Sustainable intensification of food production through resilient farming systems in West & North Africa

Deliverable D3.2
Demonstration Trials

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ABSTRACT

This document represents Deliverable D3.2 of Work Package 3 (“Multiple Agro-Ecological Zone – [AEZ] - and crop-specific demonstration trials utilizing various agro-ecological tools and approaches”) of the Horizon 2020 (Call: H2020-SFS-2018-2020) funded project “Sustainable intensification of food production through resilient farming systems in West & North Africa” (SustInAfrica; Grant Agreement: 861924).

The AEZ - and crop-specific demonstration trials, as the main tool used for reaching WP3 goals (Targeted design & implementation of demonstration trials for resilient & sustainable agricultural production and delivery of ecosystem services), contributes to all the other project’s WPs, in generating on-farm data for assessing the ecosystem service delivery, the sustainability, productivity and profitability of the crop production technologies introduced by the SustInAfrica.

The D3.2 proposes different but complementary agroecological practices for sustainable crop production, and we establish the rationale of the proposed practices for each crop and region. Taking into account the rationale and background, but with the project aim in mind, we establish the protocols to be used for the on-farm crop-specific trials. Accordingly, the D3.2 describes the protocol for experimental on-farm trials on crops of high economic (cotton, pineapple, olive, maize, millet) and nutritional value (olive and pineapple) in multiple environments. The D3.2 also provides detailed information on the agro-ecological specifications and related societal environment of the demonstration trials. Demonstration trials on nine crops in 13 AEZs and a total of 39 communities in targeted African countries, namely Burkina Faso, Egypt, Niger, Ghana and Tunisia, are described in this deliverable.

The trials in each of the targeted regions adopt the on-farm participatory mechanism called Mother and Baby experimental design. This design facilitates interactions among farmers, researchers and other experts, to develop and test various agronomic practices in a quantifiable and repeatable manner and as well evaluate performance across a range of management practices and edaphic conditions. The “mother trials” are to be implemented and controlled by researchers in cooperation with local extension services and farmers in targeted communities called core communities, while the “baby trials” will be implemented by farmers on their plots in core and other communities. The “baby trials” will serve as replicates of subsets of the “mother trial”.

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List of abbreviations and acronyms

AEZ Agro-Ecological Zone
CSC Cloud Standardization Coordination

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Ha Hectare
MBT Mother and Baby Trial
MET Multi-Environment Trials
MoFA Ministry of Food and Agriculture
OFD On-Farm Demonstrations
OFE On-Farm Experiments

Field: "A field is a piece of land in a parcel separated from the rest of the parcel by easily recognizable demarcation lines, such as paths, cadastral boundaries, fences, waterways or hedges. A field may consist of one or more plots, where a plot is a part or whole of a field on which a specific crop or crop mixture is cultivated." (Food and Agriculture Organization [FAO] Term Portal)[1]
Multi-Environment Trials (MET): When on-farm experiments (OFE) are conducted at many sites and repeated for more than one year, they are labelled as MET.
Mother and Baby Trials (MBT): MBTs are multi-environment trials. "Researchers doing METs of varieties often describe the design as a **'mother and baby trial'**. 'Mother and baby' describes a useful design concept but does not adequately specify what the design is. The concept is that two linked trials are done. The first (mother) is usually a researcher designed and managed trial comparing all options in each main environment. The second (baby) is typically an on-farm trial spread around farms in each main environment, perhaps designed and implemented using participatory principles." (Coe, 2012)
On-Farm Demonstrations (OFD): "Pure" demonstration trials do not apply a scientific experimental design that allows for valid statistical analysis and inferences.
On-Station Experiments/Trials (OSE): OSE are field trials that are conducted in a controlled environment such as a research facility. OSE make use of a scientific experimental design that allows for valid statistical analysis and inferences.
On-Farm Experiments/Trials (OFE): OFE is conducted in farmers' fields and make use of a scientific experimental design that allows for valid statistical analysis and inferences.
Pilot farms: Farms where "new" or innovative practices and/or technologies are tested or presented.
Plot: "A plot is a part or whole of a field on which a specific crop or crop mixture is cultivated." (FAO Term Portal)

[1] http://www.fao.org/faoterm/viewentry/en/?entryId=170688

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1. Introduction

In this task, we will implement and run crops of high economic (cotton, pineapple, olive, maize) and nutritional value (olive, pineapple, vegetables) on a farm in specific trials added by farmer experiments with farmer-specific targets based on the findings in T3.1. As explained in D3.1, on-farm experiments will be conducted as multi-environment trials ("Mother and Baby Trials"). One mother trial will be implemented in a selected community of each of the research locations (Agro-Ecological Zone - AEZ) (core community) and will follow a scientific experimental design. There will be one "core community" per AEZ (see selection criteria in Section 1.3). The "mother trials" will be implemented and controlled by a researcher in cooperation with local extension services, while the "baby trials" will be implemented by farmers on their plots. The "baby trials" will serve as replicates to the "mother trial".

The farming systems and practices to be tested should contribute to biodiversity and ecosystems services and enhance the resilience and sustainability of crop productivity. Trial variants will be based on the decisions made in T3.1 and will take place in selected communities within the 5 African countries in West Africa and North Africa within a total of 15 AEZ sites. The farming systems will involve organic and agro-ecological farming practices. These practices will be defined by diverse integration of innovative agro-ecological and agronomic practices that promote sustainability of agricultural systems by increasing organic matter in the soil, which increases natural pest and disease control or decreases pest pressure. Accordingly, the agro-ecological practices will include cover crops, intercropping, crop rotations with forage legumes, alley crops, farmyard manure, mulching methods, and reduced tillage. Agricultural practices such as the optimization of planting date, and plant density, and smart farming technologies (in this case, pest and disease management developed in WP2) will be tried. In some cases, agro-forestry will become relevant and will be tried. In this document, the farming systems, agro-ecological and agricultural practices are described for each country, crop and AEZ as already established in D3.1.

1.1 General Objective

The overall objective of WP3 is to identify agricultural practices which contribute to/increase the sustainability and resilience of farming systems and the related ecosystems services in 15 AEZ of five countries in North and West Africa.

1.2 Deliverable

The deliverable for Task 3.2 is as follows: "crop-specific demonstration trials utilizing various agro-ecological tools and approaches: Detailed information on co-selected demonstration trials, their agro-ecological specifications, and related societal environment".

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2. Trials in Ghana

2.1 Pineapple

2.1.1 Milestones and Responsibilities

The respective timeline and milestones as well as the responsible teams are described in **Error! Reference source not found.**.

Table 0.1. Tasks, milestones and teams involved in pineapple trials

Tasks	From (Month)	To (Month)	Milestone	Teams involved;
Expert interviews	July 2021	August 2021	3 of experts identified, 2 of experts interviewed	Fatimah, Kwame, Michael, Ransford, Research assistants (2)
Expert group formation	July 2021	August 2021	Expert group formed	Fatimah, Kwame, Michael, Ransford Research assistants (2)
Expert group meetings	August 2021	September 2021	2 of Expert group meetings organized	Fatimah, Kwame, Michael, Ransford Research assistants (2)
Trial design for each region/community	September 2021	November 2021	Trials designed for each community	Fatimah, Kwame, Michael, Ransford Research assistants (2)
Trial implementation	September 2021	August 2024	Field trials were implemented in all 3 communities	Fatimah, Kwame, Michael, Ransford Research assistants (2); Postgrad student (1)

Source: SustInAfrica Project (2020)

2.1.2 Research Framework

Background

Pineapple (Ananas comosus) is an important crop grown in Ghana, with about 2% of all Ghanaian households engaged in its production. Production in Ghana is mostly realised by smallholder farmers, offering both direct and indirect employment and livelihoods to thousands of households, most of which are in rural communities. The sector is the most developed horticultural sector in Ghana, accounting for over 40% of Ghana's non-traditional exports (Williams et al., 2017). According to the Ghana Export Promotion Authority (GEPA), Ghana exported between US$30.3 million and US$36.9 million worth of pineapples between 2016 and 2018, with 79% of the total exports going to the European Union (EU) market (http://www.gepaghana.org). Pineapple is also important for local consumption, both in the fresh market and as a raw material for local processing industries (Williams et al., 2017). Pineapple is produced in Ghana mainly through conventional or organic production systems. There have been increasing trends among farmers in switching production from conventional to organic to take advantage of the rapidly expanding premium niche in the European Union (EU) organic markets (Mensah and Brummer, 2015). While this has come with some costs in terms of meeting standards in certification, production and in managing the farms, current trends in production also indicate that there is a general decline in the number of farmers, yield and exports (Zottorgloh, 2014).

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Research problem

The productivity and profitability of pineapple production are declining in Ghana. Both abiotic and biotic constraints have been implicated. The most important climatic factors for pineapple production in Ghana are rainfall and temperature (Ministry of Food and Agriculture [MoFA], 2013). Long-term rising temperature and rainfall changes towards a longer dry season, as a result of climate change, are major constraints to productivity. Although the crop is highly tolerant to drought, the effects of drought on plant morphology and growth are substantial (Malézieux et al., 2009). Pineapple yields are also declining amidst declining soil fertility. Bad farming practices, land degradation and deforestation activities of the pineapple producers and others have modified the local climate and vegetation (Achaw, 2010). Meanwhile, the use of inorganic fertilizers in Ghana is limited due to high cost, unreliable supply, and hence poor accessibility to the smallholder farmers (Mensah and Frimpong, 2018). Under conventional production systems, continuous use of inorganic fertilizers may also lead to soil acidification, affecting soil biota and biogeochemical processes. Meanwhile, pests and diseases, weeds, poor harvesting and post-harvest handling methods have long been cited among the production constraints of pineapple in Ghana (Donkoh and Agboka, 1997). Ghana's pineapple farmers occasionally battle with pest and diseases problems on their farms. Mealybug wilt disease, associated with mealybugs, ants and viruses, as well as soil-borne pests and diseases such as root-knot and nematodes, phytophthora and fungi (fusariosis) attack pineapple at different stages (vegetative, flowering and fruiting stage), resulting in poor yield and fruit quality. Farmers are also faced with economic constraints comprising inaccessibility to credit facilities and price fluctuations. There is a need for pineapple management strategies that leverage the understanding of the environmental and ecological characteristics of the pineapple ecosystem, to improve environmental and economic outcomes of pineapple cropping systems in Ghana. Agroecology or ecological farming, applying the principles of ecology to agro-systems to develop practices relevant for organic farming, will be instrumental in this endeavour. Ecological farming will take into account conservation of natural resources, adapted and sustainable soil fertility management and the sustainable conservation of biodiversity in the production system (Soler et al., 2011).

Research objectives

Table 0.1 presents the research objectives.

Table 0.1. Research objectives

Research objectives: Soil fertility and water conservation
1. To provide empirical evidence on the effect of compost application on selected soil quality parameters (soil carbon, water holding capacity, etc.) and pineapple productivity, profitability and labour demand.
2. To provide empirical evidence on the effect of biochar application on selected soil quality parameters (soil carbon, water holding capacity, etc.) and pineapple productivity, profitability and labour demand.
3. To provide empirical evidence on cover cropping on evaporation and soil water storage in organic pineapple cropping systems and pineapple productivity, profitability and labour demand.
4. To provide empirical evidence on the interactive effect of combined compost and biochar application on selected soil quality parameters (soil carbon, water holding capacity, etc.) and pineapple productivity, profitability and labour demand.
Research objectives: Plant health/pests, diseases and weeds management

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1. To provide empirical evidence on the effect of flower strips on enhancing local beneficial insect diversity and delivering integrated pest management in pineapple cropping systems.
2. To provide empirical evidence on the effect of cover cropping on enhancing local beneficial insect diversity, weeds management and delivering integrated pest management in pineapple cropping systems.
3. To provide empirical evidence on the effect of compost on controlling soil pests and diseases in pineapple cropping systems.
4. To provide empirical evidence on the effect of biochar on controlling soil pests and diseases in pineapple cropping systems.
5. To provide empirical evidence on the interactive effect of combined application of compost and biochar on controlling soil pests and diseases in pineapple cropping systems.
Research objectives: Nutrition/fruit quality
1. To provide empirical evidence on the effect of compost application on selected fruit quality parameters.
2. To provide empirical evidence on the effect of biochar application on selected fruit quality parameters.
3. To provide empirical evidence on the interactive effect of combined compost and biochar application on selected fruit quality parameters.

Research questions

Table 0.2 presents the research questions.

Table 0.2. Research questions

Research questions: Soil fertility and water conservation
1. What are the effects of compost application on selected soil quality parameters (soil carbon, water holding capacity, etc.) and pineapple productivity, profitability and labour demand in pineapple cropping systems?
2. What are the effects of biochar application on selected soil quality parameters (soil carbon, water holding capacity, etc.) and pineapple productivity, profitability and labour demand in pineapple cropping systems?
3. What are the interactive effect of combined compost and biochar application on selected soil quality parameters (soil carbon, water holding capacity, etc.) and pineapple productivity, profitability and labour demand?
4. How does the use of cover crops (*Mucuna b.*) decrease evaporation and increase soil water storage?
Research questions: Plant health/pest and disease management
1. How does flower strips enhance the diversity of local beneficial insects and deliver integrated pest management in pineapple cropping systems?
2. How does cover crops (*Mucuna b.*) enhance the diversity of local beneficial insects and deliver integrated pest management in pineapple cropping systems?

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3.	How does the use of cover crops (*Mucuna b.*) reduce weed infestation?
4.	How does the application of compost help in controlling soil pests and diseases in pineapple cropping systems?
5.	How does the application of biochar help in controlling soil pests and diseases in pineapple cropping systems?
6.	How does the combined application of compost and biochar help in controlling soil pests and diseases in pineapple cropping systems?
Research questions: Nutrition/fruit quality	
1.	How does compost application enhance fruit quality parameters in pineapple?
2.	How does biochar application enhance fruit quality parameters in pineapple?
3.	How does the combined application of compost and biochar enhance fruit quality parameters in pineapple?

Research hypotheses

Table 0.3 presents the research hypotheses.

Table 0.3. Research hypotheses

Hypotheses: Soil fertility and water conservation
H_1: Application of compost and biochar, either solely or in combination, will improve soil parameters (soil carbon, water holding capacity, etc.). H_2: Application of compost and biochar, either solely or in combination, will improve pineapple productivity, profitability. H_3: Application of compost and biochar, either solely or in combination, will increase labour demand in pineapple cropping systems.
H_4: Cover cropping will reduce evaporation and enhance soil water storage in organic and conventional pineapple cropping systems. H_5: Cover cropping will improve pineapple productivity, profitability but increase labour demand in pineapple cropping systems.
Hypotheses: Plant health/pest and disease management
H_1: Flower strips will minimize pest and diseases infestation in pineapple cultivation.
H_2: Flower strips enhance the diversity of local beneficial insects in pineapple cropping systems.
H_3: Cover crops (*Mucuna b.*) will minimize pest and diseases infestation in pineapple cultivation.
H_4: The application of compost and biochar, either solely or in combination, will help in controlling soil pests and diseases in pineapple cropping systems.
Hypothesis: Nutrition/fruit quality
H_1: The application of compost and biochar, either solely or in combination, will affect fruit quality parameters or pineapple.

2.1.3 Research Methodology

Expert group

The aim of the Expert Group (including approximately 4 farmers, 2 researchers and 2 extensionists) is the integration of further information and feedback on the trial design as well as the accompaniment during trial implementation. Table 0.1 present the membership of the Expert Group.

Table 0.1: Expert Group for pineapple trial

Expert (Affiliation)	Expertise	Responsibility
Researcher: Dr Kwame Frimpong (University of Cape Coast - UCC)	Soil science	Group lead
Researcher: Dr. Michael Adu	Crop Science	Group co-lead
Researcher: Dr Kofi Boa (Warren Buffet Centre for No-Till Agriculture)	No-till agriculture	Advisor on composting and biochar
Private consultant: Mr Mark Tutu Sarpong	Pineapple processor and trader	Advisor on pineapple trade trends and profitability
Private consultant: Mr Mohammed Seidu Labaran	Pineapple Agronomy	Advisor on pineapple agronomy and variety behaviour
Farmer 1 (Ankwanda): Mr Appiah	Farming	Assist in farmer selection and farmer group formation; monitoring of fieldwork
Farmer 2 (Ankwanda):	Farming	Assist in farmer selection and farmer group formation; monitoring of fieldwork
Farmer 3: (Nkontrodo)	Farming	Assist in farmer selection and farmer group formation; monitoring of fieldwork
Farmer 4: (Ayensudo)	Farming	Assist in farmer selection and farmer group formation; monitoring of fieldwork
Agric. Extension Agent of MoFA: Mr Sarpong	Agric. Extension Agent	Assist in farmer selection and farmer group formation; monitoring of fieldwork
Researcher: Dr Kwadwo Kusi Amoah (UCC)	Agronomist	Technical advice on pineapple breeding and agronomy
Researcher: Dr Josiah Tachie-Menson (UCC)	Weed Scientist and Biometrician	Technical advice on weed control and experimental design

Site selection

The sites for the pineapple production will be within the following three communities, namely Ankwaanda, Nkontrodo and Ayensudo. However, Ankwaanda has been designated as the core community. The three communities were purposively chosen based on their location in terms of closeness to market, an agricultural institution, and project stakeholders as well as farmers' practice, accessibility regarding availability of roads and acceptability by local opinion leaders. The sites were also selected based on climatic conditions, availability of land, farmers' experience, accessibility and potential for close monitoring, processing industry, irrigation facilities, research institutions, farmers' willingness to participate, and gender inclusiveness. The presence of the farmers' groups was also taken into account. These decisions were made in consultation with the officers at the Komenda/Edina/Eguafo/Abirem (KEEA) Municipal - Ministry of Food and Agriculture (MoFA) office.

Farmer selection / sampling

In each community, an opinion leader and an experienced pineapple farmer have been identified. Project details have been explained to the identified persons and they have been tasked to assemble willing farmers to form a group for the project. The farmers' selected criteria also included their method of farming systems (conventional or organic), willingness, membership of farmer associations, where applicable, knowledge in organic pineapple production, years of farming, and age. The project focus, objectives and expectations will be explained to the identified farmers willing to be part of the

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project. The focus of the project will be the organic pineapple producers in the community. Some generalisations about the farmers are the size of holding (about 1 acre), variety of pineapple grown (Sugarloaf), physical access to the marketplace, and nature of cooperative/group. The organic farmers in the core community, Ankwanda, belong to a farmer group consisting of about 15 farmers and their produce are often purchased by one company.

Plot selection

In the selection of sites, efforts will be made to control and reduce the variation of natural factors as best as possible. Thus, fields and/or plots for demonstration will be chosen on relatively uniform soils and topography. Even so, pre-experimental soil analyses will be conducted, and any significant variation will be accounted for as covariance in the analyses. Additionally, all plots and fields will be prepared in the same way except for the treatments that shall be tested. Ideally, the plots will be 25 x 25m. The core community, Ankwanda, will host the mother trial consisting of thirty (30) plots. It will also host 6 baby trials, each established on a farmer's field. Each baby trial is a subset of the mother trial and will consist of the control treatment in addition to three other selected treatments, amounting to four plots on each farmer's field. The second community, Nkontrodo, will host 6 baby trials on 6 farmers' fields. This will also consist of the control treatment in addition to 3 other selected treatments, amounting to four plots on each farmer's field. Given that each treatment from the Mother trial will appear twice in the baby trials, the third community, Ayensudo, will have 3 treatments, including the control treatment.

Treatments

Based on the challenges of agricultural production in the Komenda region identified in D3.1, the following treatments (see Table 0.2) have been suggested for the pineapple trial:

Table 0.2. Suggested treatment for pineapple trial

Treatment	Treatment description
1	T1 = Control: Framers' current organic pineapple production practice
2	T2 = Organic pineapple production with biochar
3	T3 = Organic pineapple production with compost
4	T4 = Organic pineapple production with compost and biochar
5	T5 = Organic pineapple production with cover crop
6	T6 = Organic pineapple production with flower strips

'Treatment 1 – Farmer practice: This will be site-specific. It is the various organic production practices in the selected communities. This includes the use of various rates of organic amendment such as poultry manure, and the use of plastic or crop residue as mulch.

Other Treatments (Interventions to be tested): The aim is to utilize ecological production principles to manage the pineapple production challenges identified herein. Accordingly, the treatments to be tested must follow the principles of agro-ecology, be low in external inputs, and be multi-functional, diverse, and interconnected in their role in protecting biodiversity, soil, water and the climate. The technologies should also be economically viable and possible to apply them to both smallholdings and large farms (Tirado, 2015). Biochar, composting, cover cropping, and flower strips are all nature-based interventions that satisfy the principles of ecological farming and hence their choice to be tested in the work. Both biochar and compost will be applied at 10 tons ha^{-1} equivalence.

Experimental design

The 'mother and baby trial' design will be used in this project. The mother trials will be located at Ankwanda and UCC Research Farms and will be managed by researchers. The treatments will be randomly allocated to blocks that contain all treatments, in both mother trials and there will be 3

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replications at each mother trial site. Figure 2-1 illustrates the mother trials in the core community. The baby trials will be located in all three communities and will be managed by farmers, with support from researchers. Each baby trial will use a subset of three treatments, plus the control treatment, involving 6 farmers from each community, summing up to 18 farmers in all for the baby trials. Wherever possible, female farmers will be included in the baby trials. The plots will measure 25 m x 25 m and will be planted in double rows[2] (0.50 m by 1.15 m) (Spironello et al., 2004). There are two methods of planting pineapple: the single row method and the double row method. The double row method of planting gives a population of about 44,000 to 76,000 plants per hectare" (Mercedes M. Arcelo - Production Guide for Pineapple). The spacing between plants will be 0.4m. Crop and soil sampling will exclude edge plants but samples from multiple sections within the plots. The insect collection will be performed only in some of the defined treatments. Therefore, we will consider the edge effects and the need for a 25 m buffer zone between plots on insect collection via the spatial distribution of the treatments in the trials.

