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

Deliverable D1.6

Analysis of ecosystems services

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ABSTRACT

This report on the Analysis of Ecosystem Services (ES), is the Deliverable WP1.6 for task WP1.2c *Baseline data collection and analysis of ecosystems services*. The theoretical framework for the evaluation of Ecosystem Services was selected to be the *Common International Classification of Ecosystem Services* – CICES, including Provisioning, Regulation and Cultural Services. Depending on the scale and comparability of the data obtained for the agroecosystems studied, the levels of analysis will be adjusted using qualitative or quantitative elements. Mapping and assessment of ES associated with the selected farming systems will be made in association with WP2 (geospatial assessments) and data shared from WP1, WP2, WP3 and WP5 (crop species, cropping systems, soil, water, climate, InsectaMon, socio-economical systems, etc.), for ES modelling and calculation of trade-offs between the different ES, and transmitted to WP5 to evaluate the sustainability of the SustInAfrica actions.
Due to delays in the collection of baseline data in the field, and the different rhythms of implementation of the field trials in different countries, this analysis was not possible in its plenitude, thus this document will be later connected to Deliverable WP3.3 (M54) when the baseline will be compared to the final outputs of the SustInAfrica.

Table of Contents

List of abbreviations and acronyms

AEZ	Agro-Ecological Zone
CICES	Common International Classification of Ecosystem Services
ES	Ecosystem Services
GIS	Geographic Information System
InVEST	Integrated Valuation of Ecosystem Services and Trade-offs
NDVI	Normalized Difference Vegetation Index
RGB	Red, Green, Blue (visible spectrum)
RUSLE	Revised Universal Soil Loss Equation
RWEQ	Revised Wind Erosion Equation
sp.	Species (singular)
spp.	Species (plural)
UAV	Unmanned Aerial Vehicle or Drone
vs.	versus
WP	Work Package

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1 Introduction

Ecosystem Services are defined as the contributions that ecosystems make to human well-being, that provide them with goods and benefits[1].

The selected framework for the Ecosystem Services (ES) evaluation was that of the *Common International Classification of Ecosystem Services* - CICES (v5.1 at https://cices.eu/resources/)[1] – developed by the European Environment Agency (EEA), based on the Millennium Ecosystem Assessment (MA); and optimized afterwards[2].

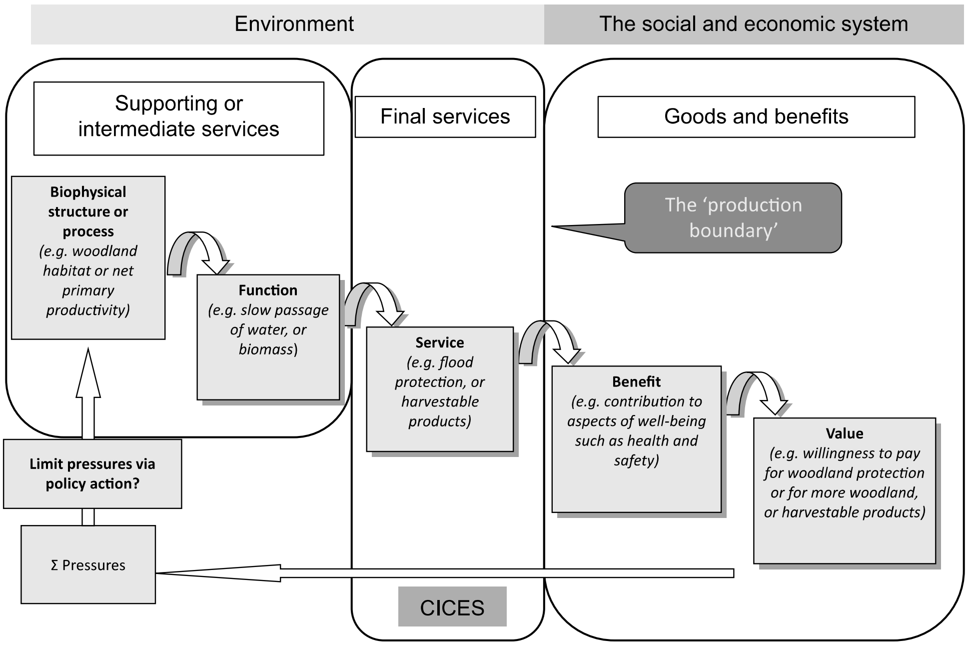

Figure 1 – CICES model (cascade model), from Haines-Young and Potschin, 2018[1].

