SustInAFRICA

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

WP3

Deliverable D3.1

Synthesis of knowledge for defining site specific trials

Task leader: BOKU

Involved partners: ATB, CIHEAM, ISEG, FC.ID, UCC, UDS, UDDG, UAM, CU, HUSD, IO

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ABSTRACT

The present deliverable represents the jointly prepared synthesis of knowledge for defining site-specific guidelines for the implementation of on-farm demonstrations (OFD) and on-farm experiments (OFE). Thus, D3.1 will ensure harmonized and standardized knowledge development on field trials.

The guidelines for the OFD and OFE have been developed based on a problem analysis in the respective regions. According to the specific security situation and infrastructure in the research locations, OFDs will be conducted on selected pilot-farms or on land of the local extension service or research facilities in the participating communities and serve as a mere demonstration of innovative agroecological practices, that aim for an improved productivity and enhanced ecosystem services delivery, but will not be analysed statistically.

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 (AEZ) and will follow a scientific experimental design. The "mother trials" are implemented and controlled by a researcher in cooperation with local extension services, while the "baby trials" are implemented by farmers on their plots. The "baby trials" serve as replicates to the "mother trial". Due to the COVID-19 restrictions in the participating countries the OFD and OFE were merely designed by researchers without validation by farmers and extensionists through the intended group discussion. However, the group discussions will be conducted as soon as travel restrictions are suspended (possibly summer/autumn 2021).

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Glossary

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." (FAO Term Portal)[1]

Multi-environment trials (MET): When on-farm experiments (OFE) are conducted at many sites and repeated over 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 allow 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 are conducted in farmers' fields and make use of a scientific experimental design that allows for valid statistical analysis and inferences

Pilot farms: Farms were "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)

Abbreviations

Ha - Hectare

MBT – Mother and baby trial

MET – Multi-environment trials

OFE – On-farm experiments

OFD – On-farm demonstrations

RCBD – Randomized complete block design

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

1 Introduction

1.1 Objectives

The overall objective of WP3 is to identify agricultural practices which contribute / increase the sustainability and resilience of farming systems and the related ecosystems services in 13 AEZ, of five countries in North and West Africa.

Specific objective of **Task 3.1:**

To provide options for the implementation of trials in Task 3.2, based on specific African contexts built on WP1 findings and the local farmers and advisory services experiences, to secure best knowledge integration from different sources.

1.2 Deliverable

The deliverable for Task 3.1 is as follows: "Set of AEZ- and crop-specific guidelines for the implementation of agro-ecological demonstration trials (BOKU, M08): Instructions how to repeat and implement best agricultural practices and crops in similar AEZs."

1.3 Description of Task 3.1:

"WP3/Task 3.1: This task compiles all written and oral information, and experiences for all 13 AEZ to inform the trial concept in T3.2. We include knowledge gained in WPs 1 & 2, as well as expert interviews for each crop in each AEZ. Multiple actors from the 13 AEZs will lead and summarise the expert interviews, while BOKU will prepare and summarise. The co-identified and co-designed trial concepts will be then implemented in T3.2. The findings will be summarised and the consequences for the trial concept discussed with an expert group (farmers, advisors and research team) in each target AEZ, identified in the start phase of WP3. These groups will also permanently accompany the trials with field walks and in discussion groups of all tasks in WP3. Gained results in T3.1 will be provided to WP4 as background knowledge for training, teaching and dissemination." (Source: Proposal SustInAfrica)

In this task all information is compiled, that is of relevance for the conceptualization and implementation of field trials (see Task 3.2). Findings can be further used as background knowledge for training, teaching and dissemination in WP4 (Task 4.1/4.2). As sources of task 3.1 we used information collected in WP1 (literature review), information provided by African partners and additionally information provided through expert interviews.

Findings will be discussed with an expert group (farmers, extensionists and research team) in each target AEZ, and as far as necessary modifications will be made.

1.4 Milestones and responsibilities

The tasks that need to be conducted for the deliverable 3.1, the respective timeline and milestones as well as the responsible teams are described in

Table 1.

Table 1. Tasks, milestones and teams involved

Tasks	From (month)	To (month)	Milestone	Teams involved; lead in bold letter
Expert interviews	M02	M03	M04[2]	**BOKU** + *ATB, CIHEAM, ISEG, FC.ID, UCC, UDS, UDDG, UAM, CU, HUSD, IO*
Group discussion: discussing site-specific trial design options with expert group (farmers, extension officers, researcher)	M05	M07	M08[3]	**BOKU**, *ATB, CIHEAM, ISEG, FC.ID, UCC, UDS, UDDG, UAM, CU, HUSD, IO*
Deliverable ready: AEZ and crop specific trial guidelines			M08	**BOKU**, *ATB, CIHEAM, ISEG, FC.ID, UCC, UDS, UDDG, UAM, CU, HUSD, IO*

Source: Own

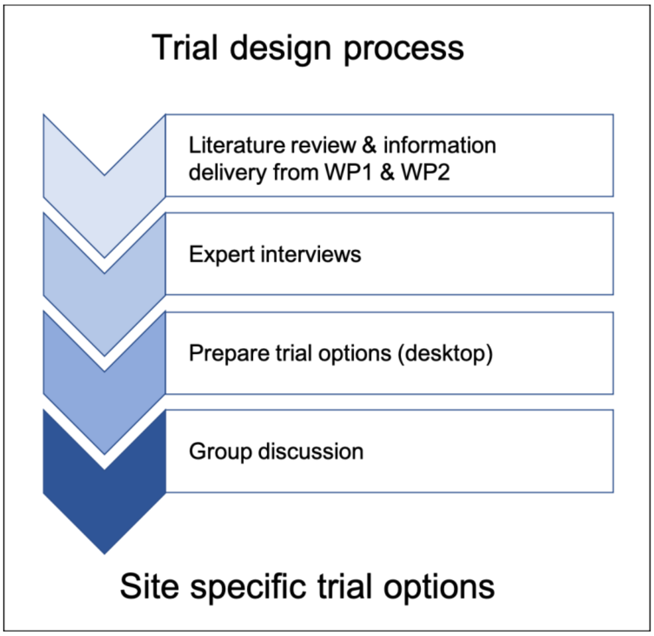
1.5 Methodology for data collection

To ensure the viability of the trial design for each participating country and the respective regions, the trial design process includes a review of the relevant literature, knowledge generated in WP1 and WP2 as well as expert interviews and a group discussion (researchers, extension officers, farmers) (Figure 1).

[2] Note that not all expert interviews could be conducted until April 2021 due to the COVID-19 restrictions in the partner countries.

[3] Note that not all activities could be conducted until April 2021 due to the COVID-19 restrictions in the partner countries.

Figure 1. Trial design process



Source: Own

1.5.1 Expert interviews

In each AEZ experts (researchers and extensionists) have been selected. The experts were consulted to gather information for the set-up of on-farm demonstrations and on-farm experiments for different target crops (Table 2).[4]A summary of the conducted interviews is provided in the Annex (0).

Table 2. Experts and their specific expertise

Country	Expertise	Expert (Affiliation)
Tunisia	Olive farming systems	*Researcher:* Amel B. Hamouda (Olive Tree Institute, Tunisia) *Researcher:* Olfa Boussadia (Olive Tree Institute, Tunisia)
Egypt	Wheat, rice, (olive)	No interviews conducted due to pending status of the Heliopolis University
Niger	Cereals (millet, sorghum)	*Researcher*: Toudou Adam Zaki (University of Niamey)
Burkina Faso	Cotton	*Researcher:* Désiré Jean-Pascal Lompo (University of Dedougou)
Ghana	Mango	*Researcher:* Benjamin Badii (University of Development Studies, Ghana)
	Maize	*Researcher:* Osei Kingsley (UCC, Ghana)
	Pineapple	*Researcher*: Michael Adu (UCC, Ghana)

[4] Until now (April 2021) due to the Covid-19 pandemic and the restrictions in the partner countries extensionists and those without a (stable) internet connection could not be interviewed yet. However, the interviews will be conducted at a later stage when the restrictions are suspended (possibly in summer/autumn 2021), especially those with local extensionists that are active in the target communities.

General	On trial implementation	*NGO:* Paul Wagstaff (Self Help Africa)

Source: Own

1.5.2 Expert group discussion

The aim of the expert group discussion is the integration of further information and feedback on the trial design options from local stakeholders including approx. 4 farmers, 2 researchers and 2 extensionists.

So far (as of April 2021) the expert group discussions could not take place due to the Covid-19 pandemic and the restrictions in the partner countries. Currently the plan is to establish the group discussion in summer/autumn 2021 (Table 3).

Table 3. Group discussions overview

Country	Farming / cropping system	Group discussion organizer/responsible	Timeframe
Tunisia	Olive farming systems	Researcher: Olfa Boussadia (IO)	Summer/ autumn 2021
Egypt	Wheat, rice, (olive)	Researcher: Pending (see Table 2)	
Niger	Cereals (millet, sorghum)	Researcher: Mahamane Larwanou (UAM)	
Burkina Faso	Cotton	Researcher: Désiré Jean-Pascal Lompo (UDDG)	
Ghana	Mango	Researcher: Kwame Frimpong (UCC)	
	Maize		
	Pineapple		

Source: own

2 Theoretical background for trials

2.1.1 General introduction: on-farm demonstrations vs. on-farm experiments

The following section describes possible types and set-ups of on-farm demonstrations (OFD) and on-farm experiments/trials (OFE) that are considered viable for SustInAfrica's purposes and goals. In the scientific literature different definitions are used for OFD and OFE. For some authors OFD also include scientific experimental designs that allow for statistical analysis (Pappa et al., 2018) while others differentiate between OFE and "pure" demonstration trials (Piepho et al., 2011). For our purposes we differentiate between on-farm demonstrations and on-farm experiments or on-farm experimental trials (see Table 4)[5].

[5] As Warren et al. (2020) and Piepho et al. (2011) with the term on-farm demonstrations we refer to „pure" demonstration trials, which are only conducted on a single farm or plot without replications which means that no scientific experimental design is applied. Therefore, we do not use the term trial for "pure" on-farm demonstrations while the term "on-farm experiment" we use equally to the term "on-farm trials or on-farm experimental trials".

Table 4. On-farm demonstrations versus on-farm experiments

Trial / demonstration types	Description	Scientific experimental design & analysis
On-farm demonstrations	a) **One-field demonstration** = the innovative practice is applied to one field	No
	b) **Split-field demonstration** = one field is split into two halves with one applying an innovative practice and the other half the farmers practice (control)	No[6]
On-farm experiments	OFE conducted as multi-environment trials ("mother and baby trials") (see 2.1.3.1 Multi-environment trials (MET))	Yes

Source: Own, adapted from Piepho et al. (2011) and Warren et al. (2020)

OFD and OFE represent valuable methods to introduce and demonstrate innovative agricultural practices and/or technologies to farmers, extensionists and other interested stakeholders. Furthermore, they enable the evaluation and validation of the performance of selected practices and technologies under field conditions in cooperation between researchers, extensionists and farmers. OFD as well as OFE serve for knowledge creation in science and agricultural practice, knowledge transfer as well as educational and training opportunities from two different perspectives – the more practical reality and that of science (Pappa et al., 2018; Warren et al., 2020).

The specific aims of this combination include both researchers and practitioners' interests (

Table 5).

Table 5. Aims of OFD and OFE within SustInAfrica

Aims of OFD & OFE	**Description**
Science	▪ To conduct and test new, sciences-based practices/technologies in practice ▪ To implement solutions at farm level / under farm conditions ▪ To validate and demonstrate new technologies under farm conditions
Dissemination/ Innovation uptake	▪ To test how far innovations/technologies work in practice ▪ To support farmers decision making to uptake new practices and foster uptake of innovations by farmers
Knowledge creation/transfer, education & training	▪ To integrate different experiences and knowledge from farmers, extensionists and researchers (local and international!) ▪ To promote knowledge creation in science and practice as a result of the cooperation between farmers, researchers and extensionists ▪ To enter into a collaborative learning process ▪ Raise farmer awareness ▪ To offer a training and learning site under farmers conditions

[6] In case the split-field demonstration is not only applied on one farm but replicated on several farms a statistical analysis can be conducted. However, if only applied as a demonstration on a single farm, no valid quantification is possible.

Source: Own, adapted from Pappa et al. (2018)

2.1.2 On-farm demonstrations

For SustInAfrica's purposes the following two options for on-farm demonstrations are considered viable:

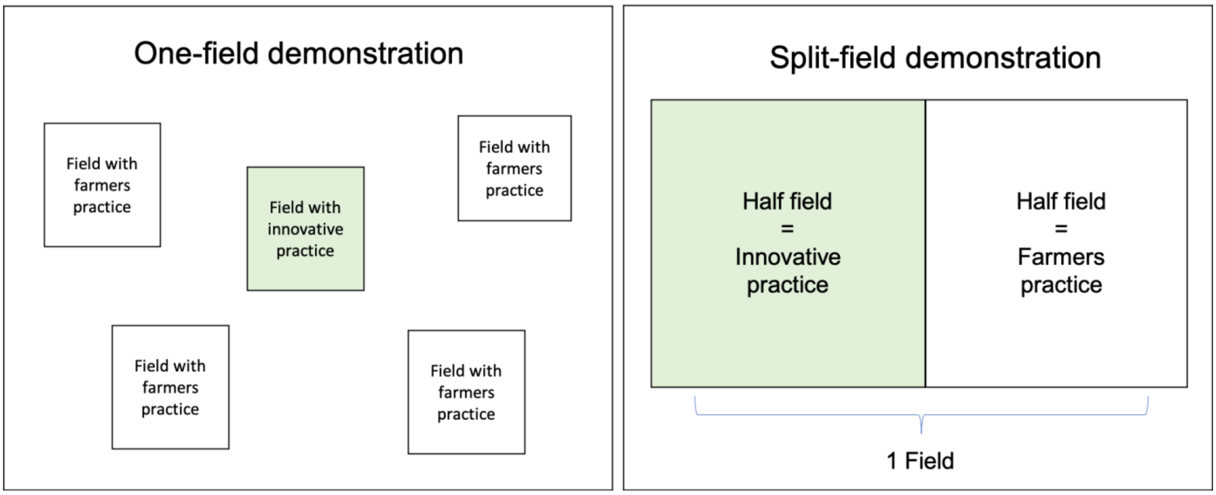
a) One-field demonstration[7]

The one-field demonstration is the simplest form of an on-farm demonstration where an agricultural innovation and/or technology is applied and presented on one field or more fields (Figure 2, left). The One-field demonstration represents one treatment in one field. However, usually the field with the innovation is compared to another neighbouring field(s), where a standard management practice was applied (farmers practice/control). The one-field demonstration can serve to demonstrate and discuss an agriculture innovation with interested farmers, for example on how to implement the innovation (e.g., timing, amounts) and what effects can be observed in a production environment (e.g., yield quantity, yield quality, erosion etc.). However, the one-field demo cannot be used to quantify the effects of an innovation compared to a farmers practice (control) as the outcomes / effect could be occurring due to other factors such as soil type or differences in management.

b) Split-field demonstration[8]

In a split-field demonstration, a field is split into two parts, where on one half an innovative practice is applied while on the other half a farmer`s practice (Figure 2, right). Such a set-up provides a better visual side-by-side comparison and possibly more information than a comparison of two different practices on different fields as in the one-field demonstration. Also, in split-field demonstrations the chance is higher that the management on the same field is similar compared to a field-to-field comparison as in the one-field demonstration. However, the split-field demonstration is also not viable for a quantification of effects due to the possible spatial variability within fields.

Figure 2. One-field and split-field demonstration



Source: own

The following Table 6 provides an overview of aspects to be considered when planning one-field and split-field demonstrations.

[7] The one-field demonstration is labelled as proof-of-concept by Warren et al. (2020)

[8] The split-field demonstration is labelled as strip trial by Warren et al. (2020)

Table 6. Summary of the major characteristics of the one-field and split-field demonstration designs

Charactristics	One-field demo	Split-field demo	Remarks
Site selection	To control and reduce variation of natural factors as best as possible, fields and/or plots for demonstration should be chosen on relatively uniform ground.		
Include current farmers practice as a control	Yes (comparison with neighbouring field)	yes	
Scientific experimental design	no	no	Lacking replication and/or randomisation (and blocking)[9]
Size of field/plots -Annual crops	Minimum 6 x 5 m (per plot/treatment) [10]	Minimum 6 x 5 m (per plot/treatment)	Usually, field length and one or two tractor passes wide (in mechanized farming)
-Perennial crops	Minimum 4 – 12 trees	Minimum 4 – 12 trees	Depends on the number of trees per ha planted

Source: Own, adapted from (Petersen, 1994; Rao & Coe, 1991; Warren et al., 2020)

2.1.3 On-farm experiments (trials)

On-farm experiments (OFE) are conducted on farmers' fields. The application of OFE has for long time been closely related to participatory research in development projects and farming systems research, especially under low input conditions, aiming for the conception and diffusion of agricultural "innovations" (Kool et al., 2020; Piepho et al., 2011; Riley & Alexander, 1997). As OFE are conducted under field conditions they are of high practical relevance and validity but may exhibit lower precision due to increased heterogeneity and therefore reduced controllability of biophysical as well as socio-economic factors. Commonly, in OFE fewer treatments are applied per trial, experimental error variance is usually more pronounced and research plot sizes are larger. However, with an appropriate research design and sufficient replications results are comparable to on-station experiments (Piepho et al., 2011). OFE usually apply classical a **randomised complete block design** (RCBD) (Piepho et al., 2011).

When OFE are conducted at many sites and for more than one year with the aim to gain a broader insight into the performance of systems (Johnson, 2006), such complex OFE provide results equalling **multi-environment trials** (MET) (Piepho et al., 2011).

2.1.3.1 Multi-environment trials (MET)

Multi-environment trials are trials that are conducted in multiple environments or contexts. The term "environments" in MET refer to different contexts investigated by the trial (Coe, 2012a):

- **Biophysical environments** (e.g., weather, soil) of research sites
- **Social, cultural and economic** environment of research sites (e.g., differences of outcomes between poorer and wealthier farmers; differences in production objectives (for consumption

[9] But even if "only" demonstrations are implemented in single villages or communities, data could be gathered on farmers perceptions of the demonstrated practices/technologies.

[10] Snapp et al. (2002b) f.e., used 8m x 8m plots in maize-legume systems; Franke et al. (2019) used 6m x 6m plots and van Vugt et al. (2018) 10m x 10m plots (plot = treatment) in maize-soybean cropping

or for sale); gender analysis (e.g., differences in values, use and adaptation of options between men and women or groups)

Therefore, MET aim for generating knowledge about what is repeatable across different environments and/or the underlying reasons for non-repeatability or interaction with the environment. Thus, the application of MET is specifically useful in researching agro-ecological intensification[11] (AEI) and the respective AEI practices as these are highly context specific (Ibid).

In our research we aim to: i) determine the impact of the applied (agroecological) practices (options) on specific ecological, social and economic variables (measured with in WP1 determined indicators) and ii) assess effect sizes to explain reasoning of data variability. According to Coe (2012:7): "Discussion of any interactions requires one or more **response variables** – the things we can measure and use to describe the performance of options. These will need defining in the objectives." Furthermore, the **treatment x environment interaction** or **option x context interaction** is an "interaction between a treatment effect and environment simply means that the size of the effect is not the same in different environments."

The following

Table 7 provides some examples of diverse topics and its application with METs.

Table 7. Examples of METs

Topic	Objectives	Treatments or options	Environments or contexts
Breeder's trial	Determine whether varieties are stable over a range of environments	Varieties developed through breeding	Representative sites in the agro-ecozones in which the crop is grown
Participatory variety selection	Understand geographical variation in farmers preferred traits and assessment of new varieties	Varieties developed through breeding	Communities within a target area
Local adaptation of soil management	Measure the extent to which soil management options are adapted to specific landscape positions	Alternative improved soil management options	Landscape positions with differing soil and water relations (valley bottoms, hillsides and hill tops)
Participatory technology development	Allow farmers to test and evaluate alternative technology designs	New technologies developed by a participatory project	Farmers with varying skills, interests and resources
Developing local fertilizer recommendations	Develop non-uniform fertilizer recommendation	Different fertilizer rates	Sites sampling a wide range of soil and agroecological environments
Targeting options and niche matching	Understand how available options are	Alternative crop x management options	Socio-ecological niches identified from

[11] "Agro-ecological intensification" (AEI) hypothesises that increase understanding and use of ecological principles and processes can bring sustainable benefits to smallholder farm families. (…) Another aim of AEI is to reduce risk to farmers. Some of the risks faced, such as those due to the weather, are due to variable environments. Thus, METs are needed to evaluate the risks and investigate how to reduce them." (Coe, 2012:2)

	adapted to specific socio-ecological niches		participatory farming system analysis

Source: Coe, 2012

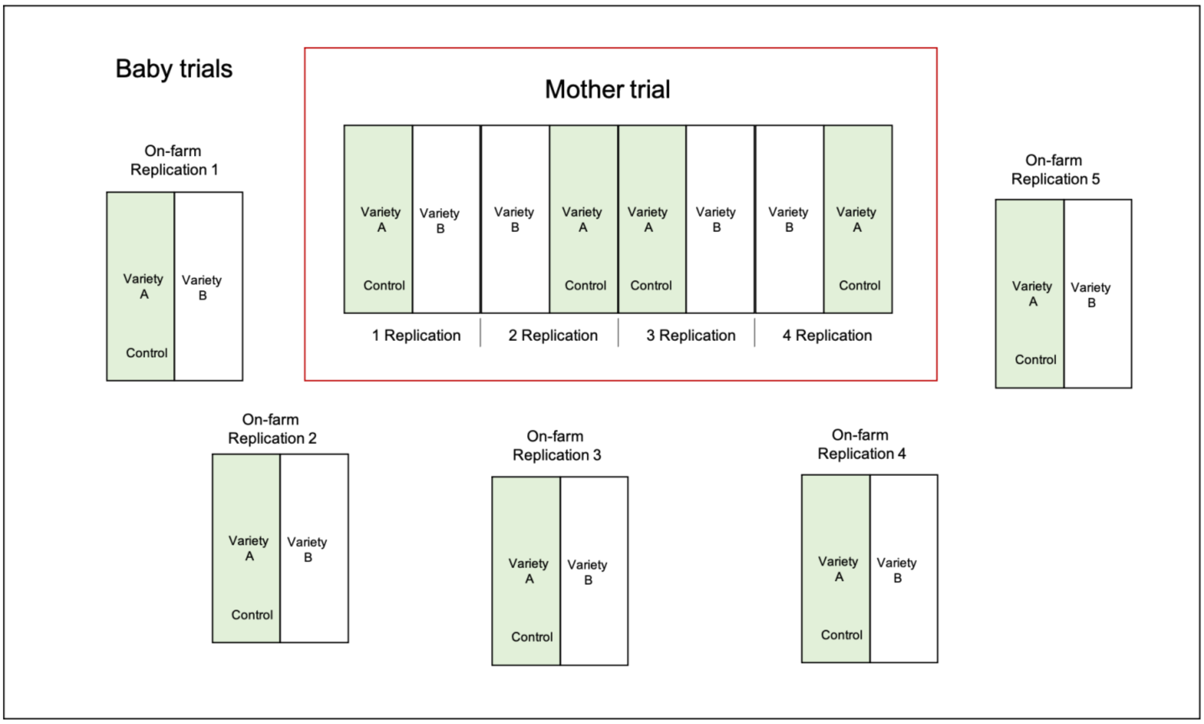
MET Option 1: Multi-year mother and baby trial design

The ‘mother and baby’ trial design is a different description for a multi-environment trial (e.g., sometimes used by researchers doing METs of varieties)[12]. The mother trial is hereby a centrally located trial, usually on a nearby research station or centrally located in a village/community. The mother trial is managed by researchers and tests many technologies (with replications on the same site) while the baby trial is farmer managed (with support from a field technician) only uses a subset of three or fewer technologies (treatments), plus a control for in minimum 2 years. The design allows a systematic cross-checking of quantitative data collected from the mother trial with baby trials on a specific theme (Snapp, 2002a). Commonly, on-farm replicates or baby trials are conducted on less than 20 farms due to logistics and resource constraints (Kool et al., 2020).