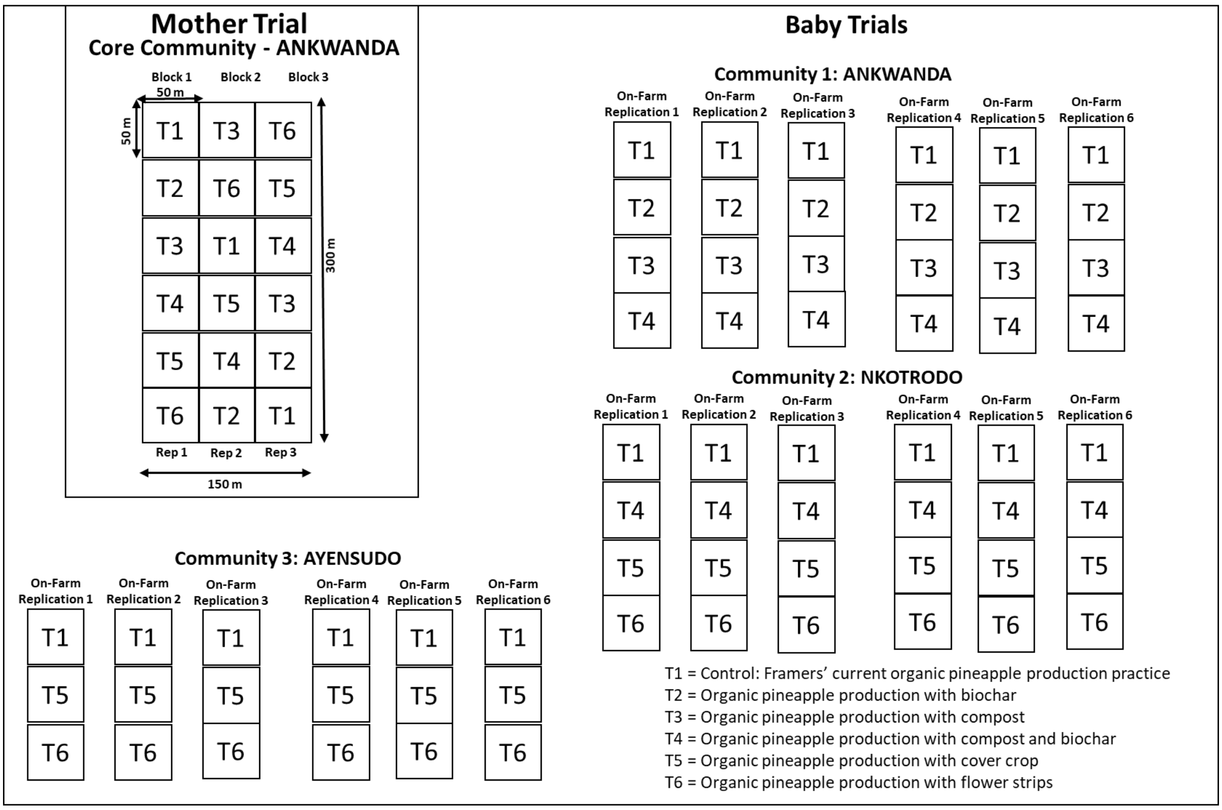

Figure 2-1. Mother trials in core community

Baseline data collection of research sites

To ensure reproducibility of the study, a systematic description of the research sites' abiotic environment and former cropping system management will be conducted (see D3.1). The data will be collected during the baseline assessment (Task 1.2.b).

[2] "There are two methods of planting pineapple; the single row method and the double row method. Single row method – rows are generally spaced at 80 to 100 cm apart, and the plants are set at 25 to 30 cm in a row. A hectare of land will give a population density of 33,000 to 50,000 plants. Double row method – the required distance is 20 to 30 cm in a row, 50 cm within a double row, and 80 to 100 cm between double rows. This will give a population of about 44,000 to 76,000 plants per hectare" (Mercedes M. Arcelo - Production Guide for Pineapple).

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Trial data collection: physical crop sampling

The sampling strategy will be based on deliverable D1.1 from WP1. The above-ground biomass of the pineapple plants and the progress of growth will be estimated using three indicators:

- the number of leaves[3]
- the D leaf[4]: The 'D' leaf length will be measured with a rule. The 5th or 10th 'D' leaf in a few or several rows will be pulled to obtain the desired sample size and ensure that the person doing the sampling does not bias the result. The leaves will be weighed together and divided by the total number to obtain the average 'D' leaf weight for the field" (Fournier et al., 2010; Newsletter of the Pineapple Working Group, International Society for Horticultural Science).
- the plant weight: Foliar mass of the pineapple will be estimated using a crop log which involves establishing logging stations containing a given number of plants (usually 100 plants) at representative locations within uniform fields. Once logging stations have been selected, plant weights will be estimated as follows: 1) Plants in the field will be visually classified by approximate size. Thus, plants will be assigned to the relative size classes - small, medium and large or classes - very small, small, medium, large, and very large. Subsequently, one plant corresponding to each size class will be pulled from the soil outside of the logging station and the plant will be weighed and the weight recorded. The number of plants of each size class will then be counted in the logging station and the total count should equal the number of plants in the logging station. The number of plants in each size class will be multiplied by the weight of the representative plant for that size class and the total weight for the three or five classes will be summed up and the total divided by the number of plants in the logging station (Newsletter of the Pineapple Working Group, International Society for Horticultural Science).

On maturity, yield and physical characteristics of fruits that will be tested include weight, volume, overall length, maximum width, shape and pulp firmness. Total Soluble Solids (TSS), the ratio of TSS/acidity and titrable acidity are some of the fruit quality parameters that will be measured, following standard procedures.
There will also be some general crop and soil sampling. This will include crop performance parameters such as chlorophyll content, leaf area index, radiation capture, vegetation cover and soils' pH, texture, water holding capacity, total N, and total carbon.

Sampling Protocol for Sticky Traps

A minimum of 2-3 sticky traps with pheromone (attractive traps) targeting the adult male mealybugs will be placed at the centre of each plot. The optimal distance between each pheromone trap is 10 m. The traps will be set up during the activity of the adult male mealybugs. The traps will be assembled on sticks and placed near a pineapple plant bearing a unique identification number. Images of the traps will be taken with a smartphone during the pest activity periods on a weekly basis. Images will be centred and focused on the sticky trap, strong surface reflections will be avoided and depicted insects will be sufficient to be recognisable by experts. The images will be uploaded to the Cloud

3 The use of leaf number is another way of estimating the above-ground mass of a pineapple plant because about 80% of the vegetative mass of pineapple plant is of green leaves. However, it can be difficult and time consuming to count the number of leaves.

4 "The D leaf is defined as the youngest physiologically mature leaf on the plant and also is the tallest leaf on the plant. The 'D' leaf is always easy to pull from the plant and has leaf margins that are more-or-less parallel all the way to the leaf base. The D leaf usually shows an angle of 45º from the vertical axis of the plant. It is a reliable and commonly used growth index). A sampling of 'D' leaves can indicate how growth is progressing as well as provide tissue for analysis of plant nutritional status. As pineapple plants grow, 'D' leaves get progressively longer and heavier and 'D' leaf weight at the time of forcing was highly correlated with fruit weight at harvest. It should however be noted that the D' leaf weight or length at forcing and fruit weight at harvest likely will not be the same for all cultivars or all countries or locations (Fournier et al., 2010; Newsletter of the Pineapple Working Group, International Society for Horticultural Science).

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Standardization Coordination (CSC) cloud along with the trap ID and acquisition date for later image annotation (Luke) and AI model training (UH) of InsectaMon. The sticky traps will be changed after one month.

UAV Campaigns

UAV flight campaigns will be conducted at the mother trial as well as over selected smallholder pineapple fields. The dates of the UAV campaigns will be selected along the growth stages: two within the vegetative and two in the regenerative growth phase as well as the abundance of the mealybug and the distribution of the wilting disease. The UAV will be equipped with the Altum camera, including multispectral and thermal bands. All drone flights will be conducted by DEX. Imagery will be acquired from 25 m altitude with an image overlap of 80% to enable photogrammetric generation of orthoimages and SfM 3D point clouds. Furthermore, higher altitude flights will be conducted in order to collect spatial data of the surrounding environment. Ground Control Plates (GCP) will be used for geometric correction. All images of each campaign will be uploaded to the CSC cloud along with the GCP data for photogrammetry and remote sensing analysis (ATB).
For building a UAV based model for crop performance and vitality assessment, ground-truthing measurements of chlorophyll activity and leaf area index (LAI) will be performed in the plots with SPAD-502Plus chlorophyll meter and LAI-2200C LAI meter at the pineapple crops and the intercrops. Effects on plant health due to pest insect distribution will be assessed with the high-resolution UAV imagery by aligning the image data with the collected insect data in the trials. Additionally, the impact of the wilting disease, which is a virus infection spread by the vector mealybug will be assessed. The extent of the flight campaigns will exceed the mother trial area to include high-resolution information of the surrounding environment in the analysis to better assess ecosystem service effects, e.g., coming from landscape elements (bushes, tree-rows, flower-strips, etc.).

Satellite Remote Sensing and Monitoring of Pineapple

At three selected smallholder pineapple fields, 10 plots will be located in representative areas with a dimension of 10 x 10 m. Plot dimensions will be measured with GNSS. Ground-truthing measurements of chlorophyll activity and leaf area index (LAI) will be performed in the plots with SPAD-502Plus chlorophyll meter and LAI-2200C LAI meter in the pineapple crops. SPAD measurements will be performed on the D-leaf of the pineapple plant. For each plot, an average of five equally distributed, single measurements will be performed for one integral plot measurement. The measurement dates of ground-truthing data collection will be aligned with the growth stages of the pineapple crops.

Sampling Protocol for Beneficial Organisms and Biodiversity

The insect sampling focuses on flying and ground-dwelling species. One malaise trap (a passive trap for flying insects) is set up in the centre of each plot. In addition, 8 pitfall traps (passive traps for ground-dwelling insects and arachnids) are set up around the malaise trap forming a square (see Figure *2-2.* Design of traps setting in plots for sampling of flying and ground-dwelling insectsFigure 2-2). On the top of each pitfall trap, cover hoods are placed to protect the traps from high evaporation and overflooding in case of important rainfall. The minimum distance between each pitfall trap is 5 m. The minimum distance between each malaise trap is 50 m. The minimum number of replicates for statistical robustness is 5 replicates per treatment (i.e., 5 malaise traps and 5x8=40 pitfall traps). Traps are filled with propylene glycol. One sampling period is 2 weeks long and the traps are collected and checked once a week. There will be 4 sampling times in a year in order to cover the different seasons and represent the biodiversity along the year. The collected insects will be placed in tubes filled with ethanol (>90%) and stored in the fridge at a maximum of 2 °C or in the freezer at -20 °C until further manipulation. The main pest insects and the most abundant species (representing 80% of the biomass) will be counted and identified to species level if possible. If not possible, we will aim at identifying the lowest taxonomical level possible. Some samples (10 females and 10 males of each species, if possible)

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will be sent to Luomus, Finland, as vouchers and for biomass estimation. Functional traits will be measured on a sub-sample to try and link the abundance and diversity of arthropods to ecosystem services.

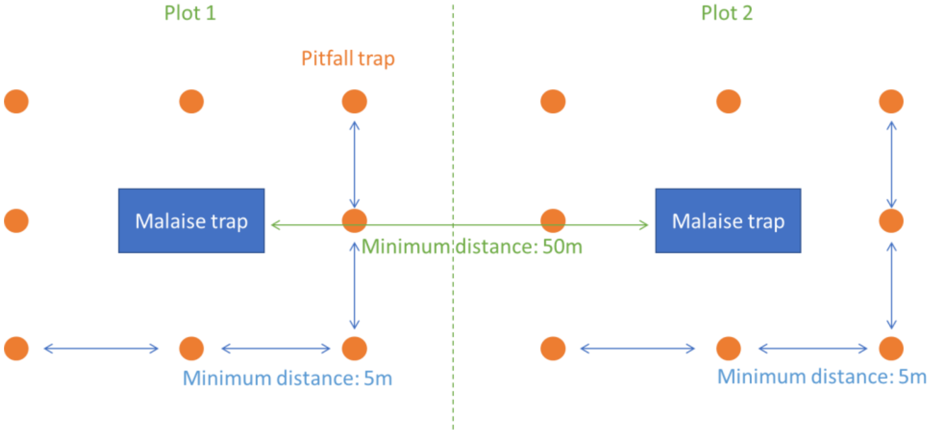

Figure 2-2. Design of traps setting in plots for sampling of flying and ground-dwelling insects

2.1.4 Personnel and equipment

Personnel

Requirements for personnel for the pineapple trials have been presented in Table 0.1.

Table 0.1. Personnel requirements

No. of people	Role & responsibility	Qualifications needed
2 per field	Manual collection of pineapple	Technician and workers
2 per field	Crop sampling for insect's pest Monitoring insect traps	Technician and worker
2 per laboratory	Counting the number of insects/traps identifying insect species	Technician and worker

Material and equipment

Material and equipment requirements have been presented in Table 0.2.

Table 0.2. Material and equipment requirements

Material / Equipment	Acquired at [country] / Return to [country]
Pheromone yellow sticky traps	Acquired in Europe
Regular yellow sticky traps	Acquired in Europe
Malaise traps	Acquired in Europe
Bottle to collect insects from malaise traps	Acquired in Europe
Pitfall traps and cover hood	Acquired in Europe
Propylene glycol	Acquired locally or in Europe
Ethanol (>90%)	Acquired locally
Tubes/small bottles for storage of insects	Acquired locally

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2.1.5 Time Schedule

Month & Year	Task (How will data be collected)	Community	Responsible	Staff involved
December 2021	Land preparation	Ankwaanda, Nkontrodo and Ayensudo	Workers, farmers, researchers (Crop and soil scientists)	4
	Soil sampling	Ankwaanda, Nkontrodo and Ayensudo	Students and experts from soil science	4
Season 2022				
Febuary	Treatments application, gathering and grading of planting materials (Suckers)	Ankwaanda, Nkontrodo and Ayensudo	Workers, farmers, expert from soil and crop science, and student	3
March	Planting of pineapple suckers	Ankwaanda, Nkontrodo and Ayensudo	Workers, farmers and student	6
June December	Data collection	Ankwaanda, Nkontrodo and Ayensudo	Student, experts from soil and crop science	6
	Growth parameters (Height, number of leaves, D-leaf)	Ankwaanda, Nkontrodo and Ayensudo	Student, experts from soil and crop science	6
Season 2023				
January	Flower induction (forcing)	Ankwaanda, Nkontrodo and Ayensudo	Workers, farmers ans student	5
May – July	Harvesting of pineapple fruit	Ankwaanda, Nkontrodo and Ayensudo	Workers, farmers	5
	Yield data collection	Ankwaanda, Nkontrodo and Ayensudo	Students, experts from crop and soil science	6
	Fruit quality data	Ankwaanda, Nkontrodo and Ayensudo	Experts from engineering, crop science and soil science	6

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2.2 Mango

2.2.1 Milestones and Responsibilities

The details of tasks, milestones and the team involved in the mango trials have been presented in Table 0.1.

Table 0.1. Tasks, milestones and teams for mango trials

Tasks	From (Month)	To (Month)	Milestone	Teams involved; lead in bold letter
Expert interviews	September 2021	August 2021	3 of 5 experts identified; 3 of 5 experts interviewed	- **Gazali**, Frederick, Benjamin and Halim + 2 field assistants
Expert group formation	September 2021	October 2021	Expert group formed	- **Gazali**, Frederick, Benjamin and Halim + 2 field assistants
Expert group meetings	September 2021	October 2021	3 of Expert group meetings organized	- Gazali, **Frederick**, Benjamin and Halim + 2 field assistants
Trial design	October 2021	December 2021	Trials designed for each locality	- Gazali, Frederick, **Benjamin** and Halim + 2 field assistants
Trial implementation	December 2021	August 2024	Field trials implemented in all 3 localities	- Gazali, Frederick, Benjamin and **Halim** + 2 field assistants

2.2.2 Research Framework

Background

The following section serves as conceptual framework for the trials and their implementation according to the project proposal and inputs provided by the expert group, identified in the Tamale AEZ experts' consultations.

Research problem

The mango agro-ecosystem in Ghana is characterized by interacting features of diverse environmental and ecological factors which are complex and challenging to manage. An agro-ecology concept needs to be developed to help improve the sustainable management of agriculture and natural resources. There is need for management strategies that improve environmental and economic outcomes of mango cropping systems from an understanding of the environmental and ecological characteristics of the ecosystem. Agronomic activities for mango production such as tillage, manure and fertilizer application, intercropping, pruning, slash-and-burn, use of growth regulators, and pest and disease control have had significant impact on the mango agro-ecosystem, and have also impacted faunal and floral diversity (Badii et al., 2015). Pest control solely relies on the use of synthetic and/or botanical pesticides, which have both direct and indirect effects on beneficial organisms via food sources and habitats (Richard, 2010). The success of any biodiversity rescue plan will, to a large extent, depend on the use of agroecological practices while implementing viable framework directive on the sustainable use of pesticides (Richard, 2010). Biological control, pollination, soil formation, carbon dioxide capture through photosynthesis, flood mitigation and methanotroph bacterial activity are all ecosystem services which farmland can provide in abundance, if properly managed.
The utilization of specific agroecological practices and understanding its effects on ecosystem services and insect pests of mango will not only minimize the use of chemical pesticides but also reduce the pressure on the natural environment and help sustain and/or maintain natural resources. This research

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will serve as a gateway to minimizing the use of synthetic insecticides and adoption of best practices in improving biodiversity and ecosystem services in mango production in Ghana.

Rank problems by importance

- Low productivity and agriculture not sensitive to gender and nutrition outcomes
- Not enough information on Plant pest and diseases population dynamics and heavy reliance of synthetic chemical control measures
- High soil degradation Soil health
- Biodiversity losses and ecosystem services erosion

Research objectives

The research objectives are presented in Table 0.1.

Table 0.1. Research objectives

Research objectives: Crop productivity/ Gender and nutrition
1. To determine the influence of agroecological practices on flower set, flower abortion, as well the growth (plant height, leaf number) and yield (podding, seed yield and biomass) of intercrop species.
2. To determine the effect of agroecological practices on the quality of harvested mango fruits (dropping, weight and brix degree).
3. To determine the effect of agroecological practices on reduction in farm labor for women.
Research objectives: Plant health/pest and disease management
1. To determine the influence of selected agro-ecological practices in enhancing arthropod biodiversity (abundance and diversity) within the orchards and in the semi-natural elements implemented?
2. To determine the influence of selected agro-ecological practices on 1) reducing the main pest populations (insects and weeds) and their damage as well on 2) the natural enemy populations (abundance and diversity)?
3. To develop an artificial intelligence-based tool to identify the main pest insects (the fruit fly complex) based on imagery to aid the development of a Decision Support System for Integrated Pest Management.
Research objective: Ecosystem services
To determine the selected agro-ecological practices on the ecosystem services of pollination, biological control, erosion control, weed control.

Research questions

The research questions have been presented in Table 0.2.

Table 0.2. Research questions

Research questions: Crop productivity/ Gender and nutrition
1. Do agroecological practices influence the flower set, flower abortion, as well the growth (plant height, leaf number) and yield (podding, seed yield and biomass) of intercrop species?

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2.	Do agroecological practices influence the quality of harvested mango fruits (dropping, weight and brix degree) and micro-nutrient uptake in intercrops?
3.	Do agroecological practices reduce in farm labour for women?
Research questions: Soil fertility and water conservation	
1	What are the effects of intercropping and biochar application on soil organic matter, micronutrient availability water holding capacity of soils in the Tamale AEZ?
2	What are the effects of intercropping and biochar application on soil moisture, water use efficiency and soil erosion?
3	What are the effects of biochar application and intercropping on soil carbon and nitrogen reserve and microbial population?
Research questions: Plant health/pest and disease management	
1.	What is the influence of selected agro-ecological practices on arthropod biodiversity (abundance and diversity) within the orchards/fields and in the semi-natural elements implemented
2.	Do the selected agro-ecological practices influence 1) the main pest populations (insects and weeds) and their damage as well 2) the natural enemy populations (abundance and diversity)
3.	Can artificial intelligence-based tools be develop to identify the main pest insects (the fruit fly complex) based on imagery to aid the development of a Decision Support System for Integrated Pest Management
Research question: Ecosystem services	
1.	Does the agro-ecological practices increase the ecosystem services of biocontrol, pollination via an increase of biodiversity

Research hypotheses

Table 0.3 presents the research hypotheses.

Table 0.3. Research hypotheses

Hypothesis: Crop productivity/ Gender and nutrition
H_1: Intercropping and biochar application will increase yield and nutritional quality of mango as well as intercrops
H_2: Intercropping and biochar application will improve the quality of harvested mango fruits (dropping, weight and brix degree) and increase the concentration of micro-nutrient in fruits and intercrops
H_3: Intercropping and biochar application will reduce farm labour for women
Hypothesis: Soil fertility and water conservation
H_1: The use of intercropping and biochar will improve soil organic carbon and soil moisture, but biochar may decrease micro-nutrient availability
H_2: The use intercropping and biochar will improve soil moisture, water use efficiency and decrease soil erosion

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H_3: The use intercropping and biochar will improve soil carbon and nitrogen reserve and microbial population
Hypothesis: Plant health/pest and disease management
H_1: The selected agro-ecological practices will influence arthropod biodiversity (abundance and diversity) within the orchards
H_2: The selected agro-ecological practices will influence 1) the main pest populations (insects and weeds) and their damage as well 2) the natural enemy populations (abundance and diversity)
H_3: Artificial intelligence-based tools and imagery will help to identify the main pest insects (the fruit fly complex) and aid the development of a Decision Support System for Integrated Pest Management

2.2.3 Research Methodology

Expert Group

The aim of the Expert Group (including approximately 4 farmers, 2 researchers and 2 extensionists) is the integration of further information and feedback on the trial design as well as the accompaniment during trial implementation. Table 0.1 presents the Expert Group for Mango production.

Table 0.1: Membership of Expert Group for mango production

Expert (Affiliation)	Expertise	Responsibility
Researcher: Benjamin Badii	Entomologist	Insect Monitoring
Researcher: Gazali Isssahaku	Agricultural Economist	Baseline Surveys
Researcher: Abdul-Halim Abubakari	Sustainable Agriculture	Field trials
Researcher: Frederick Kankam	Pathology	Integrated pests and diseases management
Farmer 1: (Margaret Nansori): Kunbungu	Farmer	Managing the baby trials
Farmer 2: (Fatili Mohammed): Tamale Metro	Farmer	Managing the mother trials
Farmer 3: (Fuseini Alhassan): Gushie	Farmer	Managing the baby trials
Farmer 4: (James Kwabena): Nyankpala	Farmer	Managing the baby trials
Farmer 5: (Edwin Ayamdo) Kukobila	Farmer	Managing the baby trials
Agric. Extension Agent of MoFA: Mr Iddi Issah	Agric. Extension Agent	Advising farmers regarding the practices
Researcher: Mr Abdulai Fuseini (University for Development Studies - UDS)	Snr Research Assistant	Responsible of data collection

Site selection

The sites for the mango production were selected within the following five communities: Tamale Metro, Kunbumgu, Nyankpala, Kukobila and Gushie. Tamale Metro has been designated as the core community.