The evaluation of ES will be applied to agroecosystems which are communities of plants and animals, interacting with their physical and chemical environment, modified by people to produce food, fibre, fuel and other products for human consumption and utilization[3].

Ecosystem Services, provided by the SustInAfrica selected farming systems, will be assessed, and mapped, according to the CICES classification, into three categories, namely: provisioning, regulation, and cultural ecosystem services. **Provisioning** services in these agroecosystems will be evaluated based on indicators derived from agricultural productivity. The **Regulation (and maintenance)** services are related to the sustainability of the agroecosystem and nature's water, soil, biodiversity, carbon, and nutrient cycles. Human perception and connection to the agroecosystem (e.g., cultural, spiritual, and aesthetic) will be the reference for the **Cultural** ES.

By comparing the different countries, agro-ecological zones (AEZ), farming systems, agricultural practices, or plant species, concerning their potential to provide particular ES, we expect to deliver a

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picture of the trade-offs that each case represents. This will help stakeholders to decide on more sustainable pathways, according to their aspirations and objectives.

2 Services to Evaluate

The CICES services are organised in a hierarchical structure, starting with the major sections Provisioning services, Regulation (and maintenance) services and Cultural services. The ES we plan to tackle in SustInAfrica, are those more closely related to the SustInAfrica agroecosystems.

2.1 Provisioning services

Section	Division	Group	Class	Service	Indicator	Data origin
Provisioning	Biomass	Cultivated plants	nutrition	harvestable crop	crop yield (food & fodder)	WP1 (crops), WP3 (trials)
			materials	harvestable (e.g. cotton) crop fibber	crop yield	WP1 (crops), WP3 (trials)
				harvestable crop residues usable (e.g.) as mulch	Amount of crop residues	WP1 (crops), WP3 (trials)
		Wild plants	materials	wild vegetation usable as cover/mulch	area covered by wild plants within plots	WP2 (remote sensing), WP3 (trials)
	Genetic material	Cultivated plants	seeds	harvestable seeds usable for reseeding	seed yield	WP1 (crops), WP3 (trials)

2.1.1 Provisioning of Biomass (food, fodder, fibres and others) from crops & wild plants

The ES of ***Biomass Provisioning*** is one of the main metrics for the project, by reason of SustInAfrica - Sustainable Intensification being related to an expected increase in production. The objective is to quantify the cultivated products that nature provides and contribute to human well-being. Besides the provision of the main products, the crops (food, feed, or fibres), if other parts of the crops are also used by the farmer (e.g., straw for mulching, as firewood, for construction materials), or even wild spontaneous plants used as soil cover or mulch, if quantified, can be evaluated as ES as well.

The main indicator is the crop (or animal) yield – the relative amount of main crop/animal product (for food, feed and fibre materials) and of other by-products (e.g., crop residues), per unit of area, cultivated (e.g., kg/tree.ha)[4]. Data about this indicator will be collected for the baseline and during crop seasons (see WP1.2b & d, for baseline). If available, evaluation of measures/estimates of the amount of other plant parts used (like crop residues or manure) can be integrated. Other information necessary to calculate the yield like the cultivated area (e.g. m^2, ha), seeding density or number of

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plants/area, either is reported by the farmer or, depending on the crop and location, collected by UAV/satellite (e.g. cultivated area, number of trees or shrubs) in WP2.