Figure 3 depicts an example of a mother and baby trial design approach where the centrally, researcher managed mother trial compares two treatments, in this case a new variety with a farmers’ variety (variety B = control). The mother trial follows a paired comparison, in this case with a total of 4 replications on site. The baby trials act as further replicates on the farmers plots (e.g., in the same village or community). The baby trials are conducted on a farmers’ field where the field is split into two halves comparing the two treatments (new variety A against the farmers variety B = control).

[12] Coe (2012a:9) describes the mother and baby trial approach as follows: “Researchers doing **multi-environment trials** 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. The investigation on each individual farm may be much simpler than the full trial, involving only a selection of the options and not replicated within farm. A well-designed mother and baby trial should be able to answer both biophysical and socio-economic questions about options and their interaction with context.”

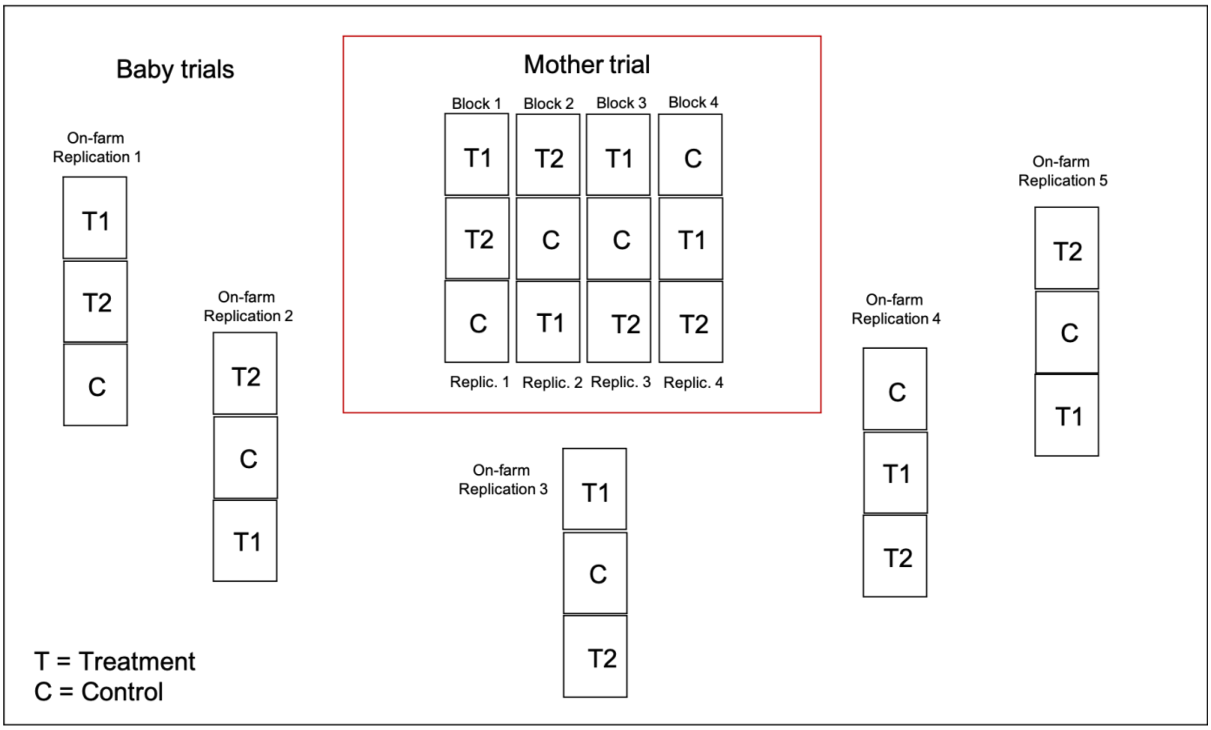
Figure 3. Mother and baby trial design with one treatment and control



Source: Own

Figure 4 shows an example of a mother and baby trial design approach where the centrally, researcher managed mother trial compares two treatments and a control. The mother trial follows a randomized complete block design (RCBD) with in total 4 replications and blocks on site. The blocks from the mother trial serve as replicates on the farmers' fields.

Figure 4. Mother and baby trial design with two treatments and a control

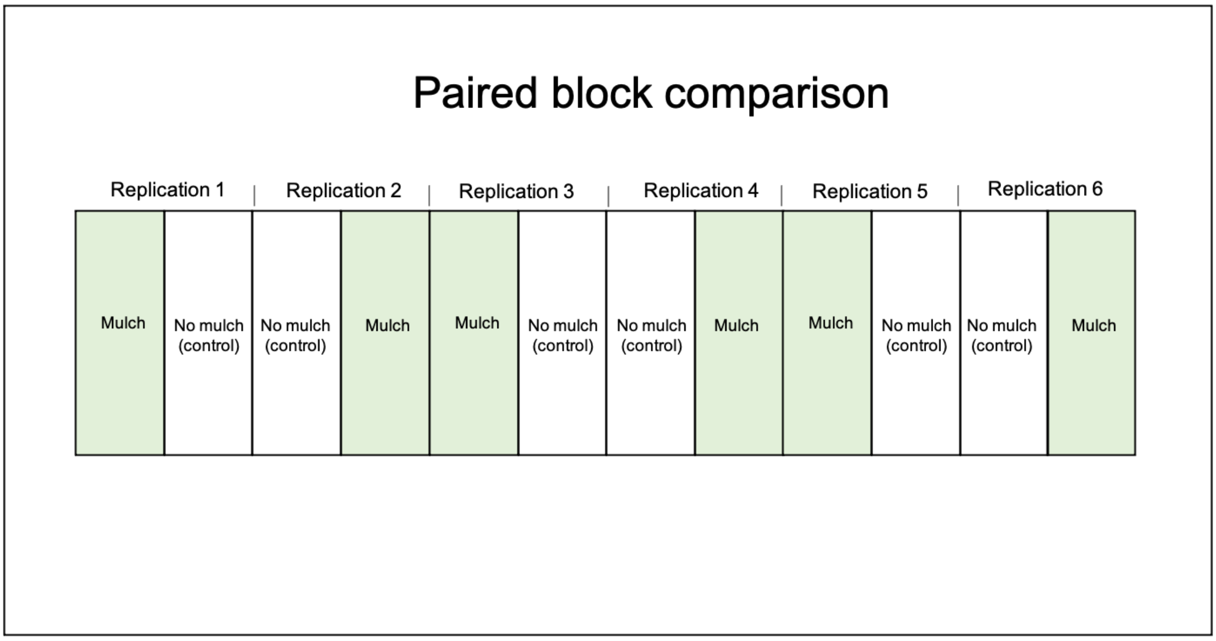


Source: Own, adapted from Davis et al. (1999)

MET Option 2: Paired block comparison

In cases where the implementation and management of a mother trial is not feasible, different other trial types for on-farm experiments with a scientific experimental design can be conducted on the farmer's fields. A paired block comparison with a minimum of three replications is a feasible design for implementation either on one or various farms allowing statistical analysis (Figure 5). Each pair (block) of plots (treatments) should be laid out on homogenous or similar ground.

Figure 5. Paired block comparison

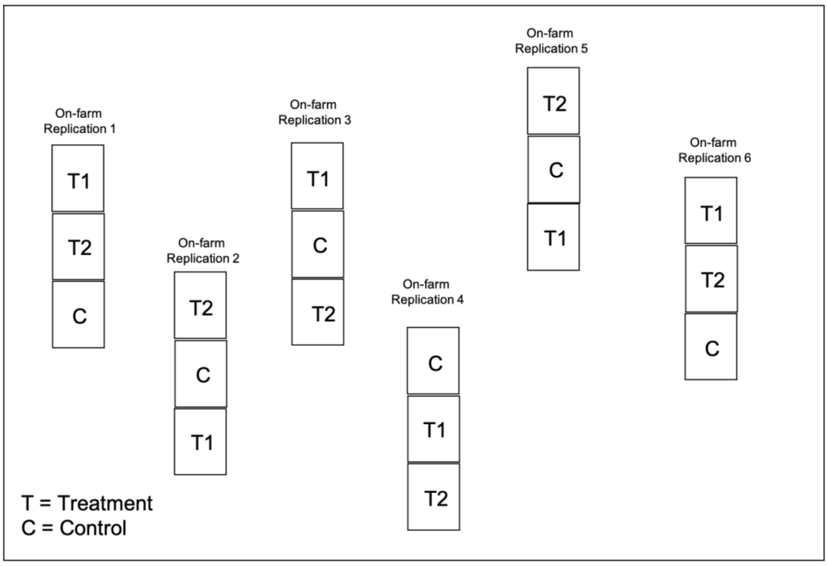


Source: Own, adapted from Sooby (2001)

<u>MET Option 3: Block comparison</u>

The block comparison as depicted in Figure 6 is another possibility for a trial design when the implementation of a mother trial is not feasible. The design is a randomized complete block design (RCBD) with single blocks of three or more treatments being hosted by different farms (each farm serves as replicate) (see e.g., van Vugt et al., 2018).

Figure 6. Block comparison



Source: Own, adapted from Meertens (2008) and van Vugt et al. (2018)

2.1.3.2 Guidelines for MET implementation

The design of MET follows the general principles of a controlled research design such as randomization, blocking, and replication (Piepho et al., 2011). The following Table 8 describes the steps to be considered for designing the research trials for SIA. But most important before one can start with a trial design is to determine the objective of the research trial, because all following steps are being built on objectives the SustInAfrica project will define by September 2021 (D3.2 "Demonstration trials").

Table 8. Steps in the trial design process

Design step	Description
Research topic	▪ Determine a research topic (e.g., Soil fertility trials)
Objective[13]	▪ Determine and describe the objective of the trial (e.g., improving soil fertility)
Research question(s)	▪ Determine the research question(s) (e.g., 1. Which effect has a chosen treatment (f.e. compost) on soil fertility parameters?; 2. How does the treatment affect the productivity of a crop? Etc.)
Hypothesis	▪ Describe the hypothesis that guides the trials (e.g., the treatment with compost will improve water holding capacity and productivity of the respective crop)
Site selection[14]	▪ Determine environments / contexts (biophysical, social, cultural, economic) ▪ Determine sampling strategy or explain choice of site selection, respectively
Farmer selection /sampling[15]	▪ a) **Random sampling** of farmers and plots (if random sampling not possible = check for possibility of bias)[16]

[13] "The objectives determine the design and much of the analysis and interpretation of an MET. Trials (or other studies) that start with a vague 'let's try it and see what happens' objective are rarely productive." (Coe, 2012)

As we were not able to involve farmers sufficiently until now (April 2021) due to COVID-19 restrictions, we lack participatorily defined objectives and research questions. We need agreement with farmers of what they view as feasible for them, otherwise we risk improper implementation of field trials by farmers.

[14] For example, if we want to find out if a crop variety preference by farmers depends on market distance, we need to choose research sites accordingly (farms with varying distances to markets). In the baseline assessment in WP1 data will be collected on environmental conditions and socio-economic characteristics. Therefore, farmers may be grouped according to specific environmental and/or socio-economic aspects. According to Snapp (2002:10): "(…) it is highly recommended that on-farm trials be conducted at representative, well characterized sites, so that results can be extrapolated to recommendation domains. "

Example from Snapp (2002:13): „Representative villages in key agroecosystems were chosen on the basis of information from community meetings, consultations with extension staff, and government statistics on population density and agroclimatic data (Snapp et al. 2002a). The selected villages had to be representative of four major agro-ecozones and in terms of population density and access to markets. "

[15] If we want to determine differences between men and woman, we need to involve sufficient farmers accordingly at each research site.

[16] "And as it may not be feasible to randomly select farms and farmers to take part in a trial, we need to understand when self-selection will introduce biases, the consequences, and what can be done about it." (Coe, 2012:3)

	▪ b) **Non-random sampling** (consult with local extensionist, village chief and/or lead farmers); decide for selection criteria (e.g., experience in growing crop, motivation, diversity in age, gender, resource endowment)
Plot selection	▪ a) **Random sampling** of farmers and plots (if random sampling not possible = check for possibility of bias) ▪ Plots used should have the same crop in the last year
Experimental treatments	▪ Determine agricultural practices (options) that are being compared in which (environmental/socio-economic) context ▪ Determine experimental units, one-factorial or two-factorial ▪ One control (=farmers practice)
	▪ **Test criteria:** e.g., yield, quality, weed infestation, disease infestation etc.
	▪ **Test factor** (manipulated variable): e.g., seeding density, crop variety, manure/fertilizer amounts, tillage type, pre-crop, etc.
	▪ **Factor levels:** e.g., fertilizer application rate (low, middle, high)
	▪ **Plot size:** Plot size is determined by the objective.[17] However, longish side-by-side plots are recommended as thus heterogeneity can be captured well, therefore, reducing between-plot variance. Nevertheless, square shaped plots are possible as well. ▪ **Annuals:** Minimum 6 x 5 m to 100 x 100 m (per treatment plot)[18] ▪ **Perennials[19]:** Minimum 4 – 12 trees
Randomize	The treatments have to be randomly allocated to blocks. Randomization ensures unbiased estimates of treatment effects and valid estimates of error.
Block	Create a block which contains all treatments. Blocking is important for error control.
Replicate[20]	Each block needs to be replicated (minimum 3 replications, better 4 to 6). Replication ensures unbiased estimates of treatment effects and valid estimates of error. Replicates can be on site or also on different farms (e.g., see mother and baby trial approach)
Control	Define and describe the control (farmers practice) to which the treatment will be compared with (see Kool et al., 2020)
Control for variation	To control and reduce variation of natural factors as best as possible, fields and/or plots for demonstration should be chosen on relatively uniform

[17] Plot size highly depends on the objective: „Steiner [1987] recommends plots of 30 m 2 for on-farm cereal and arable legume variety trials. However, if economic analysis, including labour input, is contemplated, then plots of up to 1000 m 2 are needed [McIntire and Fussell, 1989]" (Rao & Coe, 1991:277)

[18] Snapp et al. (2002b) e.g., used 8m x 8m plots in maize-legume systems; Franke et al. (2019) used 6m x 6m plots and van Vugt et al. (2018) 10m x 10m plots (plot = treatment) in maize-soybean cropping

[19] Plots with perennials need to be comparable plots (e.g., if some farmers have 8 trees and others have 20 trees we have to check for comparability of sites).

[20] There are statistical methods to calculate the exact number of replications necessary for any given experiment, but in most cases between four and six replicates is adequate for on-farm experimentation.

	ground. Additionally, all plots/fields should be treated the exact same way except for the treatments that shall be tested.[21]
Sampling strategy (yield from plots)	Determine: ▪ sampling unit (e.g., quadrat size to be harvested) ▪ sampling size (number of quadrats) ▪ sampling scheme See deliverable D1.1 from WP1
Data collection	▪ Determine what data needs to be collected, when, how, by whom

Source: Own, adapted from (Coe, 2012a; Petersen, 1994; Piepho et al., 2011; Rao & Coe, 1991)

Reproducibility

Causal relations from a studies results can only be established if the experimental design and the results can be reproduced. Therefore, a systematic description and definition of the studied population and the setting (environment) in on-farm experiments is essential (Kool et al., 2020).[22]

At each research site basic data need to be collected before the trials are implemented (baseline data collection) as well as during implementation (e.g., climate/weather data) (Table 9). Additional data might be collected as decided in cooperation with WP1 (indicators).

Table 9. Basic data from each research site

Soil	Climate / weather	Cropping system
▪ Soil type	▪ Long-time climate mean	▪ Nutrient and water management
▪ Soil fertility[23]	▪ Temperature (daily mean / min. / max.)	▪ Pest and weed management
▪ Total soil nutrients / pH value	▪ Precipitation (mm)	▪ Crop information (incl. pre-crops)
▪ Soil surface / inclination	▪ Specific weather events (extreme rains, drought periods etc)	▪ Land preparation
▪ Position to the sun		▪ Field history (for the last 5 years, crops grown, tillage, weed management, yields, inputs applied)

[21] Example 1: Choose fields for experiments that have the same weed pressure.

Example 2: In case there is a slope in the field or rocky areas, the research plots / treatments should equally run across such areas to ensure that all treatments are affected by the variation uniformly.

Example 3: The inclusion of small depressions or outcroppings in the field should be avoided. The research plots should be placed on either side of it by using the depression as an alley or border.

Example 4: Plot borders should be used to avoid runoff or drift from adjacent fields in order to avoid or minimise the influence on the results.

[22] "Most studies fail to explicitly define and describe the research population and/or environment in which (they expect) the experimental finding to work. We propose that experimental studies should minimally address: (1) under what conditions the treatment effect occurs and (2) for whom the experimental findings are relevant. Agronomy journals could include these suggestions in their guidelines for reviewers. In addition, we advocate for more transparency about the selection criteria used for research site, farmer and field selection and a reflection on the possible implications of such selection for the experiment's external validity. Especially studies using a 'farmer practice' treatment should critically reflect on what (diverse) farming realities this researcher-constructed treatment is representative of." (Kool et al., 2020:17)

[23] Soil fertility is "the ability of the soil to supply essential plant nutrients and soil water in adequate amounts and proportions for plant growth and reproduction in the absence of toxic substances which may inhibit plant growth" (www.fao.org)

Source: Own, and Kool et al. (2020)

2.1.3.3 Guidelines for the management of MET

The management of MET is crucial as in any other experiment. Therefore, it must be ensured that crop management is appropriate (e.g., land preparation, planting, pest control etc.) and uniform across plots and sites (Coe, 2012b).[24]

Table 10. Management procedures

Management procedure	Description
Organise a team at each site	▪ 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 NGO staff and farmers. ▪ An expert group (researchers, extensionists, farmers) will accompany the trial implementation throughout the project with field walks and discussion groups. The field trials will start in the project year 2022. Until then the groups will be constituted for each region.
Develop a protocol	▪ (e.g., what needs to be measured, when and how). The protocols and methods for the data collection are developed in WP1 and are described in deliverable D1.1 (survey and assessment toolbox for data collection). For each research site (community) a protocol will be provided.
Management of farmer plots	▪ Management of every plot on the farm (baby trial) should be the same except for the difference in treatments, but not necessarily between different farms (baby trials). This is part of the block effect[25]. ▪ Management of mother trials: implemented and managed by researchers. ▪ Reach a common understanding with farmers of which management factors will be uniform and which can be individually adapted by farmers.
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
Monitoring	▪ Routine monitoring for observation of compliance, decisions on management (e.g., pest control), and to keep farmers engaged ▪ Monitoring to look for surprises

Source: Own, and Coe (2012b); Meertens (2008)

[24] „Remember that if management varies by site, then site and management effects will be confounded. For example, groundnut agronomy recommends ridging in dry locations and flat planting elsewhere. If a variety trial is done at a dry site with ridging and a wetter site without, the climate and agronomic practice are confounded." (Coe, 2012b)

[25] For example, not all farmers will do the weeding at the same time. Another example, "it will rarely make sense for planting date to be the same calendar date at each site. Planting date should be determined by something objective that can be applied at each site – e.g., two days after the first significant rain, or when most farmers have started planting." (Coe, 2012b)

2.1.3.4 Guidelines for the analysis of MET

For the analysis of MET the same general principles are valid as for other data analysis when conducting research trials with a scientific experimental design, although MET contain some specific challenges which need to be considered (Coe, 2012c).[26]

Data collection, management and preparation

A protocol will be established for data collection for each experimental site and the data reception. Spreadsheets will be prepared in Microsoft Excel to ensure a uniform data reception and processing.[27]

Data analysis

The statistical analysis is determined by the objective and the subsequent trial set-up. Small variations may ask for a change in the statistical model used (see e.g., Piepho et al., 2011, p. 723).[28] The following Table 11 provides an overview of different modes of statistical analysis that might be viable for the analysis of trials in SustInAfrica.

Table 11. Selected data analysis methods

Statistical tests	Description	Sources
T-test	The t-test can be applied when comparing a pair of data for statistical significance of results (e.g., from a paired comparison trial).	Meertens (2008)
Analysis of variance (ANOVA)	E.g., statistical analysis of RCBD. Determination of experimental error or variation among the replications and test for significance of differences measured between treatments.	Meertens (2008)
Multivariate analysis, multivariate regression analysis	E.g., in case multiple trait and environment data are going to be analysed.	Montesinos-López et al. (2019)
	E.g., adaptability analysis of performance of technologies compared across a range of environments, where average yield or edaphic factors are used as an environmental index.	Snapp (2002a)
Mixed models	E.g., factor analytic models for modelling variance and covariance from multi-environment trial data.	Van Eeuwijk et al. (2001)

Source: Own, adapted from sources right column

[26] On-farm research results are often very variable; therefore, one needs to look carefully for information and patterns in data. E.g., soil fertility measures: variable results could be due to differing carbon contents on farms but also due to differing quality of management by farmers. Thus, if we want to measure soil fertility improvements, we have to consider these factors and include them in design and analysis. Careful observation during experiments is essential as well as the discussion of results with farmers.

[27] See also: Garlick, 2010. Data Management for Multi-environment trials in Excel. Statistical Services Center, University of Reading, UK.

