EIP-AGRI Focus Group
Climate-smart (sub)tropical food crops in the EU

Technical practices and innovative solutions to achieve agroecological sustainable and resilient food crops in both subtropical continental and outer-most regions in the EU

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INTRODUCTION - MOTIVATION

It is now more generally accepted that the development of climate-smart tropical and subtropical food crops requires a sustainable intensification of agroecological and resilient farming systems. This calls for a transition from an intensive, mono-cropped, and chemical-dependant conventional agriculture to more ecologically-friendly, multifunctional multi-cropped or crop-livestock production systems.

The European Union has nine outermost regions that are located at a significant distance from mainland Europe. Despite the distance from the European continent, farmers in those regions share common problems and face similar challenges. These problems include market accessibility, farmers' net profit, production costs, agricultural land abandonment and climate change impacts that call for mitigation and adaptation strategies. Farmers need strong support to face these realities and require information, training and facilitation, among others, to adapt to the new evolving agricultural settings.

This mini-paper explores some technical practices and innovations needed at the farm, landscape, or regional spatial levels to achieve that goal. Based on the analysis of similarities and differences in farming practices between EU outermost regions and mainland EU, the objective is to identify best practices that could easily and safely be adopted by farmers on both sides of the Atlantic (7 regions) and Indian (2 regions) oceans as well as in continental Europe.

The technical practices and innovative solutions presented in this mini-paper include innovative cropping systems, use of performant varieties, integrated pest and disease management solutions, and/or the use of technology to achieve optimized crop-management.

Tropical and subtropical food crops in the outermost regions of the EU

Tropical and subtropical food crops are food crops that are grown in the relevant climatic regions of our planet. These crops require the specific and unique environmental conditions formed by specific temperature and precipitation (and of course humidity) ranges. They include well-known crops such as bananas, sugarcane, avocado, custard apple, mango, peanuts, sweet potato, and a wide range of citrus trees, but also lesser-known crops such as zattes, dasheens, bread fruits.

However, some of these crops are also cultivated in other regions of the world including mainland Europe. For example, orange and kiwi are widely cultivated in Greece, Italy, Portugal and Spain. Avocado custard apple and mango can be found in Spain. The use of modern greenhouses allows the cultivation of crops such as eggplant, even in northern European countries. As an example, in the Netherlands, the ratio of eggplant exports to imports is almost threefold and, taking into account the lower production cost and selling cost of this crop compared to i.e. French Guiana in European supermarkets, makes the production of eggplant and many other (sub)tropical crops unprofitable for the outermost regions. Similarly, in the case of oranges, for example, it is very difficult for Greek orange producers, to compete with the low cost of imported orange juice ice-cubes from Brazil. This and other challenges will be further discussed in a following section.

The channels to market (sub)tropical crops produced in the EU outermost regions range from sale for local consumption including visitors (tourists), to exports to mainland Europe and the rest of the world. However, the total production costs, including costly and high carbon footprint inputs (chemical-organic), packing costs and expensive transport, are high and make their production unprofitable compared to mainland production.

Facing upcoming challenges

Farmers face a number of challenges related to globalisation: easy access of the same products from other countries with lower cost, high production cost due to imports of chemical inputs (fertilizers, pesticides) for their production; the lack of training programs; the intensive agriculture, with the production of the same

product with lower cost under greenhouses in countries of, normally, prohibitive environmental conditions; the market concurrence, transportation cost incorporated in selling cost of products from the outermost regions; and the reduction of quality due to transportation conditions/problems.

Furthermore, they are dealing with climate change challenges, ranging from extreme events (floods and scarcity of water resources, windfalls, temperature extreme events and wide temperature fluctuations) that leave farmers helpless in facing everyday reality. Climate change is one of the risks that farmers must face as crops and livestock are negatively impacted by rapid and steady global warming and by the increased frequency of extreme climate events that harm quantity, quality and stability of food production. This has an important effect on crop and livestock production with high social, food security and sustainability risks.

In both continental Europe and the outermost regions, some technical practices and innovative solutions have been developed to start an agroecological transition at different scales. However, they generally appear to be limited to certain crops, to certain farming systems, and/or to one given scale.

The objectives of this mini-paper are:

- To list and describe examples of effective technical practices and innovative solutions that have been implemented so far in continental Europe and its outermost regions to achieve agroecological, sustainable and resilient farming systems, such as agroforestry and mixed farming systems.