2.1.2 Provisioning of Genetic material – Harvestable crop seeds/plants

The provision of genetic material, in the form of harvestable seeds usable for reseeding, or the use of suckers/slips in pineapple, or other tree cuttings for plant regeneration, may be quantified depending on it being a practice implemented by the farmers. It will not have an impact if farmers buy all their seeds and plants, for every growing season.

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2.2 Regulation (and maintenance) Services

Section	Division	Group	Class	Service	Indicator	Data origin
Regulation and Maintenance	Regulation of physical, chemical & biological conditions	Regulation of baseline flows and extreme events	hydrological cycle and water flow regulation	cover crops/mulch retaining water and releasing it slowly	soil humidity + amount of irrigation water + shadowing + soil type	WP1 (crops, soils, water), W2 (remote sensing and innovation), WP3 (trials)
			control of erosion rates	crops and cover vegetation preventing or reducing the incidence of soil erosion	plant's covered area vs. naked soil (e.g. NDVI)	WP1 (crops, soil, water), WP2 (remote sensing, climate), WP3 (trials)
			wind protection	wind barrier, protecting from (sand)storms	presence of trees forming a wind barrier (area, density, location, of trees)	WP1 (crops, climate), W2 (remote sensing), WP3 (trials)
		Regulation of soil quality	decomposition and fixing processes and their effect on soil quality	decomposition of plant residues	soil nutrients & organic matter	WP1 (crops, soils, climate), WP3 (trials)
				N-fixation by legumes	area with (or use of) legume plants	WP1 (crops), WP3 (trials)
		Regulation of atmospheric composition and conditions	regulation of chemical composition of atmosphere	storage of carbon by crop plants & crop systems	above ground biomass or harvested biomass + soil organic matter & carbon + crop root traits	WP1 (crops, soil, water), WP2 (remote sensing), WP3 (trials)
		Lifecycle maintenance, habitat and gene pool protection	pollination	agroecosystems providing a habitat for native pollinators	abundance/ diversity of pollinators and flowering crops	WP1 (crops), WP2 (insects), WP3 (trials)
		Pest and disease control	pest control	agroecosystems providing a habitat for native pest control agents	abundance/ diversity of plants and insects + plant traits + vegetation structure + vegetation health indexes	WP1 (crops), W2 (insects, remote sensing)

The delivery of the regulation ES will be one of the focuses of the analysis of the resilience and sustainability of the cultural practices supported by SustInAfrica, as the project's aim is to achieve fully functioning systems, able to support biodiversity and deliver a range of services in the long term.

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2.2.1 Regulation & maintenance of the hydrological cycle

The service of regulation of the hydrological cycle in agroecosystems, can be related to the capacity to maintain soil humidity provided by some crop systems (e.g. mulching, shadowing), either measured directly *in situ*, indirectly by remote sensing, or estimated from literature about the farming system (also related to irrigation) and soil type, and eventually hydrological models[5]. The soil moisture (particularly if evaluated from long term data, and not occasional measurements) is also a proxy for the capacity of the agroecosystem to retain water and prevent droughts.
In each crop system/plot, the crop species area is constant but if any soil property changes, with the introduction of a new cropping system, maybe having different results by the end of the project, thus at least two evaluations are planned (baseline and final). The source (e.g. surface water, underground) and amount of the water used in the irrigation of crops, or the presence of small water conservation features[6,7] may aid in the ponderation of the ES regarding each crop/cropping system[8].