[28] " Often, participating farmers are not willing or able to test all treatments, effectively meaning that farms are incomplete blocks. Thus, incomplete block designs may be used to allocate treatments to farms (Virk et al. 2009). When the number of treatments tested varies among farms, standard textbook designs are not suitable, and one will need to identify a reasonable design that balances treatments as much as possible (Mead 1988); that is, the number of concurrences per farm (i.e., the number of times a pair of treatments is tested on the same farm) should be as similar as possible between pairs of treatments." (Piepho et al., 2011:723)

The complexity of the trial design and therefore the statistical model may adhere to the local circumstances. Thus, more simple trial designs and methods of analysis may be necessary. A simplified analysis with a t-test can be conducted as depicted in the following example in Table 12. In this case simple qualitative daughter trial analysis cards are used for the famers. For each trait farmers answer the question: is the new variety/ treatment better, the same as, or worse, than the landrace/ control? The collected quantitative data for each trait can be analysed by applying a t-test to compare the new variety/ treatment against the control.

Table 12. Example of statistical analysis using t-test

Trait	New variety is worse than the traditional variety/ control	New variety is the same as the traditional variety/ control	New variety is better than the traditional variety/ control
Yield			+1
Early emergence		0	
Taste	-1		
Late Blight resistance			+1
Green mite population		0	

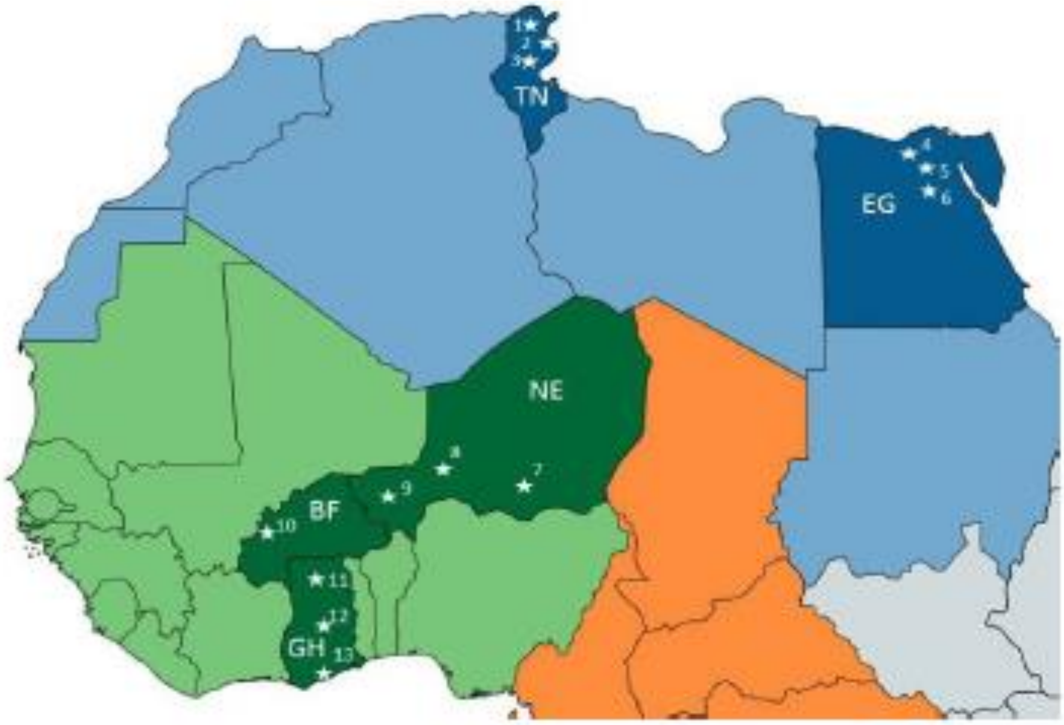
Source: Own (Interview Paul Wagstaff)

3 Site-specific trials

The following section provides basic information on the target regions and target crops for the establishment of site-specific demonstration and experimental trials.

On-farm demonstrations and on-farm experiments (trials) will be implemented in 13 AEZ in the countries **Tunisia** (Beja (1), Sousse & Monastir (2), Kaironan (3)), **Egypt** (pending), **Niger** (Goure (7), Jiratawa (8), Kalfou (9)), **Burkina Faso** (Hauts-Bassin (10)), **Ghana** (Tamale (11), Ejura (12), Komenda (13) (Figure 7).

Figure 7. Identification of research locations



Source: Own/SustInAfrica

3.1 Proposed trials – country overview

In all participating countries the implementation of on-farm experiments (OFE) with a scientific experimental design in the form of the 'Mother and baby trial' design approach should be considered. In each region there is one core community where the trials will be tested and implemented in the first year while the other communities will be integrated in the following year (see Table 13). Each core community of the target region (AEZ) should host a mother trial which is implemented and managed by the local extension officer and a researcher. The mother trial can contain various treatments of which selected treatments can be hosted on pilot farms (baby trials). The baby trials should contain at least two treatments (1 innovative practice and 1 control = farmers practice). However, at least 12 pilot farms or baby trials should contain the same treatment to reach a sufficient number for statistical comparison of results (see Table 13).[29]

[29] We have to keep in mind that some baby trials may not be viable for analysis as farmers do not implement an innovative practice as planned.

The baby trials can be later on expanded to other communities if they are in the same main environment or context. Otherwise, another mother trial might be implemented in the "new" communities as well.

Table 13. Participating countries, regions and target crops for experimental trials

Country	Region	Target crop	Core community (Mother trial)	Pilot farms* (Baby trials)	Treatments**
Tunisia	1 - Beja	Olive	Toukaber	12	2
	2 - Sousse/Monastir		Kondar & Chraki	12 12	2 2
	3 - Kairounan		Zaafrana	12	2
Egypt[30]	4 - Behhira	Wheat, olive	pending	12	2
	5 - Giza		pending	12	2
	6 - Beni Souf		pending	12	2
Niger	7 - Goure (Zinder)	Millet	Guidan Toudou	12	2
	8 - Jiratawa (Tahoua)		Woro	12	2
	9 - Kalfou		Kankare	12	2
Burkina Faso	10 - Hauts-Bassin	Cotton	Satiri	12	2
Ghana	11 - Tamale	Mango	Libga	12	2
	12 - Ejura	Maize	Samari Nkwanta	12	2
	13 - Komenda	Pineapple	Akwanda	12	2

*Minimum should be 12 pilot farms (baby trials) per community; **Minimum should be two treatments including a control (farmers practice)

Source: Own

In case that more complex on-farm experiments (OFE) are not possible to implement due to a changing security situation in Niger and/or Burkina Faso, the implementation of on-farm demonstrations (OFD) might be considered as such trials need less supervision from a researcher. However, this can be reconsidered during the next month according to the situation in the respective countries and the local partners aims. OFE will certainly be conducted with perennial cash crops olive (Tunisia; regions 1, 2, 3), mango (Ghana; region 11), and pineapple (Ghana; region 13).

3.2 Site-specific trial information – Ghana

The following section describes the overall concepts and target crops in Ghana. The respective target crops and their regions, the associated agro-ecological zone (AEZ), the participating communities and (estimated) number of participating farmers[31] are introduced in Table 14 and Figure 8, respectively.

[30] In Egypt possibly on-farm experiments will be conducted with olive and wheat. However, due to the unsolved issues with the Heliopolis University and their missing delivery of input to the consortium no section is elaborated on Egypt. However, the general principles apply as described in section 2. The specific trials will be immediately elaborated when the institutional issues are solved.

[31] Due to COVID-19 restrictions local group discussions could not be carried until April 2021, thus, information on different matters is still missing.

Table 14. Research locations

Region	Focus crop	AEZ	Participating Communities	Estimated number. of participating farmers per community*
Komenda	Pineapple	Coastal Savanna	Nkontrodo	20
			Akwanda (core)	30
			Ayensudo	20
Ejura	Maize	Forest-Savanna Transition	Teacher Krom	20
			Kropo	20
			Samari Nkwanta (core)	30
Tamale	Mango	Savanna	Gumnihini / Water-Works	50
			Libga (core)	50
			Nabogu	50

*If number of participating farmers is already known

Figure 8. Research regions Ghana

Source: Google Earth

3.2.1 Target crop – Pineapple

Pineapple (*Ananas comosus L.*) is one of the most important non-traditional export crops in Ghana with the country ranking about as the 26th largest pineapple producer worldwide (2013). The major varieties cultivated are Sugar loaf, Queen, MD2 and Smooth cayenne. The overall production of pineapple in Ghana is characterised by small to medium scale producers with an annual production of about 120000 to 150000 tons, produced by about 170000 households (2% of total households) (Kleemann, 2011).

3.2.1.1 Climate

Komenda is located south-east in the coastal savanna region of Ghana. The climate is sub-humid warm tropical with yearly average temperatures of 27 degrees Celsius and about 1050 mm of precipitation, allowing for one crop per season under rainfed and two growing seasons per year under irrigated conditions. The soil varies between sandy and clay soils (Table 15). The climate diagrams are attached in Annex 5.1.

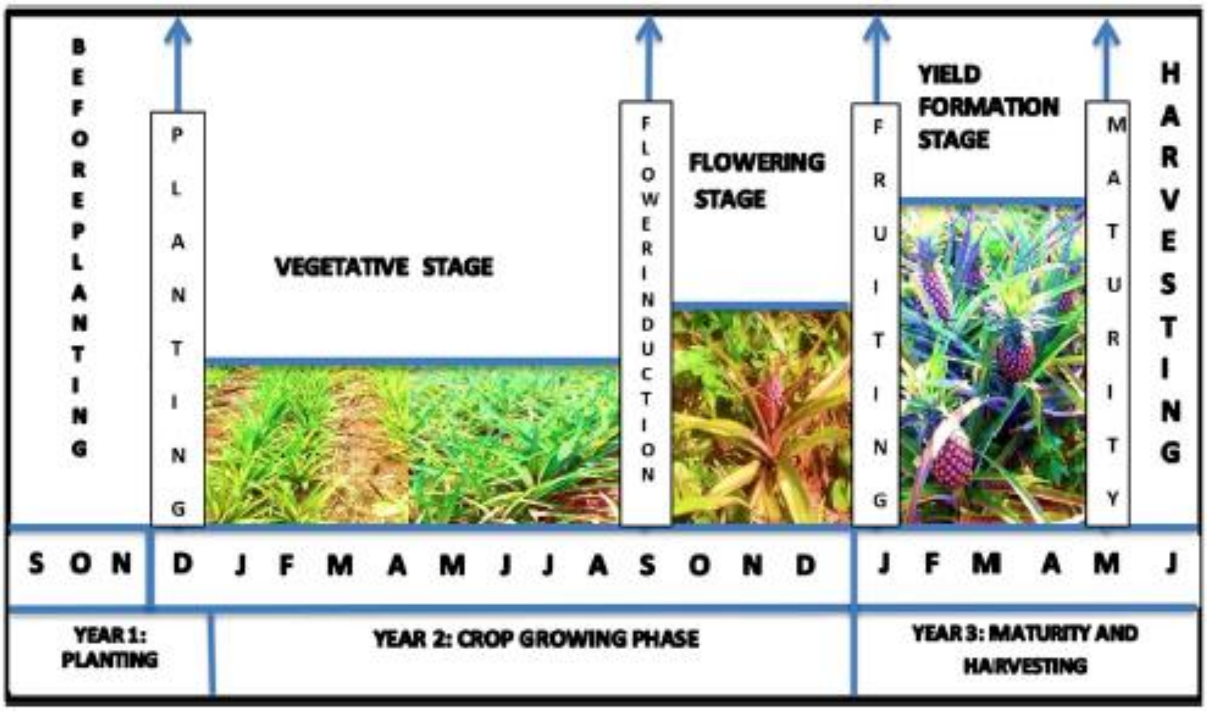
Table 15. Climate, seasons and soil types in Komenda

Region	NN (mm a-1)	T °C ∅	Seasons	Soil types
Komenda	1050	27	1 growing season (rainfed) 2 growing seasons (irrigated)	Sandy, sandy loam, clay, clay loam and sandy clay

* Main soil type/types (clay, sand, loam)
* Seasons: How many growing seasons exist in the region?

The growing seasons of pineapple spans over 18 months from planting to harvest. Planting is carried out in December followed by an eight-month vegetative stage before flowering is induced in September. Fruiting follows in January with a subsequent yield formation of three to four month with maturity and harvesting in May and June, respectively (Figure 9).

Figure 9. Growth stages of pineapple



Source: Williams et al. (2017)

3.2.1.2 Pineapple production in Komenda region

Agriculture in Komenda is dominated by subsistence farming based on traditional technologies in production. Only a few commercial farmers and organizations are active in the region producing on a larger scale. Average farm sizes are ranging between 0.3 and 1 ha (MoFA, 2021). Most of the communities rely on rainfall for crop production due to the unavailability of water sources. Pipe-borne and dug out wells are available for households in some communities in the Komenda region.

Cash crop production comprises citrus, cocoa and oil palm which are produced in the forest areas of the municipality while the main staple crops consist of maize, cassava, plantain, sweet potato and pineapple (Table 16).

Table 16. Food and cash crop production in Komenda

Food crops	2006-2010 Average ha^{-1}	Cash crops	2006-2010 Average ha^{-1}
Maize	3400	Citrus	1000
Cassava	3100	Oil palm	900
Plantain	1000		
Pineapple	130		
Sweet potatoes	23		
Vegetables	14		

Source: Adapted from MoFA (2021)

In Komenda, pineapple is mostly cultivated under rain-fed conditions and are harvested 3 times before it dies naturally on the field. Flower induction (forcing) is done for the pineapple to fruit and be harvested. All pineapple varieties are harvested 135 – 150 days after forcing. The first forcing is done 10 – 15 months after planting. The second forcing is done 7 - 8 month after first harvest. The third forcing is done 7 - 8 months after second harvesting.

3.2.1.3 Challenges

The following Table 17 summarizes some of the most important challenges in agricultural production the Komenda region.

Table 17. Challenges in agricultural production

Region	Challenges
Komenda	Pineapple mono-cropping *Phytophthora* (organic pineapple) Drought Erratic weather patterns Low prices for produce Lacking finances/credit Location of land often in distance from household's homes

Source: Own

3.2.1.4 Trial topics

In the following Table 18 examples for trial research topics, objectives, treatments and the target environments are listed. The final research topic for each region will be decided in a participatory manner involving all stakeholders.

For the purpose of trials and demonstrations, each participating community in Komenda is prepared to commit at least one acre (0.4 ha) of land to the project. They assured the team that the land would be close to the road or in places where the progress of work could be seen by many other residents and farmers, who would learn, admire, ask questions and hopefully embrace technologies.

Table 18. Overview of research topics in pineapple trials

Research topic	Objectives	Treatments or options	Environments or contexts

Example 1 Soil fertility	Improve soil fertility (soil carbon, water holding capacity etc), thus productivity	For example: (fodder) Legumes Compost Manuring Bio-slurry	Differing soil quality on farms with pineapple as the main crop
Example 2 Diversity in the production system	Increase diversity in the production system	Intercropping	Differing socio-economic contexts
Example 3 Resilience	Decrease evaporation and increase soil water storage	Cover cropping (and mulching)	Differing socio-economic contexts
Example 5 Biological control enhancement	- Enhance beneficial organism's populations - Decrease pest populations and damage - Increase diversity of habitats within or surrounding the fields to support higher insect diversity - Decrease pesticide use and application	Examples: - Flower strips, wind breaker[32] or similar - Push-pull strategies[33]	1. Landscape (composition and complexity) is known to interact with the proposed treatments and insect population dynamics.[34] 2. Organic vs conventional farming[35]

Source: own

3.2.2 Target crop – Mango

The mango sector started to develop in the late 1990s in Ghana with the introduction of grafted mango varieties. The current area under mango production in Ghana can be estimated at about 20,000 ha (2016), with a total production of about 110,000 tons, contributing 0.3% of agricultural GDP. About 40% of produced mango is consumed locally as fresh products, 30% are lost (post-harvest losses), 30% are used for processing, 1% are fresh export, 1% dried export, 2% fresh cut export (Grumiller et al., 2018). The main production areas in Ghana are the southern belt (around Accra), the Brong Ahafo region, and the Northern Zone (including Tamale) (Van Melle & Buschmann, 2013).

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[32] Wind breaking elements can help in stopping/slowing down the wind dispersion of the larval stage of the main pest of pineapple: the mealybugs.

[33] Can be used against the omnivorous ants that protect the mealybugs against their natural enemies. The ants protect the pest because they consume the honeydew secreted by the mealybugs.

[34] If not possible to test these in different landscapes, we should try to have similar landscape around the fields. If not possible, we need at least the information on the landscape in a buffer zone around the field to consider this as a co-variable/random effect.

[35] The intensive use of pesticide is known to disturb beneficial organisms and may decrease the effect of the proposed treatments. (There is no consensus in the literature though as it interacts with the landscape). Either we can consider this variable (enough replicates), or we select only one farming system.

In 2005 mango production in Ghana averaged 90 – 140 tons per acre. Since 2006, it increased to 300 tons per acre. The average start-up cost for one-acre mango orchard for the first Year 1 is US$ 2 700 for planting material, land preparation, irrigation, tools and fertilizer. In years 2 – 5 the cost is US$ 590 for running expenditures. This include cost of Irrigation, fertilization, and license fees.

Grumiller et al. (2018) estimate a significant potential in the extension of mango production for Ghana with positive effects on income and poverty reduction, especially in the dryer areas where tree crops can contribute to soil and water conservation, specifically with regard to climate change.

3.2.2.1 Climate

Tamale is located in the Northern Zone in the savanna (AEZ) of Ghana. The climate is sub-humid warm tropical with yearly average temperatures of 27.9 degrees Celsius and about 1100 mm of precipitation, allowing for one growing season under rainfed conditions (Table 19).[36] The climate diagrams are in Annex 5.1.

Table 19. Climate, seasons and soil types in Tamale

Region	NN (mm a-1)	T °C ∅	Seasons	Soil types
Tamale	1090	27.9	1 growing season (mango)[37]	Sandy loam with low fertility (Arenosol)

* Main soil type/types (clay, sand, loam)
* Seasons: How many growing seasons exist in the region?

3.2.2.2 Mango production in the Tamale region

The Northern Zone where the Tamale region is situated provides a favourable climate for mango production. Generally, mango farming in Ghana is characterized by small-scale production. However, in Tamale region larger holdings do exist with commercial operations on (organic) mango production in place. The Integrated Tamale Fruit Company (ITFC) is an example of organic mango production operating on a 150-hectare nucleus estate and additionally cooperating with around 1300 outgrowers which are supported by ITFC in various ways.

The current production systems range between small scale, extensive with unevenly spread wild mango trees which are harvested by small-scale subsistence farmers to medium and larger scale operations with grafted mango trees aimed at export either fresh or processed. The minimum holdings producing mango are about 1 ha while the larger holdings are up to 40 ha with the most common size being around 5 ha.

The wild trees can be in production for 30-40 years. Depending on the variety, the tree starts fruiting after 3 to 7 years. Once it has started, it can last for 10-15 years before yields decrease significantly. The grafted trees have a peak in yield on the 3rd year of production. Irrigation (150-200 litres of water applied to trees per week, especially under induced flowering) is used for the young trees until the 3rd year.

Farmers do not thin fruits to enhance fruiting, but they prune mostly to manage the fungal disease anthracnose, which is constitutes a serious problem in mango production in Ghana.

[36] According to the report from UDS (Ghana) for SustinAfrica there are vegetables mainly cultivated for commercial purposes during the dry season (except for one community (Libga)), while farmers engaged in cereal and other food crops (maize, rice, yam, soybean and cowpea) production in the raining season.

[37] „In the south of Ghana, there are two rainy seasons, from March to July and from September to November, with a peak in May-June. As a result, there are two harvest seasons, the main season from half May to July, and the minor season in December and January." (Pay, 2009)

In the newly established orchards, farmers practices intercropping with crops like soybean, groundnut, yam and maize. However, after a certain time, this is not possible anymore due to the vegetation coverage. Thus, farmers change strategy and leave only grass in between the tree rows grow. They manage the grass and cut it regularly to avoid fire during the dry season.

Varieties:

Varieties used are: Kent, Keitt, Amelie, and Zille. These are grafted Mango seedlings using local variety as a rootstock and the scion any of the above four varieties. Harvest season begins in April with Amelie and ends in May – June with Keitt.

Natural elements in orchards:

The surroundings of orchards vary. Farmers create borders around the field, but they do not manage the semi-natural elements around. The try to get rid of the alternative host of pests around their field and they maintain and grow shea nut trees (*Vitellaria paradoxa*) because it is one of the major fruit trees wildly present and it flowers at the same time as mango. Therefore, it is supposed to enhance pollination in the orchards.

Pest and diseases:

The most damageable insect pests for mango production are the fruit flies complex. Among this group of species, we found a quarantine and exotic invasive species: *Bactrocera dorsalis.* This species was accidentally introduced in Ghana in the early 2000's and have outcompeted most of the native species naturally present in the country (such as *Ceratitis cosyra* and *C. capitata*). In Ghana, the dominant species are *B. dorsalis* during the dry season and *C. cosyra* during the wet season (Nboyine et al., 2013)[38].

The second main pest is the mango stone weevil (*Sternochetus mangiferae*) that damage the mango seed, which cannot sprout. It is a major problem for the production of seedlings.

The next group of pests is the scale insects (order Homoptera) with the mango mealybugs (*Rastrococcus invadens*) being the most problematic species. It is an exotic species that feeds on the leaves and even fruits (under high densities). They damage the plant directly through sap sucking and indirectly due to the production of honeydew that impedes photosynthesis and favor the development of bacteria. Scale insects group also other species such as *Coccus mangiferae* or *Pseudococcus spp* that are similar to the mango mealybugs.

The farmers producing for commercial purposes are provided with a monitoring calendar. They fill in one document per plot (MoFA & GIZ, 2012). Farmers are advised by local organizations about which pest to monitor, how, when the threshold is exceeded and with which pesticides they should spray their fields if necessary (see Table 20). Usually, advisers recommend farmers what to use. The farmers purchase the agro-chemicals in a local shop. The monitoring calendar can vary depending on the agroecological zone. The use of this document may vary also depending on the variety produced. The monitoring results are written down by farmers/advisers. The pheromone traps for fruit flies are used as a preventive measure to control the pest.

It is common practice to destroy and avoid alternative plant hosts of pests and diseases belonging to the same family as mango because they harbor related pests.

Farmers collect and remove fallen fruits during the fruit maturation to impede the fruit flies to finish its biological cycle. The fruits are usually reduced to slush by crushing and use as manure for the trees.

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[38] NBOYINE, J. A., et al. Population dynamics of fruit fly (Diptera: Tephritidae) species associated with mango in the Guinea Savanna Agro-Ecological zone of Ghana. 2013.