- To explain how these technical practices and innovative solutions can contribute to develop climate-smart (sub)tropical food crops in EU.

- To understand the limits and the opportunities to develop these technical practices and innovative solutions to more crops, cropping-systems and/or different scales, taking into consideration economic feasibility.

- To suggest research needs and ideas for innovations to further develop these technical practices and innovative solutions and achieve development of climate-smart (sub)tropical food crops in Europe.

Key issues to promote climate smart best practices in EU

Climate challenges related to agriculture need climate smart practices to secure a sustainable production future. Thankfully, there are a number of tools in the palette of agricultural managers and end-users such as agroforestry, agroecology and mixed farming systems. A short description of each is presented below, giving emphasis to the advantages they provide and can be adopted for sub(tropical) crops.

Description and benefits of Agroecology

Agroecology involves various approaches to solve actual challenges of agricultural production. Although agroecology initially dealt primarily with crop production and protection aspects, in recent decades new dimensions such as environmental, social, economic, ethical and development issues are becoming relevant. Agroecological farming recognizes the multifunctional dimensions of agriculture, as well as traditional and Indigenous knowledge and practices. This means farming that not only produces food, jobs and economic well-being, but also creates cultural, social and environmental benefits.

Agroecology recognizes the value of formal scientific research and technical innovations. It also values dialogue and collaboration between researchers, farmers, rural and indigenous communities and historically marginalized groups. And it relies on deep knowledge of cropping systems and farm ecology: soil fertility, biological pest control, seed varieties, biodiversity and more. Agroecology improves the adaptive capacity of agroecosystems and reduces vulnerability to natural disasters, climate change impacts, and new and emerging environmental and economic system stresses and shocks. Agroecology also protects and promotes ecosystem

services such as pollination, natural pest control, nutrient and water recycling, carbon sequestration, climate regulation and erosion control (Pesticide Action Network website, **https://www.panna.org/;** FAO website, **http://www.fao.org/documents/card/en/c/I9037EN**). In study after study, agroecological farming has been shown to:

1) Increase ecological resilience, especially with respect to volatile weather conditions;
2) Improve health and nutrition through more diverse, nutritious and fresh diets and reduced incidence of pesticide poisonings and pesticide-related diseases;
3) Conserve biodiversity and natural resources such as soil organic matter, water, crop genetic diversity and natural enemies of pests;
4) Improve economic stability of rural communities with more diverse sources of income, spread of labour needs and production over time, and reduced vulnerability to commodity price swings; and
5) Mitigate effects of climate change through reduced reliance on fossil fuels and fossil fuel-based agricultural inputs, increased carbon sequestration and water capture in soil.

Description and benefits of Agroforestry and mixed farming systems

Agroforestry (AF) systems are land-use systems and practices where woody perennials are deliberately integrated with crops and/or animals, which can increase land productivity by 40% compared with treeless systems (SAFE website, **https://www1.montpellier.inra.fr/safe/english/index.htm** ; AGFORWARD website, **https://www.agforward.eu/index.php/en/Innovation-leaflets.html**). Mixed farming (MF) systems include the exchange of resources within and among specialised farms (cash crops or livestock) at the farm/regional level. Agroforestry and mixed farming systems are sustainable land use systems with a lower risk of crop failure, and more climate-resilient than other farming types. They contribute to carbon sequestration and to secure farmers' income because:

1) trees protect and/or support other intercropped species;
2) in case of one crop-type failure, the farmer can still get the profit of the income gained by the other crop/s present, as well as from the fruits or woods provided by the trees;
3) trees act as barriers to slow-down pest infection and invasion by their roots (physical barrier for underground transmittance) and/or by their crown supporting biodiversity and natural enemies of pest;
4) trees act as windbreaks which, in combination to the previous positive effect, protect leeward crops from winds. This is even more important in fields close to coastal areas where winds can have devastating effects on crops, either physically or by salt deposition;
5) in AF and MF systems farmers take full advantage of their whole agroecosystem in space and time as they can have year-around production, getting better prices for their products;
6) farmers gain higher profit since they need lower energy inputs in the form of fertilizers or pesticides and higher quality products.

