STRATEGIES FOR ORGANIC- AND LOW-INPUT-FARMING TO MITIGATE AND ADAPT TO CLIMATE CHANGE (SOLMACC)

A BROCHURE FOR PROFESSORS, STUDENTS AND TRAINEES

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The Scope of the Brochure and the Student Tool Box

Organic farming is an agriculture system that tries to achieve several, complementary goals; protecting ecosystem services, providing income for the farmers and healthy nutrition for consumers. Unfortunately, climate change affects every farmer, regardless if conventional, integrated or organic. In order to reduce greenhouse gas emissions and to help the farmers adapt to the negative climate change impacts, climate-friendly and resilient farming practices are needed. These should reduce GHG emissions, they should be economically and technically feasible and maintain ecosystem services. It is a challenge for the EU farmers and the EU policymakers to achieve these goals.

The project *Strategies for Organic- and Low-input-farming to mitigate and adapt to Climate Change (SOLMACC)* seeks to promote a wider adoption of innovative practices that can contribute to reaching the EU's climate change mitigation and adaptation objectives in the food and farming sector.

Professors, students, trainees and other interested persons are the future of the (organic) farming sector in the EU. Their management decisions will have an impact on whether the agriculture sector maintains ecosystem services, such as biodiversity and reduces greenhouse gas emissions from agricultural production.

Therefore, the SOLMACC project aims to increase knowledge and thereby to spread climate-friendly and resilient farming practices among relevant stakeholders. Part of this effort is the Student Toolbox, where presentations and material is provided for professors, students and other interested persons (Available at: http://solmacc.eu/toolbox/). This brochure outlines why it is important to integrate climate-friendly and resilient farming practices into the curriculum of universities, universities of applied sciences and/or trainee programs. It further presents how the SOLMACC project´s results and the work of the farmers on the demonstration farms can be included in schools 'and universities 'curricula to give students a better insight into climate-friendly farming. The brochure addresses students and trainees in the food and farming sector and was developed by the SOLMAC project team, students of the Justus-Liebig University Giessen and the Chair in Organic Farming with focus on Sustainable Soil Use, Justus-Liebig University Giessen.

This brochure describes what the SOLMACC Student Toolbox is about (Chapter 1), why it is important to learn more about climate-friendly and resilient farming practices (Chapter 2) and what students can learn from the SOLMACC project and its demonstration farms (Chapter 3). Last, an example Master Module is shown (Chapter 4).

We hope that you enjoy the provided material and wish you an interesting learning experience about climate-friendly and resilient farming practices in the EU!

Cordially,

Your SOLMACC team

Abbreviations

C	Carbon
CH_4	Methane
CO_2	Carbon dioxide
GHG	Greenhouse gas
LUC	Land use change
LULUCF	Land Use and Land Use Change
N	Nitrogen
N_2O	Nitrous oxide
SOC	Soil Organic Carbon
SOLMACC	Strategies for Organic- and Low-input-farming to mitigate and adapt to Climate Change

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1. How to Use the Student Toolbox and the Brochure?

Students from agriculture schools, universities and colleges are the farmers, farm advisors, scientists or policy makers of the future. Therefore, we believe it is vital that they learn about the challenges that climate change poses to farming as well as potential solutions to mitigate and adapt to the effects of climate change.

The SOLMACC Student Toolbox functions offers information in 4 languages (English, Italian, German and Swedish). You can access the homepage from the official SOLMACC webpage: http://solmacc.eu/toolbox/

The Student Toolbox includes:

- Scientific presentations, reports and information for students, researchers and farmers.
- Information about the SOLMACC field days at the demonstration farms in Italy, Germany and Sweden.
- Policy backgrounds and debates of agricultural legislation, such as the CAP.
- Presentations of SOLMACC events, where climate-friendly and resilient farming topics are discussed.

Regardless, if you are a professor, a student, a trainee or just generally interested in climate-friendly and resilient farming and the respective agricultural policies; we invite you to explore the provided materials on the homepage.

This brochure provides a first overview of:

- why climate-friendly and resilient farming is important (Chapter 2),
- how the SOLMACC project promotes climate-friendly agricultural practices (Chapter 3.1),
- which farms are part of the SOLMACC project, so that students can learn first-hand from the farmers (Chapter 3.2) and
- how a master module at your university could look like (Chapter 4).

2. Why is Climate Change Relevant for Agricultural Education?

Within the last years, it became clear that the European agriculture and food sector is perpetrator and victim at the same time regarding the magnitude of climate change. On the one hand, the food sector causes GHG emissions through agricultural and livestock practices, food waste, transportation, land use change (LUC) and the production of agrochemicals. The direct GHG emissions from agriculture account for around 10 % of the total EU GHG emissions in 2012.[1] The main GHG emissions from agriculture are caused by:

- Methane (CH_4): 54.5% of agricultural emissions,
- Nitrous oxide (N_2O): 43.2% of agricultural emissions and
- Carbon dioxide (CO_2): 2.3% of agricultural emissions.[2]

Methane (CH_4) emissions from enteric fermentation and nitrous oxide (N_2O) emissions from managed soils are the main contributor of direct agricultural GHG´s in the EU with 43 % and 31 %, respectively (see Figure 1). In order to reach the EU climate goals, agricultural practices need to be implemented which reduce GHG emissions from this sector.

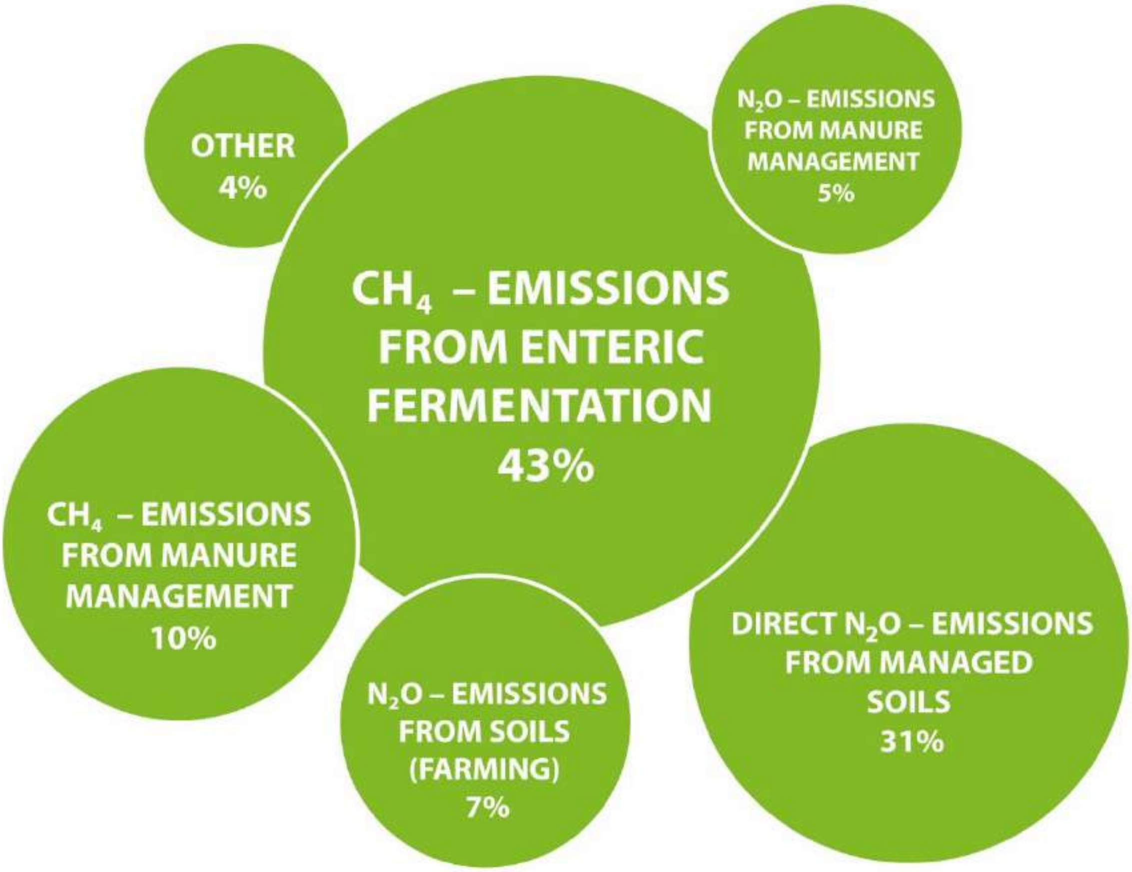

Figure 1: Direct agricultural emissions breakdown for EU in 2014 (based on Danila et al. (2016)[3], by PlanGreenIllustration)

On the other hand, agricultural production does not only need to reduce further GHG emissions, but also to protect itself from negative climate change impacts in order to still secure European's food security and farmer's

[1] Eurostat, 2015. Agriculture – greenhouse gas emission statistics. European Union. Available at: http://ec.europa.eu/eurostat/statistics-explained/index.php/Agriculture_-_greenhouse_gas_emission_statistics (03.04.2017)

[2] DANILA, A. M., FERNANDEZ, R., NTEMIRI, S., MANDL, N. & RIGLER, E. 2016. Annual European Union greenhouse gas inventory 1990–2014 and inventory report 2016: Submission to the UNFCCC Secretariat. *EEA Report No 15/2016.* European Commission, DG Climate Action, European Environment Agency, Brussels.