Table 20. Seasonal calendar for conventional mango[39]

	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Crop development												
Flowering												
Fruit development												
Rest												
Practices												
1st fertilizer (foliar)	x											
Flower induction	x											
1st combination of insecticides/fungicides		x										
2nd combination of insecticides/fungicides			x									
Minor tree pruning			x									
1st herbicide				x								
Spray against fruit abortion				x								
Collect dropped fruits				x	x	x	x					
1st insecticide alone					x							
2nd fertiliser					x							
Pheromone traps to scout for fruit flies					x	x	x					
2nd insecticide alone						x	x	x	x			
3rd combination of insecticides/fungicides						x						
2nd herbicide						x	x					
Manure						x	x					
Preventive fungicide						x	x	x				
Harvest				x	x	x	x	x				
Major pruning									x			
fungicide after prunning									x			
3rd herbicide										x		
3rd fertiliser										x		
4th combination of insecticide and fungicide											x	
Fire belt											x	x
Insecticide												x

Source: Interview with Benjamin Badii; MoFA and GIZ (2012)

Some farmers are currently aware of natural enemies, especially the red ant (*Oecophylla longinoda*) that is a fierce predator of fruit fly larvae. They know how to protect them and try to not use pesticide when these beneficial insects have been seen in the field. Currently, farmers do not use inundation biological control[40], but partly they use conservation biological control[41].

Farmers check their fields regularly for indices of damage estimation depending on the pest. For mango destined for the local market, the extension agency sends advisers to visit farmers during the harvest. However, this system is not properly implemented and well organized. For mango produce aimed at

[39] General comment: the pest control is less strict for mango destined for local market. The rules are stricter for mango exported (quarantine pest)

[40] The voluntary release of natural enemies in the environment with the expectation it will multiply and control the pest, but not permanently

[41] The modification of the environment or practices to protect and enhance natural enemies naturally occurring in the fields

international markets, there are stricter measures in place to avoid any quarantine pests. Inspections are conducted to detect and select the good fruits, which is done by advisers. However, the damage estimations are not well recorded.[42]

3.2.2.3 Challenges

The following Table 21 summarizes some of the most important challenges in agricultural production the Komenda region.

Table 21. Challenges in agricultural production

Region	Challenges
Tamale	▪ Soil erosion ▪ Soil fertility decline due to continuous cropping ▪ Frequent droughts ▪ Erratic rainfall patterns ▪ Lacking storage (forced sales after harvest) ▪ Free roaming animals ▪ Bacterial Black Spot disease[43] ▪ Anthracnose[44]

Source: Own, country reports

3.2.2.4 Trial topics

In the following Table 22 examples for trial research topics, objectives, treatments and the target environments are listed. The final research topic for each region will be decided in a participatory manner involving all stakeholders.[45]

Table 22. Overview of possible research topics in mango trials

Research topic	Objectives	Treatments or options	Environments or contexts
Soil fertility / soil erosion	Implement measures to decrease erosion and increase soil fertility	- Intercropping (with groundnut) - Mulching - Compost-biochar mixtures[46]	Differing socio-economic contexts

[42] For purposes of our research, we can approach advisors and ask them to record the different damages for research purposes, but they don't do it if not asked.

[43] „Many small **black** water-soaked **spots** on **mango** fruits and leaves can be caused by **bacteria**. This is the so-called **bacterial black spot disease**. **Spots** appear on the leaves, stems and fruits. On the leaves the **spots** are **black** and water-soaked." https://www.plantwise.org/KnowledgeBank/factsheetforfarmers/20167800022#

[44] „**Mango anthracnose** is caused by the fungus Colletotrichum gloeosporioides var minor (also known by the name of its perfect stage Glomerella cingulata var minor). Spore production by this fungus is favoured by wet or humid weather. The dispersal of these spores is particularly favoured by rain and wind." https://industry.nt.gov.au/__data/assets/pdf_file/0005/233591/604.pdf

[45] According to Benjamin Badii (UDS, Tamale), the most important step will be the field selection. We need to find farmers that are willing to cooperate with researchers. We can monitor wild and cultivated orchards as well as commercial orchards. We can ask the farmers to do some monitoring and to avoid spraying a part of the orchards until the end of the experiment.

[46] Demonstrate the efficacy of compost-biochar mixtures regarding crop yield and micronutrient uptake: i) assess biomass availability and quality; ii) Methods of composting and charring; iii) Standardise application rates; iv) Study crop response and nutritional uptake

Biological control enhancement	Favour natural enemies abundance and diversity to control pest populations and damage through: - protection of natural enemy populations (e.g. augmentarium), - establishment of new species (e.g. ants) - or diversification of habitats and resources (e.g. flower strips, intercropping or mulching) Decrease pesticide application and use	1.Use of augmentarium (to protect parasitoids until emergence) 2.Use of weaver ant nests on trees (species naturally present in Ghana so should not become invasive) (against fruit flies and other pests) 3.Implementation of flower strips (for enhancement of pollination and biological control and biodiversity) Decrease of pesticide application associated to the latter treatments	1.Landscape (composition and complexity) is known to interact with the proposed treatments and beneficial organism population dynamics.[47] 2.Organic vs conventional farming. The intensive use of pesticide is known to disturb beneficial organisms and may decrease the effect of the proposed treatments.[48]
Water management technologies	Efficient use of water and safe irrigation practices	Irrigation	Differing socio-economic contexts

[47] If not possible to test these in different landscapes, we should try to have similar landscape around the fields. If not possible, we need at least the information on the landscape in a buffer zone around the field to consider this as a co-variable/random effect.

[48] There is no consensus in the literature though as it interacts with other factors e.g. the landscape. Either we can consider this variable (enough replicates), or we select only one farming system.

3.2.3 Target crop – Maize

Maize (*Zea mays* L.) is the main staple crop in Ghana: "It is produced predominantly by smallholder resource poor farmers under rain-fed conditions. The crop is well adapted and grows in most of the ecological zones of Ghana including the northern savannah. It provides a major source of calories in many parts of Ghana. It has nearly replaced traditional staple crops like sorghum and pearl millet in northern Ghana. An average maize grain yield on farmers' fields is about 1.7 t/ha as against an estimated achievable yield of about 6.0 t/ha." (Adu, 2014)

3.2.3.1 Climate

The region of Ejura is located Ashanti in the center of Ghana in the Forest-savanna transition zone (AEZ). The climate is sub-humid warm tropical with yearly average temperatures of 25.6 degrees Celsius and about 1484 mm of precipitation. The transitional AEZ is characterised by bimodal rainfall of the semi-deciduous Forest and Guinea Savanna zones – Major and minor seasons for two maize cropping cycles per year (Table 23)[49]. From January to April are the warmest months whereas July to August are the coolest month in the region of Ejura. In April the "Easter wind" are commonly occurring which can cause lodging to crops. The climate diagrams are attached in Annex 5.1.

Table 23. Climate, seasons and soil types in Ejura

Region	NN (mm a-1)	T °C ∅	Seasons	Soil types
Ejura	1484	25.6	2 growing seasons (rainfed)	Forest and savanna ochrosols group[50] Range from sandy loam to clay

* Main soil type/types (clay, sand, loam)
* Seasons: How many growing seasons exist in the region?

Source: http://www.kumasi.climatemps.com/index.php

3.2.3.2 Maize production in the Ejura region

The recommended planting calendar for major Ghanaian staples, including maize is given in Figure 10. Table 24 shows that depending on the agro-ecological zone and the season, the planting time for maize will vary. Given that Ejura lies in the transitional zone, it experiences both forest and savanna climatic conditions and therefore has bimodal type of rainfall of the semi-deciduous Forest and Guinea Savanna zones. Thus, farmers would normally plant maize Mid-March to end-April for the major season and Mid-July to early-September for the minor season (Table 24). Early planting of maize is associated with higher yields when rainfall is normal because this enables the crop to utilize the entire growing season. However, lately, the rainfall pattern has become more erratic and therefore made it difficult for farmers to get the planting time right. Thus, the experience of farmers has been the best guide for time of planting. The vegetative and reproduction growing stages for the major season spans May to July and harvesting is normally from August to September (Figure 10). For the minor season, the vegetative and reproduction growing stages spans October to November and harvesting follow from December to January (Figure 10).

[49] "The district has bimodal rainfall. The raining season is April- November. The major season is April – august whereas the minor season is August – November. The dry season occurs between November-April and during this period, the North – East trade winds (Harmattan) blows dry and dusty winds across the district. The annual rainfall for the district varies between 1,200 mm – 1,500 mm. Generally, the rainfall pattern is very erratic and unreliable. The rainy periods are associated with very high humidity's. Relative humidity as high as 90% is experienced in June and as low as 55% in February. The District is the driest in the Ashanti Region." https://mofa.gov.gh/site/sports/district-directorates/ashanti-region/164-ejura-sekyeredumase

[50] https://www.britannica.com/place/Ghana/Soils

At Ejura, maize cultivation is largely characterized by mono-cropping. Virtually all maize crop farmers use fertilizers in their operations. The standard fertilizer requirement farmers' use per acre is 2 bags of compound fertilizer (NPK) as starter application and 1 bag urea/sulphate of ammonia as top dressing applied just before tassling. Land preparation is mechanical through ploughing with tractors. Weed control is through chemical means (herbicides). Different crops require different contact and systemic active ingredients for weed management but for maize cultivation, the widely used herbicides are Nicogan and Caliherb. Harvesting is done manually while shelling is mechanical. Maize produced in the Ejura AEZ is largely for human consumption and animal feeding. Processing is not a feature of maize produced in the AEZ.

Figure 10. Crop calendar of maize and other major food crops in Ghana

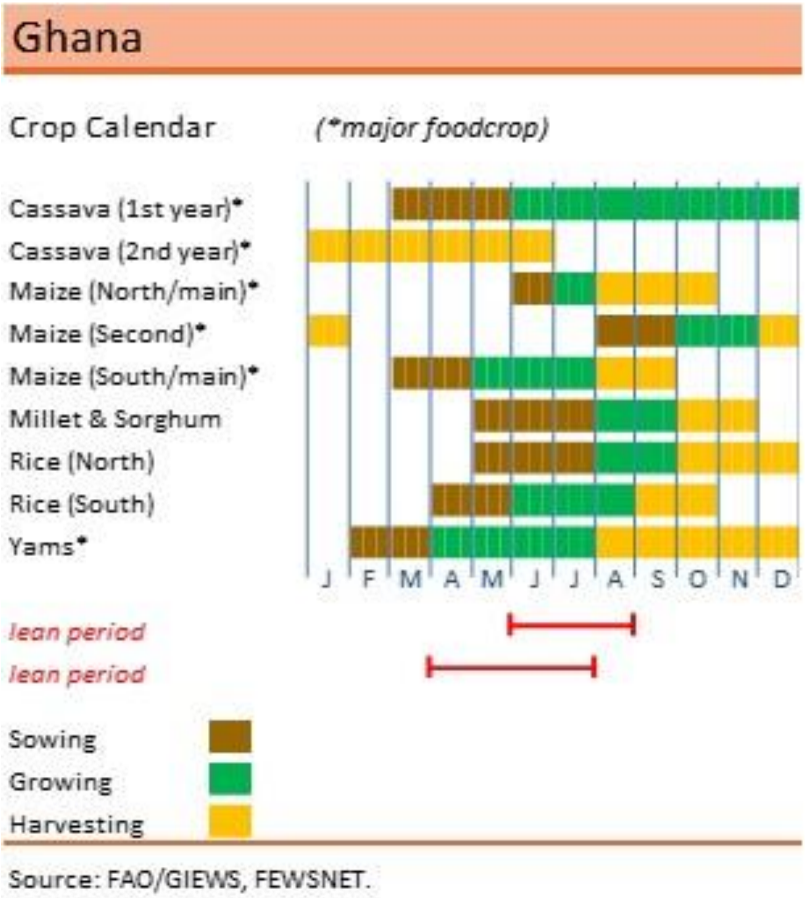


Table 24. AEZ and planting month Ghana

Agro-ecological zone	Month of planting (e.g., maize)
Major Season	
Sudan savannah	End-May to early-July
Guinea savannah	End-May to end-June
Transition	Mid-March to end-April
Forest	Early-March to end-April
Coastal savannah	End-March to End-April
Minor season	
Transition	Mid-July to early-September
Forest	Mid-July to early-September

Source: Adu (2014)

3.2.3.3 Challenges

The following Table 25 summarizes some of the most important challenges in agricultural production the Ejura region.

Table 25. Challenges in agricultural production

Region	Challenges
Ejura	▪ Declining soil fertility due to continuous cropping ▪ Striga weed ▪ Lacking knowledge on management (e.g., planting time, density, untimely application of fertilizer) ▪ Drought and non-existence of irrigation facilities ▪ Lack of control on pricing of agricultural produce ▪ Lack of standardized weight for sale of farm produce ▪ High incidence of pests and diseases ▪ Ineffective herbicides ▪ Inadequate planting services

Source: Own & Adu (2014)

3.2.3.4 Trial topics

In the following Table 26 examples for trial research topics, objectives, treatments and the target environments are listed. The final research topic for each region will be decided in a participatory manner involving all stakeholders.

Table 26. Overview of possible research topics in maize trials

Research topic	Objectives	Treatments or options	Environments or contexts
Soil fertility / resilience to drought	Improve soil fertility (soil carbon, water holding capacity etc), thus productivity	- Legumes (fodder) - Compost - Manuring - Bio-slurry	Differing landscape positions
Soil erosion	Reduce soil erosion	implement permanent semi-natural elements around the fields	Differing socio-economic contexts
Biological pest control	-Enhance beneficial organism's populations -Decrease pest populations and damage -Increase diversity of habitats within or surrounding the fields to support higher insect diversity	-Inter-cropping -Flower strips or similar -Push-pull	Consider the landscape and the farming system

3.3 Site-specific trial information – Tunisia

The following section describes the overall concepts and target crop in Tunisia. The respective target crop and regions, the associated agro-ecological zone (AEZ), the participating communities and (estimated) number of participating farmers[51] are depicted in Table 27 and Figure 11, respectively.

Table 27. Research locations in Tunisia

Region	Focus crop	AEZ	Participating Communities	Estimated number of participating farmers per community*
Beja	Olive	Subtropics – warm Subhumid	Toukaber (core)	1
			Dogga	1
			Zeldou	1
Kairouan		Subtropics – warm Semi-arid	Zaafrana (core)	1
			Chbika	1
			Barouta	1
Sousse		Subtropics – warm Semi-arid	Kondar (core)	1
			Kroussia	1
Monastir		Subtropics – warm Semi-arid	Chraki (core)	1

*If number of participating farmers is already known

[51] Due to COVID-19 restrictions local group discussions could not be carried until April 2021, thus, information on different matters is still missing.

Figure 11. Research regions in Tunisia

Source: Google Maps

3.3.1 Target crop – Olive

In Tunisia currently about 88 million olive trees cover an area of 1.811.000 hectares, which represents a third of the nationally available agricultural land (34%). The geographical repartition in the country is: 15 % of olives orchards are found in the North, 66 % in Central Tunisia and 19 % in the South. Olive orchards are mainly monoculture but sometimes they are planted with other fruit trees mainly almond.

3.3.1.1 Climate

The region of Beja is located in North-West of Tunisia. The climate is sub-humid with yearly temperatures of 18 degrees Celsius and about 626 mm of precipitation, allowing for two crops per season under rainfed conditions (Table 28).

Sousse region is located in the east center of the country. The climate is semi-arid with yearly temperatures of 20 degrees Celsius and about 350 mm of precipitation, allowing for one crop per season under rainfed conditions (Table 28).

Monastir is a coastal city in east-central of Tunisia. The climate is semi-arid with yearly temperatures of 20 degrees Celsius and about 350 mm of precipitation, allowing for one crop per season under rainfed conditions (Table 28).

The Kairouan region is located in the center of the country. The climate is semi-arid with yearly temperatures of 22 degrees Celsius and about 280 mm of precipitation, allowing for one crop per season under rainfed conditions (Table 28).

Table 28. Climate, seasons and soil types in the target regions in Tunisia

Region	NN (mm a-1)	T °C ∅	Seasons	Soil types
Beja	626	18	two crop per season (olive /cereal)	Loam/clay soil
Kairounan	280	22	one crop per season	Loam/clay soil
Sousse	350	20	one crop per season	sandy loam
Monastir	350	20	one crop per season	sandy loam

* Main soil type/types (clay, sand, loam)
* Seasons: How many growing seasons exist in the region?

3.3.1.2 Olive production in the target regions

Olive resources in Tunisia are estimated to be over 118 million olive trees. Adapted to soil conditions and climate of Tunisia, the olive tree extends over the whole agricultural land and currently occupies 1.9 million hectares. A large part of this area is cultivated in a dry environment (95.2%), which affects the productivity considered to be the lowest in the Mediterranean. Indeed, olive oil production has varied over the past five years between 100,000 tonnes and 325,000 tonnes with an average of almost 176,250 tonnes of olive oil (DGPA, 2020).

Olive populations are present in all regions of Tunisia, from north to south and from east to west. At North and in certain areas of the center, they are cultivated in association with other annual crops (cereals or fruit trees such as almonds) while that in the South, they are exclusively cultivated in monoculture (IOC, 2012).

The density varies considerably depending on rainfed or irrigated crop regime. The number of trees per hectare varies in the rainfed regime from North to South according to the precipitation averages ranging from 100 olive trees/hectare in the North where the rainfall is higher than 450 mm/year, to 70 olive trees/hectare in the center with rainfall between 200 to 350 mm/year, at 17-24 olive trees/hectare in the far South where rainfall is less than 200 mm /year (ONH, 2017).

In irrigated cultivation, it is necessary to distinguish several types of farms:

- **Extensive plantations** which originally existed under rainfed conditions, but which have been converted to irrigation in order to include intercropping (center and South) with crops such as potatoes, tomatoes, peppers, cucurbits, peas, barley, alfalfa, wheat, barley. This cultivation method characterizes several areas using groundwater to maximize profitability per hectare.
- **Classical intensive plantations** with planting densities varying from 200 to 280 olive trees per hectare, depending on the vigor of the cultivated varieties. This mode is present throughout the national territory from North to South and uses both groundwater and deep aquifers.
- **Dynamic intensive plantations** with densities between 300 and 625 olive trees per hectare. Most of these plantations are newly created with foreign varieties, mainly Arbequina, Arbosana and Koroneïki. Most of these plantations use water from the deep aquifer.
- **Hyper intensive plantations** at high densities. This system was introduced by a private company in 1999 on an area of 200 hectares. Subsequently, it expanded rapidly, reaching an area estimated at 4500 ha in 2010. The densities adopted in this method of cultivation vary between 1250 to 2500 olive trees/ha. This system is considered to be a large consumer of chemical inputs and water, this mode, which should be fully mechanized, has experienced stagnation in most areas and is currently

practiced on around 5000 hectares in Tunisia. The water used in this cultivation method often comes from deep aquifers (FAO, 2019);

Table 29 provides an overview of the characteristics of the production systems and average farm sizes in the participating communities.

Table 29. Farm sizes and production systems in Tunisia

Region	Communities	Farm sizes ∅ ha	Production systems
Beja	Toukaber (core)	10	Traditional organic olive tree plantation with spontaneous cover crops, manure and livestock production (sheep, goats and poultry), rainfed
	Dogga	5	Olive tree plantation with spontaneous cover crops, manure and livestock production (sheep), rainfed
	Zeldou	5	Traditional organic olive tree plantation with spontaneous cover crops, manure and livestock production (sheep), rainfed
Kairouan	Zaafrana (core)	10	Conventional intensive olive tree plantation with mulch and without livestock, irrigated
	Chbika	1	Conventional intensive olive tree plantation without livestock, irrigated
	Barouta	10	Conventional intensive olive tree plantation without livestock, irrigated
Sousse	Kondar (core)	10	Intensive organic olive tree plantation with spontaneous cover crops, manure and livestock production (sheep and poultry), irrigated
	Kroussia	5	Conventional olive tree with cover crop, rainfed
Monastir	Chraki (core)	1	Conventional olive tree with cover crop and livestock production (sheep, goats and poultry), rainfed

Source: Own

The Tunisian olive groves are made up of 20% of young plantations (1 to 20 years), 50% of plantations in production (20 to 70 years) and 30% of old plantations (over 70 years). Of this age category, at least 10% are planted before 1920 and are over 100 years old. These senescent plantations are mainly found in the Sahel and the South of the country (FAO 2019);

Organic olive growing is a dynamic and evolving component of the Tunisian olive sector. The olive growing area having under certified organic production increased from 127,250 ha in 2015 to 251,569 ha in 2019 (FAO 2019).

The main varieties grown in Tunisia are Chetoui and Chemlali, although there are others, called secondary, more specific to small regions like Oueslati, Chemchali, Zalmati, Zarrazi, Gerboui and Sayali, and other varieties are grown in more restricted areas. These varieties of olives, according to the use for which they are intended, are classified into two types, double aptitude or table olives (IOC, 2012)(see also Annex 5.3).

'Chemlali' which is cultivated mainly in the centre and the South of the country (arid and semi-arid region). It is present in almost 65% of olive plantations.

‘Chetoui’ which is cultivated in the north from the country, this variety is cultivated in almost 20% of Tunisian olive groves. It produces a fruity oil, with a predominant aftertaste of cut grass, which is much appreciated for its content of phenolic compounds and antioxidants.

‘Oueslati’ This variety is cultivated in the Kairouan region. The oil obtained is very balanced and fruity, slightly bitter with a flavor reminiscent of fresh almonds.

'Zarrazi' cultivated in the South, mainly in oases, presenting sometimes some local variations, this variety, besides the production of excellent table olives is much appreciated for its high oil content despite the fact that its productivity or alternating.

Irrigation:

The irrigated orchards are found in the intensive and hyper-intensive farming systems, depending on the geographical location of the orchards. Only about 4.2% of olive groves are irrigated.

Tillage:

For the dry-farmed olive orchards, soil management practices depend on the bioclimatic and edaphic conditions as well as the production system in each olive growing area. Mechanical soil tillage is the most widely applied soil management method in olive orchards. In the North the soil is generally characterized by loam and/or clay and the mean annual rainfall exceeds 400 mm. Soil management is limited to two-three tillage's per year to reduce spontaneous herbs, mainly dicotyledons and grass species. Plowing is carried out with shallow disc tools, but it negatively affects the quality of the soil by forming the plowing sole in the soil superficial layer at 20-25 cm soil depth. After a long-term period, the soil in these olive orchards has become impermeable and limits water infiltration, root growth, and caused soil erosion. Thus, the majority of olive trees in the North have small or medium vigor, and consequently a low olive yield. In the olive orchards in the center and Sahel, the soil is sandy-loam, the mean annual rainfall varies between 250-350mm, soil tillage is applied four times per year, after the autumn rains. Farmers till their soil by disc tools, mainly the offset type one time at 20-25 cm soil layer depth to destroy spontaneous growing weeds. Three soil tillage passes are also applied in autumn and spring to save water and limit the soil evaporation by shallow cultivation with a cultivator with dovetail at 10 cm soil layer. In the South, olive trees grow on sandy soil, the mean annual rainfall is less than 200 mm, and the soil of these olive orchards is mainly occupied by spontaneous herbs like *Dactylon cynodon* that negatively affects olive growth, water availability and reduces the olive production by about 30%. To destroy this spontaneous grass species, soil is frequently tilled, about 6 times per year. Plowing is carried out by a tool developed by the sfax olive growers called el 'mhacha' specified to keep the soil clean of *Dactylon cynodon* and limit soil evaporation. In the irrigated olive orchards including the high-density systems, soil is tilled three to four times per year using a disc plow and a cultivator with dovetail.