Farmer selection / sampling

In each community, an opinion leader and an experienced mango farmer have been identified. Project details have been explained to the identified persons and they have been tasked to assemble willing farmers to form a group for the project. These farmers are organic mango farmers mostly cultivate the Kent mango variety. They have access to varying from of irrigation infrastructure and they use chicken manure as the main soil amendment. They have at least 15 acres of mango plantation. their plantations have been fruiting for at least 3 years.
The selection of sites was done through the assistance of the District Director of Agriculture. The list of fruit producers in the selected localities was obtained from the District Agricultural Development

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Units (DADU) of the Ministry of Food and Agriculture (MoFA) (Table 1). Target farmers were purposively selected based on the criteria that the farmer has experienced at least, three consecutive harvests from his/her mango farm. Selected farmers were contacted through the assistance of their respective Agricultural Extension Agents (AEAs).The participating communities have been presented in **Error! Reference source not found.**.

Table 0.2. Participant communities

Region	Focus crop	AEZ	Participating communities	No. of participating farmers per community
Tamale	Mango	Savanna	Tamale	2
			Nyankpala	2
			Kumbungo	2
			Gushei	2
			Kukobila	2

Plot selection

We would select plots that are representative of mango agroecological system in northern Ghana. An orchard in Tamale would be used as the core plantation/site and other orchards supported by Integrated Tamale Fruit Company (ITFC) and the Exim Bank would also be selected. The selection would include irrigated organic orchards as well as non-irrigated ones. The plot size is 25 by 25m with distance between tree of 10m. There will be 4 mango trees per plot and plots will be separated by 25m distances.

Table 1. list of orchards in northern Ghana. Selected plots are highlighted yellow

DISTRICT	SELECTION CRITERIA	SITE DETAILS
Sawla-Tuna-Kalba	Community	**SOGOYIRI**
	GPS coordinates	N 09 ° 12.971, W 002 ° 24.290, 5m asl
	Name of farm	Kurabaso Mango Association
	Farmer	Alhaji Abubakari – 0273689326
	Farm size	47 acres (mapped area)
	Mango cultivar	Keith
	Fruiting stage	Established 2011; 1st fruited last year
	Maintenance status	Good
	Presence of wasteland	Few missing trees; few shea trees present
	Irrigation system	Present
	General comment	supported by EDIF
Bole	Community	**MANDARI**
	GPS coordinates	N 09 ° 01.956, W 002 ° 32.840, 5m asl
	Name of farm	Alakabo farms
	Farmer	Alhaji Alakabo – 0242215328
	Farm size	10 acres
	Mango cultivar	Keith, Kent, Amelie, Haden
	Fruiting stage	Fruiting (10 years old)
	Maintenance status	Good
	Presence of wasteland	Nil
	Irrigation system	Borehole and Dam present
	General comment	-
	Community	**BOLE**
	GPS coordinates	N 09° 00.197, W 002° 28.263, 4m asl
	Name of farm	Kichito farmers Association
	Farmer	Alhaji Mumuni - 0242330445

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	Farm size Mango cultivar Fruiting stage Maintenance status Presence of wasteland Irrigation system General comment	66 acres Keith, Kent Fruiting (Established 2011; 1st fruited in 2016) Good Few missing trees; few wild trees Present. Borehole sunk for irrigation but yet to be mechanized Supported by EDIF
Bamboi	Community GPS coordinates Name of farm Farmer Farm size Mango cultivar Fruiting stage Maintenance status Presence of wasteland Irrigation system General comment	**JUBOI** N 09° 00.197, W 002° 28.263, 4m asl Amos Farms Mr K. Amos – 0200895424 112 acres Keith, Kent Fruiting began last year (est. 2011) Good Nil Borehole present supported by EDIF
West Gonja	Community GPS coordinates Name of farm Farmer Farm size Mango cultivar Fruiting stage Maintenance status Presence of wasteland Irrigation system General comment	**YIPALA** N 09 ° 07.850, W 001 ° 51.910, 4m asl Kenyity Wale Plantation Association Amanga (0247281423);Castro(0247795041) 150 acres (fruiting + non-fruiting) Keith, kent + others Fruiting (oldest trees established in 2009) Good Nil No more in use
Kumbungu	Community GPS coordinates Name of farm Farmer Farm size Mango cultivar Fruiting stage Maintenance status Presence of wasteland Irrigation system General comment	**KUMBUNGU** N 09° 32.686, W 000° 56.227, 4m asl Yiri Investment Ltd Margaret Ninsori – 0261100220 30 acres Kent Fruiting Very Good Nil Borehole present Supported by EDIF
Tamale Metro	Community GPS coordinates Name of farm Farmer Farm size Mango cultivar Fruiting stage Maintenance status	**MANGULI** N 09° 32.686, W 000° 56.227, 4m asl Fatili Mango Plantations - 22 acres Kent, Keith Fruiting since past 4 years Good

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	Presence of wasteland Irrigation system General comment	Nil Present, water supplied to poly tanks for use Supported by EDIF
Tolon	Community GPS coordinates Name of farm Farmer Farm size Mango cultivar Fruiting stage Maintenance status Presence of wasteland Irrigation system General comment	**NYANKPALA** N 09° 39.686, W 001° 59.027, 5m asl SARI Mango Plantations SARI Farm Manager 15 acres Kent Fruiting since past 2 years Good Nil No more irrigated
West Mamprusi	Community GPS coordinates Name of farm Farmer Farm size Mango cultivar Fruiting stage Maintenance status Presence of wasteland Irrigation system General comment	**KUKUA** N 10° 18.248, W 000° 49.063, 4m asl Hajia Memunatu Farms Hajia Memunatu 12 acres Kent Fruiting Good Nil Tanks supplied with water for irrigation Intercrop with soybean
Savelugu-Nanton	Community GPS coordinates Name of farm Farmer Farm size Mango cultivar Fruiting stage Maintenance status Presence of wasteland Irrigation system General comment	**KUKOBILA** N 10° 06.832, W 000° 49.206, 4m asl Kukobila/ Nasia Farm Edwin – 0545394181; Isham – 0244988197 15 acres Keith, Kent Fruiting Good Nil (Old trees felled, replacement ongoing Present Induce flowering with Teckamin Max &Teckamin flower
	Community GPS coordinates Name of farm Farmer Farm size Mango cultivar Fruiting stage Maintenance status Presence of wasteland Irrigation system General comment	**GUSHIE** N 09° 49.031, W 000° 51.822, 3m asl ITFC Outgrower Sumaila (ITFC deputy manager) – 0200576808 20 acres Kent Fruiting Good Nil Present Check with Sumaila for contact to outgrower
Mion	Community GPS coordinates	**MION** N 09° 17164, W 000° 3.176, 2m asl

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	Name of farm Farmer Farm size Mango cultivar Fruiting stage Maintenance status Presence of wasteland Irrigation system General comment	Sambu Mango Farmers Association Yakubu 0243984308 60 acres Kent, Keith Fruiting Good Nil Present
Zabzugu	Community GPS coordinates Name of farm Farmer Farm size Mango cultivar Fruiting stage Maintenance status Presence of wasteland Irrigation system General comment	**ZABZUGU** N 09° 26.073, E 000° 21.990, 7m asl Zabzugu-Dan Tobaa Smallholder Mango Mohammed (Captain) 0242605414 70 acres Keith, Kent Fruiting from last year Good Nil Present, dam available Initially funded by ADB , now by EDIF/GSOP
Gushegu	Community GPS coordinates Name of farm Farmer Farm size Mango cultivar Fruiting stage Maintenance status Presence of wasteland Irrigation system General comment	**NAYUGU** N 09°48.844, W 000° 16.511, 6m asl Nayugu mango plantations Fuseini Alhassan (farmer) – 0208290642 19 acres Keith, Amelie, kent (mixed) Fruiting (3rd year of fruiting) Good Few wild trees, few missing trees Present, Dugout for irrigation Supported by Ghana Social Opportunity Proj.
Sissala East	Community GPS coordinates Name of farm Farmer Farm size Mango cultivar Fruiting stage Maintenance status Presence of wasteland Irrigation system General comment	**WALEMBALE** N 10° 25.958, W 002° 01.640, 3m asl Balice Farms 0244096178 66 acres Kent, Keith Fruiting began last year Good Few vacancies, few shea trees Tanks filled with water for irrigation Sopported by EDIF
Nadowli-Kaleo	Community GPS coordinates Name of farm Farmer Farm size Mango cultivar Fruiting stage	**JANG** N 10° 11.975, W 002° 28.180, 5m asl Matco mango plantation Steve (manager)0243812700, Matthew (owner) – 0244290413 50 acres Kent, Keith Fruiting (1st fruited 4 years ago)

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	Maintenance status Presence of wasteland Irrigation system General comment	Good Nil Present, Boreholes connected to tanks Supported by EDIF
	Community GPS coordinates Name of farm Farmer Farm size Mango cultivar Fruiting stage Maintenance status Presence of wasteland Irrigation system General comment	**KALEO** N 10° 10.975, W 002° 38.180, 5m asl KANT Farms Mr Kant 18 acres Keith, Kent Fruiting from last 2 years Good Nil Present Supported by EDIF
Wa Municipal	Community GPS coordinates Name of farm Farmer Farm size Mango cultivar Fruiting stage Maintenance status Presence of wasteland Irrigation system General comment	**PIISI** N 09 ° 56.308, W 002 ° 27.656, 5m asl Kalgaston Plantation Kala 67 acres Keith Fruiting (first harvested in 2016) Good Nil Present, borehole and pipes connected Supported by EDIF
Wa East	Community GPS coordinates Name of farm Farmer Farm size Mango cultivar Fruiting stage Maintenance status Presence of wasteland Irrigation system General comment	**JEYIRI** N 09 ° 49.253, W 002 ° 13.418, 8m asl Hamdallah farms Maulvi Bin Salih 0208118949, 0207413912 120 acres Keith, Kent Fruiting (1^{st} fruited in 2016) Very good Nil Present Citrus, ruminant, poultry, and fish farming
Kasina-Nankani	Community GPS coordinates Name of farm Farmer Farm size Mango cultivar Fruiting stage Maintenance status Presence of wasteland Irrigation system General comment	**KOLOGU** N 10 ° 41.202, W 001 ° 03.262, 4m asl K-Nankani fruit and vegetable farmers' assoc. Charles Amoah – 0240995853/0200333981 50 acres Keith, Kent Fruiting (Established in 2011) Good Nil Present (Borehole used for irrigation; water available upto about March)
Builsa North	Community GPS coordinates	**NAMOSA** N 10° 41.884, W 001°, 07.654

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	Name of farm Farmer Farm size Mango cultivar Fruiting stage Maintenance status Presence of wasteland Irrigation system General comment	Mango City Company Ltd Andy 0247120031, Mamshie 0244125337 120 acres Keith Fruiting (Established in 2011) Good Few wild trees present; mostly shea& Kapok Present (Boreholes + tanks; women water)

Treatments

The farming practices in different mango farming systems in mango agro-ecosystems will be tested to investigate their contribution to biodiversity and ecosystems services and enhance the resilience and sustainability of mango productivity and quality in Ghana. Trial variants will be based on the decisions made in T3.1 and will take place in selected orchards within 5 communities in the northern guinea savanna ecological zone of Ghana. The farming systems will involve organic and agro-ecological farming and conventional practices. Accordingly, the agro-ecological practices will include cover crops, intercropping, biochar and smart irrigation practices using the BLUELEAF concept will be tested. The selected agro-ecological practices will be implemented and their effects on soil health, mango yield and quality, insect biodiversity and ecosystem services assessed.
Based on the research problems identified in 2.4.1 and our research objectives, the following treatment combinations (see Table 0.3) will be implemented in a split-plot factorial design.

Table 0.3. Treatment combinations

Treatment	Treatment description
1	T1 = Control 1: Farmer practice (Irrigated organic mango plot)
2	T2 = Control 2: (Non-irrigated organic mango plot)
3	T3 = Irrigated organic mango plot with groundnut intercrop
4	T4 = Non-irrigated organic plot with groundnut intercrop
5	T5 = Irrigated organic mango plot with biochar
6	T6 = Non-Irrigated organic mango plot with biochar

- Framer practice 1 (T1) is irrigated organic mango plot. This practice relies on the use of organic manure (mainly chicken manure) for soil fertility management and the use of botanicals (mainly Neem leaf extract) for pest and disease control under irrigation.
- Farmer practice 2 (T2) is the same than T1, but not under irrigation
- Treatment 3 (T3) is a modification of farmer practice 1, by addition of a leguminous cover crop. The reason for the inclusion of this treatment is to increase soil fertility by nitrogen fixation, increasing organic matter increasing soil moisture and erosion control. Groundnut production is also an opportunity for additional income generation and is regarded as women cash crop in northern Ghana. Groundnut production provides additional opportunities for value addition and agro-processing.
- Treatment 4 (T4) is a modification of T2 by the addition of leguminous intercrop. The same reason given for the choice of intercrop in T3 applies here.
- Treatment 5 (T5) is a modification of farmer practice T1, by addition of a biochar as soil amendment. The soils in northern Ghana are low in organic matter and are also generally acidic. So, the inclusion of biochar is important for improving the physical and chemical conditions of the sandy acidic soil characteristics of soil in northern Ghana.

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- Treatment 6(T6) is a modification of farmer practice T2, by addition of biochar as soil amendment. The same reason given for the choice of biochar treatment given under treatment 5 applies here.

Experimental design

The main experiment is a design as a split plot design with irrigation and non-irrigated plots set up as main plots with 4 sub-plots consisting of Conventional, Intercropped, Biochar plots. This results in six (6) treatment combinations with 5 replications, given a total of 30 experimental units. The main trial or the mother trial will be set up in Tamale, near UDS. Baby trials would be set up in four Communities (Nyankpala, Kumbungu, Kukobila and Gushie). Eight farmers (4 irrigated and 4 non-irrigated farmers) would be involved in the baby trials. Plot layout for mother and baby trial is presented in Figure 2.3. and Figure 2.4. below. Experimental units will consist of 25m x 25m (400m^2) plots with 4 mango trees per plot. Distances between plots will be 25m apart. This will mean a total of 61,875m^2 (6.187 ha, or about 15.468 acres) will be needed for the mother trial. Standard planting distances for sole intercrop of groundnuts 45 cm x 10 cm will be adopted. Rates of biochar (approximately 1-1.7 tons per ha) would be worked out proportional to the chicken manure applied in farmer's field.

Mother trial

	Irrigated			**Non-irrigation**		
R1	T1	T3	T4	T2	T3	T4
R2						
R3						
R4						

Figure 2-3. Plot layout for mother trial

Number of trials	**Irrigated**	
4	T1	T2

Baby trial

Number of trials	**Non-Irrigated**	
4	T3	T4

Figure 2-4. Plot layout for baby trial

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Baseline data collection of research sites

To ensure reproducibility of the study, a systematic description of the research sites abiotic environment and former cropping system management will be conducted (see D3.1). The data will be collected during the baseline assessment (Task 1.2.b).

Trial data collection

Physical crop sampling

Groundnuts

Growth and Yield parameters

- Plant height with Carpenter's rule method,
- Leaf number with a detailed count
- Leaf Area Index with a leaf area meter
- Seed yield with electronic weight
- Biomass with electronic weight

Mango fruits

- Flower count
- Fruit number
- Fruits dropping,
- Fruit weight
- Brix degree

Method of crop sampling

Determination of yield in mango production:

The following approaches may be considered for the determination of yield in research plots involving mango:

1. Under natural flower induction, it is known that 60 % of the flowers in all the varieties will drop naturally. Thus, the total number of flowers from the count of the flower drops can be estimated.
2. Flowers may also be induced with chemicals such as Paclobutrazol or potassium nitrate. Under induced flowering only 25 % of the flowers will drop naturally and once this 25% is counted, the total flower count can be determined.
3. Flower count can also be done by measuring the tree crown and dividing that into 4 quadrants. One quadrant can then be counted, and total flower count extrapolated.
4. For fruit count, it is known that 40 % of the fruits on the tree will drop naturally without any aid. Therefore, natural occurring fruit dropping can be counted, and the total number of fruits deduced from that. Subsequently fruits weight would be determined by weighing scale.
5. Brix degree will be determined by a refractometer

General Sampling

- pH, 1 KCL (Richards, 1954)
- Organic matter (FAO, 1974; Walkley, 1974)
- Total N, Kjeldahl-N (Bremner and Mulvaney, 1982)
- Organic carbon, Modified Walkley–Black wet oxidation (Nelson and Sommers, 1982)
- Soil Moisture, moisture meter
- Disease regulation and weed control (Neindow, et al, 2020)
- Micro-nutrient concentration in fruits (ICP-OES after microwave digestion)

Insect monitoring

- Insect species composition and diversity

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- Insect population dynamics and relative abundance
- Natural enemy populations (abundance and diversity)

Sampling protocol for yellow sticky traps (InsectaMon task)

A minimum of 2-3 yellow sticky traps with pheromone (attractive traps) targeting the fruit fly complex will be placed at the centre of each plot. The optimal distance between each pheromone traps is about 10 m. The traps will be set up during the pest activity. The traps will be located in the canopy at about 1m height, with unique identification number. The fruit flies are continuously active from March to July. Images of the traps will be taken with a smartphone during the pest activity periods on a weekly basis. Images will be centred and focused on the sticky trap, strong surface reflections will be avoided and depicted insects will be sufficient to be recognisable by experts. The images will be uploaded to the CSC cloud along with the trap ID and acquisition date for later image annotation (Luke) and AI model training (UH) of InsectaMon. The sticky traps will be changed after one month.

UAV flight campaigns for plant health assessment and mother trial characterization

Two UAV flight campaigns will be conducted at the mother trial: one during flowering (December-January) and one during fruit development period of the olive trees (March-July). The UAV will be equipped with multispectral and thermal camera. Imagery will be acquired from 25 m altitude with an image overlap of 80% to enable photogrammetric generation of orthoimages and SfM 3D point clouds. Ground control plates (GCP) will be used for geometric correction. All images of each campaign will be uploaded to the CSC cloud along with the GCP data for photogrammetry and remote sensing analysis (ATB).

For building a UAV based model for crop performance and vitality assessment, ground truthing measurements of chlorophyll activity and leaf area index (LAI) will be performed in the plots with SPAD-502Plus chlorophyll meter and LAI-2200C LAI meter at the olive crops and the intercrops. Effects on plant health due to pest insect distribution will be assessed with the high-resolution UAV imagery by aligning the image data with the collected insect data in the trials. The extent of the flight campaigns will exceed the mother trial area to include high-resolution information of the surrounding environment in the analysis to better assess ecosystem service effects, e.g., coming from landscape elements (bushes, tree-rows, flower-strips etc.).

Ground truthing measurements for satellite remote sensing monitoring of Mango

At three selected mango orchards, 10 plots will be located in representative areas with a dimension of 10 x 10 m. Plot dimensions will be measured with GNSS. Ground truthing measurements of chlorophyll activity and leaf area index (LAI) will be performed in the plots with SPAD-502Plus chlorophyll meter and LAI-2200C LAI meter in the olive crops and the intercrops. For each plot, an average from five equally distributed, single measurements will be performed for one integral plot measurement. The measurement dates of ground truthing data collection will be aligned with the phenological stages flowering, fruit formation, fruit development and maturing of the olive trees.

Sampling protocol for beneficial organisms and biodiversity estimations

The insect sampling focuses on flying and ground-dwelling species. One malaise trap (a passive trap for flying insects) is set up in the centre of each plot. In addition, 8 pitfall traps (a passive traps for ground-dwelling insects and arachnids) are set up around the malaise trap forming a square (see Figure 2.2). On the top of each pitfall traps, cover hoods are placed to protect the traps from high evaporation and overflooding in case of important rainfall. The minimum distance between each pitfall trap is 5m. The minimum distance between each malaise trap is 50m. The minimum number of replicates for statistical robustness is 5 replicates per treatment (i.e. 5 malaise traps and 5x8=40 pitfall traps).

Traps are filled with propylene glycol. One sampling period is 2 weeks long and the traps are collected and checked once a week. There will be 4 sampling times in a year in order to cover the different

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seasons and represent the biodiversity along the year. They take place in December-January (flowering), April-May (beginning fruit formation), June-July (end of fruit development) and September-October (resting time for the crop).
The collected insects will be placed in tubes filled with ethanol (>90%) and stored in the freezer or fridge until further manipulation. The maximum storage temperature in the fridge is 2 °C, the minimum temperature in the freezer is -20 °C. The main pest insects and the most abundant species (representing 80% of the biomass) will be counted and identified to species level if possible. If not possible, we will aim at identifying to the lowest taxonomical level possible. Some samples (10 females and 10 males of each species, if possible) will be sent to Luomus, Finland, as vouchers and for biomass estimation. Functional traits will be measured on a sub-sample to try and link abundance and diversity of arthropods to ecosystem services.

2.2.4 Personnel, Material and Equipment Required

Personnel requirements

A field technician should be responsible at each site for trial set-up, monitoring, measurements, treatments (e.g., weeding, spraying) in cooperation with the local extension service or Non-Governmental Organization (NGO) staff and farmers. The personnel requirements have been presented in Table 0.1.
Local staff should be responsible for the following:

- Taking notes: For example, record any disease, insect, or weed problems that could affect growth of the crops
- Record contributions and opinions stated by the farmer
- Routine monitoring for observation of compliance, decisions on management (e.g., pest control), and to keep farmers engaged
- Monitoring to look for surprises

Table 0.1. Personnel requirements

No. of people	Role & responsibility	Qualifications needed
1 field technician per site	Field Technician	BSc Agriculture
1 researcher	setting up, checking and collecting insect traps in plots	Msc. Agriculture
1 researcher	yield assessment	Msc. Agriculture
1 researcher	intercrop implantation…	Msc. Agriculture

Material and equipment

Table 0.2. Material and equipment requirements

Material / Equipment	Acquired at [country] / Return to [country]	Responsible
pheromone sticky traps against fruit fly complex	Acquired in Europe	Stéphanie Saussure
malaise traps	Acquired in Europe	Stéphanie Saussure

bottle to collect insects from malaise traps	Acquired in Europe or locally	to be identified
pitfall traps and cover hood	Acquired in Europe	Stéphanie Saussure
propylene glycol	Acquired in Ghana	Stéphanie Saussure
ethanol (>90%)	Acquired locally or in Europe	to be identified
tubes/small bottles for storage of insects	Acquired locally	Stéphanie Saussure
GPS equipment	Acquired in Europe	Young Giles
Ipads	Acquired in Europe	Young Giles
Biochar	Acquired locally	Abdul-Halim Abubakari
Drip irrigation kit	Acquired locally	Abdul-Halim Abubakari
Chicken manure	Acquired locally	Abdul-Halim Abubakari
Field tags and labels	Acquired locally	Abdul-Halim Abubakari

2.2.5 Time Schedule

Table 0.1. Time schedule

Month & Year	Task (How will data be collected)	Community	Responsible	Staff involved
November 2021	Training for data collection	all		
winter 2021	Baseline survey (semi-quantitative)			
winter 2021	Baseline physical crop sampling			
Season 2022				
January-February	1st insects sampling for 2 weeks		Benjamin Badii	1 student or technician
April-May	2nd insects sampling for 2 weeks		Benjamin Badii	Frederick Kankam
June-July	3rd insect sampling for 2 weeks		Benjamin Badii	Frederick Kankam
September-October	4th insect sampling for 2 weeks		Benjamin Badii	Frederick Kankam
March-July	pheromone trapping of the main pests. Changing traps and taking picture for InsectaMon		Benjamin Badii	Frederick Kankam
May 2022	Harvest – physical crop sampling		Frederick Kankam	Abdul-Halim Abubakari

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2.2 Maize

2.3.1 Milestones and Responsibilities

The respective timeline and milestones as well as the responsible teams are described in Table 0.11.

