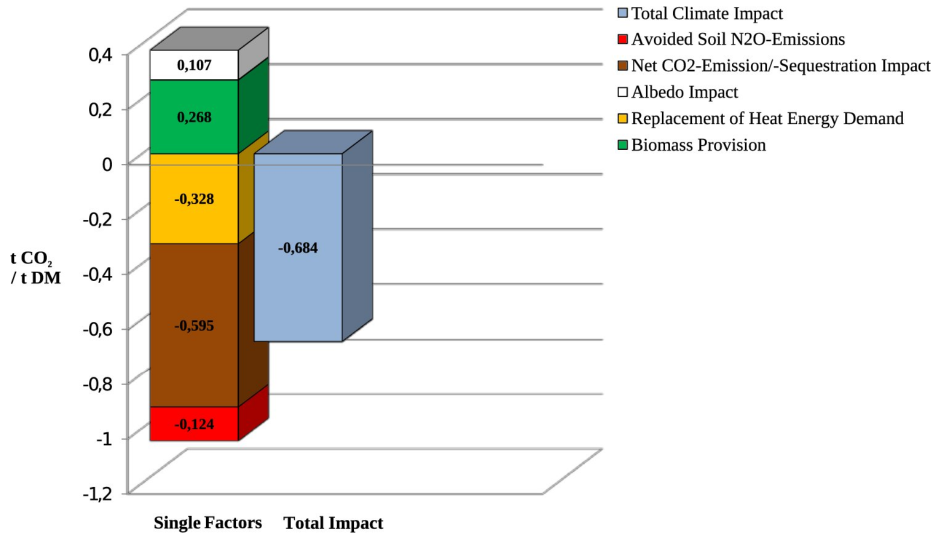


Figure 6. Climate impact (CO_2 emissions and savings) of a large-scale biochar system per tonne of wheat straw (DM) as annual feedstock (Meyer et al. 2012). The balance on the right side of the figure already includes the following minor climate impacts: Emissions: biomass transport (0,001 t CO_2 / t DM), production of the pyrolysis plant (0,02 t CO_2e / t DM) and the biochar transport to the field (0,001 t CO_2 / t DM). Savings: reduction in fertilizer production (- 0,034 t CO_2e / t DM).

by Meyer et al. 2012) by the excess heat of the pyrolysis process constitutes the next major CO_2-saving. Additionally, the assumed reduction in soil N_2O-emissions has an important cooling effect on the climate. The reduction of the GHG emissions caused by the production of nitrogen fertilizer has a minor impact. The reduction of the CO_2- and CH_4-emissions of an outdoor storage of the feedstock has not been assessed.

As illustrated on the right side of the figure, the net climate impact of the straw-based pyrolysis biochar system examined by Meyer et al. 2012 is positive. There is no reason to assume that the climate impact of a rose residues based biochar system in Ethiopia will deviate drastically from the illustrated result.

References

Abate, E., Hussein, S., Laing, M., Mengistu, F., 2016. Soil acidity under multiple land-uses: assessment of perceived causes and indicators, and nutrient dynamics in small-holders' mixed-farming system of northwest Ethiopia. Acta Agriculturae Scandinavica, Section B — Soil & Plant Science.

Agegnehu, G., Nelson, P.N., Bird, M.I., 2016. The effects of biochar, compost and their mixture and nitrogen fertilizer on yield and nitrogen use efficiency of barley grown on a Nitisol in the highlands of Ethiopia. Sci. Total Environ. doi:10.1016/j.scitotenv.2016.05.033

Berihun, T., Tadele, m., Kebede, F., 2017.. The application of biochar on soil acidity and other physico-chemical properties of soils in southern Ethiopia. J. Plant Nutr. Soil Sci. 2017, 000, 1–8. DOI: 10.1002/jpln.201600343

Byrne, C.E., Nagel, D.C., 1997. Carbonized wood monoliths – characterization. Carbon, vol 35 pp267-273

Downie, A., Monroe, P., Crosky, A., 2009. Chapter 2: Characteristics of Biochar – Physical and Structural Properties. In J. Lehmann & S. Joseph (Eds.), Biochar for Environmental Management: Science and Technology, Earthscan. pg. 13-29. ISBN: 978-1-84407-658-1