[3] Ibid.

income. Weather extremes, water scarcity and rising temperatures challenge farmers in many European regions already now and strategies are required to make farming enterprises and operations less vulnerable to these weather fluctuations and climate changes.

Considering the implications of climate change on agriculture production and productivity, it is essential that future farmers learn more about climate change and climate-friendly/resilient farming practices.

The SOLMACC Student Toolbox provides further information on:

- how agriculture leads to further GHG emissions,
- how agriculture production is influences by climate change and
- what farmers can do to reduce GHG emissions.

3. What Can We Learn From SOLMACC?

To reduce GHG emissions from the agricultural production in the EU diverse measures, strategies and approaches can be applied. One approach with a large mitigation potential is the **conversion from conventional to organic farming techniques**. Recent meta-studies reveal that soil organic carbon stocks were 3.5 metric tons per hectare higher in organic than in non-organic farming systems and that organic farming systems sequestered up to 450 kg more atmospheric carbon per hectare and year through CO_2 bound into soil organic matter[4].

Furthermore, a global analysis of 18 studies has shown that area-scaled nitrous oxide emissions from organically managed soils are on average 492 kg CO_2 eq. per hectare and year lower than those from non-organically managed soils [5]. With regards to methane fluxes on arable land, organic management leads to marginally higher uptake rates (ø 3.2 kg CO_2 eq. ha^{-1} a^{-1}) compared to non-organic management. Additionally, organic agriculture can help to reduce GHG emissions from:

- Fossil fuel consumption
- The use of synthetic agrochemicals (fertilizers, pesticides, herbicides)
- Energy used at the farm
- The use of concentrate feed[6].

The superior effects of organic farming systems compared to conventional farming systems on GHG emissions are more likely to be observed for field crops, dairy and mixed farms and less likely for pure livestock, fruit and vegetable farm [7]. Furthermore, the superiority of GHG mitigation of organic farming depends on the measurement units. In many cases, if GHG emissions are based on the yields of products, the so called output-based measures (GHG/kg product), the mitigation potential of organic farming systems is reduced. Mainly, because organic agriculture tends to have, on average, lower yields than conventional agricultural systems. On an area-based measurement (GHG/ha/year), the positive effects of organic farming are unambiguously visible. In particular, if co-benefits of organic farming systems are considered as well (e.g. biodiversity protection, animal welfare, maintenance/enhancement of soil fertility)[8].

Besides the conversion from conventional to organic agriculture, other mitigation practices can be utilized to reduce GHG emissions. These can be applied for both organic and conventional farms. The SOLMACC project concentrates on 4 overarching practices, which are:

1. Optimized nutrient management
2. Optimized crop rotations
3. Optimized tillage management
4. Agroforestry

These practices and their potential for climate change mitigation are explained shortly below and further information about the practices and their implementation at the SOLMACC demonstration farms can be utilized at the SOLMACC Student Toolbox online.

[4] GATTINGER, A., MULLER, A., HAENI, M., SKINNER, C., FLIESSBACH, A., BUCHMANN, N., MÄDER, P., STOLZE, M., SMITH, P., SCIALABBA, N. E.-H. & NIGGLI, U. 2012. Enhanced top soil carbon stocks under organic farming. *Proceedings of the National Academy of Sciences,* 109**,** 18226-18231. AGUILERA, E., LASSALETTA, L., GATTINGER, A. & GIMENO, B. S. 2013. Managing soil carbon for climate change mitigation and adaptation in Mediterranean cropping systems: A meta-analysis. *Agriculture, Ecosystems & Environment,* 168**,** 25-36.

[5] SKINNER, C., GATTINGER, A., MULLER, A., MÄDER, P., FLIEBBACH, A., STOLZE, M., RUSER, R. & NIGGLI, U. 2014. Greenhouse gas fluxes from agricultural soils under organic and non-organic management — A global meta-analysis. *Science of The Total Environment,* 468–469**,** 553-563.

[6] BELLARBY, J., FOEREID, B. & HASTINGS, A. 2008. Cool farming: Climate impacts of agriculture and mitigation potential. Greenpeace International, Amsterdam.

[7] LEE, K. S., CHOE, Y. C. & PARK, S. H. 2015. Measuring the environmental effects of organic farming: A meta-analysis of structural variables in empirical research. *Journal of Environmental Management,* 162**,** 263-274.

[8] MEIER, M. S., STOESSEL, F., JUNGBLUTH, N., JURASKE, R., SCHADER, C. & STOLZE, M. Ibid.Environmental impacts of organic and conventional agricultural products – Are the differences captured by life cycle assessment? 149**,** 193-208.

3.1 The Implemented Climate-Friendly and Resilient Farming Practices of SOLMACC

The 12 demonstration farms of SOLMACC, situated in Italy, Germany and Sweden, implemented 4 climate-friendly and resilient farming practices each.

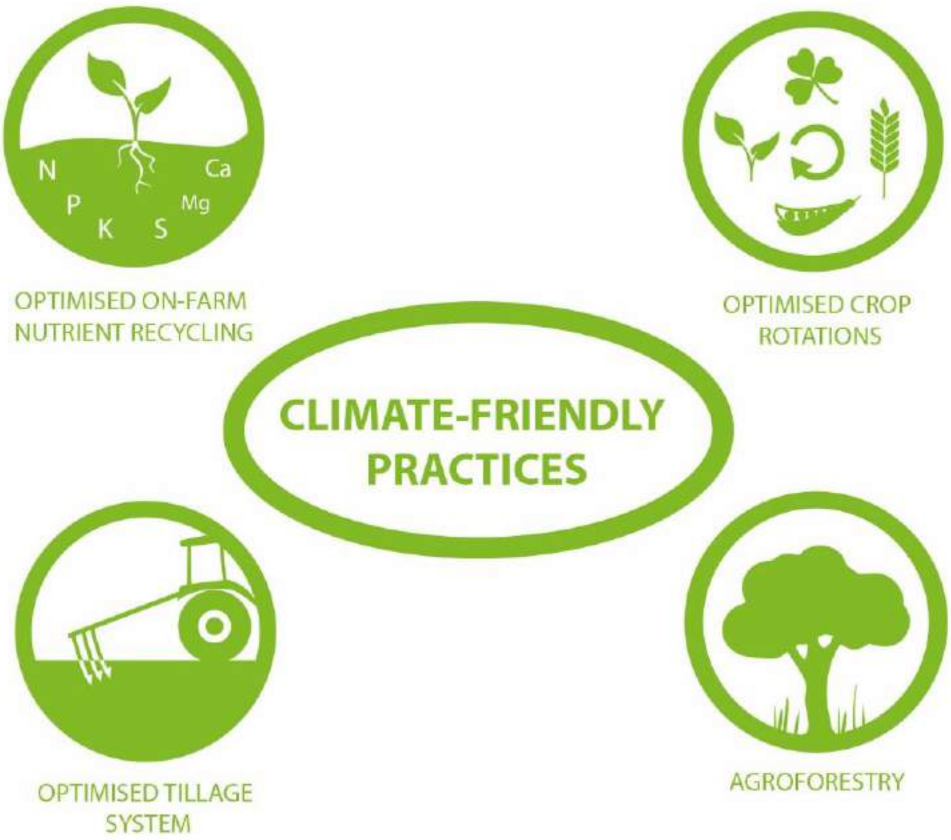

Figure 2: The 4 implemented climate-friendly agricultural practices of the SOLMACC farms (PlanGreenIllustration, 2017)

3.1.1 Optimized Nutrient Management

Organic agriculture aims at closing on-farm nutrient cycles and thereby reducing the import of external inputs. Nitrogen (N) is one of the most limiting factor in plant nutrition and therefore often fertilizer needs to be applied to allow sufficient plant growth[9] These are in conventional agriculture mainly synthetically produced products, while organic agriculture utilizes animal derived fertilizers (manure, slurry, biogas slurry), plant derived products (mulching, compost) or N-enhancing crop rotation systems. The production, storage and application of N fertilizers can lead to environmental impacts, such as global warming (due to N_2O emissions), air pollution/eutrophication (due to leaching/emissions of NH_3) and groundwater contamination (due to leaching NO_4). Furthermore, anaerobic conditions during the turnover of organic matter (e.g. in compost production or manure management) cause methane emissions. Along with further specialisation in the organic farming sector, however, nutrient gaps occur, especially in the case of farms with no or little livestock and poor access to cost-effective organic fertiliser. The solution lies in an optimisation of on-farm nutrient cycles.