Traditionally, the olive trees were planted on marginal lands with poor soil to valorize the adaptive capacity of the olive species. Indeed, the high frequent soil management practices not adapted to the soil types has caused soil degradation, decreasing soil organic matter, currently below 0.6% in rainfed olive orchards.

The soil tillage under the canopy in autumn-winter (depth lower than 20 cm) is used against olive flies to bury the pupae. The soil tillage under the tree canopy is used against the 2nd generation of olive moth in autumn and summer (10 cm).

Fertilization:

Smallholder olive farms represent more than 70% of the olive growing area and have less than 5ha. A minority of these smallholder farmers uses sheep manure, especially in the Sahel and center. Although this type of management promotes a good development of olive trees and guarantees an acceptable production and oil with an appreciable quality. But for the majority of other olive growers does not apply organic fertilizer especially due to the unavailability of manure and the high prices for the manure available.

Since 1984 the Ministry of Agriculture subsidized nitrogen fertilizer for olive production. A large number of olive growers benefits from the contribution of 3kg ammonium nitrate (33% N)/tree split into 2 intakes (1kg/tree in autumn and 2kg/tree in spring).

After a long period of studies and tests on the development of the olive mill wastewater as fertilizer, the agricultural ministry has authorized the spreading of the olive mill wastewater since 2011. Wastewater in olive groves is used as fertilizer at the rate of 50m3/ha.

The use of compost as a fertilizer in olive orchards has been tested under field conditions in different olive growing areas of Tunisia. Results are very promising in relation to the soil quality and tree performance as well as yields and oil production without affecting the oil quality. But farmers refuse the introduction of compost due to the high cost of compost and the application.

Mineral fertilization is applied for intensive and hyper-intensive farming systems. It is applied in autumn, before fruit ripening, and in spring, before flowering. The quantity of fertilizers is chosen based on soil analysis, leaves diagnostics and growth stage.

Intercropping:

A few farmers use green manure based especially on leguminous species as biofertilizer mainly in the northern areas in which rains exceeds 400 mm/year.

It is common to cultivate other crops under the tree canopy in small orchards with irrigation. The companion crops range from alfalfa, potato, tomato, pepper to other vegetables (center area). Usually, animal grazing is common only in the local production system of the Sahel "Meskat".

In olive orchards with vegetable intercropping, the risk is higher for the occurrence of *Verticillium wilt*, which is a soil borne pathogens that can survive many years in the soil.

Management of surrounding areas:

Farmers do not actively manage the surroundings of orchards, although many farmers have planted living fences with cactus (*Opuntia ficus-indica*).

Seasonal calendar:

The biological cycle of the olive tree is biennial. During the first year, the tree develops twigs that remain entirely vegetative. During the second year, the olive tree produces fruit on the wood of the previous year and fructification begins with floral induction and continues until fruit ripening (Table 30).

Table 30. Season calendar of irrigated olive

	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Crop development																								
Resting time																								
Cluster formation																								
Full bloom																								
Fruit set																								
Fruit development																								
Maturity																								
Practices																								
Pruning																								
Tillage			x						x			x			x							x		x
Fertilization		x	x				x		x				x	x					x		x			
Harvest																								
Olive fruit fly monitoring					x	x	x	x	x	x	x	x	x											
Collection of dropped fruits						x	x	x	x	x	x	x	x											
Insecticide (if necessary)																								

Olive moth monitoring	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Insecticide (if necessary)			x												x									

Source: Own

<u>Pest management:</u>

There are two agencies that are responsible for pest monitoring in olive groves, the Regional Agricultural administration authority (CRDA) and the Regional plant protection service, which support farmers in monitoring and management of pest and disease.

The agencies install traps at a suitable time and check them regularly. The decision to spray against pests is taken only when the economic thresholds are exceeded.

Farmers do already apply alternatives to pesticides such as para-pheromone and bait traps. However, farmers do not use augmentative or inoculation biological control, even for parasitoids. The three main insecticides used are: Dimethoate, Spinosad and Bt.

3.3.1.3 Challenges

The main challenges in olive production in most parts of Tunisia is the loss of soil due to soil erosion and soil fertility, which is mainly, but not exclusively, due to: i) the lack of elements which reduce erosion of the soil, and ii) lack of sources of organic matter. As a consequence, important ecosystem services are hampered, which might reduce sustainability in the long term (Table 31).

Therefore, sustainable innovations are based on: i) providing elements which reduce soil erosion (e.g., spontaneous or seeded temporary cover crops and shredded tree pruning) , ii) creation of micro habitats for the development of a diverse microflora, meso and macro-fauna (e.g., no tillage, spontaneous or seeded temporary cover crops and shredded tree pruning's plus mechanical control of the cover crops avoiding the use of herbicides), iii) increase soil organic matter inputs (manure, composted olive mill pomace and soil application of the remains of the cover crops and shredded tree pruning's) and contributing to sequester carbon and many other beneficial soil and farm properties related to organic matter, iv) retain nutrient within the farm, and v) biological pest and diseases control.

Table 31. Main challenges in olive production

Region	Challenges
all	Low soil carbon stocks, maintenance of plant health (pest and disease → olive fruit fly constitutes the main problem[52], followed by the olive moth, and as the jasmine moth is the third major problematic pest), drought, salinity of soils

3.3.1.4 Trial topics

In the following Table 32Table 26 examples for trial research topics, objectives, treatments and the target environments are listed. The final research topic for each region will be decided in a participatory manner involving all stakeholders.

[52] The most important natural enemy is a parasitoid wasp named *Psytallia concolor.*

Early harvesting will occur in autumn if there is a high infestation of olive flies to protect the yield.

Table 32. Overview of possible research topics in olive trials

Research topic	Objectives	Treatments or options	Environments or contexts
Soil fertility	Increase soil carbon content	- Manure - Compost	Differing socio-economic contexts
Soil erosion	Reduce soil erosion	- Cover cropping - Intercropping	Differing landscape positions
Biological pest control	Favour natural enemy abundance and diversity to control pest populations and damage through: - protection of natural enemy populations (e.g. augmentarium design for the olive fruit fly?), - use of beneficial species (inoculation?) - or diversification of habitats and resources (e.g. flower strips, mowed ground cover between rows, creation of corridor with hedges, or intercropping) Reduce application and use of pesticides	Use of augmentarium? (to protect parasitoids of fruit flies) - Ants (e.g. *Tapinoma nigerrimum)* seem to be more important against the olive moth and other pests - Implementation of flower strips (pollination and biological control) or mowed ground cover (biological control) - Decrease of pesticide application associated to the latter treatments	1. Landscape (composition and complexity) is known to interact with the proposed treatments.[53] 2. Organic vs conventional farming[54]
Olive yield	Increase productivity and optimize oil quality	- Organic fertilisation - Cover cropping - Biological control approach using Hymenoptera braconidae	
Salinity	Reduce salinization	Irrigation	

[53] If not possible to test these in different landscapes, we should try to have similar landscape around the fields. If not possible, we need at least the information to consider this as a co-variable/random effect.

54 The intensive use of pesticide is known to disturb beneficial organisms and may decrease the effect of the proposed treatments. Either we can consider this variable (enough replicates), or we select only one farming system.

3.4 Site-specific trial information – Burkina Faso

The following section describes the overall concepts and target crop in Burkina Faso. The respective target crop and regions, the associated agro-ecological zone (AEZ), the participating communities and (estimated) number of participating farmers[55] are introduced in Table 33 and Figure 12, respectively.

Table 33. Research locations in Burkina Faso

Region	Focus crop	AEZ	Participating Communities	Estimated number of participating farmers per community*
Hauts-Bassin	Cotton	Tropics – warm / Semi-arid/Sub-humid	Satiri (Hout province)(core)	30
			Bobo Dioulasso (Houet)	50
			Bekuy (Tuy province)	15
			Bereba (Tuy)	15

*If number of participating farmers is already known

Figure 12. Research region in Burkina Faso

Source: Google maps

3.4.1 Target crop – Cotton

3.4.1.1 Climate

The region of Hauts-Bassin is located in the West of Burkina Faso. The climate is semi-arid to sub-humid warm tropical with yearly average temperatures of 27,2 degrees Celsius and about 550 mm of precipitation, allowing for one crop per season under rainfed and two growing seasons per year under irrigated conditions (depending on crop) (Table 34). The climate diagrams are attached in Annex 5.1.

[55] Due to COVID-19 restrictions local group discussions could not be carried until April 2021, thus, information on different matters is still missing.

Table 34. Climate, seasons and soil types in the target regions in Tunisia

Region	NN (mm a-1)	T °C ∅	Seasons	Soil types
Hauts-Bassin	550	27,2	1 Season	n.a.

* Main soil type/types (clay, sand, loam)
* Seasons: How many growing seasons exist in the region?

3.4.1.2 Challenges

The following Table 35 summarizes some of the most important challenges in agricultural production in the research region/in cotton production in Burkina Faso.

Table 35. Challenges in cotton production in Burkina Faso

Region	Challenges
Hauts-Bassin	▪ Unsustainable Crop residues management strategy ▪ Poor and declining soil fertility ▪ Pest attacks ▪ low crop yields ▪ Deforestation and loss of biodiversity ▪ Surface and ground water pollution ▪ Soil erosion ▪ Water scarcity ▪ Poor use of water management technologies ▪ Loss of labor for crop production due to gold mining and food insecurity ▪ poor management knowledge (especially with regards to sustainable soil management & climate change mitigation)

Source: Own

3.4.1.3 Trial topics

In the following Table 36 examples for trial research topics, objectives, treatments and the target environments are listed. The final research topic for each region will be decided in a participatory manner involving all stakeholders.

However, important topic will be cotton and maize residues management, co-composting of crop residues and biochar, mixed compost and biochar application, fertiliser micro-dosing, intercropping, and Farmer Managed Natural Regeneration (FMNR).

The following questions should be addressed:

- How can we improve cotton and maize residues management to improve soil quality and crop yields while sequestering the carbon into the soil to mitigate climate change?
- For farmers with low financial means, how can we increase fertilizers usage while improving nutrient use efficiency?
- How to successfully increase food production while minimising the negative impacts on the environment?

Table 36. Overview of research topics in cotton trials

Research topic	Objectives	Treatments or options	Environments or contexts
Soil fertility management	- To increase soil carbon content - To Improve water holding capacity	- Legumes - Manure - Compost	Differing socio-economic contexts

	- To increase nutrient availability	- Biochar - Residue management	
Soil protection and restoration	Reduce soil erosion	- Cover cropping - Intercropping - Residue management - Other soil and water conservation measures	Differing landscape positions
Biological pest control	- Enhance beneficial organism's populations - Decrease pest populations and damage - Increase diversity of habitats within or surrounding the fields to support higher insect diversity - Reduce application and use of pesticides	- Inter-cropping - Flower strips or similar - Push-pull	Consider the landscape and the farming system (or the diversity of practices)
Fertilizer efficiency	Efficient application of available fertilizer	Micro-dosing	Differing socio-economic contexts (knowledge creation)

3.5 Site-specific trial information – Niger

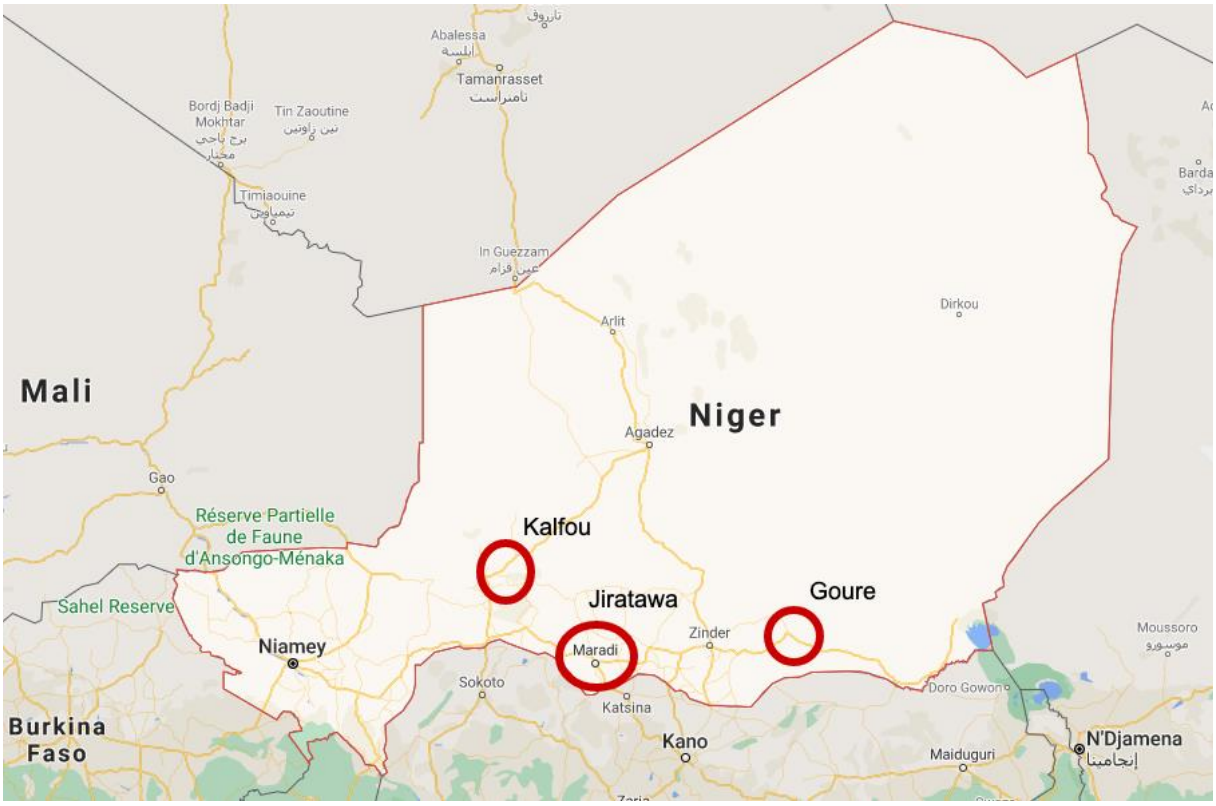
The following section describes the overall concepts and target crop in Niger. The respective target crop and regions, the associated agro-ecological zone (AEZ), the participating communities and (estimated) number of participating farmers[56] are introduced in Table 37 and Figure 13, respectively.

Table 37. Research locations in Niger

Region	Focus crop	AEZ	Participating Communities	Estimated number of participating farmers per community*
Kalfou/Tahoua	Millet	Tropics – warm Semi-arid	Guidan Toudou	5
			Dabagou	5
Goure/Zinder		Tropics – warm Semi-arid	Woro	5
			Balla	5
			Kilakina	5
Maradi/Jiratawa		Tropics – warm Semi-arid	Kankare	5
			Kontagora	5
			Ingobirawa	5

*If number of participating farmers is already known

Figure 13. Research regions in Niger



Source: Google maps

[56] Due to COVID-19 restrictions local group discussions could not be carried until April 2021, thus, information on different matters is still missing.

3.5.1 Target crop – Millet

In Niger, millet is cultivated in all agricultural regions of the country. Many wild and cultivated species exist. The plant presents a great morphological diversity. The most cultivated species is penicillary millet or small millet or pearl millet: *Pennisetum glaucum* (L.) R. Br. Millet is cultivated mainly for its grains intended for human consumption but also, increasingly, for its vegetative parts as fertilizer or animal feed.

3.5.1.1 Climate

Millet (Penisetum glaucum) adapts well to light, sandy clay, well-drained and aerated soils. It tolerates particularly difficult production conditions: drought and soil acidity. The most favorable temperatures for this culture are between 27 and 30°C. It can develop in climatic zones where the annual rainfall varies between 200 and 800 mm. In Niger, millet is mainly cultivated on light and sandy dune lands with low fertility. It is sometimes found on more fertile land, such as sandy clay terraces or on land around houses (Table 38). The climate diagrams are attached in Annex 5.1.

Table 38. Climate, seasons and soil types in the target regions in Tunisia

Region	NN (mm a-1)	T °C ∅	Seasons	Soil types
Kalfou	365 mm	16°C to 40°C and is rarely below 13°C or above 43°C.	Dry and rainy season	ferruginous soil with little washing of sandy loam texture red brown soil to ferruginous in places of sandy loam texture
Goure	400 mm	16°C to 40°C and is rarely below 13°C or above 43°C.	Dry and rainy season	red-brown soil on sandy loam-textured dunes brown soil lye in the shallows of sandy texture
Jiratawa	500 mm	16°C to 40°C and is rarely below 13°C or above 43°C.	Dry and rainy season	ferruginous soil with little lye with a sandy loam texture

* Main soil type/types (clay, sand, loam)
* Seasons: How many growing seasons exist in the region?

3.5.1.2 Challenges

The following Table 39 summarizes some of the most important challenges in agricultural production in the research region/in millet production in Niger.

Table 39. Challenges in agricultural production

Region	Challenges
all	▪ Millet yields are very low in Niger: 479 kg / ha (the world average is 900 kg / ha) ▪ Biotic constraints which cause substantial production losses: diseases (mildew, anthrax, etc.), insects (cob miner caterpillar, stem miner caterpillar, etc.), weeds (especially *Striga hermonthica),* birds (*Quelea quelea*), locusts, etc. ▪ Abiotic constraints: poor soil, recurrent droughts, floods, strong winds, etc.

	▪ Constraints linked to the production system: use of low-productivity varieties, often inadequate cropping systems, low use of inputs, etc .; ▪ Socioeconomic constraints: rural poverty, disorganization of producers, lack of financing for agriculture, weak influence of producers on the market, etc.

Source: Own

3.5.1.3 Trial topics

In the following Table 40 examples for trial research topics, objectives, treatments and the target environments are listed. The final research topic for each region will be decided in a participatory manner involving all stakeholders.

Table 40. Overview of possible research topics in millet trials

Research topic	Objectives	Treatments or options	Environments or contexts
Soil fertility	Increase soil carbon content	- Compost application (Kitchen househould wastes) - Manuring - Mulching - Farmer Managed Natural Regeneration	
Soil erosion	Reduce soil erosion	- Cover cropping - Intercropping - Residue management - Mulching - Living hedges	- Differing socio-economic contexts - Differing landscape positions
Biological pest control	- Enhance beneficial organism's populations - Decrease pest populations and damage - Increase diversity of habitats within or surrounding the fields to support higher insect diversity - Reduce application and use of pesticides	- Inter-cropping - Flower strips or similar - Push-pull - Implementation of IPM by Farmers Field schools, demonstration fields - Alternative control tests using botanical biopesticides - Biological control against the ear leafminer (*Heiliocheilus albipunctella*) by the release of *Habrobracon hebetor*	- Consider the landscape and the farming system (or the diversity of practices) - Differing socio-economic contexts

		- Deployment of available resistant varieties	
Fertilizer efficiency	Efficient application of available fertilizer	Micro-dosing	- Differing socio-economic contexts

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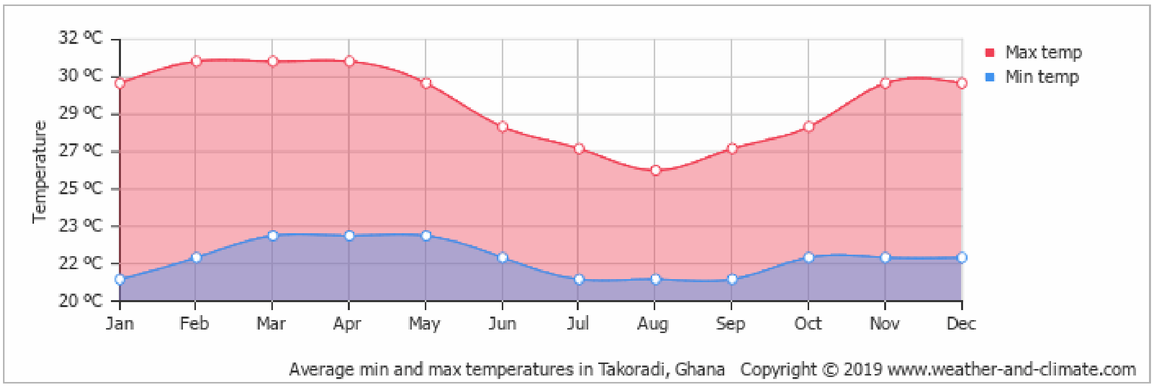
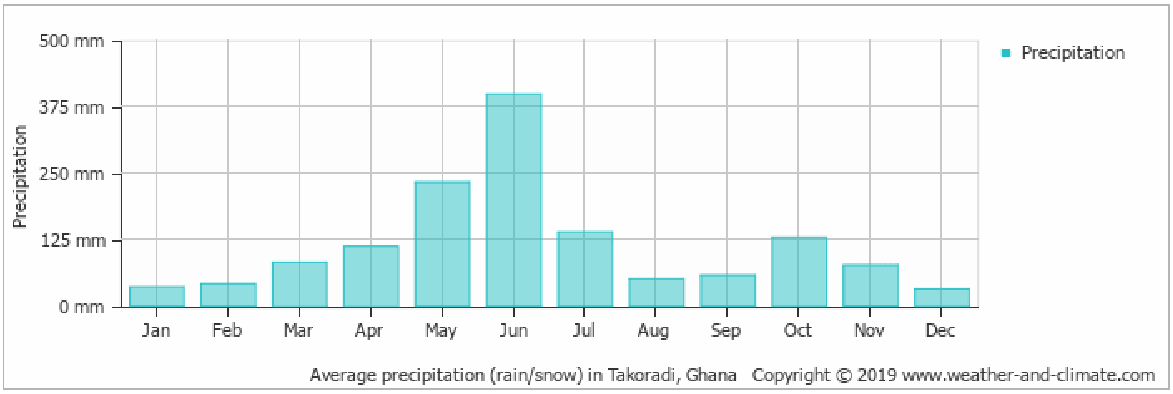
5 Annex