Dumroese, R.K., Heiskanen, J., Englund, K., Tervahauta, A., 2011. Pelleted biochar: chemical and physical properties show potential use as a

substrate in container nurseries 2018–2027.
Fascella, G., 2015. Growing Substrates Alternative to Peat for Ornamental Plants, Soilless Culture - Use of Substrates for the Production of Quality Horticultural Crops, Dr. Md Asaduzzaman (Ed.), InTech, DOI: 10.5772/59596
Fischer D., Glaser B. 2012. Synergisms between compost and biochar for sustainable soil amelioration. In: Sunil K, Bharti A (Eds.) Management of Organic Waste, pp. 167-198. InTech, Rijeka, Croatia, doi:10.5772/31200
Genesio, L., Vaccari, F. P., Miglietta, F., 2016. Black carbon aerosols from biochar threats its negative emissions potential, Global Change Biology 22(7): 2313–2314.
GIZ - ISFM+ Baselinestudy, 2015. Baseline Report (Phase 1) on the Integrated Soil Fertility Management Project (ISFM+) in Ethiopia
Grabolle, A., Loitz, T., Bexte, C., Grondey, A., Koch, S., Laskowki, F. 2007. Pendos CO2- Zähler. ISBN 978-3-86612-141-6
Guthapfel, N., and Gutzwiller, S., 2016. Final report: Dried coffee husk for cooking in gasifier stoves, Ethiopia. REPIC
Handbook for Greenhouse Rose Production in Ethiopia, 2011. DLV Plant, Wageningen UR, CBI, EHPEA
Hengsdijk, H., Jansen, H., 2006. Agricultural development in the Central Ethiopian Rift valley: A desk-study on water-related issues and knowledge to support a policy dialogue. Wageningen, Plant Research International B.V.. 32 pp.
Kammann, C., Ratering, S., Eckhardt, C., Müller, C., (2012): Biochar and Hydrochar Effects on Greenhouse Gas (Carbon Dioxide, Nitrous Oxide, and Methane) Fluxes from Soils. In: Journal of Environmental Quality 41. doi:10.2134/jeq2011.0132
Kassa, M.A., 2017. Review on Environmental Effects of Ethiopian Floriculture Industry. Asian Research Journal of Agriculture 4(2):1-13, 2017; Article no. ARJA. 31884. DOI: 10.9734/ARJA/2017/31884
Khorram, M.S., Zhang, Q., Lin, D., Zheng, Y., Fang, H., Yu, Y., 2016. Biochar: A review of its impact on pesticide behavior in soil environments and its potential applications. Journal of Environmental Sciences 44, 269–279. doi:10.1016/j.jes.2015.12.027
Kim, D. S., & Ferreira, C. I. 2008. Solar refrigeration options–a state-of-the-art review. International Journal of refrigeration, 31(1), 3-15.
Lemma, E., 2011. Assessment of soil acidity and determination of lime requirement for different land-use types: The case of Degem woreda, North Shoa zone, Northwestern Ethiopia. MSc Thesis, Addis Abeba University, Ethiopia.
Meyer S., Bright R., Fischer D., Schulz H., Glaser B. (2012). Albedo Impact on the Suitability of Biochar Systems To Mitigate Global Warming. Environmental Science & Technology 46 (22): pp 12726–12734, doi: 10.1021/es302302g
MoANR – Ethiopian Ministry of Agriculture and Natural Ressources, 2016. Field Guide Technical Implementation – Integrated Soil Fertility Management. Sustainable Land Management Programme (SLMP) Training Series. Addis Abeba.
Moncada, J., 2001. Spatial distribution of pesticide contamination potential around lake Naivasha, Kenya. MSc Thesis at International Institute for Aerospace Survey and Earth Sciences, NL.
Northup, J., 2013. Biochar as a replacement for perlite in greenhouse soilless substrates. Graduate Theses and Dissertations. Paper13399. Iowa State University.
Pink GmbH. 2017. Kühlsysteme. Retrieved June 02,2017 from: http://www.pink.co.at/kuehlsysteme.htm
Reggentin, L. 2016. Die Reise der Rose. Deutsche-Verkehrs-Zeitung. Retrieved May 26,2017 from: http://www.dvz.de/rubriken/logistik-verlader/single-view/nachricht/die-reise-der-rosen.html
Schwarz, A. 2013. Thermische Kühlung - Kühlen mit Wärme. VDI Presentation CT Energie. Retrieved May 26,2017 from: https://www.vdi.de/fileadmin/vdi_de/redakteur/bvs/bv_karlsruhe_dateien/SorTech-KuehlenMitWaerme_2013.pdf
Srikhirin, P., Aphornratana, S., & Chungpaibulpatana, S. 2001. A review of absorption refrigeration technologies. Renewable and sustainable energy reviews, 5(4), 343-372.
Steiner, C., Harttung, T., 2014. Biochar as a growing media additive and peat substitute. Solid Earth, vol 5, pp995–999. doi:10.5194/se-5-995-2014
Tian, Y., Sun, X., Li, S., Wang, H., Wang, L., Cao, J., Zhang, L., 2012. Biochar made from green waste as peat substitute in growth media for Calathea rotundifola cv. Fasciata. Scientia horticulturae

143, 15–18.