Agroforestry is already practiced in certain outermost regions of the EU but it has to be further implemented. This cannot happen unless farmers are supported primarily by information (training programs and subsequent support and provision of information) and secondarily by subsidies to support the conversion of their farms from conventional/intensive to agroforestry/extensive systems.

Examples of best practices:

Agroforestry in the outermost regions of the EU

In the following parts of this mini-paper, some successful examples are given from previously examined agroforestry practices and how they can be implemented in some of the EU outermost regions (based on the Focus Groups initial report and Agrest 2014).

Guadeloupe: It is characterized by a typical tropical climate and it is a biodiversity hotspot. Based on the local website (Region Guadeloupe 2020) the natural hazards the islands face range, among others, from hurricanes to floods. Being a popular touristic destination, its needs for primary production products (food) are high which, combined with the great distance from mainland Europe, urges for the production of high-quality food that allows a sufficient profit to the farmer. The specific environmental challenges can be met using trees, from the lush flora of the islands. The use of N-fixing trees can contribute manifold in the farming systems from lowering fertilization needs to understory crop protection from extreme climate events. Based on Imbert et al. (2004), the traditional taro (*Colocasia esculenta*) cultivation can be a useful tool in building an effective "buffer zone" in the swamp forest of Guadeloupe (F.W.I.). In another silvoarable system of *Gliricidia* tree combined with a perennial grass (for fodder), the importance of N-fixing species in the N economy of the system was proven (Nygren et al. 2000). The importance and contribution of N-fixing trees such as *Gliricidia* is evidenced in other studies coming from Guadeloupe. There are numerous examples that can be implemented by farmers in the islands ranging from silvopastoral to silvoarable.

Martinique: The highly diverse ecosystems support tourism and the economy of the island. Based on **AFD** (2020) the island is facing economic problems making the adoption of successful farming systems a smart option to counteract unemployment. Agroforestry is an ideal farming system for tropical regions and there are many examples that can be adopted by local farmers. In a study by Archimede et al. (2012) it is mentioned that banana farms can be switched to mixed farming systems with ruminants feeding banana by-products.

Figure 1. Agroforestry in banana-based farming systems in Martinique. ©P. Champoiseau, 2019

French Guiana: An amazing country, 96% covered by the Amazon forest, facing several, among others, economic challenges. It is described as a kingdom of forests, rivers and animals, so it has all the prerequisites for the successful implementation of numerous agroforestry practices. Besides, 80% of the farms follow traditional agroforestry practices (slash and burn). The work of Davy and Palisse (2018) verify the practice of traditional mixed farming systems by local inhabitants, which are hardly encouraged by public authorities.

Reunion Island: Another biodiversity paradise with more than one third of its surface covered by forests and wild plants. It is an amazing region with more than 232 endemic flowering plants that need to be preserved while supporting local population and farmers' income. Surprisingly and based on the Focus Groups initial report and Agrest (2014), almost half of the farms produce sugarcane as a monoculture practice. There is a decline in the production of some crops like vanilla and geranium production. It is important to mention an agroforestry plot established in 2005 (Figure 1). It isa 2 ha farm in the south of the island (Saint Pierre) that consists of an orchard of 'José mango' and a diversified market gardening area.. The 'Jose Mangoes' are native from the island and were obtained by grafting. They are famous for their round shape and unique perfume. Since 2019, a small agroforestry farm (FERME ZOUMINE) was created in the south of the island, which includes diversified market gardening and small livestock.

Figure 2. Surrounded by a dense ravine rich in biodiversity (endemic, exotic and plant pests), the farmer benefits from a natural barrier and a permanent reservoir of insects necessary for the conservation (Photo and contribution by Sandrine Baud)

Figure 1. A variety of products is produced on the farm (© S. Baud)

Figure 4. Composting on the farm (© S. Baud)

The farmer (Sandrine Baud) has 2 areas where she works focusing on soil health and biodiversity. The farmer does not work with hybrid (F1) varieties so that she can reproduce her own seeds. She makes a lot of compost and uses all the biomass to improve soil quality through amendments and fertilizers. She uses companion plants, trap plants or refuges (Fig.2). The entire farm is equipped with ferti-irrigation and drip irrigation (with programmer, filtration, hydraulic pumps). She performs soil analyses, works with CIRAD and l'Armefhlor on projects in agroecology or in organic farming. She is using science and other information to feed her ecological and agronomic approach.