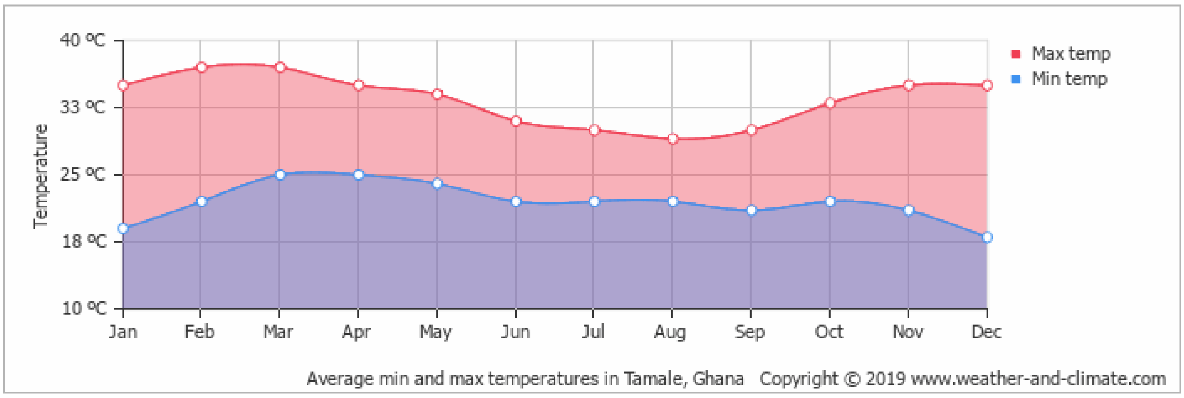
5.1 Temperature and precipitation diagrams

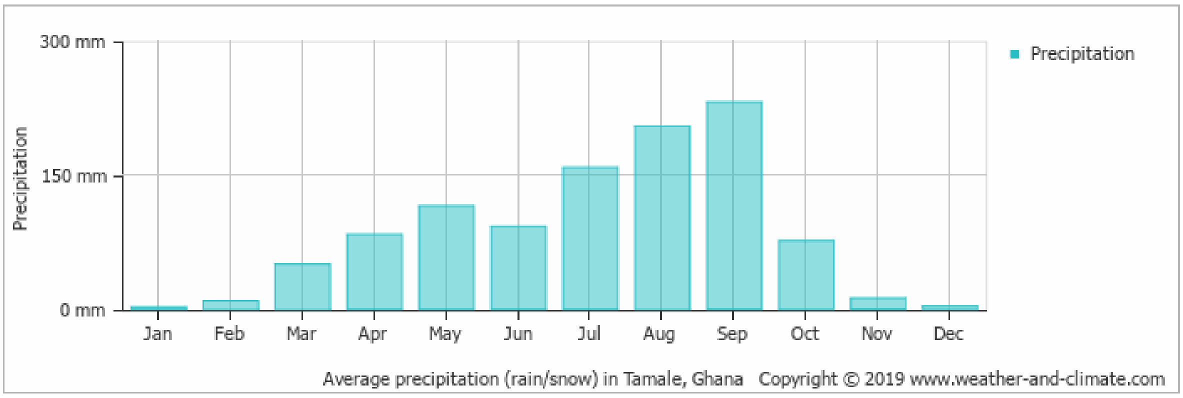
Cape Coast region (Komenda):



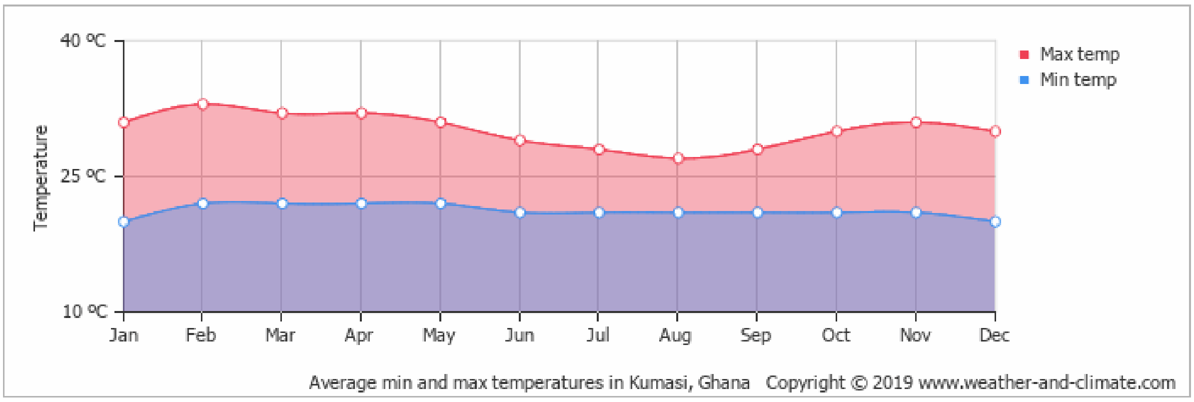


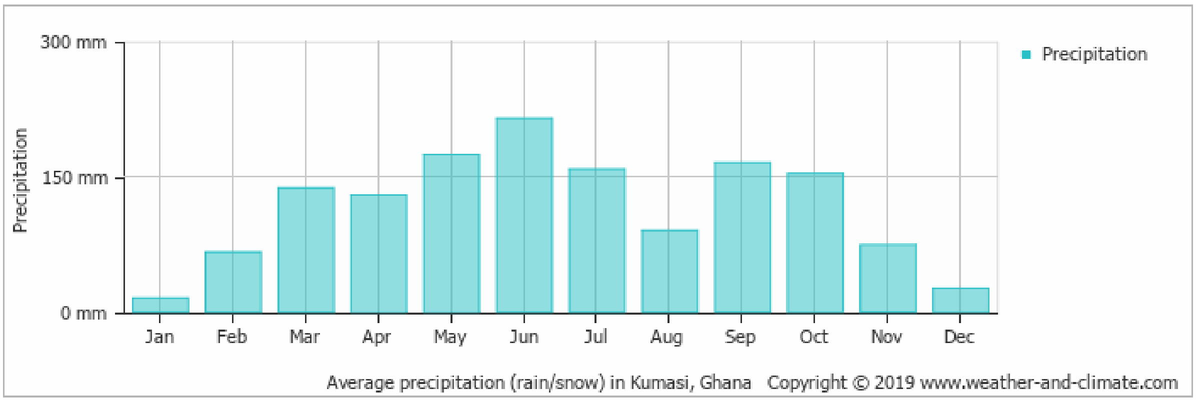
Tamale region, Ghana:




300 mm
150 mm
0 mm
Precipitation
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Precipitation
Average precipitation (rain/snow) in Tamale, Ghana Copyright © 2019 www.weather-and-climate.com

Ejura, Ghana:


40 ºC
25 ºC
10 ºC
Temperature
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Max temp
Min temp
Average min and max temperatures in Kumasi, Ghana Copyright © 2019 www.weather-and-climate.com


300 mm
150 mm
0 mm
Precipitation
Jan
Feb
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Jun
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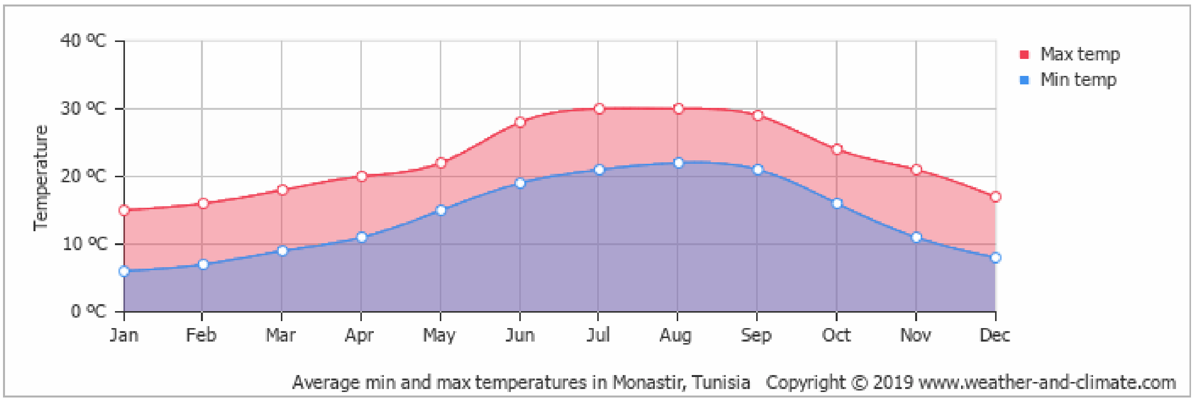
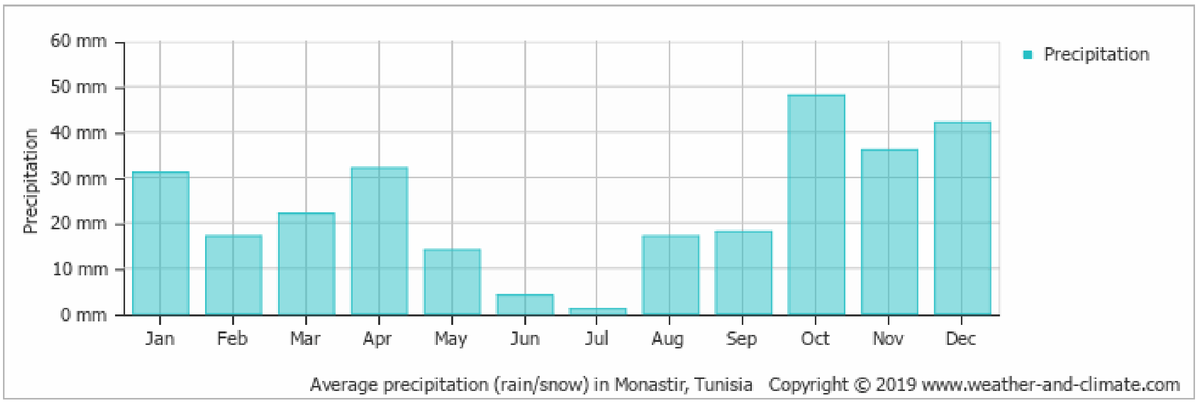
Precipitation
Average precipitation (rain/snow) in Kumasi, Ghana Copyright © 2019 www.weather-and-climate.com

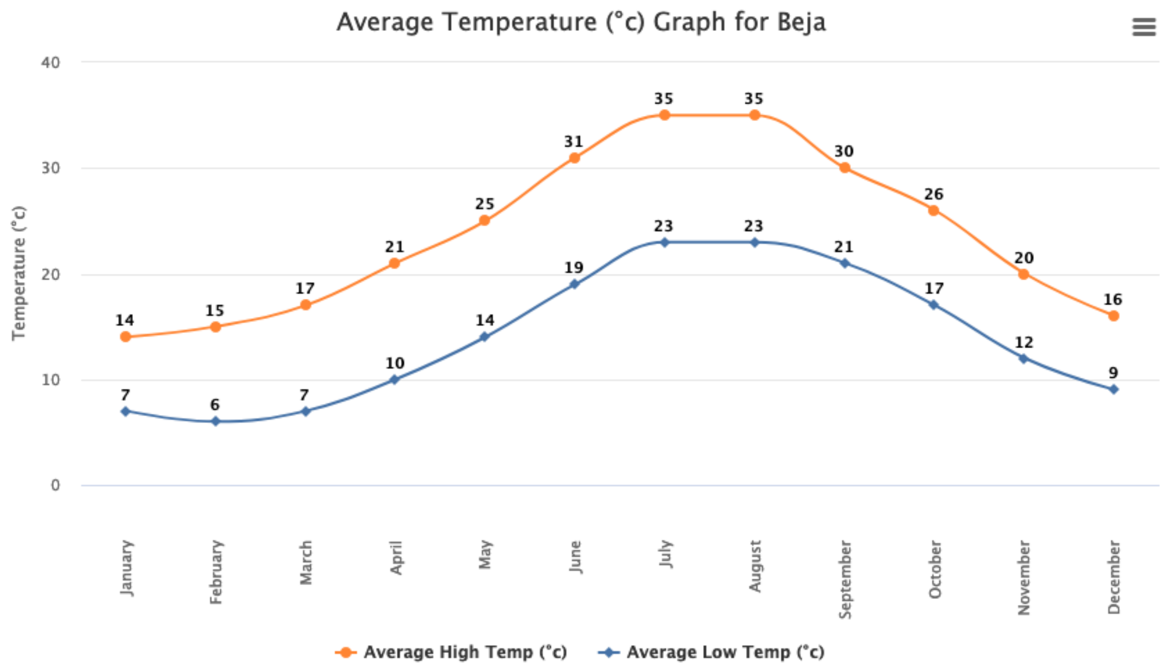
Sousse, Monastir, Kairounan – Tunisia:



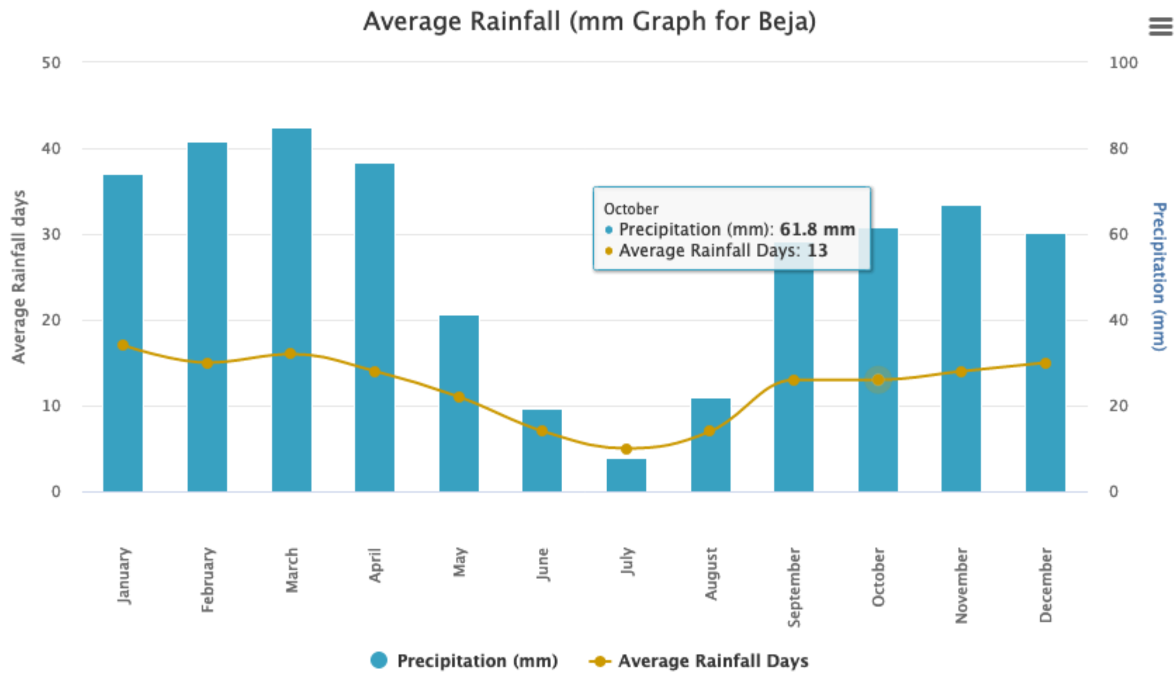


<u>Beja – Tunisia:</u>[57]

Monthly Average Temperature

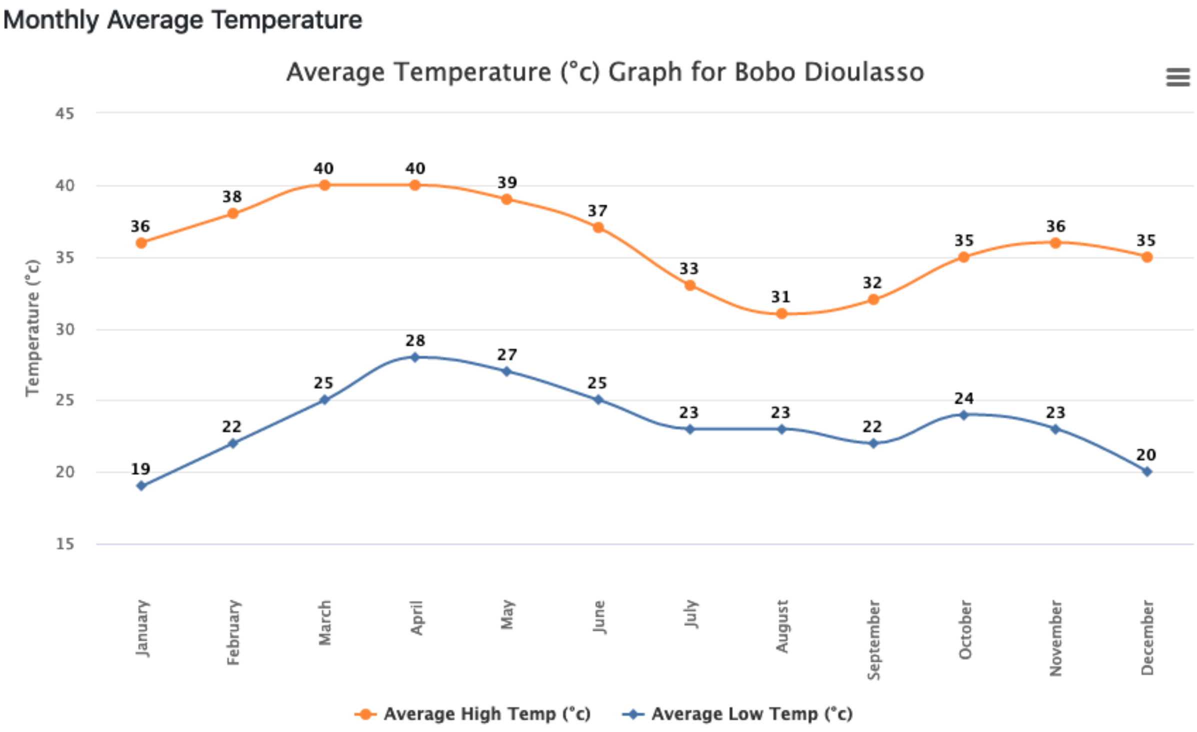


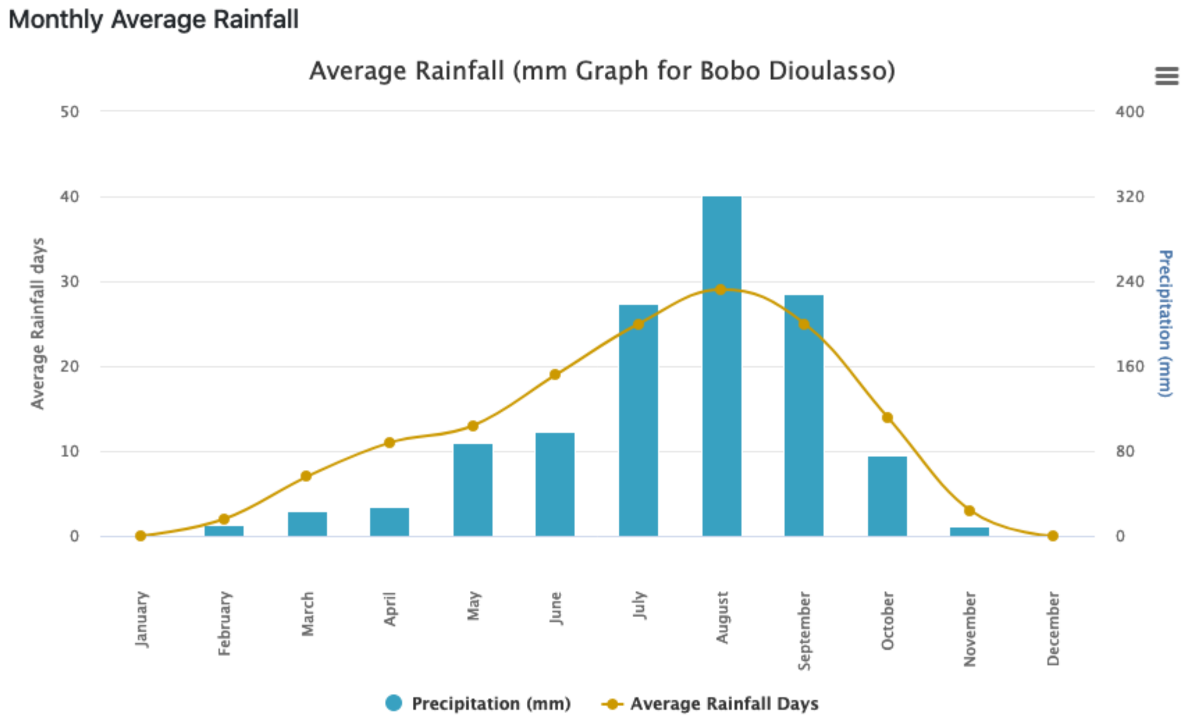
Monthly Average Rainfall



[57] Source: https://www.worldweatheronline.com/beja-weather-averages/bajah/tn.aspx

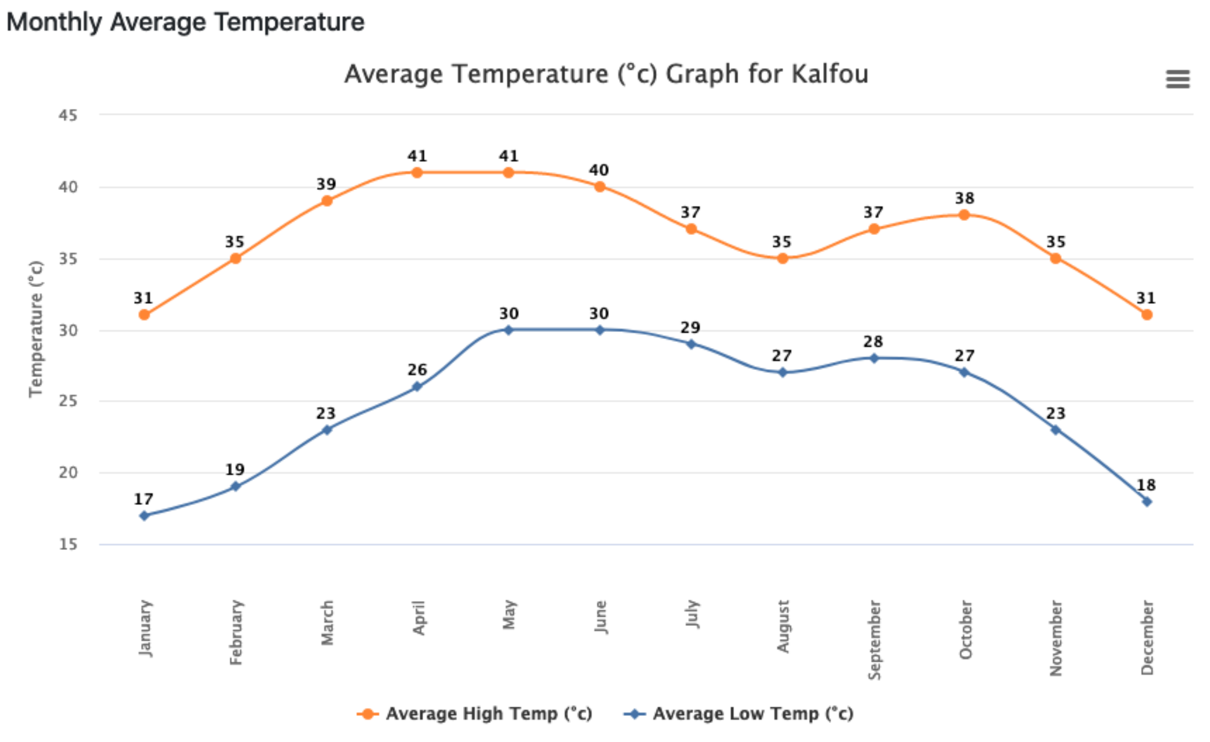
Hauts-Bassin, Burkina Faso:[58]