[9]LEITHOLD, G., HÜLSBERGEN, K.-J. & BROCK, C. 2015. Organic matter returns to soils must be higher under organic compared to conventional farming. *Journal of Plant Nutrition and Soil Science,* 178**,** 4-12.

Possible options, besides others, could be:

- Composting of farmyard manure from livestock or composting of grass-clover and livestock manure and/or other materials (e.g. residues from wine and olive processing)[10]
- Biogas production from liquid wastes and utilization of biogas slurry, clover-grass silage for fertilisation.
- Cooperation between stockless farms and mixed farms (e.g. by exchanging grass-legume biomass harvested at the stockless farm with biogas slurry produced at the mixed farm) to close nutrient cycles and to reduce import of livestock feed[11].

3.1.2 Optimized Crop Rotations

The crop rotation has a direct influence on GHG emissions of the farm. While conventional farming is mainly consisting of single crops (monocultures), organic farming utilizes crop rotations that help to maintain soil fertility. The use of leguminous crops in the crop rotation cycle can help to stabilize or enhance soil fertility, sequester carbon (C), fixing N and therefore reducing GHG emissions[9]. Also, the introduction of cover crops into the crop rotation as green manure increases soil organic carbon (SOC) stocks with a mean C – sequestration rate of 0.32 Mg ha^{-1} a^{-1} without a decline in yields of the farming system or carbon losses in other systems[12].

In organic livestock farms, grass-legume leys (alfalfa, red and white clover, etc.) are a relatively common practice, as the grass-legume mix can be used as fodder and the positive effects on soil fertility, pest management and nitrogen fixation in the soil are well known. However, for stockless farms even under organic management, the grass-legume biomass management (e.g. mulching) causes a loss of financial value and nutrients, along with further nitrous oxide released.

In order to reduce GHG emissions on the farms, SOLMACC farmers implement different changes in their crop rotation systems, depending on their farm structures, size and technical/financial possibilities. For example, they:

- Introduced/extended grain legumes in their crop rotation systems, such as soya, beans, winter peas and lupines. These legumes substitute cereals cropped and help to fix nitrogen (reducing of N_2O emissions) and additionally sequester carbon.
- Introduced/extended forage legumes in the crop rotation.

3.1.3 Optimized Tillage Management

Tillage practices influence the soil carbon contents and if too intensive and frequent tillage is performed, CO_2 emissions are released from the soil. Reduced tillage practises are common in conventional farming. However, they often depend on the use of agrochemicals to decrease associated weed pressure and thus crop yield reductions. In organic farming, reduced tillage is a challenge, because of the higher weed pressure associated with a reduction of tillage. A reduced tillage intensity can lead up to 7.6 % lower yields compared with conventional tillage, whereby there are differences between the classes of reduced tillage systems, management practices and environment. With regards to shallow non-inversion tillage there is no significant reduction in yield and weed incidence compared with the conventional plough[13]. However, reduced tillage systems have a potential GHG mitigation through the

[10] SCHADER, C., JUD, K., MEIER, M. S., KUHN, T., OEHEN, B. & GATTINGER, A. 2014. Quantification of the effectiveness of greenhouse gas mitigation measures in Swiss organic milk production using a life cycle assessment approach. *Journal of Cleaner Production,* 73**,** 227-235.
[11] MÖLLER, K. & STINNER, W. 2009. Effects of different manuring systems with and without biogas digestion on soil mineral nitrogen content and on gaseous nitrogen losses (ammonia, nitrous oxides). *European Journal of Agronomy,* 30**,** 1-16.
[12] POEPLAU, C. & DON, A. 2015. Carbon sequestration in agricultural soils via cultivation of cover crops – A meta-analysis. *Agriculture, Ecosystems & Environment,* 200**,** 33-41.
[13] COOPER, J., BARANSKI, M., STEWART, G., NOBEL-DE LANGE, M., BÀRBERI, P., FLIEßBACH, A., PEIGNÉ, J., BERNER, A., BROCK, C., CASAGRANDE, M., CROWLEY, O., DAVID, C., DE VLIEGHER, A., DÖRING, T. F., DUPONT, A., ENTZ, M., GROSSE, M., HAASE, T., HALDE, C., HAMMERL, V., HUITING, H., LEITHOLD, G., MESSMER, M., SCHLOTER, M., SUKKEL,

reduction of fuel consumption and an increase SOC stock compared to ploughed systems. There is no effect observed for N_2O and CH_4 emissions[14].

It is shown, that tillage intensity can be reduced also on organic farms, which can vary from less frequent and less deep ploughing over ploughless up to organic no-till. A change of the tillage practice, however, often needs additional means of weed control and nutrient provision such as the implementation of crop mixtures and green manure crops, if no synthetic herbicides are applied. The project TILMAN-ORG (project duration 2011-2014) analysed how reduced tillage is practicable without the application of herbicides. The results show that for organic farming that ideally farmers should:

- reduce the intensity of ploughing by operating less deep and less frequent
- replace the mouldboard plough with other machinery (e.g. specific cultivator, disc harrow, skim plough, roller crimper will be rented if applicable)
- apply reduced tillage depth
- optimise crop rotationusing cover crops and tillage timing to reduce weed pressure.

The SOLMACC farmers apply different reduced tillage/no-tillage techniques, depending on their local climate, soil types, crops cultivated and their technical/economic possibilities in order to reduce GHG emissions associated with tillage practices.

3.1.4 Agroforestry

Agroforestry and landscape element (e.g. boundary hedges) have a great potential to sequester carbon at farm fields, can improve dry matter yields of the entire farming systems, help to increase the nitrogen-use efficiency and reduce N – surpluses[15]. Palmer et al. (2007) estimates the carbon sequestration potential of agroforestry trees in Europe over a 60 year growing period between 5-179 t C ha-1, depending on the tree species. Besides the carbon sequestration potential, the authors highlight that agroforestry systems provide ecosystem services including the reduction of erosion, decrease of nitrogen leaching and the increase of biodiversity[16].

Therefore, agroforestry systems reduce GHG emissions on the farm and provide additional co-benefits for the environment and the farmer.

During the past three decades, agroforestry has become recognised globally as an integrated approach to sustainable land use because of its environmental benefits. Within the last decade, agroforestry "re-entered" again also the European agriculture, including organic productions. Agroforestry is a term describing a system that combines trees, crops and potentially also livestock, managed as a whole production unit. The main agroforestry systems in Europe are:

- Shelterbelts/windbreaks consisting of one or more rows of trees planted on the farm where the biomass from trees can be utilized for bioenergy purposes.
- Riparian buffer strips consisting of trees that can filter surface run-off, protect stream banks and shorelines from erosion.
- Alley cropping systems, consisting of perennial trees, planted in single or grouped rows and annual agricultural crops grown in alleys between tree rows.
- Silvopastures combining planted trees with livestock and/or forage production in one pasture.

W., VAN DER HEIJDEN, M. G. A., WILLEKENS, K., WITTWER, R. & MÄDER, P. 2016. Shallow non-inversion tillage in organic farming maintains crop yields and increases soil C stocks: a meta-analysis. *Agronomy for Sustainable Development,* 36**,** 22.

[14] KRAUSS, M., KRAUSE, H.-M., SPANGLER, S., KANDELER, E., BEHRENS, S., KAPPLER, A., MÄDER, P. & GATTINGER, A. 2017. Tillage system affects fertilizer-induced nitrous oxide emissions. *Biology and Fertility of Soils,* 53**,** 49-59.