Table 0.1. Tasks and responsibilities

Tasks	From (month)	To (month)	Milestone	Teams involved; Lead in bold letter
Expert group formation	February 2021	February 2021	Expert group formed	**Fatimah**, Kwame, Michael, Ransford Research assistants (2), MoFA staff, SIA Experts, Experts from Crops Research and Soil Research Institute of Ghana.
Expert interviews	March 2021	April 2021	6 of experts identified; 6 of experts interviewed	**Fatimah**, Kwame, Michael, Ransford, Research assistants (2)
Expert group meetings	June 2021	October 2021	2 of Expert group meetings organized	**Fatimah**, Kwame, Michael, Ransford Research assistants (2), MoFA staff, SIA Experts, Experts from Crops Research and Soil Research Institute of Ghana
Trial design for each region/community	August 2021	October 2021	Trials designed for each community	Fatimah, Kwame, **Michael**, Ransford Research assistants (2), MoFA staff, SIA Experts
Trial implementation	Major season April 2022	Major season June 2022	Field trials implemented in all 3 communities	Fatimah, **Kwame**, Michael, Ransford Research assistants (2); Postgrad student (1 Farmers, extension agents, input dealers, NGO staff
	Minor Season September 2022 Repeat in 2023, if possible	Minor season November 2022		

Research framework

The following section serves as conceptual framework for the trials and their implementation according to the project proposal and inputs provided by the expert group, identified in the Ejura region and finally decided by the experts.

Background

Agricultural production in sub-Saharan Africa (SSA) is under increasing pressure to meet the food and nutrition security needs of the growing population whilst contending with the challenges of climate change and variability, degraded and infertile soils (Hobbs, 2007; Ngwira et al., 2012). Smallholder farmers in SSA often grow cereal crops such as maize (Zea mays L.) in continuous monoculture for food security even when there is limited profitability (Baudron et al., 2012). Raising agricultural production requires a shift towards more sustainable cropping systems to help reverse soil degradation, reduce labour investments and improve production (Masvaya et al., 2017). Intercropping maize with cowpea

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is one of the most popular mixed cropping combinations under small-holder rain-fed agriculture in the tropics (Abdulraheem & Emmanuel, 2014).
It is important to note that cowpea and maize have different growing requirements and require distinct cultivation practices. The underground cowpea residue must remain in the soil to achieve the full nitrogen and organic matter benefits of a cowpea-maize rotation (Uzoh et al., 2019).
The farming systems will include organic and agro-ecological farming practices. These practices will be defined by diverse integration of innovative agro-ecological and agronomic practices that promote sustainability of agricultural systems by increasing organic matter in soil and increasing natural pest and disease control or decreasing pest pressure. Accordingly, the agroecological practices will include cover crops, intercropping, crop rotations with forage legumes, alley crops, farmyard manure, mulching methods, reduced tillage, among others. Agricultural practices such as the optimization of planting date, plant density among others and smart farming technologies (in this case pest and disease management developed in WP2), will be tested). In some cases, agroforestry will be relevant and tested. In this document, the farming systems, agro-ecological and agricultural practices are described for each country, crop and AEZ as already established in D3.1.

Research problem

Soil fertility decline is a major biophysical factor affecting maize production in Ghana (Logah et al., 2010). Soil degradation as a result of soil erosion and nutrient depletion is one of the most important environmental and economic problems in Ghana (Adu, 2012). Low soil fertility, drought, diseases and insect pests are the dominant constraints in maize productivity in the Ejura district. Low soil fertility results in low yield, drought leads to stunted growth, and pests and diseases affect the yield and quality of maize. Farmers in the study area also have a preference for low soil nitrogen (low N) tolerant, drought tolerant, disease and pest-resistant varieties that require lower inputs. When nitrogen fertilizer is added to the field, intercropped cowpea uses the inorganic nitrogen instead of fixing nitrogen from the air and thus compete with maize for nitrogen (Adu-Gyamfi et al., 2007). Varieties improved for yield have had low adoption rates among small scale farmers. Productivity of maize remains low in the smallholder sector because the crop continues to be grown under stress-prone environments and with limited resources. The challenges identified at Ejura include poor soil fertility, soil erosion, water scarcity, poor management knowledge (especially with regards to plant protection, climate change adaptation and mitigation, production of preferable certified organic products).

Research objectives

Table 0.2. Research objectives

Research objective: Soil fertility/ quality
1. To assess effect of biochar, compost and inorganic fertilizer application in maize-cowpea monocropping, intercropping or rotation systems on soil quality and soil ecosystem services (soil nutrient, soil carbon, water holding capacity, etc.)
Research objectives: Plant health/pest and disease management
1. To assess effect of biochar, compost and inorganic fertilizer in maize-cowpea monocropping, intercropping or rotation system on soil biodiversity.
2. To examine the effect biochar, compost and inorganic fertilizer in maize-cowpea monocropping, intercropping or rotation system on beneficial microorganisms
Research objectives: Crop yields, nutritional quality and farmer incomes
1. To assess effect of biochar, compost and inorganic fertilizer in maize-cowpea monocropping, intercropping or rotation system on crop yields and nutritional quality.

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2. To examine the effect of maize-cowpea monocropping, intercropping or rotation system on farmer incomes.
Research objective: Farmers willingness to adopt
1. To examine the factors (profitability, gender inclusion, nutrition, etc.) that influence farmers adoption of maize-cowpea monocropping, intercropping or rotation system.

Research questions

Table 0.3. Research questions

Research question: Soil fertility/ soil quality
1. How does the application of biochar, compost and inorganic fertilizer in maize-cowpea monocropping, intercropping or rotation systems improve soil quality and soil ecosystem services (soil nutrient, soil carbon, water holding capacity, etc.)?
Research questions: Plant health/pest and disease management
1. How does the application of biochar and inorganic fertilizer in maize-cowpea intercropping or rotation systems improve soil biodiversity?
2. How does soil amended with biochar and inorganic fertilizer in maize-cowpea intercropping or rotation enhance population of beneficial microorganisms?
Research objectives: Crop yields, nutritional quality and farmer incomes
1. How does the application of biochar, compost and inorganic fertilizer in maize-cowpea monocropping, intercropping or rotation system improves crop yields and nutritional quality?
2. How does the effect of maize-cowpea monocropping, intercropping or rotation system increase farmer incomes?
Research question: Farmers willingness to adopt
1. How does the factors (profitability, gender inclusion, nutrition, etc.) influence farmers adoption of maize-cowpea monocropping, intercropping or rotation system?

Research hypotheses

Table 0.4. Research hypotheses

Research hypothesis: Soil fertility/ quality
H_1: Application of biochar, compost and inorganic fertilizer application in maize-cowpea monocropping, intercropping or rotation systems cannot improve soil quality and soil ecosystem services (soil nutrient, soil carbon, water holding capacity, etc.).
Research hypotheses: Plant health/pest and disease management
H_1: Application of biochar, compost and inorganic fertilizer in maize-cowpea monocropping, intercropping, or rotation system cannot enhance soil biodiversity.
H_2: Biochar, compost and inorganic fertilizer application in maize-cowpea monocropping, intercropping or rotation system does not increase beneficial microorganisms.
Research hypotheses: Crop yields, nutritional quality and farmer incomes
H_1: Biochar, compost and inorganic fertilizer applied in maize-cowpea monocropping, intercropping or rotation system cannot improve crop yields and nutritional quality.
H_2: Maize-cowpea monocropping, intercropping or rotation system following biochar, compost and inorganic fertilizer cannot increase income of farmers.

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Research hypothesis: Farmers willingness to adopt
H_1: Factors such as profitability, gender inclusion, and nutrition do not influence farmers' adoption of maize-cowpea monocropping, intercropping or rotation system.

2.3.2 Research Methodology

Expert Group

The aim of the expert group (including approximately 4 farmers, 2 researchers and 2 extensionists) is the integration of further information and feedback on the trial design as well as the accompaniment during trial implementation. The Group was formed through consultation and personal contact with MoFA and CSIR and discussion with experts. The membership of the Expert Group has been presented in Table 0.1.

Table 0.1. Membership of Expert Group for maize trial

Expert (Affiliation)	Expertise	Responsibility
Researcher: Dr Kwame Frimpong (UCC)	Soil science	Group lead
Researcher: Dr Kofi Boa (Warren Buffet Centre for No-Till Agriculture)	No-till agriculture	Advisor on composting and biochar
Private consultant: Dr. Kingsley Osei	Research	Advisor on maize agronomy and Ejura agroecological conditions
Farmer 1: Samari Nkwanta	Farming	Assist in farmer selection and farmer group formation; monitoring of field work
Farmer 2: Teacher Krom	Farming	Assist in farmer selection and farmer group formation; monitoring of field work
Farmer 3: Ejura	Farming	Assist in farmer selection and farmer group formation; monitoring of field work
Farmer 4: Kropo	Farming	Assist in farmer selection and farmer group formation; monitoring of field work
Agric. Extension Agent of MoFA: Mr Daniel Lomotey	Agric. Extension	Farmer mobilization and farmer group management; farmer filed day organization
Researcher: Dr Farncis Tetteh (Soil Research Institute)	Soil Fertility	Technical advice on maize agronomy and soil fertility management
Researcher: Dr Kwadwo Obeng-Antwi (UCC)	Maize breeding and agronomy	Technical advice on maize breeding and agronomy

Site selection

The sites for the maize and cowpea cultivation will be selected within the following three communities: Samari Nkwanta, Kropo and Teacher krom. The three communities were chosen based on their location in terms of closeness to market, an agricultural institution and project stakeholders as well as farmers' practice and accessibility regarding availability of roads and acceptability by local opinion leaders. The communities were chosen after consultation with the MoFA and the Ejura Municipal Assembly. The sites will be selected based on carefully considered criteria, including climatic conditions, availability of land, farmers' experience, accessibility and potential for close monitoring, processing industry, irrigation facilities, research institutions, farmers' willingness to participate, and

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gender inclusiveness. The closeness of the sites to the main roads and the presence of the farmers' group were also taken into account.

Farmer selection / sampling

In each community, an opinion leader and an experienced maize farmer have been identified. Farmers who are willing to participate in the project will be identified including at least 40% female farmers. The farmers' selected criteria also included their method of farming systems (either monocropping or mixed cropping) scale (subsistence or commercial), availability of livestock, their willingness, indigenous knowledge and previous experience in maize and cowpea production, years of farming, and age. The project focus, objectives and expectations will be explained to the identified farmers willing to be part of the project.

Plot selection

In the selection of sites, efforts will be made to control and reduce the variation of natural factors as best as possible. Thus, fields and/or plots for demonstration will be chosen based on the uniformity of the inherent soil physicochemical properties and topography. Even so, pre-experimental soil analyses will be conducted with standard laboratory methodology and any significant variation observed will be accounted for as covariance in the analyses. Additionally, all plots and fields will be prepared and managed in the same way except for the treatments that shall be tested.

Treatments

Based on the challenges of agricultural production the Ejura region identified in D3.1, the following treatments (see Table 0.2) have been suggested for the pineapple trial:

Table 0.2. Project treatment description

Treatment	Treatment description
1	T1 = Control1: maize monocrop with traditional farmer practice (farmers' current maize production practice)
2	T2 = Control2: maize monocrop with conventional maize production (planting for Food and Jobs recommendation)
3	T3 = Maize monocrop with site Specific fertilizer recommendation by Soil Research Institute of Ghana
4	T4 = Maize-cowpea intercropping with planting for Food and Jobs fertilizer recommendation
5	T5 = Maize-cowpea rotation with Planting for Food and Jobs fertilizer recommendation with biochar
6	T6 = Maize-cowpea intercrop with biochar and Planting for Food and Jobs fertilizer recommendation
7	T7 = Maize-cowpea rotation with biochar and site-specific fertilizer recommendation by Soil Research Institute of Ghana
8	T8 = Maize monocropping with biochar and site – Specific fertilizer recommendation by Soil Research Institute of Ghana
9	T9= Maize monocropping with compost and site – Specific fertilizer recommendation by Soil Research Institute of Ghana
10	T10 = Maize monocropping with compost, biochar and site – Specific fertilizer recommendation by Soil Research Institute of Ghana

Trial 6 to 10 will only be done on the mother trials for experimental purposes. Compost or biochar will be applied at 10 tons ha^{-1} equivalence.

Experimental design

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The 'mother and baby trial' design will be applied as described in deliverable 3.1. The mother trials will be located at Teacherkrom and Ejura Agricultural College and will be managed by researchers and selected students. Farmer field days will be organised at the mother trials sites with selected farmers and extension officers to enable them to appreciate the focus and expected outcomes of the trials. The treatments will be randomly allocated to blocks, with each block containing all treatments. There will be 3 replications at each mother trial site. The baby trials will be located in all three communities and will be managed by farmers, with support from researchers and extension staff. Each baby trial will use a subset of three treatments, plus the two controls, involving 6 farmers from each community and summing up to 18 farmers in total for the baby trials. Wherever possible, female farmers will be included in the baby trials. Each plot will measure, at most, 6 m x 6 m. The planting distance will be chosen based on the recommendation from MoFA at the Ejura AEZ. Prior to the start of the trials, the design, varieties and management approaches will be discussed with the stakeholders to secure their by-ins and fine-tune the implementation strategy, if necessary.

Variety selection

The maize and cowpea varieties for the trial will be selected based on advice from MoFA, Crops Research Institute and the local farmers. This will be discussed and agreed at a stakeholder forum.

Sources of inputs

Recommendation from Ministry of Food and Agriculture (MoFA) and experts from soil and crop research institute.

Baseline data collection of research sites

To ensure reproducibility of the study, a systematic description of the research sites abiotic environment and former cropping system management will be conducted (see D3.1). The data will be collected during the baseline assessment.

Trial data collection

Key data

- Farmer's willingness to participate in SustInAfrica
- Land availability for plots implementation
- History of community participation in projects
- Farmers and other stakeholders current and desired farming practices and crops
- Farmer's revenue expectations
- Farmers technological readiness
- Market accessibility and influence from outsiders (e.g., commercial farming)

Physical crop sampling

The sampling strategy will be based on deliverable D1.1 from WP1. The above-ground biomass of the maize plants and the progress of growth will be estimated using four indicators:

- Plant height
- Ear height
- Plant canopy
- Chlorophyll index

On maturity, yield and physical characteristics of crop that will be tested include:

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- Fresh/ Dry Weight
- Number of ears per plant
- Ear length
- Ear diameter
- Grain yield
- 100 or 1000 grain weight
- Aboveground dry biomass yield (t/ha)

Other ecosystem service indicators that will be measured include soil water retention capacity, soil microbial population dynamics and soil microbial activity, and maize nutrient use efficiencies.

Laboratory analysis

Standard laboratory procedures will be used to determine the selected parameters with the help of a laboratory technician and laboratory protocols.

2.3.3 Gender, Socio-Cultural, Profit and Nutrition Considerations

The potential impact on gender relations will be assessed using the Voice, Choice, and Control Framework; returns to family labor and women's workloads. The Voice, Choice & Control framework analyses how the technology will increase or reduce women's agency in deciding to adopt/reject the technology and women's control over the inputs, assets and outputs of the technology. Technologies aimed at smallholder farming households are unlikely to be adopted unless the new technology produces significant increases in returns to family labor, however, this must be achieved without increasing women's labor requirements. Women's labor requirements and returns to family labor will be tracked during the development and field trials of the technologies using standard socio-economic research tools (daily clocks, seasonal calendar) and there is also potential, subject to data protection legislation to trial the use of smartphone activity tracking apps and fitness monitors.

2.3.4 Personnel, Material and Equipment

We will ensure that crop management practices such as land preparation, planting and pest control are appropriate and uniform across plots and sites (Coe, 2012).

Personnel requirements

Table 0.1. Personnel requirements

No. of people	Role & responsibility	Qualifications needed
12	Organise a team at each site	A field technician, the expert group (researchers, extensionists, farmers)
2	Develop a protocol	researchers
5	Management of farmer plots	1 researcher and 4 farmers
2	Monitoring data during the fieldwork	researcher
2	Initial soil sampling	Soil scientists
3	Biomass collection	Soil and crop scientists

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Material and equipment

Table 0.2. Material and equipment requirements

Material / Equipment	Acquired at [country] / Return to [country]	Responsible
Seeds	Ghana	Researcher/ Farmers
Rakes, cutlass	Ghana	Researcher/ farmers
Wheelbarrow	Ghana	Researcher/ Farmers
Pegs, rope/ garden line	Ghana	Researcher/ Farmers

2.3.5 Time Schedule

Table 0.1. Time schedule

Month & Year	Task (how will data be collected)	Community
Season 2022		
April – June	Soil sampling	Teacher krom, Ejura and Kropo
	Planting/ harvesting	Teacher krom, Ejura and Kropo
	Data collection	Teacher krom, Ejura and Kropo
September - November	Soil sampling	Teacher krom, Ejura and Kropo
	Planting/ harvesting	Teacher krom, Ejura and Kropo
	Data collection	Teacher krom, Ejura and Kropo

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3. Trials in Tunisia

3.1 Olive

3.1.1 Milestones and Responsibilities

Table 0.1. Milestones and responsibilities

Tasks	From (Month)	To (Month)	Milestone	Teams involved; Lead in bold letter
Expert interviews	July 2021	August 2021	3 of experts identified; 5 of experts interviewed	**Saida El Fekih**, Olfa Boussadia, Amel Ben Hamouda, 2 engineers, 3 Extension Agent.
Expert group formation	October 2021	November 2021	Expert group formed	**Olfa Boussadia,** Amel Ben Hamouda, Saida El Fekih, Mohamed Ayedi, 2 engineers, 3 Extension Agents**.**
Expert group meetings	May 2021	November 2021	7 of Expert group meetings organized	**Olfa Boussadia**, Amel Ben Hamouda, Saida El Fekih, Ayedi Mohamed, Mohamed Braham, Hatem Zgali, Nadia Chaieb, 2 engineers, 3 Extension Agent
Trial design for each region/community	November 2021	December	Trials designed for 2 communities	**Olfa Boussadia**, Sofiane Abdelhamid, Amel Ben Hamouda, Hatem Zgallai, Nadia Chaieb, Hanen Kefi
Trial implementation	November 2021	August 2024	Field trials implemented in all 3 communities	**Olfa Boussadia**, Sofiane Abdelhamid, Amel Ben Hamouda, Hatem Zgallai, Nadia Chaieb, Hanen Kefi, 3 recruited engineers

3.1.2 Research Framework

Research Problem

The olive tree represents the most important crop in the target regions. It has a nutritional value in the Tunisian diet and a high socio-economic importance. More than 97% of the olive area is conducted under dry farming system. Additionally, soils of Tunisian olive orchards have low water holding capacity and low soil fertility, and are exposed during the dry season, to long periods of soil water deficit, coincided with the active fruit growth and oil synthesis.

Olive tree-crop lands include deep brown or alluvial soils with a well-balanced texture. These soils are found into many bio-climatic areas. Olive trees extend over 1.9 million ha of the Tunisian land.

In the North (Beja) soils can be rich in organic matter and show cracking during dry season (topomorphic and lithomorphic verti soils) or have a fine texture, a well-developed polyhedral structure and calcareous accumulations.

In the center, the soil is an iso-humic (brown soils with coarse texture in Sahel and low steppe. Some areas like Sidi El Hani, Monastir, are characterized by saline-sodic soils found in depressions and in the Sebkhas (Mtimet, 1999).

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Tunisia is known as an underprivileged country in water resources; and water scarcity is evident in certain regions. The amount of surface water is distributed in the extreme north with 930 Mm^3 (36%) and in the centre with 320 Mm^3 (12 %). The ground water level is between 100 m in the north and 600 m in the center respectively (Semide, 2008).
In general, the structure of Tunisian soils is poor due to the low organic matter content (less than 1%) the low calcium carbonate, the pH alkalinity (>7.8), and the moderate share of calcareous (>15%). Also, the cation exchange capacity is low and the nutrients circulation and roots assimilation is limited (Gargouri et Mhiri 2003 ; Boussadia 2004).
This critical situation causes the vulnerability of olive tree to pests' infestation added to the poor knowledge of the main pests and their monitoring by farmers.
In order to identify the main factors of the olive tree sustainability in Tunisia, the study of the different areas of olive cultivation should be linked to the different levels of the soil-plant-atmosphere system. It should specify the classes of soil and its interaction with the climate and the landscape.

Research Objectives

Table 0.1. Research objectives

Research objectives: Soil fertility
1. To provide the most favorable conditions for trees growth, by managing organic matter and enhancing soil biological activity
2. To minimize losses of energy, soil, water, nutrient, etc., by conservation and regeneration of soil and water resources
3. To diversify species and genetic resources in the olive agroecosystem over time and space at the field and landscape level
Research objectives: Plant health/pest and disease management
1. Provide olive production (quantity and quality) by managing olive insect pests.
2. Minimise the spray of pesticides and enhance beneficial organisms by using yellow sticky traps with pheromones.

Research Questions

Table 3-0.2. Research questions

Research questions: Soil fertility
4. What are the effects of 'No tillage' on the water holding capacity, soil erosion and olive productivity?
5. What are the effects of cover crop (Fenugreek, winter wheat and *Faba bean*) on the water holding capacity, soil erosion, soil fertility and olive productivity?
6. What are the effects of compost on the water holding capacity, soil fertility and olive productivity.
Research questions: Plant health/pest and disease management
What are the effect of tillage/no tillage on insect pests of olive?

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1.	What are the effects of cover crop (Fenugreek, winter wheat and *Faba bean*) on olive insect pest abundance?
2.	What are the effects of compost on olive pest abundance?