2.2.2 Regulation (control) of soil erosion

The service of control of erosion in agroecosystems, can be related to soil protection, with the existence of crops covering the naked soil as much as possible (area and time), as well as the use of cropping systems that favour conservation tillage or non-tillage. Living and dead biomass covering the soil, protect it from direct exposure to elements (rain, wind) that lead to erosion (soil loss). Factors affecting soil erosion are rainfall, wind, erodibility or soil type, absence of vegetation, slope and land management. Considering the data that can be obtained from the field plots, either simple approaches such as using the information on farming systems and NDVI (remote sensing - scale dependant), or more complex ones can be applied.
Among the latter, soil retention [ton. $ha^{-1}.year^{-1}$] can be calculated as the difference between a model which calculates soil loss without vegetation cover (structural impact) and a model including the current land use cover pattern. Modelling can be made using the Revised Universal Soil Loss Equation (RUSLE)[21]; or the Revised Wind Erosion Equation Model (RWEQ), which focuses on erosion from precipitation or wind, respectively; or the InVEST SDR model[9], among others. For primary Data collection, the land use/land cover, particular to each cropping system (species, patterns, crop cycles, timings) is required. For RUSLE, the management practice (C) and conservation practice (P)**,** slope steepness and length (LS) = digital elevation model and NDVI, the rainfall erosivity (R) and the soil erodibility (K) are needed. For the RWEQ, required factors are the (WF) weather factor, the (EF) wind-erodible fraction of soil, (SCF) soil crust factor, (K') soil roughness factor, and (COG) combined crop factors. For the InVEST model to be applied, the digital elevation model (DEM), the land use/land cover including nearby watersheds, the rainfall erosivity, the soil erodibility (K), and the topsoil particles finer than coarse sand (1000 µm) are needed.
Unless mulch is applied to covering the cultivated soil completely, the plant cover may vary enormously during the growing season, thus knowing the values at the start and end of the growing season, an average value of soil protection can be estimated.

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2.2.3 Regulation of microclimate - wind protection

The service of wind barrier in agroecosystems, can be related to the presence of plants that reduce the speed and movement of air, reducing the scale or frequency of wind damages (e.g. sand storms[10,11,12]), and maintain humidity and buffer temperature changes. The presence of trees forming barriers may protect from windstorms, while their density may affect erosion, humidity, microclimate, etc. Only crude estimates are possible if based on species and cropping systems only, without remote sensing at an adequate scale. This may be separated into two ES (microclimate + wind protection) depending on data availability and detail. Data of interest are: the abundance of large trees and shrubs, their fragmentation, pattern (e.g., hedgerows[13], green fences, orchards), wind, temperature, humidity, radiation (microclimate) and NDVI, mostly from remote sensing origin, and spanned to a long dataset.

2.2.4 Maintenance of soil quality

The service of maintenance of soil quality in agroecosystems, can be related to soil fertility, either by looking at the nutrient cycle (soil de/composition – nutrients and organic matter content) or to the presence of nature's naturally nitrogen-fixing plants, the legumes, in the cropping system[14]. The basic soil properties (e.g., soil type, field capacity, capillary moisture, cation-exchange capacity and base saturation, organic matter, nitrogen, phosphorous, potassium, fertilisers) are an indicator of its potential fertility, as long as precipitation is not limiting. The presence of legumes that fixate nitrogen can be evaluated from their presence in the crop inventories and area/density metrics (cropping system details).

2.2.5 Regulation & maintenance of the atmosphere composition (carbon storage)

This is a service of climate regulation (carbon sequestration/storage)[14]. It is related to the regulation of the concentration of gases in the atmosphere (e.g., greenhouse gases), by means of the crop species and cropping systems used, that may contribute to the storage of carbon, in the form of the plant's organic matter or immobilized in the soil. This contribution can be evaluated by knowing the plant's biomass (e.g., above ground biomass by remote sensing, below ground biomass from databases on species traits), the species used and the cropping system (e.g., area; annual/perennial species; burning or removal vs. incorporation, of crop residues and cover crops), as well as soil analysis (carbon and organic matter). Considering annual variations in climate and crops, an annual evaluation is recommended.