[15] LIN, H.-C., HUBER, J. A., GERL, G. & HÜLSBERGEN, K.-J. 2016. Nitrogen balances and nitrogen-use efficiency of different organic and conventional farming systems. *Nutrient Cycling in Agroecosystems,* 105**,** 1-23.

[16] PALMA, J. H. N., GRAVES, A. R., BUNCE, R. G. H., BURGESS, P. J., DE FILIPPI, R., KEESMAN, K. J., VAN KEULEN, H., LIAGRE, F., MAYUS, M., MORENO, G., REISNER, Y. & HERZOG, F. 2007. Modeling environmental benefits of silvoarable agroforestry in Europe. *Agriculture, Ecosystems & Environment,* 119**,** 320-334.

The SOLMACC farmers established different agroforestry and landscape elements. Some of them already had established agroforestry systems with the start of the project. Therefore, agroforestry activities focus on:

- Optimising the use and shape of existing agroforestry elements
- Advising and encouraging farmers to plant new agroforestry elements
- Modelling the impact of agroforestry and landscape element on GHG emissions at farm levels.

3.2 First Hand Experiences – The SOLMACC Demonstration Farms and Farmers

Since the beginning of the project in 2013, a total of 12 innovative, organic farms situated in Germany, Italy and Sweden (see Figure 3) implement organic farming practices with the potential for GHG mitigation and climate change adaptation.

For the implementation, a bottom-up approach is applied. The farmer priorities were taken into account for the design and the final implementation of a set of four practices addressing on-farm nutrient recycling, crop rotation, soil tillage and agroforestry. This bottom-up approach was chosen to raise the farmers' motivation for climate-friendly agriculture also beyond the duration of the SOLMACC project.

An advisory team consisting of scientists from the Research Institute of Organic Agriculture (FiBL), a farm advisor and the representatives of the national organic famer´s association support the farmers individually during the 5 years, to guarantee that the practices are well implemented and proceeded.

All the farms organize open field days regularly, where the implemented SOLMACC practices are demonstrated and explained to students, other farmers and interested persons. During these events, scientific presentations about climate-friendly and resilient farming are held and there´s room for open discussions and exchange.

German demonstration farms

The demonstration network in Germany is coordinated by the advisory service of Bioland. The Bioland Beratung GmbH and its associates give expert advice to over 5000 organic farming businesses in all federal states and all associations as well as in the EU. The SOLMACC demonstration farms are:

Bioland farm Kreppold
Bioland farm Kornkammer Haus Holte GbR
Bioland farm Pfänderhof GbR
Bioland farm Gut Krauscha

Swedish demonstration farms

Ekologiska Lantbrukarna is coordinating the demonstration network in Sweden. The Swedish SOLMACC farms are:

Hånsta Östergärde
Körslätts Gård
Trägsta Gård
Sötåsen

Italien demonstration farms

The Italian demonstration network is coordinated by the Italian Association for Organic Farming (AIAB). It is organized by regional chapters coordinated by the federal office in Rome. AIAB promote organic farming as a model of rural development. The Italian SOLMACC farms are:

Azienda agricola Fontanabona
Azienda agricola Caramadre
Azienda agricola Mannucci Droandi
Azienda agricola Tamburello

Figure 3: Distribution of demonstration farms in Europe

3.2.1 German SOLMACC Farms

Bioland farm Kreppold

The Bioland farm Kreppold lies in Baveria and farms a total of 112 ha sandy to loamy soils consisting of cereals and legumes (64 ha), grassland (20 h), root crops (23 ha) and field vegetables (5 ha). The focal points of operation are arable farming and suckler cow husbandry (40 GV).

On this farm you can learn more about:

- how cattle manure, hedgerows and tree strips can be composted climate-friendly,
- how grain legumes help to reduce GHG emissions and
- how weed pressures by reduced tillage practices can be managed.

Implemented improved practises:

Work Package	Key activities	Expected results
Improved on-farm nutrient management	**Forage-manure cooperation and composting of on-farm residues** 1. Third cut of forage legumes is collected by a nearby organic livestock farm instead of mulching. In exchange 10-15 m^3/ha cattle slurry is brought back to croplands. 2. Composting is performed with cattle manure and garden waste from private houses.	With this practice, N_2O emissions from mulching are avoided, N fixation of forage legumes is increased and organic fertilisation of croplands enables better yields and C sequestration. Due to the regular turning of the compost piles, CH_4 emissions are reduced. Regular compost application contributes to C sequestration in soil.
Optimised crop rotations with legumes	**Introduction of grain legumes and maintenance of existing forage legumes** Farm introduced soya beans in recent years and together with other grain and forage legumes, the proportion of legumes in crop rotation is 34 %.	Legume crops contribute to N fixation (reduction of N_2O emission) and C sequestration.
Optimised tillage systems	**Reduced tillage and undersown crops** Farm avoids ploughing after grain legumes. Furthermore, basic tillage operations are avoided for grass-clover due to undersown clover in sunflower.	By employing these practices diesel consumption will be reduced along with humus accumulation in soil (C sequestration).
Agroforestry	**Hedgerows and tree strips along agricultural fields** The farm installed hedgerows and tree strips, along with 6 ha forest. Part of the woody biomass is used for composting; the energetic use of wood chips replaces fossil fuel	This lead to C sequestration in above- and belowground biomass and in soil. CO_2 mitigation due to replacement of fossil fuels.

Bioland farm Kornkammer Haus Holte GbR

The stockless Bioland farm Korn-Kammer Haus Nolte is situated in North Rhine-Westphalia and has a total of 200 ha with mainly loess soil. The roots of Mr. Liedmann lie in the ecologic movement. Being a carpenter, 1987 he just started organic farming in order to do something practically in terms of ecology. Insofar ecology and sustainability of organic farming is something that concerns him to date. The source of his knowledge is thorough observations and experimenting.

On his farm you can learn more about:

- how organic arable farming can be done without own livestock manure,
- how cooperation among farmers help to maintain soil fertility and
- how agroforestry elements can be used to heat your house.

Implemented improved practises:

Work Package	Key activities	Expected results
Improved on-farm nutrient management	**Anaerobic treatment (biogas) of on-farm residues** Maize is replaced by grass clover mixture and first cut of grass clover mixture is shipped to nearby biogas fermentation plant, instead of mulching. Production of electricity and heat energy Liquid and solid residues are brought back to croplands.	N_2O emissions from mulching are avoided, N fixation of forage legumes is increased and organic fertilisation of croplands enables better yields and C sequestration. Replacement of fossil fuels.
Optimised crop rotations with legumes	**Maintenance of existing grain and forage legumes** Cereals instead of broad beans, forage legumes (1^{st} cut) instead of conventional maize as substrate for biogas production. Cropping of forage and grain legumes is maintained	Legume crops contribute to N fixation (reduction of N_2O emission) and C sequestration.
Optimised tillage systems	**Reduced tillage** Farm avoids ploughing after spelt cropping (3x working with grubber; depth: 10 cm). No ploughing prior to potatoes, too.	By employing these practices diesel consumption will be reduced along with humus accumulation in soil (C sequestration).
Agroforestry	**Hedgerows and tree strips along agricultural fields** The farm installed hedgerows and tree strips. Part of the woody biomass is used for heating.	This lead to C sequestration in above- and belowground biomass and in soil. CO_2 mitigation due to replacement of fossil fuels.

Bioland farm Pfänderhof GbR

The Pfänderhof farm is located in Bavaria cultivate on 48 ha loess clay soils and alluvial soils field vegetable crops (23 ha) and clover grass / grain (18 ha) primarily. In addition, potatoes are grown (5 ha). There is little (2 ha) grassland on the farm.

An important issue for Johannes and Florian Pfänder is the concept of a largely closed farm cycle especially with regard of his own farm having many intensive vegetable crops but no animal husbandry. A conscious decision for vegetarianism of the whole family is an important foundation for running the farm. This forms the basis for the renunciation of farm animals as well as animal manure (except some minor amounts of horse dung from neighboring farms).

On his farm you can learn more about:

- how compost can be produced by plant residues,
- how undersown clover helps to promote reduced tillage and
- how wood chips can be utilized for farm house heating.