Research Hypotheses

Table 0.3. Research hypotheses

Hypotheses: Soil fertility	
1.	No tillage prevents soil erosion and improves soil texture and structure.
2.	Cover crop improves soil fertility and maintain soil humidity.
3.	Compost improves soil fertility and retain nutrients.
Hypotheses: Plant health/pest and disease management	
1.	The yellow sticky traps constitute an effective control and monitoring tool to suppress olive insect pests.
2.	When applying cover crop, pest numbers are reduced depending on the plant species used.
3.	No tillage reduces insect pest pressure.

3.1.3 Research Methodology

Expert Group

The aim of the expert group (including approximately 4 farmers, 2 researchers and 2 extensionists) is the integration of further information and feedback on the trial design as well as the accompaniment during trial implementation. The details of the Expert Group have been presented in Table 0.1.

Table 0.1. Membership of Expert Group

Expert (Affiliation)	Expertise	Responsibility
Researcher: Dr Olfa Boussadia (IO)	ecophysiologist	Group lead
Researcher: Dr Saida El Fekih (IO)	Agroeconomist	Survey
Researcher: Dr Amel Ben Hamouda (IO)	Entomologist	Insect traps Installation and monitoring
Farmer 1: Salah Ben Ismail	Private olive owner and member of North West Olive Oil Cluster	organize the mother trial
Farmer 2: Anis Ben Taher	Mayor and Tunisian Union of Agriculture and Fisheries member	Organize the baby trial
Farmer 3: Kamel Dorri	Director of Professional Center for Agricultural training of Barouta	Organize baby trial
Farmer 4: Habib Majdoub	Director of Professional Center for Agricultural training of Jammel	organize the mother trial
Chahinaz Azizi	Agric. Extension Agent	Farmer contact and extension
Kamel Gazah, Engineer in Territorial Agricultural Extension Unit	Agric. Extension Agent	Farmer contact and extension

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Researcher: Dr Nadia Chaieb	Agronomist	Cover crop Installation and monitoring
Researcher: Dr Hatem Zgallai	Agronomist	Cover crop Installation and monitoring

Site Selection
The sites were chosen according to a rainfall gradient (from north to centre). Sites present soils of different textures. The two selected sites provide extension and training tools.

Farmer Selection & Sampling
In each community, an olive grower has been chosen according to his expertise in the field, his intellectual level, his social position and above all his willingness to collaborate with research institutions and integrate international projects.

Plot Section
In the selection of sites, efforts will be made to control and reduce the variation of natural factors as best as possible. Thus, fields and/or plots for demonstration are chosen on olive trees density and the minimal distance between traps to avoid pheromone interference phenomena. Additionally, all plots and fields will be prepared in the same way except for the treatments that shall be tested.

Treatments
Based on the challenges of agricultural production the Beja region identified in D3.1, the following treatments have been suggested for the olive tree trial in Table 3.6.

Table 0.2. Treatment description in Beja

Treatment	Treatment description
1	TC = Control, rainfed farmer practice (farmer's' current olive tree production practice)
2	T1 = No tillage olive tree production
3	T2 = Olive tree production with cover crop (*winter wheat*)
4	T3 = Olive production with cover crop (fenugreek)

In Sousse / Monastir AEZ, the treatments presented in Table 3.7. have been suggested for the olive tree trial:

Table 0.3: Treatment description in Sousse/Monastir

Treatment	Treatment description
1	TC = Control: Rainfed/ irrigated farmer practice (farmer's' current olive tree production practice)
2	T1 =No tillage olive tree production
3	T2 = Olive tree production with cover crop (*Faba bean*)
4	T3 = Olive production with cover crop (Fenugreek)
5	T4= Olive production with compost / manure 2 tons per hectare

- **Treatment 1 – Farmer practice:**

In Beja, the soil is generally loam and/or clay and the mean annual rainfall around 500 mm. Soil management is limited to two-three tillages per year, using offset disc, at a depth of 5-7 cm, to destroy spontaneous herbs, mainly dicotyledons and grass species. In Sousse Monastir, the mean annual rainfall around 300 mm, the soil was mechanically tilled 3-4 times per year at a depth of 15-25 cm using a cultivator with dovetail. Tillage was made perpendicular to the slope for both regions.

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The farmers apply biannually pruning, after the 'On' year (year of production) by renewing the branches that have previously produced and favouring the ventilation and penetration of light into the canopy.
Monitoring and control of insect pests was made by the plant protection services of the Ministry of Agriculture and pesticides use depend on economic thresholds.
However, olive fruit fly infestations vary according to the geographical zones. Indeed, the pest attacks were high in coastal regions like Sousse/Monastir.

- **Treatment 2 – No tillage:**

No-tillage is the most important measure for the protection of the soil against erosion. No tillage allows spontaneous vegetation cover. The best plant cover is the one that grows on our land. the wild seed bank that will favour the development of plant covers in woody crops, as well as a large number of living organisms that they have great importance in the processes that facilitate the recycling and the availability of nutrients.

- **Treatment 3 and 4 - Organic farming / cover crop:**

The cover crop treatment is chosen as a soil protection against erosion, a Filter against the sun's rays, preventing the evaporation of the water a significant contribution of nutrients and organic matter important for culture and a limitation of the runoff of rainwater and maintenance of water reserves.
The plant cover constitutes an excellent habitat, where a large number of living beings take refuge and feed, they also maintain the balance of our olive groves, like the auxiliary insects that help prevent pests and diseases.

- **Treatment 5 - Organic farming / compost:**

Positive effects of using composted olive by product (leaves, wood pruning and olive waste) are widely acknowledged on improving some ecosystems services such as: i) nutrient retention and synchronization between nutrient supply and demand, reduction in nutrient loss and, consequently, in environmental pollution (e.g., nitrate leaching) and ii) biodiversity protection.

Experimental design

The 'mother and baby trial' design will be used. One mother trial will be located at Beja (Toukaber, rainfed olive production) and 2 at Monastir / Sousse AEZ (Jammel, rainfed olive production and Kondar, irrigated olive production). Mother trials will be managed by researchers. The treatments will be randomly allocated to blocks, which contain all treatments. There will be 3 replications at each mother trial site. The baby trials will be located in all three communities and will be managed by farmers, with support from researchers and extension staff.
In Beja AEZ, each baby trial will use a subset of control and one treatment, involving 3 farmers in the three communities. The Plot will be limited by four olive trees. The plot area is 64 m^2. Each treatment will be replicated in 3 Plots. The mother trial area is 1280 m^2. Figure 3.1. shows the experimental design for the olive trial in Beja.

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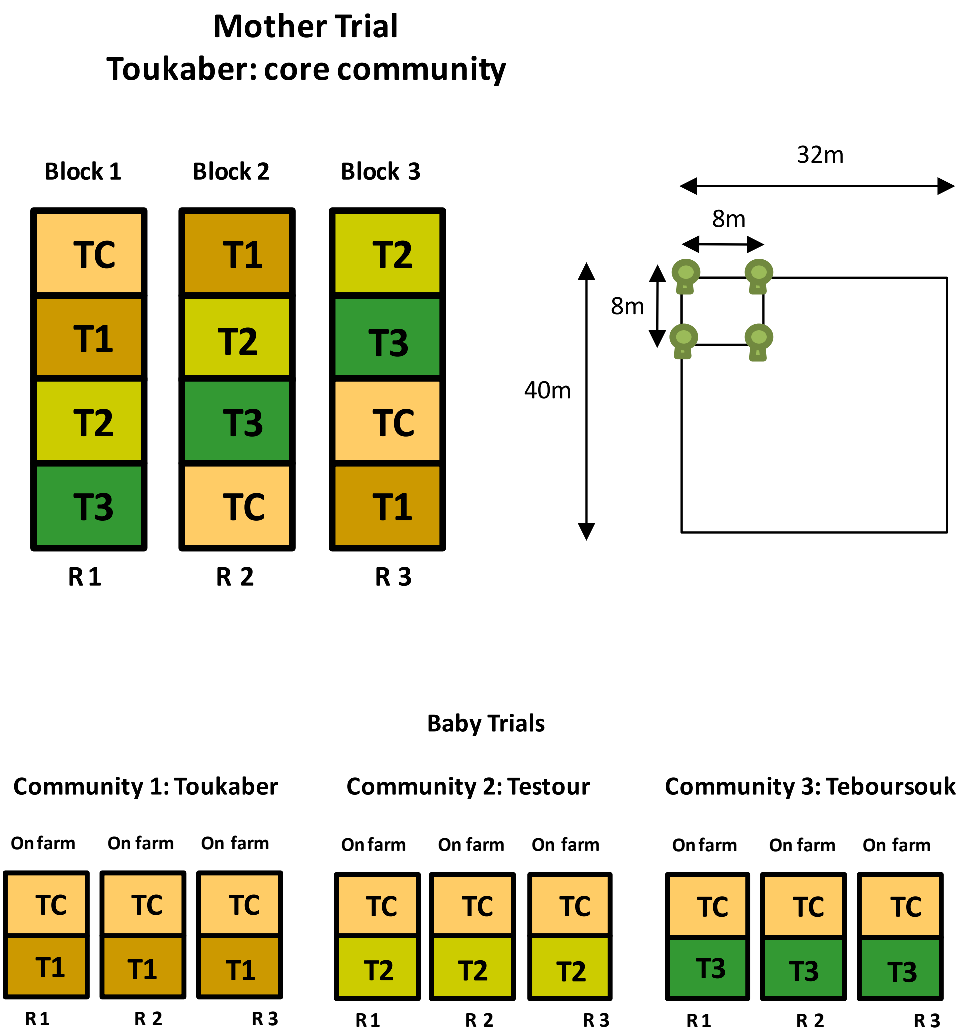
Beja AEZ



TC: Control, farmer practices (rainfed olive production practice)
T1: No tillage olive tree production
T2: Olive tree production with cover crop (winter wheat)
T3: Olive tree production with cover crop (fenugreek)

Figure 3-1. Experimental design for olive trial in Beja AEZ

In Monastir/ Sousse AEZ, each baby trial will use a subset of control and two treatments, involving 6 farmers in the three communities. The Plot will be limited by four olive trees. The plot area is 3600m^2. Each treatment will be replicated in 3 Plots. Figure 3.2. shows the experimental design for the olive trial in Sousse / Monastir. The mother trial area is 5.4 ha.

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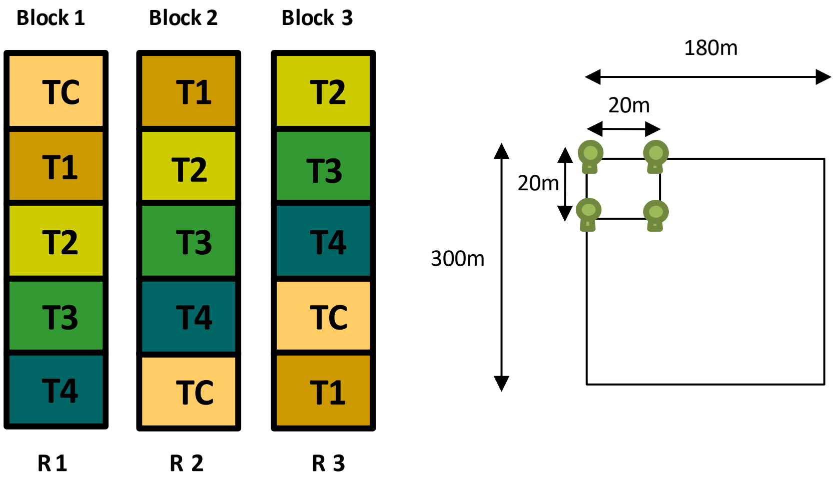
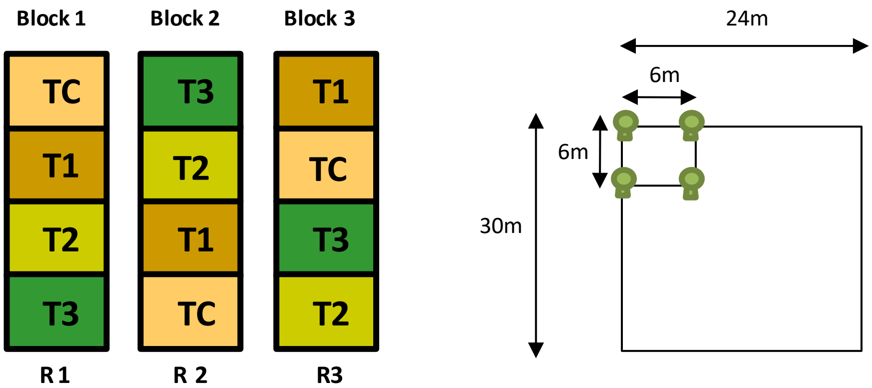
Sousse/Monastir AEZ

Mother Trial
Jammel: core community



TC: Control, farmer practices (rainfed olive production practice)
T1: No tillage olive tree production
T2: Olive tree production with cover crop (*Faba bean*)
T3: Olive tree production with cover crop (Fenugreek)
T4: Olive production with compost

Mother Trial
Kondar: core community



TC: Control, farmer practices (irrigated olive production practice)
T1: No tillage olive tree production
T2: Olive tree production with cover crop (*Faba bean*)
T3: Olive tree production with cover crop (Fenugreek)

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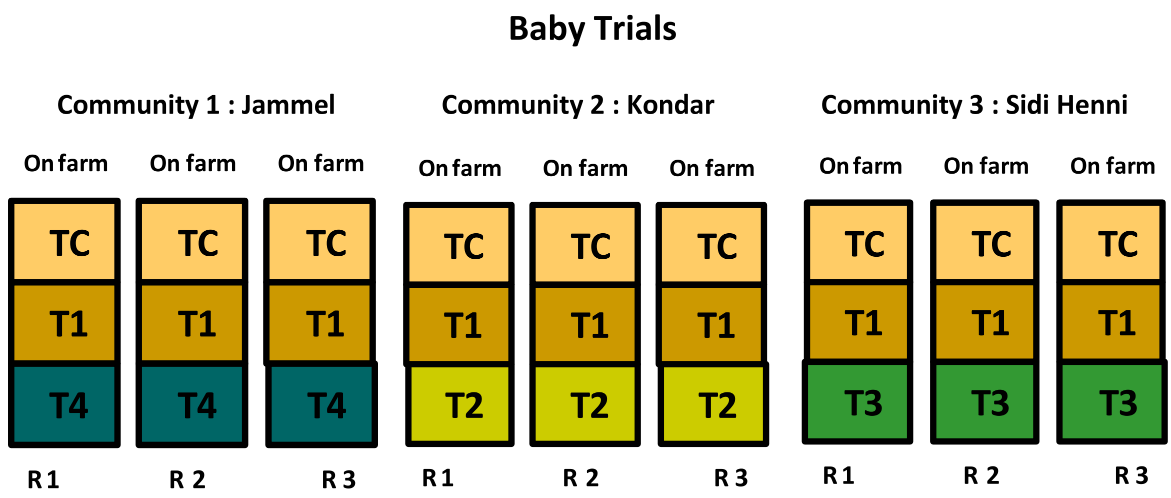

TC: Control, farmer practices
T1: No tillage olive tree production
T2: Olive tree production with cover crop (*Faba bean*)
T3: Olive tree production with cover crop (Fenugreek)
T4: Olive production with compost

Figure 3-2. Experimental design for olive trial in Sousse/Monastir AEZ

Experimental designs represented in the two AEZ (Beja and Monastir/Sousse) are theoretical. Implementation of theses designs can be modified according to the field conditions, biodiversity characteristics and allocated budget.
Experimentations related to insect pest dynamics and biodiversity will be implemented only in Sousse/Monastir AEZ, although in mother or baby trials. The number of trees and replications will be taken into account according to the interference distance for each kind of traps (Yellow sticky traps, Pitfall and Malaise traps).

Trial management and data collection

To ensure reproducibility of the study, a systematic description of the research sites abiotic environment such as weather and landscape composition and former cropping system management will be conducted (see D3.1). The data will be collected during the baseline assessment (Task 1.2.b).

<u>Physical crop sampling</u>
Physical crops will be sampled during the baseline (if manageable) and onwards yearly on participating farms.

- Method of crop sampling

<u>Fruit sampling in olive plots for oil content and ripening index:</u>
Sampling: A random sample of 500 g of olive will be harvest from four groups of three trees per cultivar during the harvest season every 10 days; approximately days 5, 15 and 25 of September, October, November and December. The fruit sampling must be random and should not be influenced by the colour of the fruit.

Ripening index: External color of the pulp will be recorded in a random sample of 30 fruits per tree, using the following scale (Figure 3-2).

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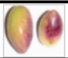
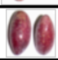
Olive	Color	Index
	Green	0
	Light-green	1
	Purple spots in less than half of fruit skin	2
	Purple spots in more than half of fruit skin	3
	Violet-black skin	4

Figure 3-2. Skin color for ripening index

Source: Frías et al. (1991)

Oil content and fruit traits: From the 500 g sample, three random subsamples of around 25-30 g will be selected. The number of fruits will be counted. Each sub-sample will be placed in a glass petri dish with a fireproof paper. Each subsample will be weighted independently to calculate fruit weight. Then, samples will be transferred to an air-forced oven at 105ºC during a minimum of 42 hours. The sub-samples will be again weighted to calculate fruit dry weight. Each three sub-samples of the same tree will be stored together until evaluation.

Sampling protocol for monitoring *Bactrocerca oleae*

Fruit sampling:

To monitor fruit infestation, we must check the fruit susceptibility to the attack of *B. oleae* by the determination of fruit diameter. The fruit will be considered susceptible for the pest infestation when the diameter reaches 6mm. Since this period, 10 fruits/tree will be collected every two weeks from at least 20 trees from plots. Fruits will be dissected for detecting damage such as oviposition punctures, larvae, pupae, and empty galleries due to larval feeding. Infested olives should be dissected under stereomicroscope to determine the developmental instar of the fly and the infestation rate.

Infestation rate = (number of infested olives / total number of examined olives) × 100

Treatment threshold: 10% for olive oil and 1% for table olive

Dissection of females (fertility):

To monitor *B. oleae* fertility, 50 females will be collected per two weeks from traps from the start of the first summer generation and ovary status will be noted, the number of ripe eggs per ovary and the percentage of mature females.

Sampling protocol for monitoring *Prays oleae*

Anthophagous generation: 50-100 flower clusters/tree will be collected from approximately 10-20 trees when flowering is about to start (% of infested clusters and density of hatched eggs/100 clusters).

Carpophagous generation: Depending on the extent of infestation, 10-30 fruits/tree will be collected from 10 trees every two weeks from fruit set (% infested fruit, density of hatched eggs/100 fruits).

Phyllophagous generation: Leaf samples will be collected once (100 leaves/tree from 10 trees) at the last mature larval instar–start of pupation: larval density/100 leaves.

The economic threshold for damage

1st generation: 4-5 % infested flower clusters

2nd generation: 20-30% infested fruit (small oil-olives)

Lower threshold for table olives

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Sampling protocol for monitoring *Palpita unionalis*

Shoot sampling:

Around ten young shoots will be collected from 5–10 trees from early Spring until October–November.

Sampling protocol for yellow sticky traps (InsectaMon task)

A minimum of 2-3 yellow sticky traps with pheromone (attractive traps) targeting the olive fruit fly and the olive moth will be placed at the centre of each plot. The optimal distance between each pheromone trap is 10 m. The traps will be set up during the pest activity. The traps will be located in the canopy at about 1m height with a unique identification number. The fruit flies are continuously active from June to December. The olive moth is active in March-April, May-June, and September-October. Images of the traps will be taken with a smartphone during the pest activity periods on a weekly basis. Images will be centred and focused on the sticky trap, strong surface reflections will be avoided and depicted insects will be sufficient to be recognisable by experts. The images will be uploaded to the CSC cloud along with the trap ID and acquisition date for later image annotation (Luke) and AI model training (UH) of InsectaMon. The sticky traps will be changed after one month.

UVA Campaigns

Two UAV flight campaigns will be conducted at the mother trial: one during flowering (April-May) and one during the fruit development period of the olive trees (June-July). The UAV will be equipped with a multispectral and thermal camera. Imagery will be acquired from 25 m altitude with an image overlap of 80% to enable photogrammetric generation of orthoimages and SfM 3D point clouds. Ground control plates (GCP) will be used for geometric correction. All images of each campaign will be uploaded to the CSC cloud along with the GCP data for photogrammetry and remote sensing analysis (ATB).

For building a UAV based model for crop performance and vitality assessment, ground-truthing measurements of chlorophyll activity and leaf area index (LAI) will be performed in the plots with SPAD-502Plus chlorophyll meter and LAI-2200C LAI meter at the olive crops and the intercrops. Effects on plant health due to pest insect distribution will be assessed with the high-resolution UAV imagery by aligning the image data with the collected insect data in the trials. The extent of the flight campaigns will exceed the mother trial area to include high-resolution information of the surrounding environment in the analysis to better assess ecosystem service effects, e.g., coming from landscape elements (bushes, tree-rows, flower-strips, etc.).

Due to the current juridical situation in Tunesia regarding drone use, a company will be commissioned to conduct the UAV flights.

Measurements for Remote Sensing

At three selected olive orchards, 10 plots will be located in representative areas with a dimension of 10 x 10 m. Plot dimensions will be measured with GNSS. Ground-truthing measurements of chlorophyll activity and leaf area index (LAI) will be performed in the plots with SPAD-502Plus chlorophyll meter and LAI-2200C LAI meter in the olive crops and the intercrops. For each plot, an average of five equally distributed, single measurements will be performed for one integral plot measurement. The measurement dates of ground-truthing data collection will be aligned with the phenological stages flowering, fruit formation, fruit development and maturing of the olive trees. **Error! Reference source not found.** shows the number of replicates per region, agro-ecological practices and community associated with the number of traps which will be set up.

Sampling protocol for beneficial organisms and biodiversity estimations

The insect sampling focuses on flying and ground-dwelling species. One malaise trap (a passive trap for flying insects) is set up in the centre of each plot. In addition, 8 pitfall traps (passive traps for ground-

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dwelling insects and arachnids) are set up around the malaise trap forming a square (see Fig 2.2.). On the top of each pitfall trap, cover hoods are placed to protect the traps from high evaporation and overflooding in case of important rainfall. The minimum distance between each pitfall trap is 5 m. The minimum distance between each malaise trap is 50 m. The minimum number of replicates for statistical robustness is 5 replicates per treatment (i.e., 5 malaise traps and 5x8=40 pitfall traps).
Traps are filled with propylene glycol. One sampling period is 2 weeks long and the traps are collected and checked once a week. There will be 4 sampling times in a year in order to cover the different seasons and represent the biodiversity along the year. They take place in January-February (resting time for the crop), April-May (flowering), June-July (fruit development and pest pressure) and September-October (fruit maturation and pest pressure).
The collected insects will be placed in tubes filled with ethanol (>90%) and stored in the fridge at a maximum of 2C or in the freezer at -20C until further manipulation. The main pest insects and the most abundant species (representing 80% of the biomass) will be counted and identified to species level if possible. If not possible, we will aim at identifying the lowest taxonomical level possible. Some samples (10 females and 10 males of each species, if possible) will be sent to Luomus, Finland, as vouchers and for biomass estimation. Functional traits will be measured on a sub-sample to try and link the abundance and diversity of arthropods to ecosystem services.