Tirado, S.M., Michel, F.C., 2010. Effects of Turning Frequency, Windrow Size and Season on the Production Of Dairy Manure/Sawdust Composts. Compost Science & Utilization 18, 70–80.

Tiquia, S.M., Richard, T.L., Honeyman, M.S., 2002. Carbon, nutrient, and mass loss during composting. Nutrient Cycling in Agroecosystems 62, 15–24. doi:10.1023/A:1015137922816

Verma, R., Badole, W.P., Deewan, P., Meena, V.S., 2014. Carbon and Weight Loss during Composting of Wheat Straw by Different Methods. Annals of Biology 30 (2) :354-357

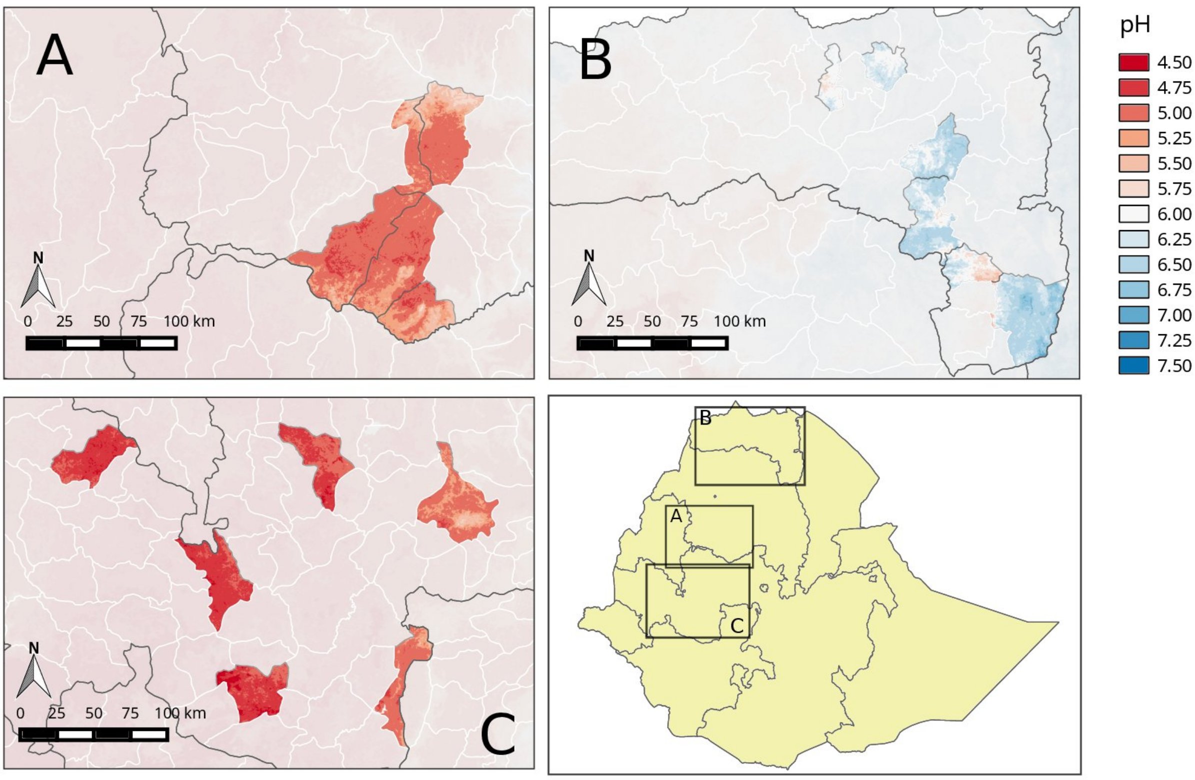
Appendix A

Livelihood zones within the ISFM+ project woredas, according to An Atlas of Ethiopian Livelihoods (USAID, 2011)

Region	Livelihood Zone
Amhara	
	Abay Beshilo River Basin
	Central Highland Barley and Potato
	South-West Woyna Dega Wheat
	South-East Woyna Dega Teff
Tigray	
	Alaje Ofla Highland
	Central Mixed Crop
	Middle Tekeze
	Enderta Dry Midland
	Raya Valley
	West Central Teff
Oromia	
	Chebo-Inchini Enset, Barley & Cattle
	Didessa-Gibe-Wama Valley Sorghum, Maize & Oilcrops
	Nadda-Gilgel Gibe Maize, Teff and Sorghum
	Nole-Meko-Diga Teff & Cattle
	Wellega Coffee, Maize & Sorghum
	Muger-Abay-Jema Sorghum & Teff Belt
	Jimma-Illubabur Coffee, Cereals & Chat