Implemented improved practises:

Work Package	Key activities	Expected results
Improved on-farm nutrient management	**Composting of on-farm residues** All on-farm residues are composted. Fresh piles are consisting of biomass of forage legumes, waste from vegetable processing, straw and soil from carrot washing.	Due to the regular turning of the compost piles, CH_4 emissions are reduced. Regular compost application contributes to C sequestration in soil. Furthermore, N_2O emissions from mulching are avoided and N fixation of forage legumes is increased.
Optimised crop rotations with legumes	**Maintenance of existing grain legumes as well as summer and winter green manure lay with legume grasses** High percentage of green manure leys with forage legumes is maintained as well as grain legumes. Grain legume instead of corn and leys instead of cash crops.	Legume crops contribute to N fixation (reduction of N_2O emission) and C sequestration.
Optimised tillage systems	**Reduced tillage and undersown crops** Farm avoids ploughing prior to all arable crops (except vegetables). Furthermore, basic tillage operations are avoided for grass-clover due to undersown clover in spelt and oats.	By employing these practices diesel consumption will be reduced along with humus accumulation in soil (C sequestration).
Agroforestry	**Hedgerows and tree strips along agricultural fields** The farm installed hedgerows and tree strips, along with 0.9 ha forest. Part of the woody biomass is used for composting and use for energy (wood chips).	This lead to C sequestration in above- and belowground biomass and in soil. CO_2 mitigation due to replacement of fossil fuels.

Bioland farm Gut Krauscha

The Gut Krauscha farm is located in Saxony and on a total of 350 ha mainly arable crops (230 ha) and grassland (120 ha) are cultivated. Additionally, approximately 5,500 m hedges grow on the farm.

Climate change mitigation & adaptation is a very important topic for Mr. Mautschke as an organic farmer who knows about the challenges of our time: Nature conservation and environmentally friendliness are an important concern. With his activity in the SOLMACC-Project he wants to give a convincing example for other farmers around.

On his farm you can learn more about:

- how grain legumes can be successfully managed
- how to make compost from use grassland cuts and
- how forest areas can be utilized for a farmer in the region.

Implemented improved practises:

Work Package	Key activities	Expected results
Improved on-farm nutrient management	**Composting of on-farm residues** All on-farm residues (biomass of forage legumes, grassland cuts and cattle manure) are composted.	Due to the regular turning of the compost piles, CH_4 emissions are reduced. Regular compost application contributes to C sequestration in soil. Furthermore, N_2O emissions from mulching are avoided and N fixation of forage legumes is increased.
Optimised crop rotations with legumes	**Maintenance of existing grain legumes as well as summer and winter green manure lay with legume grasses** Cropping of winter peas, yellow lupines and forage legumes is maintained.	Legume crops contribute to N fixation (reduction of N_2O emission) and C sequestration.
Optimised tillage systems	**Reduced tillage** Farm avoids ploughing after winter peas. Furthermore, ploughing depths is reduced.	By employing these practices diesel consumption will be reduced along with humus accumulation in soil (C sequestration).
Agroforestry	**Hedgerows and tree strips along agricultural fields** The farm installed hedgerows and tree strips, and possesses ca. 20 ha forest. A substantial part of the woody biomass as wood chips is used in a wood cogeneration plant, which produces electricity, heat and biochar and therefore replaces fossil fuel.	This lead to C sequestration in above- and belowground biomass and in soil. CO_2 mitigation due to replacement of fossil fuels.

3.2.2 Swedish SOLMACC Farms

Hånsta Östergärde

Hånsta Östergärde is a mixed organic farm located in Vattholma, 20 km north of the town Uppsala. The farm is run by Ylwa and Kjell Sjelin. They have 170 ha of arable land, 10 ha grazing land and 100 ha of forest land. The animal production consists of 15 livestock, 30 ewes and 10 sows which are all kept outdoor throughout the whole year. During the winter cows, pigs and sheep are kept in winter pens close to the farm center on fields with ley which is plowed the next spring.

On their farm you can learn more about:

- how mobile livestock systems can utilized,
- how intercropping of spring and winter cereals can be managed and
- how piglets can be grown in the forests.

Implemented improved practises:

Work Package	Key activities	Expected results
Improved on-farm nutrient management	**On-site, mobile livestock systems** During the winter cows, pigs and sheep are kept in winter pens on fields with ley and access to open sheds with straw bedding. Hens are kept in movable houses which during the summertime are moved over the leys.	Through these activities input costs and associated CO_2 emissions are saved related to produce feedstuffs for the animals as well as transportation of feedstuffs and manure.
Optimised crop rotations with legumes	**Introduction of grain legume mixtures and maintenance of existing forage legumes** Introduction of triticale-winter pea mixed culture. Furthermore farm maintains the 28.6% proportion of forage legumes in the crop rotation (2 out of 7 years) instead of going for 1 year of cereal cropping.	Reduction of N_2O emission due to integrating of N fixing crops (grain & forage legumes) and reduced N fertilisation. Additional C – sequestration.
Optimised tillage systems	**Reduced tillage through cropping alternative** Planting spring and winter cereals simultaneously in the spring. Winter cereal grows slower and stays low until the spring cereal is harvested. It is then overwintered and harvested the next year. From 2014 there is also a small trial on the farm with perennial wheat and barley lines.	By employing these practices diesel consumption will be reduced along with humus accumulation in soil (C - sequestration).
Agroforestry	**Hedgerows and tree strips along agricultural fields** The farm installed hedgerows and tree strips which lead to C sequestration in above- and belowground biomass and in soil. New tree strips on grassland/arable land are in planning.	This lead to C sequestration in above- and belowground biomass and in soil. Part of the woody biomass is used for heating, which leads to CO_2 mitigation due to replacement of fossil fuels.

Körslätts Gård

Körslätts farm is an organic chicken farm located in Skåne, in the far south of Sweden. Magnus Bengtsson tends the farm which has been certified as organic since 2000. Today, the farm consists of 130 hectares of fields, 90 hectares of forest and chicken. Additionally, Magnus runs a machine station. The chicken farming generates deep litter manure which is stored under roof. Since the farm tries to become as self-sufficient as possible when it comes to fodder, it is important to grow as much protein crops and grain as possible. Magnus Bengtsson wants to improve the crop rotation by growing ley with catch crops. He has planned 10 hectares for several types of catch crops, managed in different ways.

On his farm you can learn more about:

- how chicken manure can be utilized for compost production,
- how a farmer can produce its own chicken fodder and
- how agroforestry elements can be utilized for house heating.

Implemented improved practises:

Work Package	Key activities	Expected results
Improved on-farm nutrient management	**Reduced storage of on-farm residues** The farm introduces winter rapeseed as a new crop which makes it possible to empty the on-farm manure storage when fertilizing this autumn sowed crop. By emptying the storage in the autumn the manure collected during the summer months does not need to be stored until spring. In this way CH4 and N20 emissions are significantly reduced.	Due to the coverage with a fleece, CH_4 and N_2O, but in particular emissions are reduced. This would also avoid drying off and nutrient leakage. Regular compost application contributes to C sequestration in soil. Furthermore, N_2O emissions from mulching are avoided and N fixation of forage legumes is increased.
Optimised crop rotations with legumes	**Maintenance of existing grain and forage legumes** Cropping of forage and grain legumes is maintained. Introduction of triticale-winter pea mixture to improve and stabilise protein yields from on-farm crops.	Contribution to N fixation (reduction of N_2O emission) and C sequestration.
Optimised tillage systems	**Reduced tillage** Farm avoids ploughing in prior to cash crop cultivation and employs undersown cultivation of catch crops.	By employing these practices diesel consumption will be reduced along with humus accumulation in soil (C sequestration).
Agroforestry	**Hedgerows and tree strips along agricultural fields** The farm installed hedgerows and tree strips and a part of the woody biomass is used for heating. During SOLMACC there will be a focus on a 600 meters length of riperian buffer zone on both sides of a watercourse running.	This lead to C sequestration in above- and belowground biomass and in soil. CO_2 mitigation due to replacement of fossil fuels.

Trägsta Gård

Trägsta is located 70 kilometers outside of Östersund in the middle of Sweden. Here the farmers Eva and Torgny Widholm produce milk from 140 dairy cows and the farm has been managed organically since 2008. The farm consists of 260 hectares of arable land and 20 ha grazing land. The main crops cultivated are wheat, field beans, barley and peas.