3.1.4 Personnel and Equipment

Personnel

Table 0.1. Personnel requirements

No. of people	Role & responsibility	Qualifications needed
4 per field	Manual collection of olives	Technician and workers
2 per field	The weighing of number of kilos per olive tree	Technician and worker
4 per field	Manual collection of cover crop samples	Technician and workers
1 per field	Weighing of cover crop samples	Technician or worker
2 per field	Crop sampling for insect's pest Monitoring insect traps Measure of olive fruits diameter	Technician and worker
2 per laboratory	Counting the number of insects/traps Determination of infestation rate Dissection of olive fruit and *B. oleae* females	Technician and worker

Material and Equipment

Table 0.2. Material and equipment requirements

Material / Equipment	Acquired at [country] / Return to [country]	Responsible
Olive harvester / olive shaker (pneumatic)	Acquired in Europe (around 300 Euro)	to be identified
Harvest canvas (for olive)	Acquired in Tunisia	Olfa Boussadia
Plastic crates (for olive)	Acquired in Tunisia	Olfa Boussadia
Balance (for olive)	Acquired in Tunisia	Olfa Boussadia
Measuring tape of 30 m length (for other crops)	Acquired locally	Olfa Boussadia
Weighing scales (for other crops)	Acquired locally	Olfa Boussadia

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Bags/container for samples (for other crops)	Acquired locally	Olfa Boussadia
4 straight bamboo/wooden pegs/sticks with spiked end to marcate plot (for other crops)	Acquired locally	Olfa Boussadia
Set of instruction table, schedules (for other crops)	Acquired locally	Olfa Boussadia
Edding or other for marcation of bags (for other crops)	Acquired locally	Olfa Boussadia
A random number table (for other crops)	Acquired locally/printed	Amel Ben Hamouda
A sliding calliper (for diameter fruits)	Acquired locally	
A stereomicroscope (for the determination of fruit infestation and female fertility)	Acquired in Europe	Olfa Boussadia
A pruning shears (for shoots collection)	Acquired locally	to be identified
Pheromone yellow sticky traps	Acquired in Europe	Stéphanie Saussure
regular yellow sticky traps? (for insectamon maybe?)	Acquired in Europe	Stéphanie Saussure
malaise traps	Acquired in Europe	Stéphanie Saussure
bottle to collect insects from malaise traps	Acquired in Europe?	to be identified
pitfall traps and cover hood	Acquired in Europe	Stéphanie Saussure
propylene glycol	Acquired locally or in Europe	to be identified
ethanol (>90%)	Acquired locally	Stéphanie Saussure
tubes/small bottles for storage of insects	Acquired locally	Stéphanie Saussure

3.1.5 Time Schedule

Month & Year	Task (how will data be collected)	Community	Responsible	Staff involved
November 2021	Training for data collection	Toukaber	Olfa Boussadia	8
December 2021	Baseline survey (semi-quantitative)	Toukaber Jammel	Saida El fekih	4

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December 2021	Baseline physical crop sampling	Toukaber Jammel	Olfa Boussadia	4
Season 2022				
January-February	1st insects sampling for 2 weeks	Jammel	Amel Ben Hamouda/Mohamed Braham	4
April-May	2nd insects sampling for 2 weeks	Jammel	Amel Ben Hamouda/Mohamed Braham	4
June-July	3rd insect sampling for 2 weeks	Jammel	Amel Ben Hamouda/Mohamed Braham	4
September-October	4th insect sampling for 2 weeks	Jammel	Amel Ben Hamouda/Mohamed Braham	4
June-July September-mid November	Pheromone trapping of olive fruit fly. Changing traps and taking picture for InsectaMon	Jammel	Amel Ben Hamouda	4
March-April May-June September-October	Pheromone trapping of olive moth. Changing traps and taking picture for InsectaMon	Jammel	Amel Ben Hamouda	4
Mai 2022	Intercropping Harvest – physical crop sampling	Jammel-Toukaber	Nadia Chaieb/ Hatem zgallai	4
December 2022	Olive harvest – physical crop sampling	Jammel-Toukaber	OlfaBoussadia/ Sofiane Abdelhamid	8
From March to November	Shoot sampling of *P. unionalis*	Jammel	Amel Ben Hamouda/Mohamed Braham	3
From March to April	Sampling of anthophagous generation of *P. oleae*	Jammel	Amel Ben Hamouda/Mohamed Braham	3
From May to June	Sampling of carpophagous generation of *P. oleae*	Jammel	Amel Ben Hamouda/Mohamed Braham	3
June	Fruit sampling for *B. Oleae*	Jammel	Amel Ben Hamouda/Mohamed Braham	3
From September to October	Sampling of phyllophagous generation of *P. oleae*	Jammel	Amel Ben Hamouda/Mohamed Braham	3
Mars 2022 (depend of the Tunisian situation)	Focus group discussion (2 instead of 4)	Sousse community	Saida el Fekih	6

4. Trials in Egypt

4.1 Cotton

Milestones and responsibilities

The respective timeline and milestones as well as the responsible teams are described in following Table 0.1.

Table 0.1. Timelines and responsibilities

Tasks	From (Month)	To (Month)	Milestone	Teams involved; Lead in bold letter
Expert interviews	May 2021	June 2021	2 experts identified and interviewed	**Ahmed Abdelwahab**, one specialist in plant nutrition and one in Pest management, One agric. eng for sampling.
Expert group formation	July 2021	August 2021	Expert group formed	
Expert group meetings	July 2021	August 2021	4 Expert meetings conducted	
Trial design for each region/community	September 2021	November 2021	Trials designed for each community	
Trial implementation	March 2022 March 2023 March 2024 March 2025	Sept 2022 Sept 2023 Sept 2024 Sept 2025	Field trial implemented in ore com. in year 1, then in other communities in year 2,3,4	

4.1.1 Research Framework

The following section serves as a conceptual framework for the trials and their implementation according to the project proposal and inputs provided by the expert group, identified in the BEHIRA region and finally decided by the experts.

Research objectives

Table 0.1. Research objectives

Research objectives: Soil fertility
1. To provide empirical evidence on the effect of compost application on selected soil quality parameters (soil carbon, water holding capacity etc), soil microbiome.
2. To provide empirical evidence on the effect of biofertilizers application on soil nutrients' availability, soil microbiome.
3. To provide empirical evidence on the effect of intercropping on soil fertility, soil microbiome.
4. To provide empirical evidence on the effect of biological control of cotton pests on soil quality parameters and microbiome (by eliminating the negative effects of chemical pesticides)

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Research objectives: Plant health/pest and disease management
1. To enhance soil fertility for the current season and subsequent seasons.
2. To enhance the crop yield and quality.
3. To increase farmers' income through producing higher quality crop.
4. To increase farmers' income through intercropping with a cash crop.

Research questions

Table 0.2. Research questions

Research questions: Soil fertility
1. What are the effects of compost application and organic fertilization system on the water holding capacity, and thus, will it reduce the water consumption, compared to conventional system? 1.1. What are the effects of compost application on cotton productivity and profitability compared to conventional system? 1.2. What are the effects of compost preparation and application on labour demand compared to conventional system?
2. What are the effects of biofertilizers application on the water holding capacity of the trial field soil compared to control trial without biofertilizers?
3. What are the effects of intercropping on soil fertility, cotton productivity and profitability and soil microbiome of the trial field soil compared to the control trial (without intercropping)?
Research questions: Plant health/pest and disease management
1. How does the use of intercropping reduce pest and weed infestation?
2. How does the use of compost enhance plant health and thus reduce plant disease incidence?
3. How does the use of biofertilizers increase plant uptake of nutrients, reduce plant disease incidence and enhance plant health?

Research hypotheses

Table 0.3. Research hypotheses

Hypotheses: Soil fertility
1. Compost application will enhance soil quality parameters (e.g., enhance water holding capacity, thus, will it reduce the water consumption, enhance soil aeration, thus positively affecting root system growth.
2. Compost application will enhance cotton quality, profitability
3. Biofertilizers are expected to enhance soil nutrients' availability, though fixing atmospheric nitrogen and solubilizing and mineralization of essential nutrients (like phosphorus and calcium).
Hypotheses: Plant health/pest and disease management
1. Intercropping can reduce plant disease incidence and pest infestation
2. Biofertilizers will enhance plant health and reduce plant disease incidence and pest infestation
3. Compost application will enhance cotton health and plant resistance to diseases.

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4.1.2 Research Methodology

Expert Group

The aim of the expert group (including 4 farmers, 2 consultants, 1 field engineer) is the integration of further information and feedback on the trial design as well as the accompaniment during trial implementation. Details of the Expert Group have been set out in Table 0.1.

Table 0.1. Membership of Expert Group

Expert (Affiliation)	Expertise	Responsibility
Researcher: Dr. Ahmed Abdelwahab (HU)	Soil microbiology	Group lead
Consultant: Dr Abdallah Korayem (EBDA)	Plant nutrition	Plan and Supervising fertilization program
Consultant: Dr. Hasan Dahi (EBDA)	Pest control	Plan and supervising cotton disease and pest control
Farmer 1: Conventional (fertilization and pest control)	Farmer	*managing the treatment linked to his/her expertise*
Farmer 2: Conventional + intercropping	Farmer	*managing the treatment linked to his/her expertise*
Farmer 3: Conventional + biofertilizers	Farmer	*managing the treatment linked to his/her expertise*
Farmer 4: Conventional + intercropping + biofertilizers	Farmer	*managing the treatment linked to his/her expertise*
Farmer 5 (mother trial farm): Organic (fert. + pest control) + intercropping + biofertilizers	Farmer	*managing the treatment linked to his/her expertise*
Field engineer: Abdelrazik	Farm management	Sampling

Site selection

The sites for the cotton production will be within the following three communities: Aboulmatameir, Abou-Humus and Kafr Eldawwar, and the core community assigned to Aboulmatameir.

Farmer selection / sampling

In each community, a leader and experienced cotton farmers have been identified. Project details have been explained to the identified persons.

Plot selection

In the selection of sites, efforts will be made to control and reduce the variation of natural factors as possible. Thus, fields and/or plots for demonstration will be chosen on relatively uniform soils and topography. Soil analyses will be conducted, and any significant variation will be considered in the analyses. Additionally, all plots and fields will be prepared in the same way except for the treatments to be tested.

Treatments

Based on the challenges of agricultural production in the Behira governorate region identified in D3.1, the following treatments (see Table 0.2) have been suggested for the cotton trial:

Table 0.2. Treatment description

Treatment	Treatment description
1	Farmer 1: Conventional (fertilization and pest control)
2	Farmer 2: Conventional + intercropping
3	Farmer 3: Conventional + biofertilizers
4	Farmer 4: Conventional + intercropping + biofertilizers
5	Farmer 5: Organic (fert. + pest control) + intercropping + biofertilizers

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- **Treatment 1 –** Conventional practice: *Farmer applies chemical NPK fertilizers and pesticides at the recommended dose.*
- **Treatment 2 –** Conventional practice/ intercropping: *Farmer will apply chemical NPK fertilizers and pesticides at the recommended dose plus intercropping with sunflower or cowpea in every 5 rows of cotton, which shown to attract moths when planted as trap crops, and increase the farmer's income.*
- **Treatment 3 –** Conventional practice / biofertilizers: *Farmer will apply chemical NPK fertilizers and pesticides at the recommended dose plus biofertilizers (nitrogen fixing bacteria, phosphate-solubilizer and silicate-solubilizer bacteria), expecting to enhance plant's nutrients uptake,*
- **Treatment 4 –** Conventional practice / intercropping / biofertilizers: *Farmer will apply chemical NPK fertilizers and pesticides at the recommended dose plus intercropping and biofertilizers treatments, as described above.*
- **Treatment 5 (mother trial farm) organic practice / intercropping / biofertilizers –** *Farmer will apply organic fertilizer (compost) and biological pesticides at the recommended dose plus Intercropping and biofertilizers, as described above.*

Experimental design

The 'mother and baby trial' design will be used. The mother trials will be located at Aboulmatameir and will be managed by researchers. The treatments will be randomly allocated to blocks, which contains all treatments. There will be 3 replications at mother trial farm. The baby trials will be located in the core community, in the first year, then in the other two communities in year 2, 3 and 4, and will be managed by farmers, with support from researchers and extension staff.

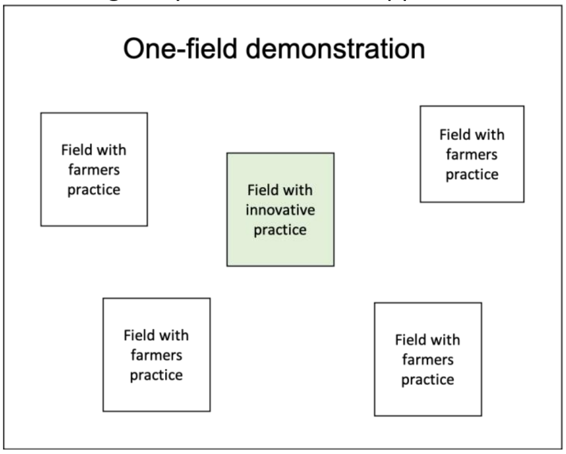

Figure 4-1. One-field demonstration

Trial management and data collection

To ensure reproducibility of the study, a systematic description of the research sites abiotic environment and cropping system management will be conducted. The data will be collected during the baseline assessment.

<u>Physical crop sampling</u>

The sampling strategy will be based on deliverable D1.1 from WP1.
Soil health parameters will be measured using the following indicators:

- Soil content of NPK

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- Soil WHC
- Total microbial count

The above-ground biomass of the cotton plants and the progress of growth will be measured using the following indicators:

- Node number of first fruiting
- Vegetative branch /plant
- Primary fruiting branch / plant
- Secondary fruiting branch / plant
- Number of boll / plant
- Individual boll weight
- Seed cotton yield

4.1.3 Personnel and Materials

Personnel

Table 0.1. Personnel requirements

No. of people	Role & responsibility	Qualifications needed
1	Collecting soil samples at the beginning, during and at end of the season.	Soil chemical and physical analyses
2	Collection of crop samples	Analysis of vegetative and cotton fibre parameters

Material and equipment

The implementation of mother trials (Abou-Almatameir) needs specific management schedule are shown in Table 0.2.

Table 0.2. Material and equipment requirements

Material / Equipment	Acquired at [country] / Return to [country]	Responsible
Push probe or hammer probe	Egypt/Egypt	Site engineer

4.1.4 Time Schedule

The implementation of mother trials (Abou-Almatameir) needs specific management schedule have been shown in Table 0.1.

Table 0.1. Time schedule

Month & Year	Task (how will data be collected)	Community	Responsible
Sept – Oct 2021	Harvest of past season	Abou-Almatameir	One Eng. In each community
November 2021	Training for data collection	Abu El Matamir Kafr El-Dawwar	Project mang. & One Eng.

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		Abou Humuus	
	Baseline survey (semi-quantitative)	Abu El Matamir	Project mang. & One Eng.
	Baseline physical crop sampling	Abu El Matamir	Project mang. & One Eng.
Feb 2022	Tillage, soil solarization and fertilization (composting in case of organic farming) Soil samples for chemical and biological analyses before 30 days after practice/process.	Abu El Matamir	to be identified
March	Making lines, watering, planting	Abu El Matamir	to be identified
April	Weeding, Irrigation at 21 days from planting	Abu El Matamir	to be identified
May	Nitrogen and potassium fertilization Soil samples from each treatment to determine chemical and biological parameters.	Abu El Matamir	to be identified
June	Irrigation and weeding.	Abu El Matamir	to be identified
July	Irrigation and weeding Spraying with Pix twice or removing the upper bud. Spraying plants with Urea (1-2%) with potassium. Soil Samples Determine rate of infestation	Abu El Matamir	to be identified
August	Irrigation and weeding	Abu El Matamir	to be identified
September	Irrigation and weeding Collecting cotton bolls	Abu El Matamir	to be identified
October	Irrigation and weeding Collecting cotton bolls Soil Samples Samples from plants to assay growth and crop quality.	Abu El Matamir	to be identified

4.2 Olive

4.2.1 Milestones and Responsibilities

The respective timelines and milestones as well as the responsible teams are described in Table 0.1.

Table 0.1. Timelines and milestones

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Tasks	From (Month)	To (Month)	Milestone	Teams involved; Lead in bold letter
Expert interviews	May 2021	June 2021	2 experts identified and interviewed	**Ahmed Abdelwahab**, one consultant in plant nutrition and Pest management, One agric. engineer for sampling
Expert group formation	July	August	Expert group formed	
Expert group meetings	July	August	4 Expert meetings conducted	
Trial design for each region/community	September	November	Trials designed for each community	
Trial implementation	December 2021	Oct 2025	Field trial implemented in ore com. in year 1, then in other communities in Y2, 3 ,4	

4.2.1 Research Framework

Research objectives

Table 0.1. Research objectives

Research objectives: Soil fertility
1. To provide empirical evidence on the effect of compost application on selected soil quality parameters (soil carbon, water holding capacity, etc.), soil microbiome.
2. To provide empirical evidence on the effect of biofertilizers application on soil nutrients' availability, soil microbiome.
3. To provide empirical evidence on the effect of intercropping on soil fertility, soil microbiome.
4. To provide empirical evidence on the effect of biological control of olive pests on soil quality parameters and microbiome (by eliminating the negative effects of chemical pesticides).
Research objectives: Plant health/pest and disease management
1. To enhance soil fertility for the current season and subsequent seasons.
2. To enhance the crop yield and quality
3. To increase farmers' income through producing higher quality crop
4. To increase farmers' income through intercropping with a cash crop

Research questions

Table 0.2. Research questions

Research questions: Soil fertility
1. What are the effects of compost application and organic fertilization system on the water holding capacity, and thus will it reduce the water consumption, compared to conventional system? 1.1. What are the effects of compost application on olive productivity and profitability compared to conventional system?

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	1.2. What are the effects of compost preparation and application on labour demand compared to conventional system?
2.	What are the effects of biofertilizers application on the water holding capacity of the trial field soil compared to control trial without biofertilizers?
3.	What are the effects of intercropping on soil fertility, olive productivity and profitability and soil microbiome of the trial field soil compared to the control trial (without intercropping).
Research questions: Plant health/pest and disease management	
1.	Does the use of intercropping reduce pest and weed infestation?
2.	How does the use of compost enhance plant health and thus reduce plant disease incidence?
3.	How does the use of biofertilizers increase plant uptake of nutrients, reduce plant disease incidence and enhance plant health?

Research hypotheses

Table 0.3. Research hypotheses

Hypotheses: Soil fertility
H_1: Compost application will enhance soil quality parameters (e.g. enhance water holding capacity, thus will it reduce the water consumption, enhance soil aeration, thus, positively affecting root system growth.
H_2: Compost application will enhance olive quality and profitability.
H_3: Biofertilizers are expected to enhance soil nutrients' availability, though fixing atmospheric nitrogen and solubilizing and mineralization of essential nutrients (like phosphorus and calcium).
Hypotheses: Plant health/pest and disease management
H_1: Intercropping can reduce plant disease incidence and pest infestation.
H_2: Biofertilizers will enhance plant health and reduce plant disease incidence and pest infestation.
H_3: Compost application will enhance olive health and plant resistance to diseases.

4.2.2 Research Methodologies

Expert Group

The aim of the expert group (including 4 farmers, 1 consultant, 1 field engineer – see Table 0.1) is the integration of further information and feedback on the trial design as well as the accompaniment during trial implementation.

Table 0.1. Membership of Expert Group

Expert (Affiliation)	Expertise	Responsibility
Researcher: Dr Ahmed Abdelwahab (HU)	Soil microbiology	Group lead
Consultant: Dr Hamed Hosny (EBDA)	Plant nutrition and Pest control on fruit trees	Plan and Supervising fertilization disease and pest control program
Farmer 1: Conventional (fertilization and pest control)	Farmer	*managing the treatment linked to his/her expertise*
Farmer 2: Conventional + intercropping	Farmer	*managing the treatment linked to his/her expertise*
Farmer 3: Conventional + biofertilizers	Farmer	*managing the treatment linked to his/her expertise*

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Farmer 4: Conventional + intercropping + biofertilizers	Farmer	*managing the treatment linked to his/her expertise*
Farmer 5 (mother trial farm): Organic (fert. + pest control) + intercropping + biofertilizers	Farmer	*managing the treatment linked to his/her expertise*
Field engineer: Ahmed Hasan	farm management	sampling

Site selection

The sites for the olive production will be within the following three communities: Belbies, Abou-hammad and El0Slheya, and the core community assigned to Belbies.

Farmer selection / sampling

In each community, a leader and experienced olive farmers have been identified. Project details have been explained to the identified persons.

Plot selection

In the selection of sites, efforts will be made to control and reduce the variation of natural factors as possible. Thus, fields and/or plots for demonstration will be chosen on relatively uniform soils and topography. Soil analyses will be conducted, and any significant variation will be considered in the analyses. Additionally, all plots and fields will be prepared in the same way except for the treatments to be tested.

Treatments

Based on the challenges of agricultural production in the Sharqiya governorate region identified in D3.1, the following treatments (see Table 4-16) have been suggested for the cotton trial:

Table 0.2. Treatment description

Treatment	Treatment description
1	Farmer 1: Conventional (fertilization and pest control)
2	Farmer 2: Conventional + intercropping
3	Farmer 3: Conventional + biofertilizers
4	Farmer 4: Conventional + intercropping + biofertilizers
5	Farmer 5: Organic (fert. + pest control) + intercropping + biofertilizers

- **Treatment 1 –** Conventional practice: *farmer applies chemical NPK fertilizers and pesticides at the recommended dose.*
- **Treatment 2 –** Conventional practice/ intercropping: *farmer will apply chemical NPK fertilizers and pesticides at the recommended dose plus intercropping with legumes, which is expected to reduce soil water evaporation.*
- **Treatment 3 –** Conventional practice / biofertilizers: *farmer will apply chemical NPK fertilizers and pesticides at the recommended dose plus biofertilizers (nitrogen fixing bacteria, phosphate-solubilizer and silicate-solubilizer bacteria) expecting to enhance plant's nutrients uptake,*
- **Treatment 4 –** Conventional practice / intercropping / biofertilizers: *farmer will apply chemical NPK fertilizers and pesticides at the recommended dose plus intercropping and biofertilizers treatments, as described above.*
- **Treatment 5 (mother trial farm)** organic practice / intercropping / biofertilizers: *farmer will apply organic fertilizer (compost) and biological pesticides at the recommended dose plus Intercropping and biofertilizers, as described above.*

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Experimental design

The 'split-field' design (see Figure *2-1*4.2.) will be used. The mother trials will be located at Belbies and will be managed by researchers. The treatments will be randomly allocated to blocks, which contains all treatments. There will be 3 replications at mother trial farm. The baby trials will be located in the core community, in the first year, then in the other two communities in year 2, 3 and 4, and will be managed by farmers, with support from researchers and extension staff.