She has grown over 150 varieties of fruits and vegetables. Old and forgotten varieties, but also traditional varieties used in local gastronomy and new varieties that adapt well to tropical conditions: ground pear, square pea, ginger, turmeric, aromatic and medicinal plants, tomatoes, eggplant, beans, zucchini, melons, salads, cabbage, asparagus, bananas, lemons, zattes (sugar-apple or sweetsop, Annona squamosa), grapefruit, lychees etc… .. Initially she was a member of a cooperative for the marketing of her products but she switched to direct sales at the farm in 2014, also doing online sales.

The farmer says: "*It took a lot of work and investment up front, but once you get the customer, the demand exceeds the supply. For mangoes, this remains difficult, they arrive at the same time in the season, organic mango is not yet valued, especially in communities. This year the export was banned due to the fruit fly "Dorsalis*"".

The farmer is also the producers of an organic CSA (Community Supported Agriculture), which distributes 23 baskets of fruits and vegetables / week on the farm. This ensures a basis of remuneration, creates links, facilitates exchanges and makes consumers aware of the issues that farmers face..

Silvopastoralism is a successful option since the local dairy plays an important role in the island's self-sufficiency (Vayssières 2014). Agroforestry is undoubtedly a farming practice to support and needed to preserve the islands' natural wealth.

Mayotte: A major concern of Mayotte farmers is the difficult access to advisory services for small farms (Rebuffel 2015). Similarly to Reunion Island, the topographic and physical environment of the island is ideal for agroforestry and mixed farming practices.

Canary Islands: The importance of *Chamaecytisus proliferus* (L. fil.) in agroforestry systems in the Canary Islands is pointed out by Francisco-Ortega et al. (1993). Agroforestry is an ideal option for the diverse natural settings and environment of the islands, combined with the environment- friendly practices presently adopted. All combinations of silvoarable and silvopastoral systems can be practiced using local species that could also be combined with agrotouristic activities.

Azores: Silvopastoralism seems an ideal option for the Azores, respecting the unique environment while producing a variety of dairy products and meat. Silvoarable systems are also an option to produce local crops. There are several research articles mentioning farming problems from the area, however, none on agroforestry and/or mixed farming systems. This points-out the need for information and training on sustainable farming systems such as agroforestry.

Madeira: the Madeira archipelago is composed of 2 inhabited (Madeira and Porto Santo) and 3 small not populated islands (Desertas Islands). The Madeira and Porto Santo food systems are facing completely different threats and challenges. Porto Santo is a UNESCO Biosphere Reserve, since 2020. This designation is due to a number of factors, such as traditional agricultural knowledge and activities, a diverse local agrobiodiversity which includes 27 food crops and 108 crop wild relative species, among them 34 forages and N-fixing species. . Porto Santo's risks and hazards are related to soil exhaustion due to intensive monoculture, and major problems are the desertification, soil erosion and severe water scarcity. Agroforestry and mixed farming systems can be an alternative to develop sustainable food systems, recover the soil, in main islands areas, or soil fertility in the remaining agriculture land under use. The provisioning (food supply), support (natural resources regeneration) and ecological (biodiversity support) services that these AF and MF systems could provide, could be important to increase the farmers' incomes and leverage cultural and agritourism activities. Several fruit perennial crops can be used in the organization of this AF and MF systems, including avocado and custard apple, in a mix with native forest species such as laurel and native shrub strata.

The threats to agriculture on Madeira Island agriculture are the abandonment of land, extreme climate events such as rising temperatures, the decrease of water resources, heavy rains, with periodical landslides and terraces destruction and soil erosion and loss. The island has an area of 741.0 square km, 25% and 47% of the territory is 1,000 and 700 meters above sea level. Sixty-five % of the surface has slopes greater than 25%. Fifteen thousand hectares of Madeira are covered by *Laurisilva*, native laurel forest, that got the classification of world heritage of humanity by UNESCO. Agriculture is practised in terraces (steep slopes) and man created agroecosystems. Despite strict protection legislation that prohibit the economic exploitation of laurel forest trees, there exist some attempts to use laurel tree and *Myrica faya* (N-fixing species) and other N-fixing shrubs species, such as *Teline maderensis* and *Genista tenera*, as elements of AF systems. According to the official data almost 8,000 hectares of land steep slopes are uncultivated and could offer an option to support silvoarable AF and MF systems as a way to recover the highly degraded landscape as a result of abandonment and, at the same time, to increase regional food sustainability, generating different food production and profit to farmers along the year. Many transition areas between laurel native forest and

agricultural or urban areas currently need and can be targeted for such kind of intervention, with implementation of AF or MF systems. The many problems to implement this strategy are the lack of farmers knowledge, high level of land ownership, lack of farmers organization and inadequacy of funding programs to support the agroforestry projects.