The farm has a biogas plant where all the manure is digested. Eventually, even bedding could be digested. The gas is used to power a electric turbine which produces electricity and spare heat is used as a heating source for residential buildings and barns.
On their farm you can learn more about:

- how roughage in the dairy cow diet can be increased to 70-80%,
- how cow manure can be utilized with a biogas plant for electricity and heat production and
- how agroforestry areas can be used for timber and wood production, while functioning as a grazing area for cows and sheep

Implemented improved practises:

Work Package	Key activities	Expected results
Improved on-farm nutrient management	**Anaerobic treatment (biogas) of liquid and solid manure** Manure is subjected to anaerobic fermentation to generate and capture CH4. This is burned in an engine to generate electricity and heat energy. Liquid and solid residues are brought back to agricultural land.	CO_2 mitigation due to replacement of fossil fuels. Higher percentage of mineral N leads to yield increase of the target plant.
Optimised crop rotations with legumes	**Extending usage of forage legume** Farm extends the utilisation period of forage legume lays from 4 to 5 years.	Legume crops contribute to N fixation (reduction of N_2O emission) and C sequestration.
Optimised tillage systems	**Reduced tillage through extending usage of forage legume leys** Farm extends the utilisation period of forage legume leys from 4 to 5 years and spares soil tillage for 1 year barley instead.	By employing these practices diesel consumption will be reduced along with humus accumulation in soil (C sequestration).
Agroforestry	**Silvopastoral system** The farm have a fenced mixed forest/grazing area on 15-20 ha, which is grazed by the young cattle. There is also a partnership with sheep from a neighbouring farm. The goal of the agroforestry activities is to develop this area with the mixed objectives of enhancing grass production in areas which are now being forested while focusing on the highest economic value on the trees which are left in the field. (Pines=timber, spruce=wood pulp, birches= firewood, grey alders= N – fixation, junipers=wildlife)	These practices lead to C sequestration in above- and belowground biomass and in soil. Part of the woody biomass is used for heating and thus replaces fossil fuel (CO_2 mitigation).

Sötåsen

Sötåsen is an agricultural college with an educational farm that is managed completely organically since 1998. The farm is located outside Töreboda in the south west of Sweden, and has 202 ha arable land, 105 ha forest, dairy cows, approximately 35 sows with piglets, sheep and a number of small animals.

On their farm you can learn more about:

- how protein crops such as lupine and field beans can be cultivated best,
- how renewable energy infrastructures, such as solar panels can be installed,
- how cow manure can be fermented to generate electricity and heat and
- how undersown clover can help to reduce tillage.

Implemented improved practises:

Work Package	Key activities	Expected results
Improved on-farm nutrient management	**Anaerobic treatment (biogas) of liquid and solid manure** Manure is subjected to anaerobic fermentation to generate and capture CH_4. This is burned in an engine to generate electricity and heat energy. Liquid and solid residues are brought back to agricultural land.	CO_2 mitigation due to replacement of fossil fuels. Higher percentage of mineral N leads to yield increase of the target plant.
Optimised crop rotations with legumes	**Maintenance of existing grain and forage legumes** Cropping of forage legumes and grain legumes is maintained.	Legume crops contribute to N fixation (reduction of N_2O emission) and C sequestration.
Optimised tillage systems	**Reduced tillage** Farm is running a field with a complete no-ploughing crop rotation side-by-side with the farms regular tillage system.	By employing these practices diesel consumption will be reduced along with humus accumulation in soil (C sequestration).
Agroforestry	**Hedgerows and tree strips along agricultural fields** The farm is making a new installation of one or two windbreaks hedges. Species selection will be based on the somewhat challenging establishing situation with heavy rodent population. To minimize costs we will primarily use bulk plants produced from seed or cuttings. New tree strips on grassland/arable land are in planning.	Hedgerows and tree strips lead to C sequestration in above- and belowground biomass and in soil. Part of the woody biomass is used for heating and thus replaces fossil fuel (CO_2 mitigation).

3.2.3 Italian SOLMACC Farms

Azienda agricola Fontanabona

The Fontanabona farm is located in the Po' Valley, a few kilometres far from Verona and the Pre-Alps. It is about 7 hectares wide. The Fontanabona family has been cultivating organically since 1982, but the field has the current characteristics since 1999. About 4 hectares of the land are reserved for kiwi crops, while in the remaining part of the land horticultural products (such as lettuce, celery, cabbage and chard) are cultivated in greenhouse and in open field, under anti-hail nets.

On their farm you can learn more about:

- how compost production can reduce GHG emissions.
- how leguminous crops can be cultivated in greenhouses and which green manure can be sow in Kiwi plantations.
- how polyethylene sheets can be utilized to reduce weed pressure, associated with reduced tillage.

Implemented improved practises:

Work Package	Key activities	Expected results
Improved on-farm nutrient management	**Improved composting of on-farm residues** All on-farm residues are composted. Fresh piles are consisting of biomass of bovine manure, the by-product of mushroom bed and some liquid residues from vinasse. Compost piles are covered with compost fleece to avoid drying off and nutrient leakage.	With improved aeration, such as ventilation or regular turning of the compost piles, CH_4 emissions are reduced. Regular compost application contributes to C sequestration in soil.
Optimised crop rotations with legumes	**Increasing proportion of forage legumes** Farm expands proportion of forage legumes to > 20%. This can be done by enriching the proportion of N fixing plant species in the current green manure mixture as well as by expanding the acreage.	Forage legumes contribute to N fixation (reduction of N_2O emission) and C sequestration.
Optimised tillage systems	**Reduced tillage** Farm reduces ploughing frequency and depth.	By employing these practices diesel consumption will be reduced along with humus accumulation in soil (C sequestration).
Agroforestry	**Hedgerows and tree strips along agricultural fields** The farm installed hedgerows and tree strips which lead to C sequestration in above- and belowground biomass and in soil.	The farm installed hedgerows and tree strips which lead to C sequestration in above- and belowground biomass and in soil.

Azienda Agricola Caramadre

The Caramadre farm is located in the Agro Romano, within the National Reserve of the Coast and near the Macchia Grande Reserve of the *WWF* Natural Oasis.
One part of the farmland is located in Maccarese (7.5 hectares including 2 hectare of cold greenhouses) and another part is located in Torre in Pietra (13 hectares). The stockless farm cultivates different kinds of vegetables and fruits such as broccoli, cabbage, cauliflower, summer melons, strawberries, salad, etc.

On their farms you can learn more about:

- how crotalaria can be utilized in greenhouses as a green manure legume and
- how pine and eucalyptus trees can be used as windbreaks for farm fields.

Implemented improved practises:

Work Package	Key activities	Expected results
Improved on-farm nutrient management	**Forage-manure cooperation and composting of on-farm residues** Biomass of forage legumes is collected by a nearby organic livestock farm. In exchange livestock manure is brought back to croplands. Composting is performed with residual grass biomass, tree prunings and vegetable waste.	With this practice N fixation of forage legumes is increased and organic fertilisation of croplands enables better yields and C sequestration. Due to the regular turning/ventilation of the compost piles, CH_4 emissions are reduced. Regular compost application contributes to C sequestration in soil.
Optimised crop rotations with legumes	**Increasing proportion of legumes** Farm expands proportion of legumes to > 10% by included green manure (crotalaria), broad bean and/or field beans.	Legumes contribute to N fixation (reduction of N_2O emission) and C sequestration.
Optimised tillage systems	**Minimum tillage** Farm avoids ploughing and introduces ploughless cultivation techniques. Further options are to introduce cover crops and the application of eucalyptus chips for weed suppression which reduces tillage intensity.	By employing these practices diesel consumption will be reduced along with humus accumulation in soil (C sequestration).
Agroforestry	**Hedgerows and tree strips along agricultural fields** The farm installed hedgerows and tree strips. Furthermore, wood chips from eucalyptus trees are used to suppress weeds and to contribute to C sequestration in soil.	The farm installed hedgerows and tree strips which lead to C sequestration in above- and belowground biomass and in soil.

Azienda Agricola Mannucci Droandi

Mannucci Droandi is a family farm located in the hamlet named Caposelvi, about 35 km far from Arezzo.

The production is based mainly on olive oil and wine according to the standards of organic farming. The farm consists of two areas: Campolucci and Ceppeto. The former is located on the eastern slopes of the Chianti Mountains at an altitude of 250 m above sea level. It has been owned by the Mannucci Droandi family since 1929 and it is composed by a large farmhouse hosting the corporate center and the cellar, different fields alternating with forests of oaks, pines and oaks. The second part of the estate, Ceppeto, consists of vineyards and olive groves planted around a large, square stone farmhouse and surrounded by dense oak and chestnut woodland. It is situated on the west side of the Chianti mountains at 350 m above sea level.

On their farms you can learn more about:

- how vine residues can be utilized for compost production,
- how vineyards can be managed with a permanent grass cover and with a minimum tillage and
- how woody biomass can be used to produce electricity and heat for farmer houses.