2.2.6 Maintenance of habitats/lifecycle (pollination)

The service of lifecycle maintenance, habitat and gene pool protection in agroecosystems, in this case, focused on pollination, is related to the number of different habitats and food sources present in the cultivated fields, available to the surrounding natural biodiversity, that contributes to a more complex local food web, to a lower impact of crop pests, and productivity of insect-pollinated crop plants, thus contributing to the final crop yield. The amount and type of pollinators attracted to the agroecosystem will be evaluated using the WP2 InsectaMon tool (e.g., total pollinators biomass, functional groups abundance and diversity, taxonomic richness and diversity of pollinators), and the attraction factors/habitat quality from the crop species and farming systems (e.g., pollination type and traits

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related to food provision to pollinators), together with remote sensing data for structure, if available (habitat diversity and structure[15,16]). The tool InVEST has a Pollination module that can be used, or other indexes adapted from the data available.

2.2.7 Regulation (control) of pests & diseases

The service of control of pests and diseases in agroecosystems can be related to the presence of specific biocontrol agents and to biodiversity, that provides complexity to the cultivated area regarding microhabitats and food sources for different species, contributing to a balanced and resilient ecosystem. Apart from data already mentioned for the pollination ES, that can relate to insects that are biocontrol agents, pests and disease vectors (InsectaMon tool, WP2), other indicators are expected to be obtained from remote sensing data regarding reflectance indexes on plant health and diseases (e.g., NDVI), enabling the ES calculation.

2.3 Cultural Services

Section	Division	Group	Class	Service	Indicator	Data origin
Cultural	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Intellectual and representative interactions with natural environment	characteristics of living systems that are resonant in terms of culture or heritage	traditional crops	crops traditionally cultivated by ancestors	WP1 (cultural services focus group)
					crops used in family celebrations	WP1 (cultural services focus group)
			characteristics of living systems that enable aesthetic experiences	beauty of nature	enjoyment experienced in contact with crop	WP1 (cultural services focus group)
	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with natural environment	elements of living systems that have symbolic meaning	crops with symbolic meaning	crops related to local / national celebrations	WP1 (cultural services focus group)
			elements of living systems that have sacred or religious meaning	crops with sacred or religious meaning	crops related to religious or spiritual ceremonies	WP1 (cultural services focus group)

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2.3.1 Cultural heritage, spiritual or symbolic meaning, aesthetics

The Cultural ES in agroecosystems can be related to the traditional, religious or spiritual value of the cropping system/crop to the local communities, as well as to the aesthetical and enjoyment value to them. To address this ES, a baseline assessment in the form of a *Focus Group* questionnaire (WP1/WP3) was developed by FC.ID: "Crops Cultural Services" (Fig. 2), and integrated into the *Focus Group* structure by ISEG. The set of questions proposed aims at interpreting the degree of connection of the local populations to the SustInAfrica crops, thus their perceptions of the goods and benefits derived from them, to estimate their relative importance.

This questionnaire (focus group) is being implemented for the baseline assessments of WP1, and is composed of:

1. Listing of traditional crops cultivated in the community (for the longest time).
2. Exploring the uses and meanings of those crops.
3. Determining the crops that are cultivated by more farmers.
4. Listing the SustInAfrica crops used by each local community, new or previously cultivated.
5. Exploring the uses and perceptions about the SustInAfrica crops in particular.

From the questionnaire, the answers will be analysed to derive a relative value to each ES in chapter 2.3 table, and an index of the cultural services provided by the SustInAfrica crops to each local community.