The actual Madeira agricultural land-use reaches almost 7,000 hectares; only 26.3% of it is dedicated to vineyards and banana monoculture. 8.1% of land-use is under AF or MF agro and livestock systems and the remaining land area is occupied by different conventional or organic farming food production systems. These food systems are mainly based in pluri-cultivation of subtropical or other fruit trees and annual crops. The most frequent crops used in these systems are banana, avocado, custard apple, mangos, passionflower, papaya, loquat and fig trees, mandarins, vineyards, dragon fruits, lemons, cherries, apples, sugarcane, sweet potato, taro, manihot, vegetables, aromatic plants, peppers, etc. This kind of design of AF or MF food systems can also include native and non-cultivated species, especially in the margins of the terrains.

Examples:

1. Island Agroforestry Association develops a local initiative called AgroMac, ruled by Mr Luis Filipe trying to create a robust agroforestry system (with permanent and non-permanent crops to produce food, feed for animals, and biomass for multiple purposes use). These AF systems are implemented in marginal lands on mountains and valleys and include practices such as green covering on soils for soil stabilisation, soil moisture retention and N fixation and organic matter incorporation using system waste and residues. AgroMac agroforestry systems has the goal to create a resilient system and an alliance between wild species from native laurel forest and food crops, including subtropical ones. The pilot AF systems are three years old and vegetable and annual crops represent the main production at this stage.

Figure 5. Fruit production mixed system join together subtropical fruit crops (papaya, mango, avocado, banana, avocado and citrus) and vegetable crops (sweet potato and sugarcane) using different cropping strategies (mixed, row, strip and alley) to increase land area use, and the ravines and bordures on the farm have a rich native vegetation and biodiversity, acting as natural barriers against undesired impacts caused from extreme weather events and pests (Photo and contribution João Coelho)

2. CDISA is a Centre for Social, Cultural and Agroforestry Development, from Jardim da Serra parish aiming to promote the cultivation of local fruit and other crop varieties and to organize local producers in valorisation and add-value to local agrodiversity and food products. The CDISA promotes the MF agro-systems, which include cherry, apple, chestnuts, sweet potato and taro varieties. Many CDISA actions are realized in cooperation with Hotel Quinta da Serra – Bio Hotel that produces its own organic food for costumers.

3. Mr João Coelho is an organic farmer and technician trained by the University of Madeira. He runs a subtropical fruit plantation of1 hectare, where subtropical crops are planted in a mixed cropping system and a multistrata design. The farmer produces throughout the year papaya, custard apple, mandarins, avocado loquat, passionflower, figs, grapes, among other small crops.

4. Mr Manuel Vicente is an organic farmer and technician trained by the University of Madeira. He designed and developed an AF system, based on permaculture practices and food forest concept. This food forest has 600 square meters and produces tropical fruits, grapes, diverse vegetables, edible flowers, and aromatic plants. Trees in the system support the food production system, namely providing biomass and N-fixing, fast-growing biomass and N-fixing species are used. This AF systems does not use fertilizer of any kind except compost and soil coverages. Phytosanitary treatments are reduced to sulphur and copper application in the vineyard. The most important healthy and sustainable indicator of a food forest is the improvement of soil quality in the system. This AF system is used as experimental pilot system for demonstration to other farmers. The permaculture initiatives are growing in Madeira, with other projects starting, among them Arambha permaculture sustainable village and Gaia, Sítio do Pomar.