Implemented improved practises:

Work Package	Key activities	Expected results
Improved on-farm nutrient management	**Improved composting of on-farm residues** All on-farm residues are composted. Fresh piles are consisting mainly of residues from vineyard Compost piles are covered with compost fleece to avoid drying off and nutrient leakage s, olive groves and wine production.	With improved aeration, such as ventilation or regular turning of the compost piles, CH_4 emissions are reduced. Regular compost application contributes to C sequestration in soil.
Optimised crop rotations with legumes	**Increasing proportion of forage legumes** Farm expands proportion of forage legumes to > 10%. This can be done by enriching the proportion of N fixing plant species in the interrow vegetation of the vineyards.	Forage legumes contribute to N fixation (reduction of N_2O emission) and C sequestration.
Optimised tillage systems	**Minimum tillage** Farm avoids ploughing in the rows and introduces ploughless cultivation techniques within the vineyards.	By employing these practices diesel consumption will be reduced along with humus accumulation in soil (C sequestration).
Agroforestry	**Diversifying the usage of existing tree crops** The farm is making use of the woody biomass from pruning and cuttings and from its woodlands for electricity generation and heating	Replacement of fossil fuel and C – sequestration.

Azienda agricola Tamburello

The Tamburello farm is placed in the valley of the Belice river, on the "Wine Route" (Palermo-Sciacca), linking up the Tyrrhenian Coast to the Channel of Sicily. It covers about 70 hectares and the land is diversified into the vineyard, oliveyard and cereals. The surrounding area is highly suited to the cultivation of olives and wine grapes and it is far from intensive farming.

It is a family farm that handed down over time the belief that a healthy soil, cultivated with patience, love and effort can give life to products of excellence. Tamburello family manages the entire production chain, from the cultivation in the field to the final phase of bottling and labeling, in order to ensure the highest quality and customer satisfaction.

On their farm you can learn more about:

- how wine production residues can be used for compost production,
- how olive groves can be intercropped with legumes and Graminaceae and Leguminouse.
- how reduced, superficial tillage can be introduced in olive groves.

Implemented improved practises:

Work Package	Key activities	Expected results
Improved on-farm nutrient management	**Composting of on-farm residues** All on-farm residues are composted. Fresh piles are consisting mainly of residues from wine production. Compost piles are covered with compost fleece to avoid drying off and nutrient leakage.	With improved aeration, such as ventilation or regular turning of the compost piles, CH_4 emissions are reduced. Regular compost application contributes to C sequestration in soil.
Optimised crop rotations with legumes	**Increasing proportion of legumes** Farm expands proportion of legumes to > 20%.	Legumes contribute to N fixation (reduction of N_2O emission) and C sequestration.
Optimised tillage systems	**Minimum tillage** Farm avoids ploughing and introduces ploughless cultivation techniques in the olive groves.	By employing these practices diesel consumption will be reduced along with humus accumulation in soil (C sequestration).
Agroforestry	**Diversifying the usage of existing tree crops** The farm is making use of the woody biomass from pruning and cuttings for heating	Replacement of fossil fuel and C – sequestration.

3.3 The Science Behind Climate Change Mitigation Monitoring and SOLMACC

One of the overarching goals of the SOLMACC project is to reduce agricultural GHG emissions within the EU and to promote a wider adoption of innovative practices that can contribute to reaching the EU's climate change mitigation and adaptation objectives in the food and farming sector. Currently, agricultural GHG emissions of the EU Member States are accounted in the GHG Emission Inventory Report of the EU.[17] The monitored EU agriculture emissions consist of GHG emissions from enteric fermentation, manure management, managed soils and other, such as emissions caused by biomass burning (see Chapter 2). They are not separated between organic and conventional nor agricultural practices per se. Additionally, GHG emissions caused by the production of synthetic agrochemicals, fossil fuel consumption of farm operations, land use and land use change (LULUCF), food processing, retailing and food waste, as well as import of food and feed are not included in the agriculture sector emission accounting. However, these emissions can be associated with the general agriculture production and the food sector of the EU and should be included into the picture[18].

Therefore, GHG emission monitoring on the EU level, requires a differentiated assessment between agricultural practices applied (e.g. organic, conventional) and the consideration of the entire farming system's GHG emissions. The implemented practices of the SOLMACC demonstration farms are therefore individually assessed regarding their GHG mitigation potential. For this, the carbon footprint of the practices is calculated by using real farm data (e.g. yields, soil carbon concentrations, machinery used on-farm) and life cycle assessment data (e.g. from *ecoinvent*) for more general emissions, such as grey energy consumed by the practice. Once, the caused GHG emissions are calculated for the SOLMACC practices, they are compared with the more commonly applied agricultural practice (baseline) to show how much GHG emissions can be saved. The goal of the SOLMACC project is that each farm can reduce its GHG emissions by at least 15% with the implementation of the improved practices.

Additionally, (organic) farming practices should be more than just climate-friendly and resilient. They need to meet the expectations of the farmers, be economically viable, technically feasible and maintain/stabilize ecosystem services. Only, if organic farming practices meet several needs, such as having a mitigation and adaptation potential, providing co-benefits for the environment and human health and if they are technically, economically and socially feasible within the local context of the farmer, they can become an interesting and recommended approach for the sustainable farming and food sector within the EU. Therefore, also socio-economic factors of the SOLMACC agricultural practices are analysed. Mainly this is done via personal communication, but also online questionnaires, workshops and seminars and gross margin calculations from the real farm costs and turnovers. Last, the environmental co-benefits, such as biodiversity protection or soil fertility, are integrated into the overall assessment of the implemented SOLMACC practices. By this, the GHG abatement costs can be derived. They shows how high the costs for the implemented practices are in relation to the environmental benefit of mitigating 1 t CO_2.[19]

To include the co-benefits of organic farming into the analysis is important, because organic farming offers much more than "just" being climate-friendly. Organic farming is a system oriented farming practices that helps to:

- Close nutrient cycles
- Increase sovereignty of the farmers from off-farm inputs (e.g. agrochemicals)
- Increase farmer's income by higher market prices of organic products
- Reduce concentrate livestock feed
- Reduce energy and fuel consumption
- Increasing SOC, microbial biomass, microbial activity and soil water holding capacity
- Maintain/enhance biodiversity and last, but not least
- Provide health benefits for its consumers.

[17] DANILA, A. M., FERNANDEZ, R., NTEMIRI, S., MANDL, N. & RIGLER, E. 2016. Annual European Union greenhouse gas inventory 1990–2014 and inventory report 2016: Submission to the UNFCCC Secretariat. *EEA Report No 15/2016.* European Commission, DG Climate Action, European Environment Agency, Brussels.

[18] BELLARBY, J., FOEREID, B. & HASTINGS, A. 2008. Cool farming: Climate impacts of agriculture and mitigation potential. Greenpeace International, Amsterdam.

[19] MORAN, D., MACLEOD, M., WALL, E., EORY, V., MCVITTIE, A., BARNES, A., REES, R., TOPP, C. F. E. & MOXEY, A. 2011. Marginal Abatement Cost Curves for UK Agricultural Greenhouse Gas Emissions. *Journal of Agricultural Economics,* 62**,** 93-118.

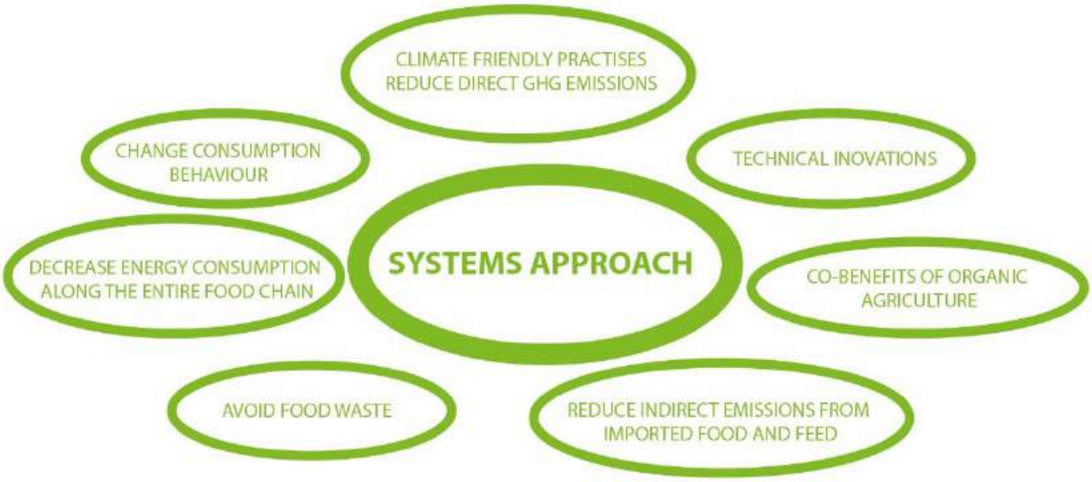

Figure 4: Illustration of a systems approach for climate change mitigation in agriculture (PlanGreenIllustration, 2017)