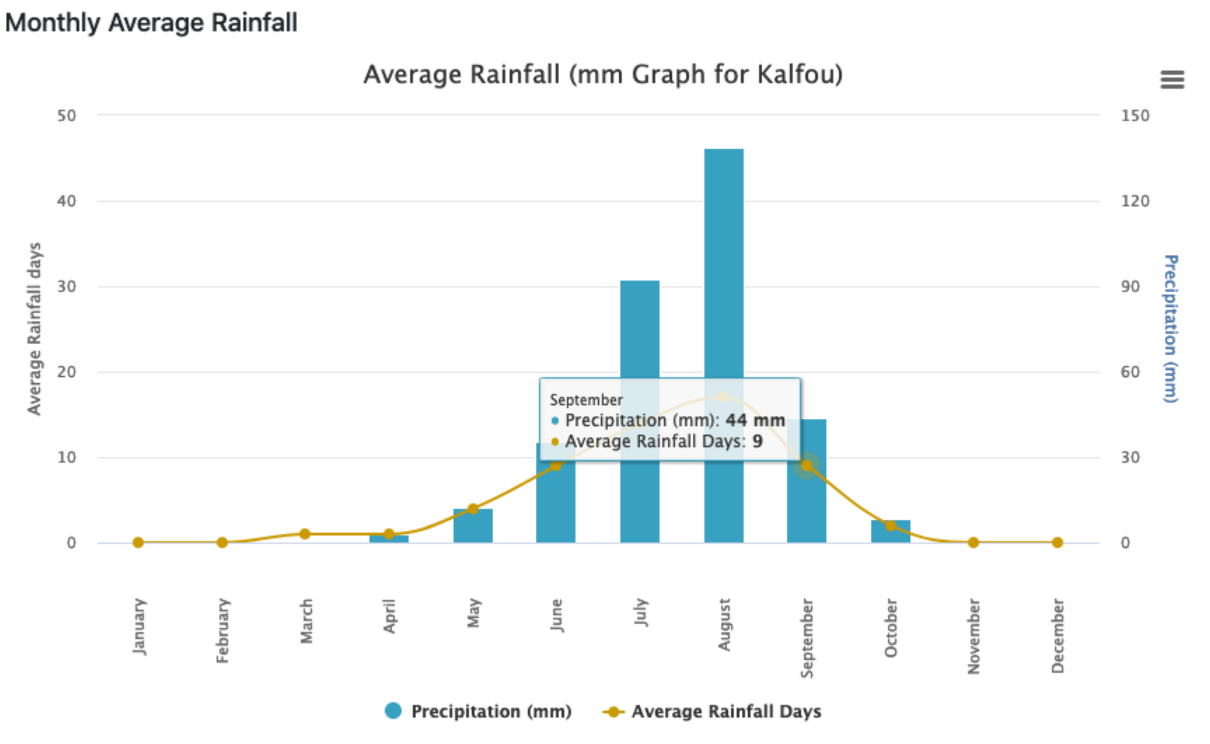




[58] Source: https://www.worldweatheronline.com/bobo-dioulasso-weather-averages/houet/bf.aspx

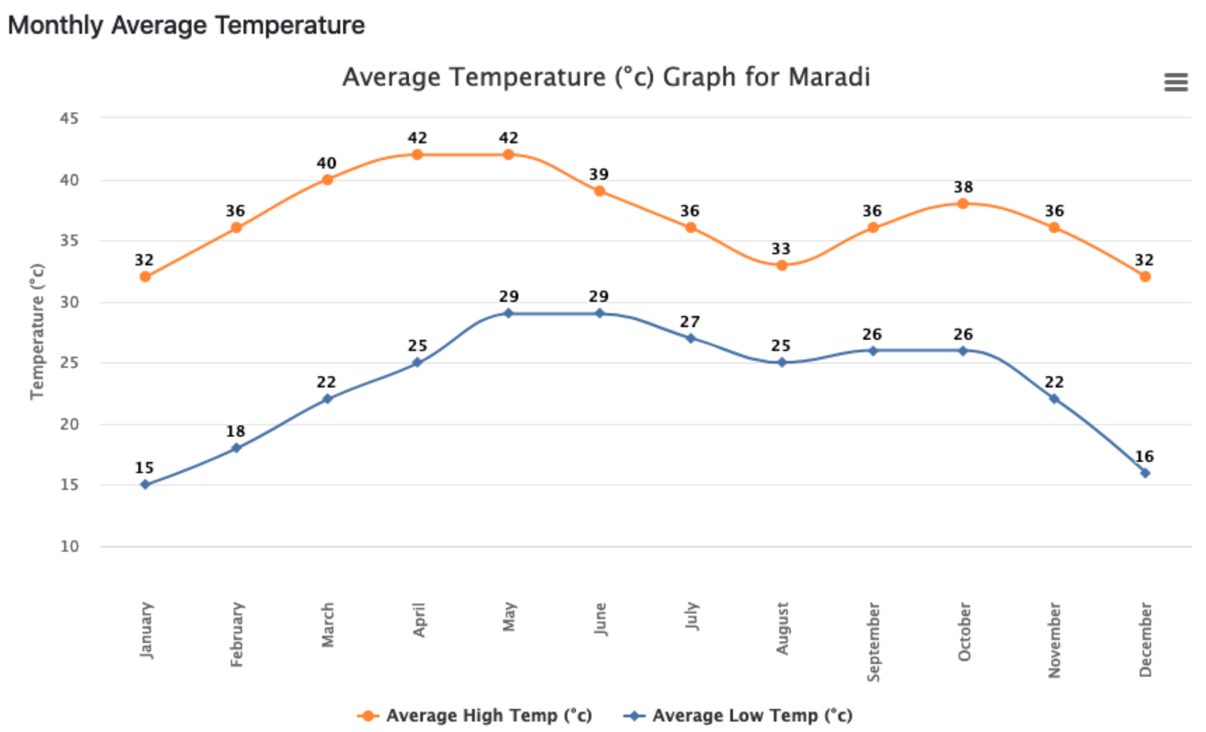
Kalfou/Tahoua, Niger:[59]

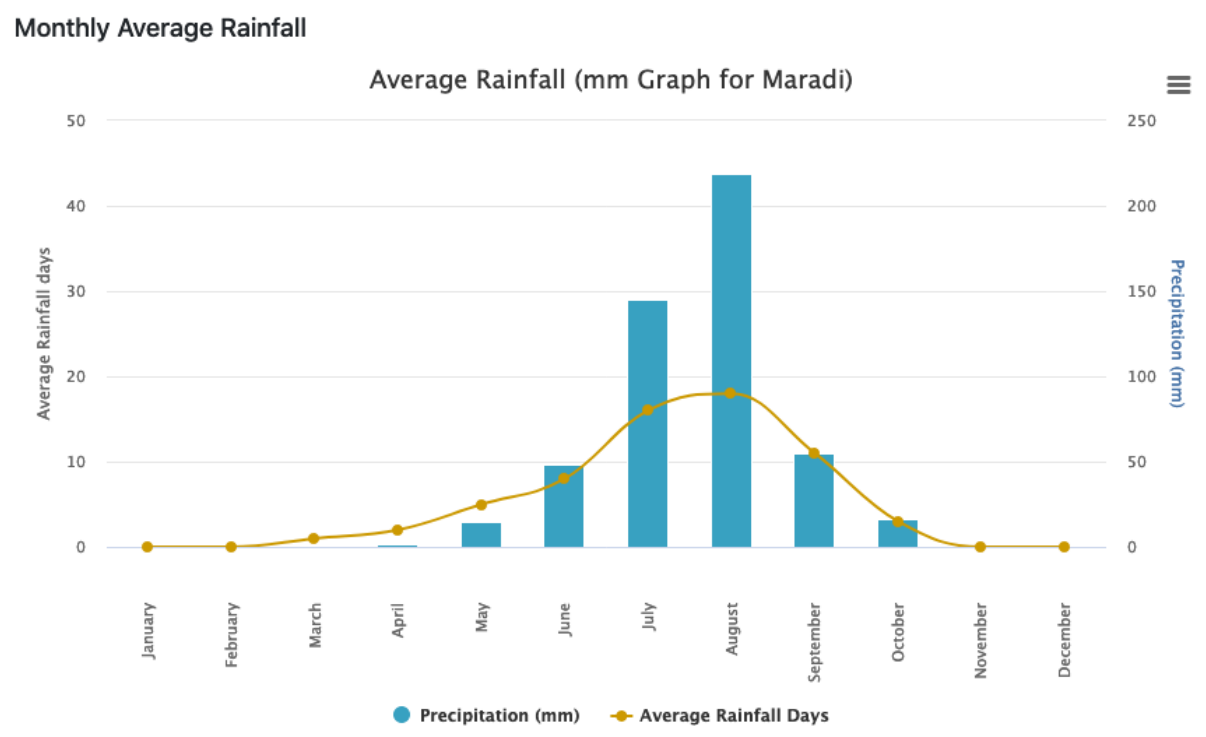




[59] Source: https://www.worldweatheronline.com/kalfou-weather-averages/tahoua/ne.aspx

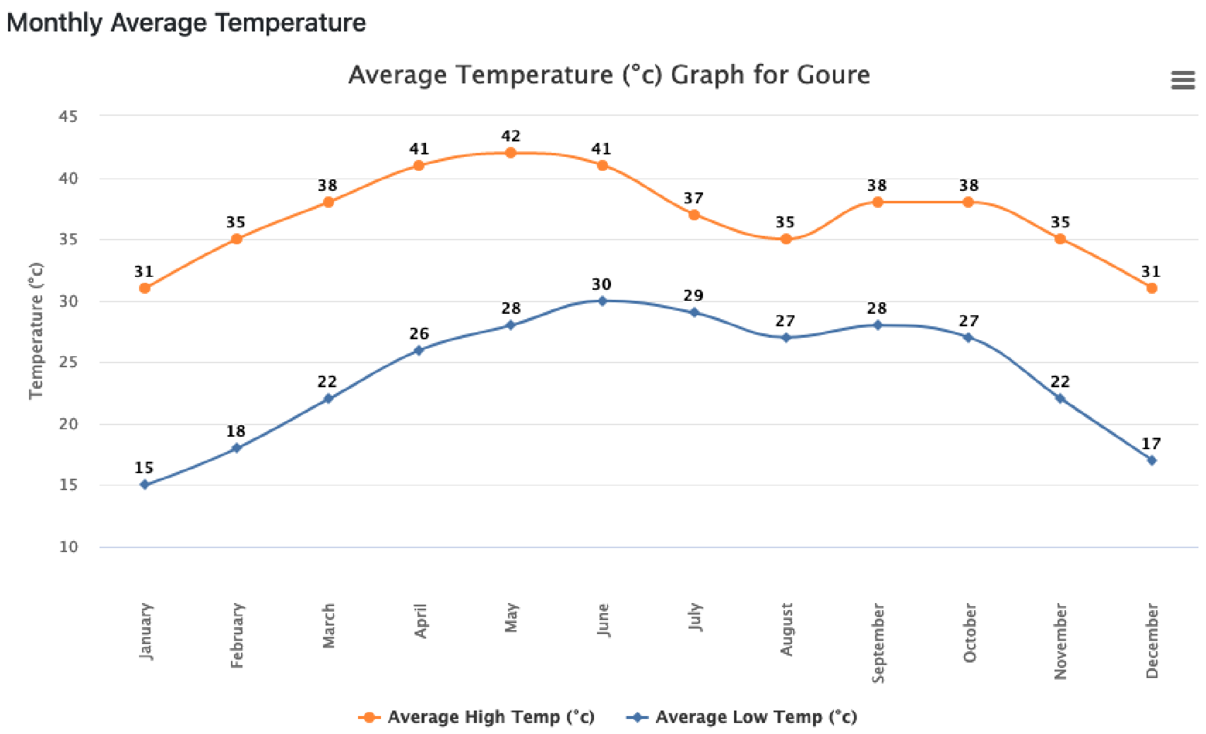
Maradi/Jiratawa, Niger:[60]





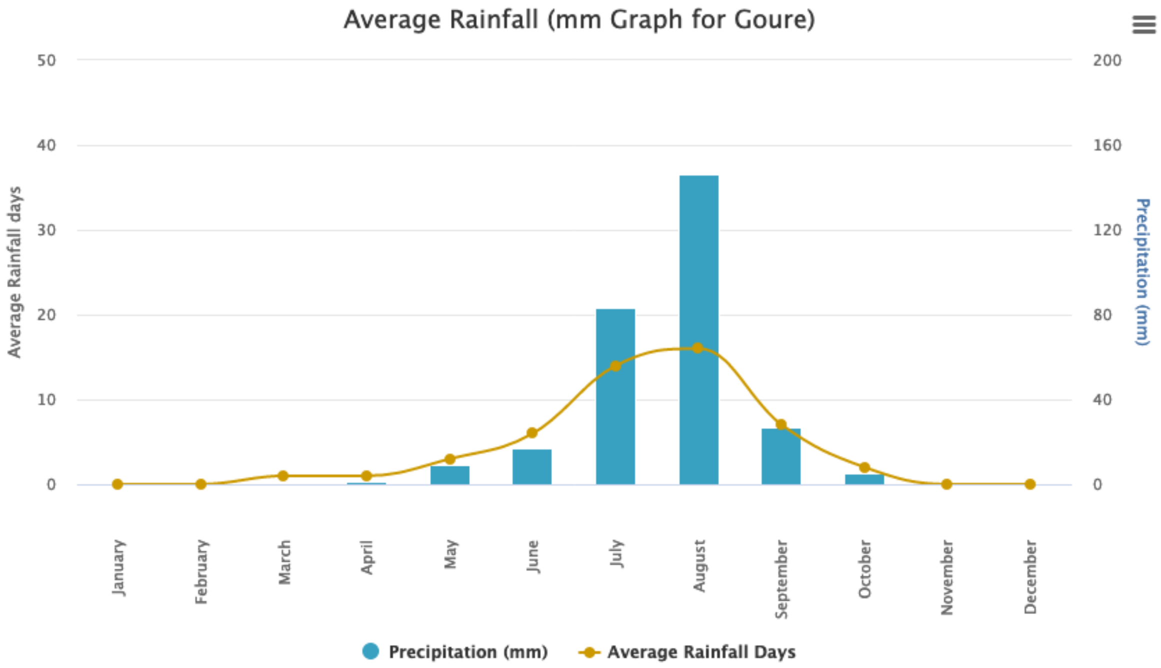
[60] Source: https://www.worldweatheronline.com/maradi-weather-averages/maradi/ne.aspx

Goure/Zinder, Niger:[61]



[61] Source: https://www.worldweatheronline.com/goure-weather-averages/zinder/ne.aspx

Monthly Average Rainfall



5.2 Interviews

Interview with researcher: Benjamin Badii (University of Development Studies, Tamale, Ghana)
When does the season starts, March/April? when is blossoming, harvest? Do you have a reference about crop growth and DD needed to pass from one growth stage to the other? ➔ See document on practices for conventional mango orchards. 2 seasons a year in Ghana? When starts the 2nd season? Is it longer than the first? There are 2 main seasons in Ghana. The first harvest starts in March, peaks in April and ends in May. Then there is a second season that peaks in June and ends in July/August. Some people now (26/02/21) have harvested unripe mangoes that they chemically mature and sell on the local market. It is not good quality, but it helps these people to make some money before the season really starts. The first season is mostly for wild cultivated production of local varieties. The second season is mostly for commercial variety with grafted trees. From March to July, there is no pest protection for wild plants. However, for the cultivated plants it is the same protection than for commercial variety. How long a tree is used in production? Does the tree susceptibility to pest change over the year? The wild trees can be in production for 30-40 years. Depending on the variety, the tree start fruiting after 3 to 7 years. Once it has started, it can last for 10-15 years before a big decrease in yield. The grafted trees have a peak in yield on the 3rd year of production. How many trees in one row on average? space between row? size of an average orchard? The minimum is 5 acres (ha), the maximum is 100 acres(ha) and the most common size is around 20 acres (ha?). Mango farming in Ghana is a small-scale production. NGOs help farmers to build cooperative (group of farmers) to manage a group of fields together. In some part of Ghana mango orchards can be separated far away from other mango orchards. You sometimes need to travel 15-30km to go from one orchard to another. This is true except in Tamale, where there are large plantations of mango (international market). Do farmer practice prunning and thinning? Farmers do not do thinning. However, they prune mostly to manage the fungal disease anthracnose, which is a big problem in mango in Ghana. They do not use pruning to enhance fruiting. Do farmers use an irrigation system? Farmers use irrigation for the seedlings until maturity to help the trees establish. After 3 years, they stop irrigation and rely on the rain and the natural water source in soil. Do farmers use intercropping for the soil between the tree rows? Are plant species chosen for the natural enemies? In the newly established orchards, farmers practices intercropping with some leguminous vegetables such as soya bean. However, after a certain time, this is not possible anymore because of the vegetation coverage. So, farmers change strategy and they let only grass in between the tree rows. They manage the grass and cut it regularly to avoid fire during the dry season. Management of surrounding areas? such as hedgerows, bushes, flower strips? The surrounding of orchards varies. Farmers create borders around the field, but they do not manage the semi-natural elements around. The try to get rid of the alternative host of pests around their field and they keep shea nut tree because it is one of the major fruit trees wildly present and

it flowers at the same time than mango. Therefore, it is supposed to enhance pollination in the orchards.

Is pests monitoring done by farmer? by advisor? Is it only for fruit flies or others too?

There are two types of pests. The first one attack vegetative and fruitive structure pest. The mango mealybugs are exotic and the major problem. They are quite common. The second main pest is the mango stone weevil that damage the mango seed, which cannot sprout. There are also the scales insects that are similar to mealybugs. It attacks vegetative and fruit structures.

And then the quarantine pest, the fruit flies with exotic invasive species and native species that form a complex of pests.

The farmers producing for commercial purposes have a monitoring calendar (document send by Benjamin). They should fill in one document per plot. They are advised by organization about which pest to monitor, how, when the threshold is exceeded and with which pesticide they should spray their fields if necessary. Usually advisers recommend farmers what to use. The farmers will then go the an agro-chemical shop where they will buy the pesticide. The monitoring calendar can vary depending on the agroecological zone they are in. The use of this document may vary also depending on the variety produced. The monitoring results are written down by farmers/advisers. The pheromone traps for fruit flies are used also as a preventive measure to control the pest.

(other pests found in CIRAD document: scale, mealybugs, thrips, cecidomyiids, whiteflies, mango bug, seed weevil, thermites, locust)

Do farmers use some economic thresholds above which they should spray, or do they apply pesticide based on the crop growth stage?

Farmers have access to economic threshold via advisors the fruit flies trapped in pheromone traps. The monitoring is only done for the fruit flies.

They are two options for pesticide spraying: spot application or generalized treatment. Are they both used in practice?

Advice from agency

Different type of insecticide used to change the active ingredient and avoid resistance? Is the pesticide spectrum considered to try to protect natural enemies and biodiversity?

Advice from agency

Management of alternative plant host of pests? for example: other fruits plantation should be far away; some weeds or wild species should be avoided?

The alternative plant that are from the same family than the mango trees are destroyed and avoided because they harbor related pests.

Monitoring, management or release of natural enemies? for example: the augmentoria.

Farmers are formed to recognized natural enemies, especially the red ant that is a fierce predator of fruit fly larvae. They know how to protect them and try to not use pesticide when these beneficial insects have been seen in the field.

They do not use innundative biological control, they use conservation BC. They do not use this augmentarium from CIRAD.

How are the damaged mango identified? Is it done visually by a person or automate process? (The fruits are fragile so probably done manually by a person before selling.) Do the companies buying the harvest differentiate the type of damages or does the farmer only know the % of rejection?

Farmers check regularly their field for indices of damage estimation depending on the pest.

For mango destinated to local market, agency send advisers to visit farmers during the harvest. But it is not put in place really, not done or well organized. They usually just sell the fruits on the market.

For the mango for international markets, there are stricter measures in place to avoid any quarantine pests. People realize an inspection to detect and select the good fruits. It is done by advisers. Damage estimation are not well recorded, this is not well advanced in structuration. They can record the different damages for research purposes, but they don't do it if not asked.

How are treated the damaged fruits in the field (damaged one that fell down) (=source of fruit flies)? Do farmers have to destroy infested trees or branches sometimes (for ex: for scale insects)?

The fallen fruits are collected and removed to impede the fruit flies to finish its biological cycle. The fruits are usually reduced to slush by crushing and use as manure for the trees.

According to Benjamin, the most important step will be the field selection. We need to find farmers that are willing to cooperate with researchers. We can monitor wild and cultivated orchards as well as commercial orchards. We can ask the farmers to do some monitoring and to avoid spraying a part of the orchards until the end of the experiment.

THREE MAIN MONITORING PERIODS FOR INSECT PESTS. Is it correct?

1. during blossoming (how long does it lasts?) Monitoring of bugs and flower cecidomyiids
2. middle of fruit enlargement and harvest for fruit flies monitoring
3. after harvest for mealybugs + scale insects + thermites + leaf-gall cecidomyiids + whiteflies.

Interview with researcher: Amel B. Hamouda (Olive Tree Institute, Tunisia)

The Tunisian context of olive production

Tunisia currently has 88 million olive trees covering 1.811.000 hectares, which represents a third of the nationally available agricultural land (34%). The geographical repartition in the country is: 15 % of olives orchards are found in the North, 66 % in Central Tunisia and 19 % in the South. Olive orchards are mainly monoculture but sometimes they are planted with other fruit trees mainly almond.

When does the season starts? when is the blossoming, harvest? Do you have a reference about crop growth and DD needed to pass from one growth stage to the other? Only 1 season a year?