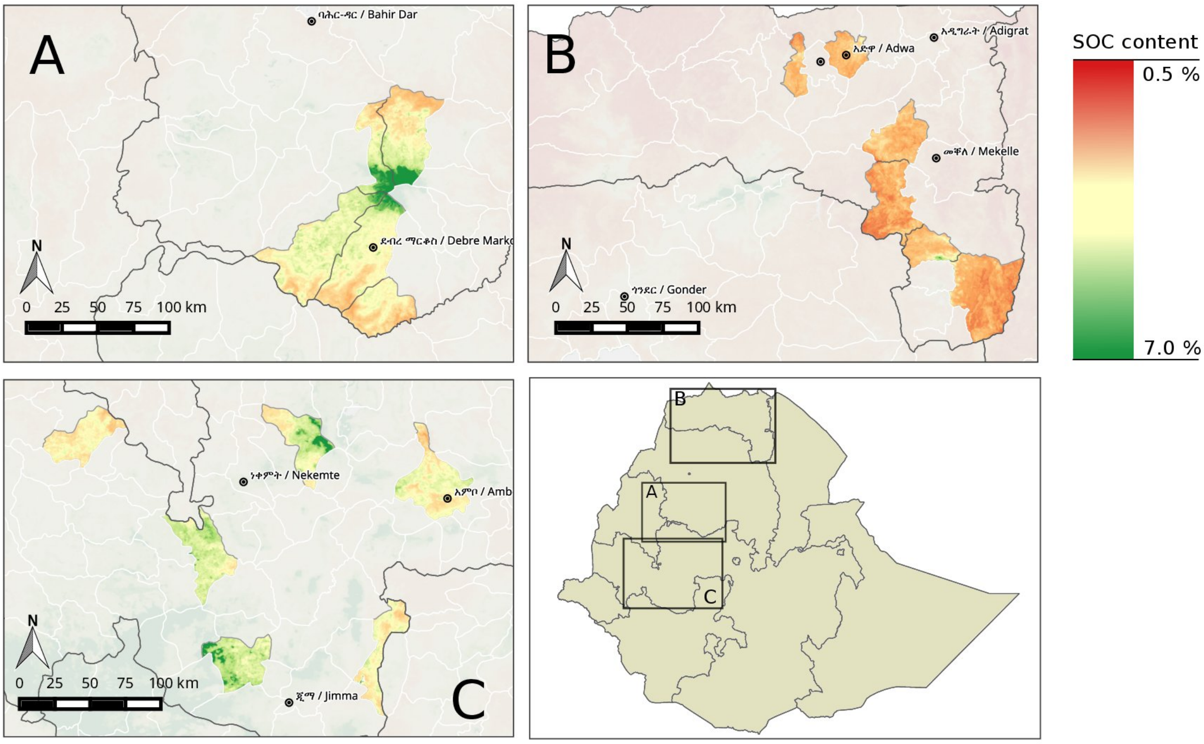
Appendix B I

pH in ISFM+ project woredas (based on data from ISRIC - soilgrids.org)



Appendix B II

SOC content in ISFM⁺ project woredas (based on data from ISRIC - soilgrids.org)



Appendix C

Clusters, towns, flower production area and waste production in priority area 2 (based on internal data from Ethiopian Horticulture Development Agency)

Parts of the priority area	Towns	ha	Waste production per year [t]
Central Oromia /West Addis		355.53	36,975
	Sebeta	120.13	
	Tefki	2.4	
	Holeta	102.1	
	Woliso	27.5	
	Menagesha	26.4	
	Addis Alem	77	
Central Oromia /South Addis		152	15,808
	Debre zeyit	132	
	koka	20	
South Oromia		428.5	44,564
	Ziway	428.5	

Appendix D

List of pesticides used in Kenyan rose production (period 1999-2000) (taken from Moncada 2001)

Alliette	Lannate	Rafast
Apollo	Meltatox	Rovral
Bavistin	Milraz	Rubigan
Bravocarb	Mitac	Saprol
Bulldock	Nemacur	Scala
Cascade	Nimrod	Spare-kill
Daconil	Nomolt	Stroby
Dimilin	Nustar	Tedion
Dithane M45	Oscar	Temik/Furadan
Dynamec	Previcur	Thiodan
Equation PRO	Pride	Thiovit
		Vydate