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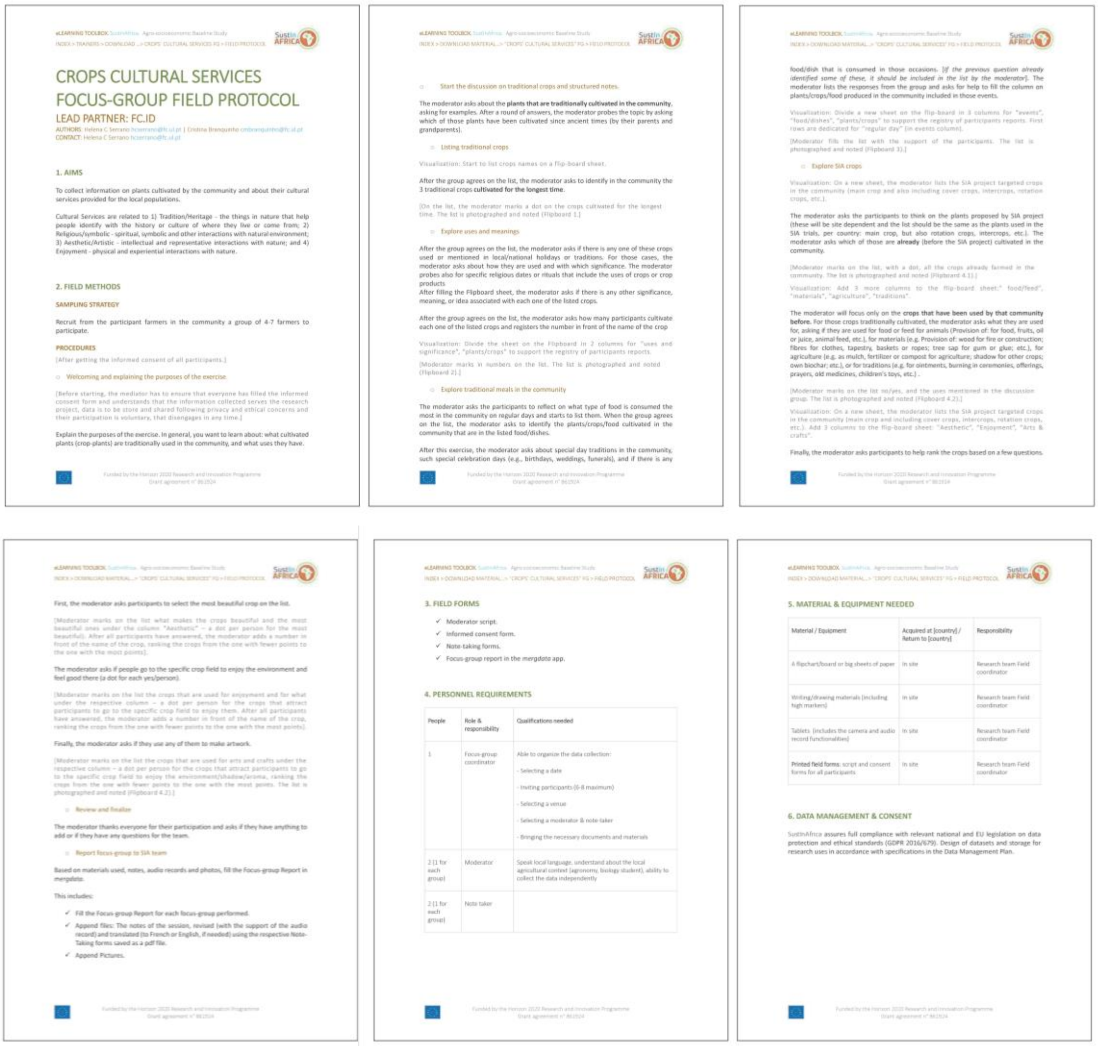

Figure 2 - Final version of the ***Field Protocol for the Focus Group on Crop Cultural Services****. Framework and questions developed by FC.ID team. Final harmonization to social sciences methodology and image of the WP1 SUSTINAFRICA model by ISEG team.*

3 Feasibility of baseline and future data and results

Considering the baseline evaluation (tasks WP1.2b, c & d) of:

1. Crops & cropping systems chosen for each country (Burkina Faso, Egypt, Ghana, Niger and TuniSustInAfrica) and AEZ[17,18] (Tropics – warm and humid to Sub-tropics -warm and arid[19]), and the production aims (e.g., increase yield or income, diversify production, reduce water use, reduce agrochemicals, protect soil).
2. Limiting factors and pressures present in each location (e.g., soil fertility, climate, water, pests).
3. Types of test setups implemented – affecting the evaluation to be relative to test factors (test vs. control) or to time (before /after).
4. Farmer's values perception of ecosystem services benefits towards their local livelihoods and food security (e.g., cultural valued crops or agricultural practices).