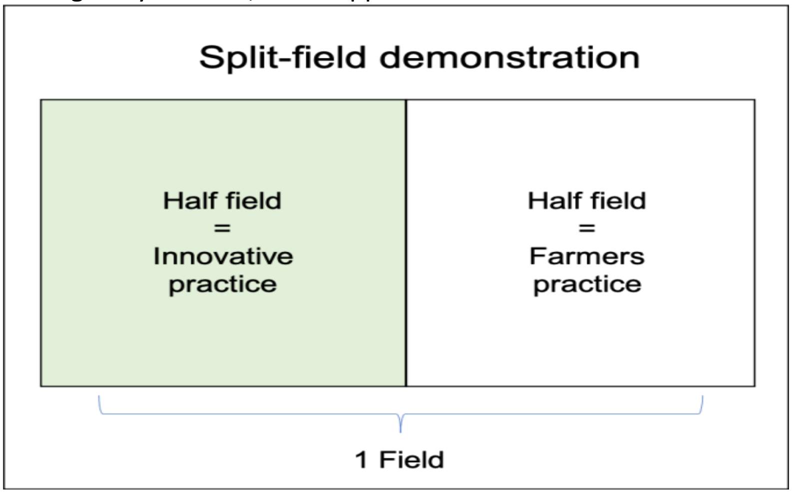

Figure 4-2. Split-field design

Baseline data collection of research sites

To ensure reproducibility of the study a systematic description of the research sites abiotic environment and cropping system management will be conducted. The data will be collected during the baseline assessment.

Physical crop sampling

The sampling strategy will be based on deliverable D1.1 from WP1.
Soil health parameters will be measured using the following indicators:

- Soil content of NPK
- Soil WHC
- Total microbial count

The total biomass of the olive tree \ will be measured using the following indicators:

- No of inflorescences/ shoot
- No of flowers/ Inflorescence
- Initial Fruit set (%)
- Average of fruit retention (%)
- Total fruit yield (Kg/tree)
- Average fruit yield (Kg/tree)

Fruit quality parameters:

- Fruit volume (ml)
- Fruit length (cm)

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- Fruit width (cm)
- Shape index (L/W)

4.2.3 Time Schedule

Implementation of mother trials (Bilbies) needs specific management schedule as presented in Table 0.1. Timelines and milestones.

Table 0.1. Timelines and milestones

Month & Year	Task (How will data be collected)	Community	Responsible	Staff involved
November 2021	Training for data collection	Bilbies & Salheya	Project manager & One Engineer	3
	Baseline survey (semi-quantitative)	Bilbies & Salheya	Project manager & One Engineer	2
	Baseline physical crop sampling	Bilbies & Salheya	Project manager & One Engineer	2
Season 2022				
July to Sept 21	1. Getting rid of the cancers below the grafting area in the vaccinated varieties. 2. Get rid of the weeds on the farm. 3. Adding organic fertilizers at a rate of (1-2) kg, according to the size and age of the tree. 4. Irrigation every two days, taking into account the increase in the number of irrigations when the temperature rises. (from 25 to 70 liters per tree). 5. Combating aphids, thrips and corpses (paper hoppers). 6. Control of scale insects by spraying any recommended biological insecticide to which any mineral oil is added. Data: vegetative growth parameters Rate of infestation	Bilbies and Salheya	Project manager & One Engineer & one technician	3
Oct.	Pruning: Data: vegetative growth parameters	Bilbies and Salheya	Project manager & One Engineer & one technician	3
Nov. – Dec.	Addition of organic fertilizer Irrigation continues until mid-November and then stops in heavy lands, and continues at spaced intervals in light (sandy) land. Controlling pests and diseases. Data: vegetative growth parameters	Bilbies and Salheya	Project manager & One Engineer & one technician	3
Jan to March 22	1. Add organic fertilizer during the pre-flowering stage.	Bilbies and Salheya	Project manager &	3

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	2. Irrigation of trees by immersion abundant irrigation during January on the cold, irrigation dates stop according to the nature of the soil and the weather condition. 3. controlling olive pests (cottony bug and olive leaf worm) with biocides and mineral oils. 4. Burning the affected branches after pruning and removing weeds Data: vegetative growth parameters And Rate of infestation		One Engineer & one technician	
April to June	1. Organic fertilization according to age, irrigation method and soil type. 2. Extreme care in irrigation during the flowering period so that the flowers do not fall 3. controlling pests with biocides that suit the type of infestation according to the EBDA guide, with periodic repeat spraying. Data: vegetative growth parameters And Rate of infestation	Bilbies and Salheya	Project manager & One Engineer & one technician	3

4.3 Date Palm

4.3.1 Milestones and Responsibilities

The respective timeline and milestones as well as the responsible teams are described in following table (Table 0.1).

Table 0.1. Milestones and responsibilities

Tasks	From (Month)	To (Month)	Milestone	Teams involved; Lead in bold letter
Expert interviews	May 2021	June 2021	2 experts identified and interviewed	**Ahmed Abdelwahab**, one consultant in plant nutrition and Pest management, One agric. engineer for sampling
Expert group formation	July	August	Expert group formed	
Expert group meetings	July	August	4 Expert meetings conducted	
Trial design for each region/community	September	November	Trials designed for each community	
Trial implementation	December 2021	Oct 2025	Field trial implemented in ore com. in year 1, then in other communities in Y2,3,4	

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4.3.2 Research Frameworks

Research objectives

Table 0.1. Research objectives

Research objectives: Soil fertility
1. To provide empirical evidence on the effect of compost application on selected soil quality parameters (soil carbon, water holding capacity, etc.), soil microbiome.
2. To provide empirical evidence on the effect of biofertilizers application on soil nutrients' availability, soil microbiome.
3. To provide empirical evidence on the effect of intercropping on soil fertility, soil microbiome.
4. To provide empirical evidence on the effect of biological control of Date plam pests on soil quality parameters and microbiome (by eliminating the negative effects of chemical pesticides)
Research objectives: Plant health/pest and disease management
1. To enhance soil fertility for the current season and subsequent seasons.
2. To enhance the crop yield and quality.
3. To increase farmers' income through producing higher quality crop.
4. To increase farmers' income through intercropping with a cash crop.

Research questions

Table 0.2. Research questions

Research questions: Soil fertility
1. What are the effects of compost application and organic fertilization system on the water holding capacity and, thus, will it reduce the water consumption, compared to conventional system? 1.1. What are the effects of compost application on Date palm productivity and profitability compared to conventional system? 1.2. What are the effects of compost preparation and application on labor demand compared to conventional system?
2. What are the effects of biofertilizers application on the water holding capacity of the trial field soil compared to control trial without biofertilizers?
3. What are the effects of intercropping on soil fertility, Date palm productivity and profitability and soil microbiome of the trial field soil compared to the control trial (without intercropping)?
Research questions: Plant health/pest and disease management
1. How does the use of intercropping reduce pest and weed infestation?
2. How does the use of compost enhance plant health and, thus, reduce plant disease incidence?
3. How does the use of biofertilizers increase plant uptake of nutrients, reduce plant disease incidence and enhance plant health?

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 861924

Research hypotheses

Table 0.3. Research hypotheses

Hypotheses: Soil fertility
H_1: Compost application will enhance soil quality parameters (e.g., enhance water holding capacity, thus, will it reduce the water consumption, enhance soil aeration, thus positively affecting root system growth.
H_2: Compost application will enhance Date palm quality and profitability.
H_3: Biofertilizers are expected to enhance soil nutrients' availability, though fixing atmospheric nitrogen and solubilizing and mineralization of essential nutrients (like phosphorus and calcium).
Hypotheses: Plant health/pest and disease management
H_1: Intercropping can reduce plant disease incidence and pest infestation.
H_2: Biofertilizers will enhance plant health and reduce plant disease incidence and pest infestation.
H_3: Compost application will enhance Date palm health and plant resistance to diseases.

4.3.3 Research Methodology

Expert Group

The aim of the Expert Group (including approximately 4 farmers, 1 consultant, 1 field engineer – see Table 0.1) is the integration of further information and feedback on the trial design as well as the accompaniment during trial implementation.

Table 0.1. Membership of Expert Group

Expert (Affiliation)	Expertise	Responsibility
Researcher: Dr. Ahmed Abdelwahab (HU)	Soil microbiology	Group lead
Consultant: Dr Hamed Hosny (EBDA)	Plant nutrition and Pest control on fruit trees	Plan and Supervising fertilization disease and pest control program
Farmer 1: Conventional (fertilization and pest control)	Farmer	*managing the treatment linked to his/her expertise*
Farmer 2: Conventional + intercropping	Farmer	*managing the treatment linked to his/her expertise*
Farmer 3: Conventional + biofertilizers	Farmer	*managing the treatment linked to his/her expertise*
Farmer 4: Conventional + intercropping + biofertilizers	Farmer	*managing the treatment linked to his/her expertise*
Farmer 5 (mother trial farm): Organic (fert. + pest control) + intercropping + biofertilizers	Farmer	*managing the treatment linked to his/her expertise*
Field engineer: Ezzat Saghlol	Farm management	Sampling

Site selection

The sites for the oli Date palm ve production will be within the following three communities: Wahat, El=Ssaf, and El-ayyat, and the core community assigned to Wahat.

Farmer selection / sampling

In each community, a leader and experienced olive farmers have been identified. Project details have been explained to the identified persons.

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Plot selection

In the selection of sites, efforts will be made to control and reduce the variation of natural factors as possible. Thus, fields and/or plots for demonstration will be chosen on relatively uniform soils and topography. Soil analyses will be conducted, and any significant variation will be considered in the analyses. Additionally, all plots and fields will be prepared in the same way except for the treatments to be tested.

Treatments

Based on the challenges of agricultural production in the Giza governorate region identified in D3.1, the following treatments (Table 0.2) have been suggested for the cotton trial:

Table 0.2. Treatment description

Treatment	Treatment description
1	Farmer 1: Conventional (fertilization and pest control)
2	Farmer 2: Conventional + intercropping
3	Farmer 3: Conventional + biofertilizers
4	Farmer 4: Conventional + intercropping + biofertilizers
5	Farmer 5: Organic (fert. + pest control) + intercropping + biofertilizers

- **Treatment 1 –** Conventional practice: *farmer applies chemical NPK fertilizers and pesticides at the recommended dose.*
- **Treatment 2 –** Conventional practice/ intercropping: *farmer will apply chemical NPK fertilizers and pesticides at the recommended dose plus intercropping with legumes, which is expected to reduce soil water evaporation.*
- **Treatment 3 –** Conventional practice / biofertilizers: *farmer will apply chemical NPK fertilizers and pesticides at the recommended dose plus biofertilizers (nitrogen fixing bacteria, phosphate-solubilizer and silicate-solubilizer bacteria) expecting to enhance plant's nutrients uptake.*
- **Treatment 4 –** Conventional practice / intercropping / biofertilizers: *Farmer will apply chemical NPK fertilizers and pesticides at the recommended dose plus intercropping and biofertilizers treatments, as described above.*
- **Treatment 5 (mother trial farm)** organic practice / intercropping / biofertilizers: *farmer will apply organic fertilizer (compost) and biological pesticides at the recommended dose plus Intercropping and biofertilizers, as described above.*

Experimental design

The 'split-field' design (Figure 4-3) will be used. The mother trials will be located at Wahat and will be managed by researchers. The treatments will be randomly allocated to blocks, which contains all treatments. There will be 3 replications at Mother trial farm. The baby trials will be located in the core community, in the first year, then in the other two communities in year 2, 3 and 4, and will be managed by farmers, with support from researchers and extension staff.

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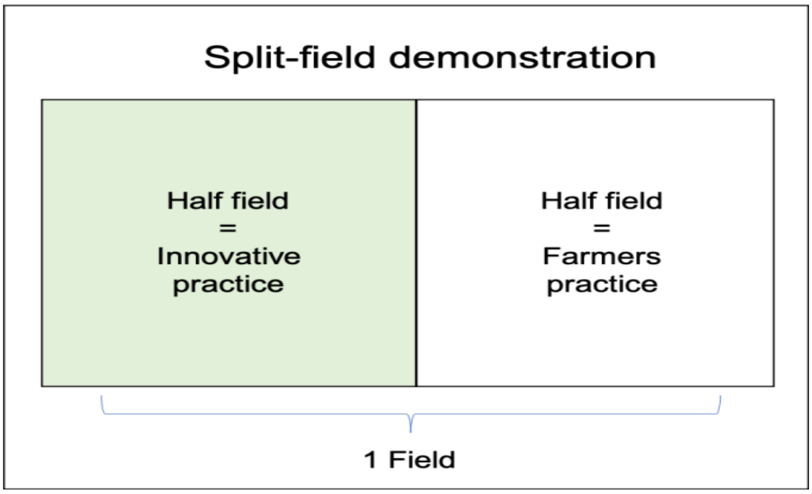

Figure 4-3. Split-field design

Baseline data collection of research sites

To ensure reproducibility of the study, a systematic description of the research sites abiotic environment and cropping system management will be conducted. The data will be collected during the baseline assessment.

Physical crop sampling

The sampling strategy will be based on deliverable D1.1 from WP1.
Soil health parameters will be measured using the following indicators:

- Soil content of NPK
- Soil WHC
- Total microbial count

The total biomass of the date palm tree \ will be measured using the following indicators:

- Fruit volume (ml)
- Fruit length (cm)
- Fruit width (cm)
- Shape index (L/W)

4.3.4 Time Schedule

The implementation of mother trials (Wahat) needs specific management schedule as as shown in Table 0.1.

Table 0.1. Time schedule

Month & Year	Task (how will data be collected)	Community	Responsible	Staff involved
November 2021	Training for data collection	Wahat, Saff, Ayyat	Project manager & One Engineer	3

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	Baseline survey (semi-quantitative)	Wahat, Saff, Ayyat	Project manager & One Engineer	2
	Baseline physical crop sampling	Wahat, Saff, Ayyat	Project manager & One Engineer	2
	Focus group discussion	Wahat		
Season 2022				
July - Sept	1. Begin harvesting the crop for early and late varieties. 2. Irrigation every 3 days to be done in the early morning.	Wahat	Project manager & One Engineer	2
Oct	1. Separation and cultivation of offshoots, transfer and planting of large trees. 2. removing the dry fronds and thorns from the new fronds and cleaning the tree from the remnants of the dates. 3. Addition of batch of organic fertilizer fr compensation. 4. Watering once a week or every 3 days depending on the tree size and age Data to record: Vegetative growth parameters	Wahat	Project manager & One Engineer	2
November	1. continue demolition and cleaning 2. Add sterile and well fermented organic fertilizer at a rate of (50-75) kg for the adult tree, to be stirred with the soil. 3. Irrigation every 15 days (twice a month) and the number of irrigation times increases if the tree basin is not wide Data to record: Vegetative growth parameters	Wahat	Project manager & One Engineer	2
December	1. Continuing with sterile and well-fermented organic fertilization for trees that were not fertilized in November at a rate of (50-75) kg for an adult tree. 2. Irrigation every 15 days and the amount of water is estimated according to the size and age of the tree and the width of the basin. Data to record: Vegetative growth parameters	Wahat	Project manager & One Engineer	2
January	1. Adding organic fertilizers at a rate of 1-2 kg, according to the age and size of the tree.	Wahat	Project manager & One Engineer	2

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	2. Irrigation every 15 days, considering size and age of the tree and climatic conditions when estimating the amount 3. Added water and in the event that the basin is not wide, 3. The first preventive spray against pollen worm disease, followed by a second application 20 days using a specialized biopesticide. Data to record: Vegetative growth parameters and Rate of infestation			
Feb	Adding (1) kg of organic nitrogen fertilizer for large trees in two batches, and the quantity decreases whenever the size of the tree is reduced. The age of the tree and the breadth of the basin. 2. Continuing watering every 15 days. 3. Collect mature male pollen and store it in a suitable place until needed, and it is preferable to collect it from stallions Not less than 5 years old. 4. Carrying out pollination in the early varieties. The thinning process can be carried out during pollination by removing some of the flower spikes or cutting off part of it. Data to record: Vegetative growth parameters and Rate of infestation	Wahat	Project manager & One Engineer	2
March	1. Conducting pollination process 2. Separating and planting the offshoots. 3. Irrigation every 7 days, 4. Moisten the soil with water while avoiding heavy irrigation. 4. The first preventive spray against the red palm weevil one week after inoculation, followed by a second spray 20 days after, to eliminate the second generation of the insect. Data to record: Vegetative growth parameters and Rate of infestation	Wahat	Project manager & One Engineer	2
April	1. Adding organic fertilizers at a rate of (1-2) kg, according to the size and age of the tree and its production capacity. 2. Continuing the pollination process for the late varieties and the thinning process, and the preventive spraying of	Wahat	Project manager & One Engineer	2

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	the red palm weevil 7 days after the pollination. 3. Irrigation every 7 days, taking into account the increase in the number of irrigations when the climatic conditions change, and the temperature rises. Data to record: Vegetative growth parameters and Rate of infestation			
May	1. Continuing thinning the “stalk/spathe” for the trees that were not thinned before. 2. Carrying out the process of curving (lowering the spikes), taking into account the balanced distribution of the load on the tree, with the process of bagging the fruits. 3. The first biological spray to prevent spiders should be before the cyst, followed by the second spray 20 days after the first. 4. Irrigation every 5 days, taking into account the increase in the number of irrigations when the temperature rises. 5. Adding organic fertilizers at a rate of (1-2) kg, according to the size and age of the tree. Data to record: Vegetative growth parameters and Rate of infestation	Wahat	Project manager & One Engineer	2
June	1. Continuing the bio-spray to prevent spiders. 2. Irrigation every 5 days, and the period between each irrigation is reduced in the case of small ponds, while avoiding heavy irrigation. Data to record: Vegetative growth parameters and Rate of infestation	Wahat	Project manager & One Engineer	2

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5. Trials in Burkina Faso

5.1 Cotton

5.1.1 Milestones and Responsibilities

The respective timeline and milestones as well as the responsible teams are described in Table 5.1.

Tasks	From (Month)	To (Month)	Milestone	Teams involved; Lead in bold letter
Expert group members identification and interviews	April 2021	May 2021	Expert group members identified and interviewed	**Désiré Lompo**, Lambienou YE, Aboubakar SAKO, Assan GNOUMOU, Yacouba TENGUERI, Seydou OUOBA, Balboné Abdou-Dramane, Amos Kombamtanga, Narcisse KARAMA
Expert group formation	May 2021	June 2021	Expert group formed	**Désiré Lompo**, Lambienou YE, Aboubakar SAKO, Seydou OUOBA, Narcisse KARAMA
Expert group meetings	July 2021	Sept. 2021	Expert group meetings organized	**Désiré Lompo**, Lambienou YE, Aboubakar SAKO, Seydou OUOBA, Narcisse KARAMA
Trial design for the core community	Sept. 2021	Nov. 2021	Trials designed for the core community	**Désiré Lompo**, Lambienou YE, Aboubakar SAKO, Seydou OUOBA, Narcisse KARAMA
Baseline surveys in all communities	Dec 2021	Feb 2022	Baseline data collected in all communities	Désiré Lompo, Lambienou YE, Aboubakar SAKO, Assan GNOUMOU, **Yacouba TENGUERI**, Seydou OUOBA, Balboné Abdou-Dramane, Amos Kombamtanga, Narcisse KARAMA
Trial implementation in the core community	March 2022	Dec. 2022	Field trials implemented in the core community Commented visits organised for 30 farmers from each of the 4 communities	**Désiré Lompo**, Lambienou YE, Aboubakar SAKO, Assan GNOUMOU, Yacouba TENGUERI, Seydou OUOBA, Balboné Abdou-Dramane, Amos Kombamtanga, Narcisse KARAMA
Trial implementation in all communities	Mars 2023	August 2024	Field trials implemented in all 3 communities	**Désiré Lompo**, Lambienou YE, Aboubakar SAKO, Seydou OUOBA, Narcisse KARAMA

5.1.2 Research Framework

Research Problem

Soil fertility

Research conducted on the soils of Burkina Faso indicate that they are generally highly deficient in phosphorus, highly deficient in nitrogen and more or less deficient in potassium. The organic matter content is also less than 1% (BUNASOLS, 1985). The low level of fertility of these soils is aggravated by their sensitivity to erosion and unsustainable farmer practices that lead to a continuous decline in soil

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fertility and therefore in productivity. In addition, population growth increases the demand for land for cultivation and housing, putting considerable pressure on the land. Under these conditions, an increase in agricultural production can only be achieved by increasing yields through the use of adequate and sustainable fertilisation.

Several studies, including those of Pichot et al. (1981), Sedogo et al. (1979), Lompo et al. (1994), show that mineral fertilisation alone cannot ensure sustainable agricultural production. PIERI (1989) indicates that the maintenance of soil fertility depends mainly on the maintenance of its organic status because of the multiple roles and functions played by organic matter in the soil. In a synthesis of experiences and prospects for maintaining soil productivity in agriculture in Burkina Faso, Lompo et al. (1994) report that organo-mineral fertilisers enable stable and higher crop yields than those obtained with exclusive use of mineral fertilisers.

A large number of innovative knowledge and technologies have been developed to enable sustainable agricultural production. The use of biochar as soil amendment is one of these innovative technologies that could improve soil quality and agricultural production while sequestering carbon in the soil. In addition, crop rotation allows for better management of soil fertility, especially when it includes leguminous plants that fix atmospheric nitrogen. The use of these technologies in the agro-ecological zone of the Haut basins Region could sustain agricultural production.