The olive tree production is biennial. During the first spring and autumn, the vegetative growth takes place in 2 waves. From December and March, the reproductive phase occurs. There is a floral induction in December/January. Then, the floral differentiation happens from late winter till April. And the flowering only happens in April/May. This is a long process. Finally, the fruit development and maturity happen from July to December. (This happens under the rainfed conditions)

How long a tree is used in production? Does the tree susceptibility to pest change over the year?

Young orchards, younger than 5 years, represents 15.5% of all orchards. The bearing orchards, 5 to 50 (!) years old, represent 75% of olive groves and the old orchards, older than 50 years, represent 9.5% of olive groves.

How many trees in one row on average? space between row? size of an average orchard?

Small and medium sized orchards. 35% of farmers have orchards smaller than 5ha and 57% have between 5 and 10ha.

In the North, there are 100 trees/ha (rainy area); 60 trees/ha in the Center and 20 trees/ha in the South. There are two dominant varieties: Chemlali (in central and southern orchards) and Chétoui (in the North).

There are 3 farming systems in Tunisia:

1. Conventional and Organic Extensive systems with a tree density lower than 60 trees/ha
2. Intensive conventional and organic systems with a density between 150 and 600 trees/ha
3. The hyper-intensive olive groves with density comprising between 600 and 1666 trees/ha! Wow! There are only introduced varieties in this case.

Do farmer practice prunning and thinning?

Yes, here prunning is important. There are 2 types of prunning: 1 after the harvest and before bloom (December-March). A medium/heavy prunning is done every second year.

At the end of winter, farmers can do the prunning to control the olive moth (3rd generation on the leaves and pupating in the canopy, crack of branches or trunk).

Do farmers use an irrigation system?

Depending on the geographical location of the orchards. When there is no irrigation system, there tree density depends on the different rainfed pattern (geographical variation). The higher the rainfall, the higher the tree density. (see Amel ppt). Traditional olive production (97% orchards) are grown under rain-fed only, with an annual rainfall maximum at 350 mm.

The irrigated orchards are found in the intensive and hyper-intensive farming systems.

Tillage:

Tillage is used here to reduce soil evaporation and to manage weeds. Usually, there are 4 tillages, 2 in spring and 2 in summer-autumn. In autumn, the depth is 8-12 cm and the direction is perpendicular to the slope, if any. In spring, in order to manage the weed, the depth is 15-25cm. If this method failed, then farmers used herbicide at that time. (most problematic species are Cynodon dactylon and Cyrsium arvense). In summer, the tillage is very superficial (2-5 cm).

Herbicides are used only in the young orchards in hyper-intensive management.

The soil tillage under the canopy in autumn-winter (depth lower than 20cm) is used against olive flies to bury the pupae. The soil tillage under the tree canopy is used against the 2nd generation of olive moth in autumn and summer (10cm).

Fertilization:

Mineral fertilization for intensive and hyper-intensive farming. It is applied in autumn, before fruit ripening, and in spring, before flowering. The quantity of fertilizers is chosen based on soil analysis, the number of fruits and growth stage. (nice!)

Manure and compost are used in traditional organic orchards for fertilization and management of the soil structure. It happens in December-January if the orchards is under rainfed conditions or after the fruit maturation in irrigated orchards. Farmers used in small quantity the olive oil mill waste.

Do farmers use intercropping for the soil between the tree rows? Are plant species chosen for the natural enemies?

It is common to cultivate other crops under the tree canopy in small orchards with irrigation. The companion crop can be potato, tomato, pepper, alfalfa or other vegetables. Usually, grazing is not done in olive groves.

In olive orchards with intercropping the risk is higher to have Verticilium wilt attack, which is a soil borne pathogens that can survive many years in the soil.

Management of surrounding areas? such as hedgerows, bushes, flower strips?

Farmers do not manage these elements and do not spray insecticide on them. They installed border around the field with a cactus: Opuntia ficus-indica. (Do they consume the fruits and leaves?)

They can install also some wind-breaker hedge with an special olive variety called Frenjivento (from Italy). No flower strips, no herbaceous border.

Is pests monitoring done by farmer? by advisor? Is it only for olive flies or others too? Do the farmers write down the result of monitoring?

(other pests found in the European report on olive production: olive fly, olive moth, black scale, olive scale, disease transmitted by insects?)

There are two agencies that are responsible for pest monitoring in olive groves. The Regional Agricultural administration authority (CRDA) and the Regional plant protection service.

The biggest problem is the olive fruit fly. 4 to 5 generations a year. Adults and larvae overwinter in the fruit and the pupae overwinter in the soil. First generation in June-July and the last one last until early winter. Widespread in costal region and intensive orchards. (They seem to like moisture → irrigation)

Different symptoms depending on the fly generation (see the ppt that Amel sends). It decreases the oil quality. This induce some fruit dropping and as in mango orchards the damaged fruits are on the ground. Secondary pests on the damaged fruit still on the trees are bacteria and fungi that profit from the puncture damage. They prefer the large, fleshy fruits. Their development is hindered if the temperature exceeds 35°C in summer and if the winter temperatures are low. The most important natural enemy is a parasitoid wasp Psytallia concolor.

Early harvesting will occur in autumn if there is a high infestation of olive flies to protect the yield.

The second one is the olive moth. Three generations a year that eat different part of the olive tree. The 1st generation is laid in the calyx of the flower buds and the larvae consume the stamens and pistils and develop on the flower cluster → destroy the flower buds. The 2nd generation is laid on the young fruit, the larvae consumes the kernel and exit from the calyx to pupate in the soil → induce fruit drop and loss. The real damage is in autumn, in spring it can be mistaken for natural fruit drop. The 3rd generation develops and consumes on leaves. They are leaf mining and pupation occurs in between two leaves or in crack of branches or trunk. They consume the terminal bud → source of inoculum for the next year and hinder the vegetative growth of the tree.

The third pest is the jasmine moth. They overwinter as larvae and several overlapping generations can occur in a year. The 1st generation emerge in March-April and the last one ends in October-November. The usually consumes only leaves and yound shoots but if the infestation is particularly heavy, they will attack also the olive fruits. They are usually not a problem except for olive nursery and young orchards. However, they became 4-5 years ago, a major pest if not controlled in Tunisia. There are no control strategy yet.

Do farmers use some economic thresholds above which they should spray, or do they apply pesticide based on the crop growth stage?

Traps are installed at suitable time and are checked regularly. The decision to spray against pest is taken only when the economic threshold are exceeded.

For the olive fly: The agencies collect females from the start of May and dissect them (50 per week) to check the ovary status and the number of mature eggs. Their goal: estimate the percentage of mature females.

They also sample 10 fruits per tree on a minimum of 20 trees to estimate the number of fruit damaged. The threshold is 10% damaged olive for olive table and 1% for olive oil.

They also monitor the temperature, if T>30-35°C then they consider the fly activity is stopped.

If they are several larvae in 1 fruit, only 1 will survive. (Maybe, the female has developed a way to assess if a fly has already laid an egg inside the fruit to optimize the survival of its offspring. If so, it is not good for farmers). Do they attack the olive variety used for the wind breaker hedge?

For the olive moth: Monitoring the weather: they do not develop under high temperature (>30-35°C) and low humidity. This increase egg and larvae mortality for the carpophagous generation (2nd). Again 1 larva only can survive per fruit, so a low density of fruit help controlling the density of the moth population.

Delta pheromone traps are used with a density of 2-3 traps/ha. They target the 1st generation flight in from late February, the 2nd from late April and the 3rd from early September. There are a pheromone capsule and a sticky card. The threshold is 100 moths captured per trap per week (varies according to the region)

Anthophagous generation (1st): The agencies sample 50-100 flower cluster per tree our of 10 to 20 trees just before the beginning of the flowering. They calculate an average of the percentage of infested cluster and the number of eggs per 100 cluster. The economic threshold is 4-5% of infested clusters.

Carpophagous generation: they collect 10 to 30 fruits per tree on 10 trees every week to calculate the percentage of infested fruit and the density of larvae per 100 fruits. The threshold is 20-30% of infested fruit for oil olives but lower for table olives.

Phyllophagous generation: one sampling of 100 leaves per tree on 10 trees during end of January to end of February and they calculate the density of larvae per 100 leaves.

For the jasmine moth: The advisers sample 10 shoots from 5 to 10 trees during early spring until November in the olive nursery and young orchards.

They are two options for pesticide spraying: spot application or generalized treatment. Are they both used in practice?

Farmers used a lot the parapheromone and bait traps.

The major one used against the olive fly is the McPhail with 1 trap every 1-2 trees. Very high density! They can use also water bottle with an attractant and possibly an insecticide also. The decision to spray is done by an adviser using Dimethoate (organophosphate, toxic for non-target species such as carabid beetles…) or Spinosad for organic orchards (from bacteria, compounds that disturb neurotransmitters action, probably broad-spectrum).

Against the olive moth: The used pheromone traps against adult with 2-3 traps per ha. If the economic threshold is exceeded, they spray for the 1st generation when the first flowers open.

They can use microbiological treatment with Bt or Spinosad on the 1st generation when the flower start opening. If the situation is exceptionally bad, they can do it again for the 3rd generation.

When the infestation is extremely heavy, farmers can use dimethoate or deltametrin on the 1st and 2nd generations. This happen when the egg hatch rate exeeds 50% and is close to 75%.

Against the jasmine moth if the infestation is severe, they will use Bt or Spinosad as soon as the first sign of attack appear in spring.

They can apply fungicide when necessary also.

Different type of insecticide used to change the active ingredient and avoid resistance? Is the pesticide spectrum considered to try to protect natural enemies and biodiversity?

Mainly three insecticides, Dimethoate, Spinosad and Bt

Are they alternative plant host for pests?

Monitoring, management or release of natural enemies? for example: the augmentoria (mango).

No. They do not use augmentative or inoculation biological control, even for parasitoids.

How are the damaged olive identified? Is it done visually by a person or automate process? Do the companies buying the harvest differentiate the type of damages or does the farmer only know the % of rejection?

No, the farmers will try to sell all his olives on the market as good and not damaged.

How are treated the damaged fruits in the field (damaged one that fell down) (=source of olive flies)? Do farmers have to destroy infested trees or branches sometimes (for ex: for scale insects)?

They take them away and use them for compost. They prune the heavily infested branches in the case of olive moth or in the case of the bacterial disease olive knot. They can destroy trees in case of heavy fungal attack of Verticillium wilt.

When do the different MONITORING start for all pests?

See above

Interview with researcher: Olfa Boussadia (Olive Tree Institute, Tunisia)

1. Current situation in Tunisia, access to farmers/field work? Can extensionists be interviewed?...

Unpredictable situation due to the covid 19. Some zones are in lockdown. We can work at 50%

2. Conducting multi-environment trials ("mother and baby trials"): What are your experiences with such trials?

I have an experience concerning the management of the irrigation according to the pluviometric gradient (North-South) of Tunisia.

The comparison between the experimental sites allowed us to adjust the irrigation doses and improve the efficiency of water use.

- Are they feasible under the local circumstances?

It's possible except major limitation (linked to covid 19/ climate damage…)

- What are possible challenges?

- Finding technical solution for soil damage according to the analyzed soil data
- Soil rehabilitation by integrating sustainable farming practices
- monitoring of pests at right time and possibility of biological trapping.
- Implement sustainable soil managements in Tunisian Olive orchards and improve olive production and olive oil quality.
- Ability to mitigate drought and valorize rainfall efficiency
- Implement an integrated farming system for food and forage

- What other issues do we have to take into account?

Olive farms include traditional and semi-intensive system in two marked pedoclimatic conditions, between low and large olive farms of private and cooperative administrative status, in simple, medium or high landscape complexity.

3. What is your experience with data collection (yield sampling) in perennial crops such as olives – can you recommend literature / manual for olive production?

yes I have experience with data collection but not only for yield sampling

we have a manuel for soil sampling, olives leaves sampling and fruit sampling

- Soil sampling to have data sets of nutrient balance and retention, and soil functional quality assessment.

Three sites will be randomly selected in the inter-row area of the olive grove.

- The standard protocol for leaves sampling to have an idea about tree nutrition and abiotic stress monitoring

a. We need to sample at least three different trees per olive treatment

b. Take around leaves per tree at least 1.5 m high to avoid juvenile tissues.

c. Leaves maybe around 15-20 cm from the branch tips.

d. Leaves of different trees should be taken always with the same orientation, the southern branches the better.

Be careful that leaves are healthy, unbitten and not damaged.

Olive leave samples should be taken at the end of spring or beginning of summer, at this time the tree is active and the weather is more stable with long sunny days.

- The standard protocol for fruit sampling to monitor flying populations of B. oleae (my collegues amel Ben Hamouda can provide it) or to have an idea concerning fruit traits and oil quality assessment.

Sampling. A random sample of 500 g of olive will be harvest for 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. No any discrimination on olive skin color will be performed at sampling harvest.
Ripening index. External color of the pulp will be recorded in a random sample of 30 fruits per tree, using the following scale (Table 1).Table 1. Skin color for ripening index (Frías et al., 1991).

Table 1. Skin color for ripening index (Frías et al., 1991)

Oil content and fruit traits. From the 500 gr sample, three random subsamples of around 25-30 g will be selected. The number of fruits will be counted. Each subsample 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 105º during a minimum of 42 hours. The subsamples will be again weighted to calculate fruit dry weight. Each three subsamples of the same tree will be stored together until evaluation.

4. Which are your preferred research questions that should be answered within our project? (with special regard to agroecological practices / possibly organic farming practices/systems)

Soil is much more than a structural support where the trees grow. It contains the food and the water for olive trees. Also provides bacteria and micro and macro fauna that help your crop to develop all their biological functions. A well-managed healthy soil might produce plenty of olives with greater profits. The most important thing is to arrive to establish a clear sustainable technical itinerary, specific to each community.

5. Which "innovative" agroecological practices should we aim for in olive production from your perspective? (or other practices to enhance productivity and ecosystem services)?

The main threats of many of the Tunisian olive groves are the lost of soil and soil fertility, which is mainly, but not exclusively, due to: i) the lack of any element which might reduce the impact of raindrop into the soil, and ii) lack of sources of organic matter. As a consequence of these, there are a reduction of supporting, regulation and cultural-aesthetic ecosystems services, which might reduce sustainability at the long term.

Therefore, the sustainable technique solution "innovative technique" are based on: i) providing elements which reduce soil erosion (e.g. spontaneous or seeded temporary cover crops and shredded tree pruning) , ii) create micro habitats for the development of a diverse microflora and micro, meso and macro-fauna (e.g. no tillage, spontaneous or seeded temporary cover crops and shredded tree pruning plus physical control of the cover crops avoiding the use of herbicides), iii) increase soil organic matter inputs (manure, composted olive mill pomace and soil application of the remains of the cover crops and shredded tree pruning) and contributing to sequester carbon and many other beneficial soil and farm properties related to organic matter, iv) retain nutrient within the farm (manure, composted olive mill pomace and soil application of the remains of the cover crops and shredded tree pruning), and v) Biological pest and diseases control (manure, composted olive mill pomace, temporary spontaneous cover crops and shredded tree pruning).

6. How many farmers will possibly be participating per community? (What is realistic if not yet known?) 3 farmers

Interview with researcher: Desire Lompo (University of Dedougou)

1. Which crop or crops do you finally want to focus on in your regions?

Participating Communities	Crop type
Satiri (Houet province)	Cotton, maize/Sorghum, legumes (cowpea, groundnuts)
Bobo Dioulasso (Houet)	Vegetables, Cereals (maize, Sorghum, pearl millet), legume (cowpea, groundnuts),
Bekuy (Tuy province)	Cotton, maize /Sorghum, legumes (cowpea, groundnuts)
Bereba (Tuy)	Cotton, maize /Sorghum, legumes (cowpea, groundnuts)

2. What are the challenges you want to work on the respective crops?

Crop	Challenge
Cotton	- Unsustainable Crop residues management strategy - Poor and declining soil fertility, - Pest attacks, - low crop yields - Deforestation and lost of biodiversity - Surface and ground water pollution - Soil erosion;

	- Water scarcity; - Poor use of water management technologies, - Loss of labor for crop production due to gold mining and food insecurity ; - poor management knowledge (especially with regards to sustainable soil management & climate change mitigation)
Maize /Sorghum	- Poor and declining soil fertility, - Pest attacks, - low crop yields - Soil erosion; - Water scarcity; - Poor use of water management technologies, - Loss of labor for crop production due to gold mining and food insecurity ; - poor management knowledge (especially with regards to sustainable soil management & climate change mitigation)
Legumes (cowpea, groundnuts)	- Insufficient use of improved seeds - Unsustainable Crop residues management strategy - Pest attacks, - low crop yields - Water scarcity; - Poor use of water management technologies, - Loss of labor for crop production due to gold mining and food insecurity ; - poor management knowledge (especially with regards to sustainable soil management & climate change mitigation)
Vegetables	- Unsustainable Crop residues management strategy - Inefficient nutrient management practices, - Pest attacks, - low crop yields - Surface and ground water pollution - Water scarcity; - Poor use of water management technologies, - poor management knowledge (especially with regards to sustainable soil management & climate change mitigation)

2. What trial design do you view as feasible for your research communities (only pure demonstrations without scientific experimental design or with scientific experimental design): both

2.1 If you want to go for demonstrations – what do you want to demonstrate?

- Cotton and maize residues management
- Co-composting of crop residues and Biochar
- Mixt compost+biochar application,
- Fertiliser micro-dosing,
- Intercropping
- Assisted Natural Regeneration

- …

2.2 if you want to do trials with a scientific experimental design, do have someone with experience in trial set-up and management in your team? Do you have experience with "mother and baby trial" approach?

- Yes we have at least four researchers with a solid experience in trial set up and management

- Yes we have experience with "mother and baby trial" approach

2.3 In case you want to apply trials with a scientific experimental design, what are your research questions that should be answered within our project? (with special regard to agroecological practices / possibly organic farming practices/systems)

- How can we improve cotton and maize residues management to improve soil quality and crop yields while sequestering the carbon into the soil to mitigate climate change?
- For farmers with low financial means, how can we increase fertilizers usage while improving nutrient use efficiency?
- How to successfully increase food production while minimising the negative impacts on the environment?

3. Any other issues we have to consider when planning and implementing the trials?

- In our AEZ, many farmers already have experience in hosting demonstration trials;
- We have to work in synergy with other projects or NGOs that are working with our selected communities: ProSol Project, OCADES, …
- …

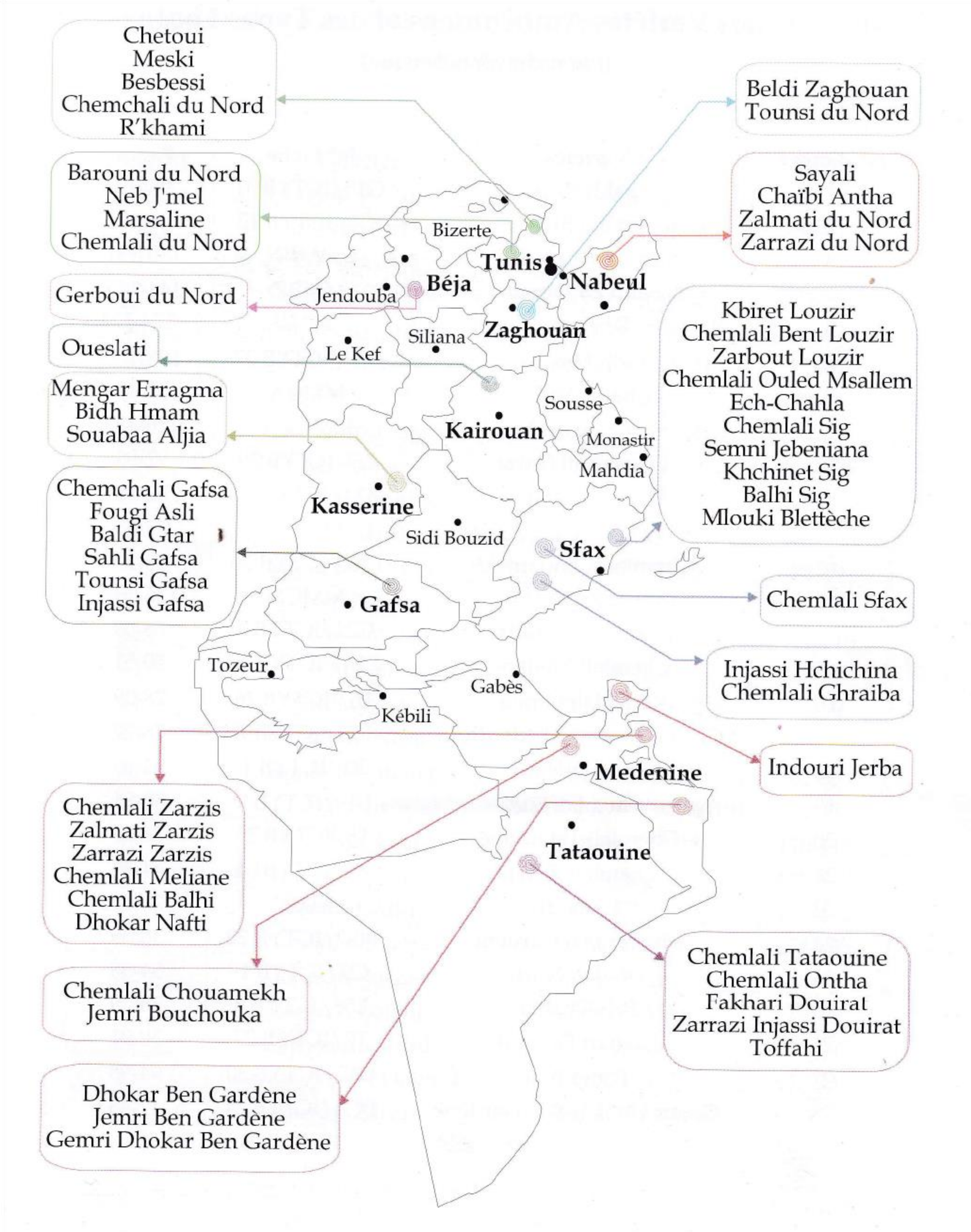
4. Other points you would like to discuss or mention?

- In Burkina Faso our project will conduct its activities in only one Agro-Ecological Zone (AEZ)
- It has been agreed that the research activities will start in only one core community. In Burkina Faso our core community is Satiri. What can we do with the other communities in the meantime?

5. How many farmers will possibly be participating per community? (What is realistic if not yet known?)

Region	AEZ	Participating Communities	No. of participating farmers per community*
Hauts-Bassins		Satiri (Houet province)	30
		Bobo Dioulasso (Houet)	50
		Bekuy (Tuy province)	15
		Bereba (Tuy)	15

5.3 Overview olive varieties in Tunisia



Source: Trigui and Msallem (2002)