Therefore, organic farming provides more ecosystem services, is more profitable and delivers further social benefits compared to conventional agriculture[20]. The rejection of pesticides, as well as synthetic mineral N – fertilizer and less use of concentrate fodder leads to lower energy consumption. In addition, numerous authors refer to higher soil organic matter (SOM), more microbial biomass and microbial activity compared to conventional agriculture[21]. Humus influences nearly all soil properties and soil functions and is therefore the most essential part of soil fertility. Thus, an increased SOM has a positive influence on aggregate stability[22], higher water holding capacity and enhanced water infiltration[23]. Therefore, soil fertility is an important driver for climate change adaption and future food production. All these positive influences of organic farming practises underline the possibility of a sustainable food production system. On the other hand, organic farming systems have a yield gap of around 19 % compared to conventional systems[24], which leads to the differentiation of emissions per measurement unit (yield- or area-based). In case of N_2O emissions, organically managed soils emit less than conventional per unit hectare. When N_2O emissions are related to yield units, the advantage of organic systems decrease. For instance, a meta-analysis by Skinner et al. (2014) reported around 492 kg CO_2 eq. ha^{-1} a^{-1} less area scaled nitrous oxide emissions, but 424 kg CO_2 eq. t^{-1} dry matter more yield scaled nitrous oxide emissions from organic systems compared to conventional[25]. In the context of climate change mitigation all farming impacts need to be considered. Thus, Gattinger et al. (2012) reported, a mean C – sequestration

[20] REGANOLD, J. P. & WACHTER, J. M. 2016. Organic agriculture in the twenty-first century. *Nature Plants,* 2**,** 15221.
[21] GATTINGER, A., MULLER, A., HAENI, M., SKINNER, C., FLIESSBACH, A., BUCHMANN, N., MÄDER, P., STOLZE, M., SMITH, P., SCIALABBA, N. E.-H. & NIGGLI, U. 2012. Enhanced top soil carbon stocks under organic farming. *Proceedings of the National Academy of Sciences,* 109**,** 18226-18231. MÄDER, P. & BERNER, A. 2012. Development of reduced tillage systems in organic farming in Europe. *Renewable Agriculture and Food Systems,* 27**,** 7-11.
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MAEDER, P., FLIESSBACH, A., DUBOIS, D., GUNST, L., FRIED, P. & NIGGLI, U. 2002. Soil Fertility and Biodiversity in Organic Farming. *Science,* 296**,** 1694-1697.
[23] PIMENTEL, D., HEPPERLY, P., HANSON, J., DOUDS, D. & SEIDEL, R. 2005. Environmental, Energetic, and Economic Comparisons of Organic and Conventional Farming Systems. *BioScience,* 55**,** 573-582.
LOTTER, D. W., SEIDEL, R. & LIEBHARDT, W. 2009. The performance of organic and conventional cropping systems in an extreme climate year. *American Journal of Alternative Agriculture,* 18**,** 146-154.
[24] PONISIO, L. C., M'GONIGLE, L. K., MACE, K. C., PALOMINO, J., DE VALPINE, P. & KREMEN, C. 2015. Diversification practices reduce organic to conventional yield gap. *Proceedings of the Royal Society of London B: Biological Sciences,* 282**,** 20141396.
[25] SKINNER, C., GATTINGER, A., MULLER, A., MÄDER, P., FLIEBBACH, A., STOLZE, M., RUSER, R. & NIGGLI, U. 2014. Greenhouse gas fluxes from agricultural soils under organic and non-organic management — A global meta-analysis. *Science of The Total Environment,* 468–469**,** 553-563.

potential of 450 kg C ha^{-1} a^{-1} (1650 kg CO2 eq. ha^{-1} a^{-1}) could contribute to compensate the negative N_2O emission[26].

The Greenpeace feasibility study[27] of agriculture turnaround modelled a future model until 2050 with an organic area ratio of 30 % and an ecological conventional agriculture with an area ratio of 70%. It includes an agricultural GHG emission reduction by 50% (35 million t CO2 eq.), increase of biodiversity and animal welfare without the use of synthetic pesticides. The authors conclude that it is only possible to realise these approaches if there is a change in consumer behaviour (reducing meat consumption by more than 50 %) and food waste is cut in halve along the entire value chain.

The mitigation of climate change requires the systems approach (see Figure 4) of the whole agriculture system, including the reduction of direct and indirect emissions, to achieve European global warming targets.

If you would like to learn more about the science of the SOLMACC project and climate change mitigation, adaptation and co-benefit assessments of agriculture practices, the SOLMACC Student Toolbox provides information about:

- how climate-friendly farming practices can be assessed regarding their GHG mitigation potential,
- how economic and technical feasibility differ depending on the farm structures,
- why potential environmental co-benefits of agriculture practices should not be neglected in a holistic analysis and
- what local farming practices mean for the EU climate change mitigation and adaptation policy goals.

[26] GATTINGER, A., MULLER, A., HAENI, M., SKINNER, C., FLIESSBACH, A., BUCHMANN, N., MÄDER, P., STOLZE, M., SMITH, P., SCIALABBA, N. E.-H. & NIGGLI, U. 2012. Enhanced top soil carbon stocks under organic farming. *Proceedings of the National Academy of Sciences,* 109**,** 18226-18231.
[27] Wirz, A., Kasperczyk, N., Thomas F. 2017. Kursbuch Agrarwende 2050 – ökologisierte Landwirtschaft in Deutschland. Greenpeace. URL: https://www.greenpeace.de/sites/www.greenpeace.de/files/publications/20170105_studie_agrarwende2050_lf.pdf

4. Example Master Module

Students and trainees can learn more about climate-friendly and resilient farming practices based on the SOLMACC Student Toolbox, the SOLMACC project results and the regular field days at the SOLMACC farms (listed in Chapter 3.2). How the SOLMACC results and materials provided can be integrated into a student curriculum is currently shown at the Justus-Liebig University in Giessen, Germany. The Master Module "Climate-relevance and resource efficiency of organic farming systems" is thought by Dr. Andreas Gattinger and his colleagues. They structured the weekly module (4h) the following way:

1. Introduction seminar: overview about the course, expectations and open questions
2. Climate change relevance & resource efficiency in conventional and organic farming systems
3. Conservation agriculture; paper presentation
4. Agroecology, permaculture and regenerative agriculture
5. Methods of measuring sustainability: concepts, indicators, system boundaries, FACE system of the University Gießen
6. Measuring sustainability in tropical farming system research: Example of the SysCom Trials in India, Kenya and Bolivia (http://www.systems-comparison.fibl.org/)
7. The SOLMACC project; Skype talk with SOLMACC partners
8. Excursion to one of the SOLMACC field days
9. The food system perspective (indirect emissions, land use change, waste)
10. Practical work I: food system solutions
11. Practical work II: food system solutions
12. The food system perspective; practical work III: presentation of food system solutions

By the end of the 12 week course, the students will have learnt:

- The influence of climate change on the agriculture production,
- what farmers can do to reduce GHG emissions and prepare for inevitable climate change risks,
- how climate-friendly and resilient practices can be implemented on farms and
- how an holistic food system approach can help to build up a sustainable food sector within the EU and abroad.

Some Impressions of SOLMACC Farmers

"Climate change mitigation and adaptation is the essential topic of our time and organic farming plays a forerunner role. Through participating in the SOLMACC-Project and the results thereof, I want to gain a feeling for the right balance between reasonable yields and C-sequestration. The results of the project shall be used on my farm for possible improvement."

Johannes Kreppold (Kreppold, Wilpersberg)

"I hope that SOLMACC will spread innovative sustainable techniques and improve farming methods countering climate change!"

Roberto Giulio Droandi (Mannucci Droandi)

"We have worked hard to make our production more efficient and rationalized. Taking the step to streamline from a climate perspective seems like a natural next step. It is important to spread our experience to others."

Torgny Widholm (Trägsta)

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