Research objectives

Table 0.1. Research objectives

Research objectives: Soil fertility
1. To show evidence on the effect of biochar used as soil amendment on selected soil quality parameters (Soil pH, soil carbon, water holding capacity, etc.) and crop (cotton, maize, legumes) productivity, profitability and labour demand.
2. To show evidence on the effects of co-composted biochar application on selected soil quality parameters (soil carbon, water holding capacity etc) and crop productivity, profitability and labour demand.
3. To determine the effects of the combined use of biochar and legumes for improving soil quality, plant nutrition, crop productivity and profitability.
4. To show evidence of the effects of microdosing of biochar/compost and mineral fertilizers on soil quality, plant nutrition, crop productivity, profitability and labour demand.
Research objectives: Plant health/pest and disease management
1. To determine the effects using maize in rotation groundnut/soybean with biochar application for controlling armyworms, while improving soil quality, plant nutrition, crop productivity and profitability.
2. To determine the effects using organic pesticides and soybean in rotation with Maize for controlling armyworms while improving crop productivity and profitability.

Research questions

Table 0.2. Research questions

Research questions: Soil fertility
1. Does the application of biochar as soil amendment in combination with farmers practice improves soil quality parameter and cotton, maize, cowpea/groundnut productivity and profitability?

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2.	What are the effects of co-composted biochar application on selected soil quality parameters and crop productivity and profitability?
3.	Does the use of biochar as soil amendment in combination with cowpea improves soil quality, plant nutrition, crop productivity and profitability?
4.	What are the effects of microdosing of biochar/compost and mineral fertilizers on soil quality, plant nutrition, crop productivity, profitability and labor demand?
Research questions: Plant health/pest and disease management	
1. What are the effects of using Maize in rotation with soybean and biochar applied as soil amendment on the control of "chenille legionnaire", and soil quality, plant nutrition, crop productivity and profitability?	
2. To determine the effects using organic pesticides and soybean in rotation with Maize for controlling armyworms while improving crop productivity and profitability	

Research hypotheses

Table 0.3. Research hypotheses

Hypotheses: Soil fertility
H_1: The application of biochar as soil amendment in combination with farmers practice improves soil quality parameters and cotton, maize, cowpea/groundnut productivity and profitability.
H_2: Co-composted biochar application improves selected soil quality parameters and crop productivity and profitability.
H_3: The use of biochar as soil amendment in combination with cowpea improves soil quality, plant nutrition, crop productivity and profitability.
H_4: Microdosing of biochar/compost and mineral fertilizers enhances soil quality, plant nutrition, crop productivity, profitability and labour demand.
Hypotheses: Plant health/pest and disease management
H_1: Using maize in rotation with soybean and biochar applied as soil amendment controls the "chenille legionnaire", while improving soil quality, plant nutrition, crop productivity and profitability.
H_2: Organic pesticides and soybean cultivated in rotation with maize reduce the negative impact of the armyworms while improving crop productivity and profitability.

5.1.3 Research Methodology

Expert Group

The aim of the Expert Group (including approximately 4 farmers, 2 researchers and 2 extensionists – see Table 0.1. Membership of Expert Group) is the integration of further information and feedback on the trial design as well as the accompaniment during trial implementation.

Table 0.1. Membership of Expert Group

Expert (Affiliation)	Expertise	Responsibility
Researcher: Dr Désiré Jean Pascal Lompo (UDDG)	Soil science	Group lead
Researcher: Dr Lambiénou Yé (UDDG)	Agroecologist	*help in his field of expertise*
Researcher: Dr Aboubacar Sako (UDDG)	Geochemist	*help in his field of expertise*
Researcher: Dr Assan Gnoumou (UDDG)	Plant ecologist	*help in his field of expertise*
Field Assistant: Narcisse Karama (ZAT-Satiri)	Agricultural technician	*help in his field of expertise*
Research Assistant: Seydou OUOBA	Agricultural technician	*help in his field of expertise*

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Farmer 1:	*to be identified*	*managing some treatment in the trials*
Farmer 2:	*to be identified*	*managing some treatment in the trials*
Farmer 3:	*to be identified*	*managing some treatment in the trials*
Farmer 4:	*to be identified*	*managing some treatment in the trials*

Site selection

In Burkina Faso, there are three main agro-ecological zones (AEZ). Due to the insecurity problems, only one AEZ was selected for the SustInAfrica project implementation: the Haut-Bassins Region. Four communities were selected in the Haut-Bassin Region: Satiri, Bobo-Dioulasso, Béréba and Békuy. Satiri has been designated as the core community because of its accessibility and good collaborations with different projects.

Farmer selection / sampling

In the core community, farmers will be identified and selected based on their willingness to participate to the research activities and to use a small part of their land for field trials.

Plot selection

In the selection of plots, efforts will be made to control and reduce the variation of natural factors as best as possible. Thus, fields and/or plots for demonstration will be chosen on relatively uniform soils and topography. Even so, pre-experimental soil analyses will be conducted and any significant variation will be accounted for as covariance in the analyses. Additionally, all plots and fields will be prepared in the same way except for the treatments that shall be tested.

Treatments

Based on the challenges of agricultural production in the Haut-Bassin Region, the following treatments (Table 0.2 and Table 0.1) are suggested for the cotton, maize and cowpea/groundnuts rotation with biochar amendment trial.

Trial 1: Soil fertility management

Table 0.2. Treatment description for trial 1

Treatment	Treatment description
1	T1 = Control: Cotton-Maize (Farmer practice, FP*); without biochar
2	T2 = Cotton-Maize with biochar
3	T3 = Maize-Cowpea-Cotton without biochar
4	T4 = Maize-Cowpea-Cotton with biochar + compost
5	T5 = Cowpea-Cotton-Maize without biochar
6	T6 = Cowpea-Cotton-Maize with biochar + compost
7	T7 = Cotton-Maize-Cowpea without biochar + compost
8	T8 = Cotton-Maize-Cowpea with biochar + compost

*Farmer practice (FP): *Cultivation of cotton in rotation with maize on 2 plots.*

Trial 2 : Armyworms of maize management using intercropping with soybean and organic pesticides

Table 0.3. Treatment description for trial 2

Treatment	Treatment description
1	T1= Control: Maize without pesticide
2	T2= Maize with pesticides (Farmer practice)
3	T3= Maize-Soybean
4	T4= Maize with organic pesticide

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Experimental design

The 'mother and baby trials' design will be used. The mother trials will be located at Satiri and will be managed by farmers under the closed supervision of researchers. For each trial, the treatments will be randomly allocated to blocks, which contains all treatments. There will be 3 replications at each Mother trial site. The baby trials will be located in all three communities and will be managed by farmers, with support from researchers and extension staff. Each baby trial will use a subset of three treatments, plus the two controls, involving 6 farmers from each community and summing up to 18 farmers in all for the baby trials. Female farmers will be included in the baby trials. The elementary plot size will be 25m^2 (5mx5m). The spacing between plots will be 0.75m and blocs will be separated by 1.5m. Plants will be separated following the recommendation for each crop.

Baseline data collection of research sites

To ensure reproducibility of the study, a systematic description of the research sites abiotic environment and former cropping system management will be conducted (see D3.1). The data will be collected during the baseline assessment (Task 1.2.b).

Physical crop sampling

The sampling strategy will be based on deliverable D1.1 from WP1. The above-ground biomass of the plants and the progress of growth will be estimated using the following indicators:
For maize and cotton:

- The plant height
- the diameter of the stems
- The plant weight
- Crop yields

For cowpea/groundnut:

- The plant weight
- Crop yields

Other ecosystem service indicators that will be measured include:

- Soil organic matter content
- Soil pH
- Pesticide residues into the soil
- Soil microbial parameters (soil respiration, microbial biomass, microbial diversity, enzymes activities)

5.1.4 Personnel and equipment needed

Personnel

Table 0.1. Personnel requirements

No. of people	Role & responsibility	Qualifications needed
04	Researchers	PhD, Doctorate
03	Research Assistant	MSc, Engineer
04	Field technician	Bachelor
25	Farmers	-

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Material and Equipment

Table 0.2. Material and equipment requirements

Material / Equipment	Acquired at [country] / Return to [country]	Responsible
Maize Seeds	Acquired at Burkina Faso	Seydou OUOBA
Cowpea Seeds	Acquired at Burkina Faso	Narcisse KARAMA
Cotton Seeds	Acquired at Burkina Faso	Narcisse KARAMA
Fertilizers	Acquired at Burkina Faso	Narcisse KARAMA
Compost	Acquired at Burkina Faso	Seydou OUOBA
Manure	Acquired at Burkina Faso	Seydou OUOBA
Cotton stems	Acquired at Burkina Faso	Farmers
Corn cobs	Acquired at Burkina Faso	Farmers
Motorbikes	Acquired at Burkina Faso	Financial agent
Plastic bags	Acquired at Burkina Faso	Seydou OUOBA
Protective grating (grillage de protection)	Acquired at Burkina Faso	Financial agent
Wheel Barrow	Acquired at Burkina Faso	Financial agent

5.1.5 Time Schedule

Table 0.1. Time schedule

Month & Year	Task (How data will be collected)	Community	Responsible	Staff involved
November 2021?	Training for data collection	Satiri	Désiré LOMPO	Lambienou YE, Aboubakar SAKO, Assan GNOUMOU, Yacouba TENGUERI, Seydou OUOBA, Balboné Abdou-Dramane, Amos Kombamtanga, Narcisse KARAMA
Décembre 2021-Février 2022	Baseline survey (semi-quantitative)	Satiri, Békuy, Béréba, Bobo-Dioulasso	Lambiénou YE	Désiré LOMPO, Aboubakar SAKO, Assan GNOUMOU, Yacouba TENGUERI, Seydou OUOBA, Balboné Abdou-Dramane, Amos Kombamtanga, Narcisse KARAMA
Décembre 2021-Février 2022	Baseline physical crop sampling	Satiri, Békuy, Béréba, Bobo-Dioulasso	Lambiénou YE	Lambienou YE, Aboubakar SAKO, Assan GNOUMOU, Seydou OUOBA, Balboné Abdou-Dramane, Amos Kombamtanga, Narcisse KARAMA
Season 2022				
May 2022	Season start --- soil and plots preparation	Satiri	Désiré LOMPO	Lambienou YE, Seydou OUOBA, Balboné Abdou-Dramane, Amos Kombamtanga,

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				Narcisse KARAMA
June-July 2022	Biochar and compost application	Satiri	Désiré LOMPO	Lambienou YE, Seydou OUOBA, Balboné Abdou-Dramane, Amos Kombamtanga, Narcisse KARAMA
July 2022	Sowing	Satiri	Désiré LOMPO	Lambienou YE, Seydou OUOBA, Balboné Abdou-Dramane, Amos Kombamtanga, Narcisse KARAMA
July-August 2022	Fertilizers application, weeding, insect protection	Satiri	Désiré LOMPO	Lambienou YE, Seydou OUOBA, Balboné Abdou-Dramane, Amos Kombamtanga, Narcisse KARAMA
October-December 2022	Harvest – physical crop sampling		Lambiénou YE	Désiré Lompo, Seydou OUOBA, Balboné Abdou-Dramane, Amos Kombamtanga, Narcisse KARAMA

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6. Trials in Niger

6.1 Millet

6.1.1 Milestones and Responsibilities

The respective timeline and milestones as well as the responsible teams are described in following table (Table 6-1).

Tasks	From (Month)	To (Month)	Milestone	Teams involved; Lead in bold letter
Expert interviews	May 2021	June 2021	2 experts identified and interviewed	A team of scientists were involved during the interview. Larwanou Mahamane, Adamou Didier and Hadizatou Alhassoumi from the project team; Mahamadou Sani, Massaoudou Moussa and Mahaman Lawan from the regions were also involved
Expert group formation	May	August	Expert group formed	
Expert group meetings	May	August	6 Expert meetings conducted	
Trial design for each region/community	June	October	Trials designed for each community	
Trial implementation	June 2022 June 2023 June 2024 June 2025	Oct 2022 Oct 2023 Oct 2024 Oct 2025	Field trial implemented in ore com. in year 1, then in other communities in year 2,3,4	

6.1.2 Research Framework

Research objectives

Table 0.1. Research objectives

Research objectives: Soil fertility
1. To provide empirical evidence on the effect of compost application on selected soil quality parameters (soil carbon, water holding capacity, etc.), soil microbiome.
2. To provide empirical evidence on the effect of biofertilizers application on soil nutrients' availability, soil microbiome.
3. To provide empirical evidence on the effect of intercropping on soil fertility, soil microbiome.
4. To provide empirical evidence on the effect of biological control of cotton pests on soil quality parameters and microbiome (by eliminating the negative effects of chemical pesticides).
Research objectives: Plant health/pest and disease management
1. To enhance soil fertility for the current season and subsequent seasons.
2. To enhance the crop yield and quality.
3. To increase farmers' income through producing higher quality crop.
4. To increase farmers' income through intercropping with a cash crop.

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Research questions

Table 0.2. REsearch questions

Research questions: Soil fertility
1. What are the effects of compost application and organic fertilization system on the water holding capacity, and thus, will it reduce the water consumption, compared to conventional system? 1.1. What are the effects of compost application on cotton productivity and profitability compared to conventional system? 1.2. What are the effects of compost preparation and application on labor demand compared to conventional system?
2. What are the effects of biofertilizers application on the water holding capacity of the trial field soil compared to control trial without biofertilizers?
3. What are the effects of intercropping on soil fertility, cotton productivity and profitability and soil microbiome of the trial field soil compared to the control trial (without intercropping)?
Research questions: Plant health/pest and disease management
1. How does the use of intercropping reduce pest and weed infestation?
2. How does the use of compost enhance plant health and thus reduce plant disease incidence?
3. How does the use of biofertilizers increase plant uptake of nutrients, reduce plant disease incidence and enhance plant health?

Research hypotheses

Table 0.3. Research hypotheses

Hypotheses: Soil fertility
H_1: Compost application will enhance soil quality parameters (e.g., enhance water holding capacity, thus, will it reduce the water consumption, enhance soil aeration), thus positively affecting root system growth.
H_2: Compost application will enhance cotton quality, profitability.
H_3: Biofertilizers are expected to enhance soil nutrients' availability, though fixing atmospheric nitrogen and solubilizing and mineralization of essential nutrients (like phosphorus and calcium).
Hypotheses: Plant health/pest and disease management
H_1: Intercropping can reduce plant disease incidence and pest infestation.
H_2: Biofertilizers will enhance plant health and reduce plant disease incidence and pest infestation.
H_3: Compost application will enhance cotton health and plant resistance to diseases.

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6.1.3 Research Methodology

Expert Group

The aim of the expert group (including 36 farmers, 3 consultants, 3 PhD students) is the integration of further information and feedback on the trial design as well as the accompaniment during trial implementation. See Table 0.1 for details of the Expert Group.

Table 0.1. Membership of Expert Group

Expert (Affiliation)	Expertise	Responsibility
Larwanou Mahamane, UAM	Ecology/Agro-forestry	Group lead
Adam Toudou, UAM	Plant pathology	scientist
Adamou Didier, UAM	Soil scientist	scientist
Ali Mahamadou, UAM	Socio-economy	Scientist
Hadizatou Alhassoumi, UAM	Gender specialist	Scientist
Fatouma Zara Lawan, Consultant	Gender specialist	Gender scientist
Moustapha Mahaman Adamou, UAM	Water/Hydrologist	Scientist
Ambouta Jean Marie Karimou, UAM	Soil scientist	Scientist
Massaoudou Moussa, INRAN	Agro-forester	Scientist
Mahamadou Sani, UT	Natural resources management	Scientist

Site selection

The sites were selected according to their distribution in the agro-ecological zones as described and presented in Table 0.2.

Table 0.2. Agro-ecological zones in Niger

	Agro-ecological zone	Sites	Crops growing under innovative irrigation systems
1	Oasian system of eastern Niger (Zinder and Diffa)	Kilakina	Onion, watermelon, cassava, and maize
2	Watershed system of Ader (Tahoua-Niger Center)	Adouna	Onion, *Cajanus cajan*, moringa, lettuce, hibiscus, millet and cowpea
3	High anthropogenic pressure zone (Niger center - Maradi)	Jiratawa	Moringa, onion, lettuce, aneth, hibiscus, millet and cowpea

Table 0.3. AEZ in Niger

AEZ	Region	Municipality	Sites	Geo-coord
Oasian system of eastern Niger	Zinder	Goure	Woro	13° 56,560' N & 10° 19,555'E
			Balla	13° 31,012' N & 7° 16,986'E
			Kilakina	13° 43,432' N & 10° 25,010'E

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High anthropogenic pressure zone -Niger center	Maradi	Jiratawa	Kontagora	13° 33,269' N & 7° 17,135'E
			Ingobirawa	13° 33,269' N & 7° 17,135'E
			Kankare Dadji	13° 29,100' N et 7° 18,269'E
Watershed system of Ader (Tahoua-Niger Center)	Tahoua	Kalfou	Guidan Toudou	14° 45' 05,93''N &05° 34' 26,99'' E
			Dabagou	14°47'10,32''N & 05° 33' 03,78''E

Farmer selection / sampling

In each community, a leader and experienced millet and cowpea farmers have been identified. Project details have been explained to the identified persons.

Plot selection

In the selection of sites, efforts will be made to control and reduce the variation of natural factors as possible. Thus, fields and/or plots for demonstration will be chosen on relatively uniform soils and topography. Soil analyses will be conducted, and any significant variation will be considered in the analyses. Additionally, all plots and fields will be prepared in the same way except for the treatments to be tested.

Treatments

Based on the challenges of agricultural production in the selected regions identified in D3.1, the following treatments (Table 0.4) have been suggested for the millet and cowpea trials:

Table 0.4. Treatment description

Treatment	Treatment description
1	Farmer 1: conventional (fertilization and pest control)
2	Farmer 2: conventional + intercropping
3	Farmer 3: conventional + biofertilizers
4	Farmer 4: conventional + intercropping + biofertilizers
5	Farmer 5: organic (fertilization + pest control) + intercropping + biofertilizers

Treatment 1 – Conventional practice: *farmer applies chemical NPK fertilizers and pesticides at the recommended dose.*
Treatment 2 – Conventional practice/ intercropping: *farmer will apply chemical NPK fertilizers and pesticides at the recommended dose plus intercropping with millet or cowpea in every 5 rows, which shown to attract moths when planted as trap crops, and increase the farmer's income.*
Treatment 3 – Conventional practice / biofertilizers: *farmer will apply chemical NPK fertilizers and pesticides at the recommended dose plus biofertilizers (nitrogen fixing bacteria, phosphate-solubilizer and silicate-solubilizer bacteria), expecting to enhance plant's nutrients uptake,*
Treatment 4 – Conventional practice / intercropping / biofertilizers: *farmer will apply chemical NPK fertilizers and pesticides at the recommended dose plus intercropping and biofertilizers treatments, as described above.*

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Treatment 5 (mother trial farm) organic practice / intercropping / biofertilizers: *Farmer will apply organic fertilizer (compost) and biological pesticides at the recommended dose plus Intercropping and biofertilizers, as described above.*

Experimental design

The 'mother and baby trial' design (see Figure 6-1) will be used. The mother trials will be located at each of the 3 regions and will be managed by researchers. The treatments will be randomly allocated to blocks, which contains all treatments. There will be 3 replications at mother trial farm. The baby trials will be located in the core community, in the first year, then in the other two communities in year 2, 3 and 4, and will be managed by farmers, with support from researchers and extension staff.

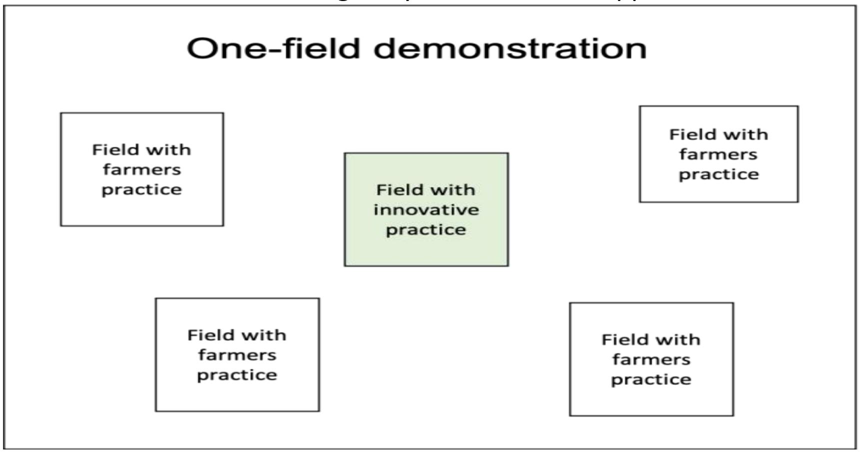

Figure 6-1. One-field demonstration

Baseline data collection of research sites

To ensure reproducibility of the study, a systematic description of the research sites abiotic environment and cropping system management will be conducted. The data will be collected during the baseline assessment.

Physical crop sampling

The sampling strategy will be based on deliverable D1.1 from WP1.
Soil health parameters will be measured using the following indicators:

- Soil content of NPK
- Soil WHC
- Total microbial count

The above-ground biomass of the cotton plants and the progress of growth will be measured using the following indicators:

- Node number of first fruiting
- Vegetative branch/plant
- Primary fruiting branch/plant
- Secondary fruiting branch/plant
- Number of boll/plant
- Individual boll weight
- Seed cotton yield

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6.1.4 Personnel and equipment needed

Personnel

No. of people	Role & responsibility	Qualifications needed
1	Collecting soil samples at the beginning, during and at end of the season.	Soil chemical and physical analyses
2	Collection of crop samples	Analysis of vegetative and cotton fibre parameters

Material and equipment

The implementation of mother trials in each of the 3 regions, needs specific management schedule and material and equipment requirements are presented in Table 0.1.

Table 0.1. Material and equipment requirements

Material / Equipment	Acquired at [country] / Return to [country]	Responsible
Push probe or hammer probe	Niger	Site engineer

6.1.5 Time Schedule

Table 0.1. Time schedule

Month & Year	Task (how will data be collected)	Community	Responsible	Staff involved
Sept – Oct 2021	Harvest of past season	All the communities	One Engineer In each community	*to be identified*
November 2021	Training for data collection	All the communities	Project manager & One Engineer	3
	Baseline survey (semi-quantitative)	All the communities	Project manager & One Engineer	2
	Baseline physical crop sampling	All the communities	Project manager & One Engineer	2
Season 2022				
May/June	Tillage, soil solarization and fertilization (composting in case of organic farming) Soil samples for chemical and biological analyses before 30 days after practice/process.	All the communities	Project manager & One Engineer	1
May/June	Making lines, watering, planting	All the communities	Project manager & One Engineer	*to be identified*

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June/July	Nitrogen and potassium fertilization Soil samples from each treatment to determine chemical and biological parameters.	All the communities	Project manager & One Engineer	*to be identified*
June/July	Irrigation and weeding.	All the communities	Project manager & One Engineer	*to be identified*
August	Irrigation and weeding	All the communities	Project manager & One Engineer	*to be identified*
September/October	Irrigation and weeding Harvesting	All the communities	Project manager & One Engineer	*to be identified*

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