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The ES will be accessed, classified and mapped (combining maps of land cover with information about the measured attributes, whenever possible), using available applications and equations/indexes (e.g., InVEST Natural Capital tools[20]; RUSLE Revised Universal Soil Loss Equation[21,]; RWEQ Revised Wind Erosion Equation[22]) or other specific geospatial (WP2) and statistical modelling tools.

The evaluation of ES in connection with the agroecosystems studied, will be made at different scales, depending on the particular ES considered, so that the comparisons and estimates for the different cropping systems and scales will show the trade-offs between the different ES. There is no single optimal solution expected.

The scales of the comparison will depend on the availability of data and of the specificities of each ES, thus the comparisons will focus on:

1. Looking at each crop/plot separately – the factors will include the different farming systems (biological vs conventional vs agroforestry; traditional vs. intensive olive groves; monocultures vs. polycultures with intercropping, rotations; etc.) and their adequacy for the SustInAfrica objectives of sustainable intensification:
    a. Relative values, between plots of different trial factors and control (e.g., the traditional farm system).
    b. Gradient among the different AEZ.
    c. Relative values, before/after the project.
2. Looking at the effects on the landscape, driven by the different farming systems and species used in the agroecosystem and their interactions with natural ecosystems nearby:
    a. Land use changes
    b. Species introductions/removals
    c. Technology adaptation & use
    d. External inputs (fertilizer, irrigation, pest control)
    e. Harvest and resource consumption
    f. Climate change
    g. Natural physical/biological drivers
3. Looking at the communities that will benefit from the crops/farming systems implemented:
    a. In the maintenance of traditions and social relations.
    b. In the adoption of new habits that improve well-being (material, health, security).
    c. In the enjoyment of the aesthetics and sensations transmitted by the crops and cultures.

The crops of high nutritional or economic value to be studied are expected to be: maize (*Zea mays*), millet (several genus), pineapple (*Ananas comosus*) and date palm (*Phoenix dactylifera*) trees, all monocot plants; and cowpea (*Vigna sp.,* a legume), cotton (*Gossypium* spp.), mango (*Mangifera indica*) trees and olive (*Olea europaea*) trees, that are dicot plants. Considering the partner countries, Egypt will focus on olive, dates and cotton production; Tunísia on olive; Burkina-Faso on maize, cowpea and cotton; Niger on millet and cowpea; and Ghana on mango, pineapple and maize/cowpea. More details on farming systems are found in deliverable D3.2 – Demonstration trials. In the framework of the UAV image collection (WP2, already made in Tunisia and Ghana) we expect to have a more detailed ES

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analysis from the imagery produced using RGB and thermal cameras (vegetation and water indexes, topography), and maybe extrapolating to satellite imagery indexes, in the areas not visited by the UAV. Regarding the framework of the InsectaMon trials, that will provide data for ES related to pollination, pest control or biodiversity, we expect to have results from Tunisia, Egypt, Ghana and maybe Niger. Considering the information obtained so far regarding the trials being implemented in the field, some partners will implement mother (demonstrative with tests and controls) and baby (replicated by farmers) trials, others just demonstration trials, with or without controls comparing to the "traditional methods" or "traditional crops".

In conclusion, only after all the trials are decided and implemented, we will be able to perform the standardization necessary to use the data and compare the results and rank their ecosystem services. Agroecosystems are ecosystems modified by human, yet they are in good condition when they support biodiversity, don't deplete abiotic resources (soil-water-air), and provide a balanced supply of ecosystem services (provisioning, regulating, cultural). Sustainable intensification requires sustainable management to reach or maintain a good condition in the agroecosystem, increasing resilience and maintaining the capacity of delivering services to current and future generations[3].

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