Figure 6: Food forest following the permaculture practices producing tropical fruits, grapes, diverse vegetables, edible flowers, and aromatic plants. The system production is based on zero inputs, and biomass and waste is used to recycle the nutrients and maintain soil fertility. The plagues control is achieved through the promotion of friendly and auxiliary biodiversity (Photo and contribution Manuel Vicente)

Agroecological practices in the outermost regions of the EU

Agroecological practices and tools can be implemented gradually in a step-by-step approach to improve conventional farming systems. The optimal and most efficient combination of tools and practices must lead to agroforestry models, but not exclusively. As for example in banana production fields in Guadeloupe and Martinique, the combination of fallow lands (25% of each farm yearly), implementation of permanent cover crops, use of ultra-low volume herbicide application tools, use of IPM disease practices to manage black Sigatoka, use of tolerant varieties and pheromone traps has led to a global reduction of pesticides by 75% over the last decades. These solutions have been implemented gradually taking into consideration economic sustainability of farms.

In the following parts of this mini-paper, we present some successful practices and tools implemented in outermost regions of the EU to promote agroecological intensification of farming systems.

Frost management

● Coping with frost by pruning, thinning, girdling, sheltering, water sprinkling, irrigation, fertilization management.

Pest and disease management

● Use of Cosmotrack traps with aggregation pheromones in monitoring and fighting against the *Cosmopolitus sordidus* (banana weevil) in Antilles and Azores banana orchards. (Photos: David_Horta_Lopes)

● Use of Tephri and Ceratrap traps with food attractants in monitoring and fighting against the *Ceratitis capitata* (frui fly) adults in Azores Islands citrus orchards. (Photos: David_Horta_Lopes)

● Use of funnel traps with specific pheromones in monitoring and fighting against the *Mythimna unipuncta (*armyworm moth) adults in Azores pastures. (Photos: David_Horta_Lopes)

● Mechanical removal of severely affected leaves of banana plants to control Black Sigatoka diseases caused by *Mycosphaerella fijiensis* (Manuel du planteur, **www.it2.fr**)
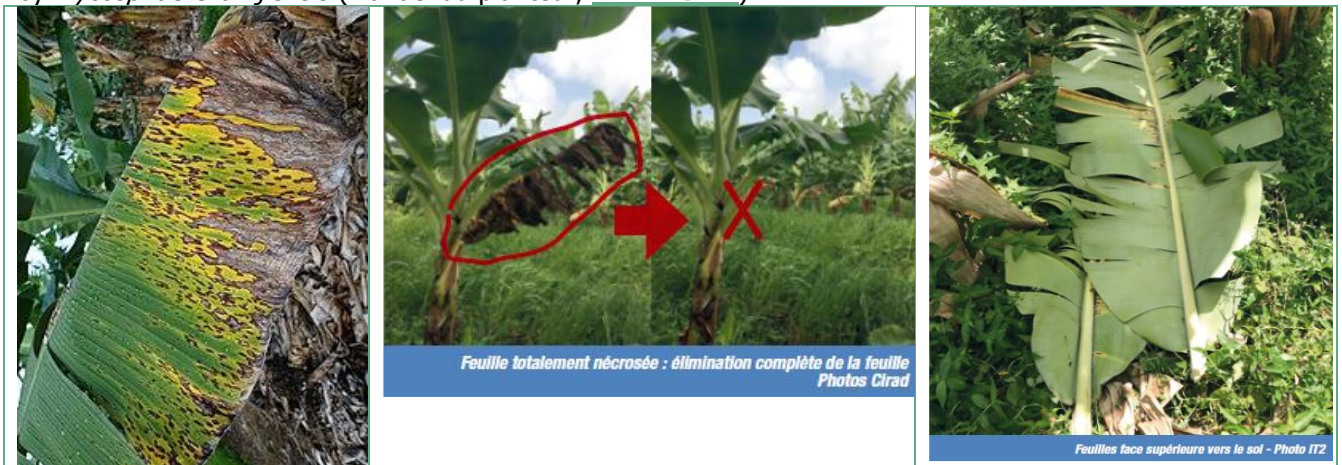
Multipurpose solutions

● Implementation of permanent cover-crops: soil permanent coverage within or between crop cycles has shown to serve multi-purpose objectives such as soil protection against water erosion, development of soil micro and macro-biodiversity, restoration of soil fertility and reduction of use of herbicides. It has been widely implemented in banana production farms in Guadeloupe, Madeira and Martinique over the last decades, and custard apples in Madeira.

Figure 7. Associated crop in Banana production in Martinique (© P. Champoiseau, 2019)

Figure 8. Implementation of *Crotalaria* spp to control soil nematodes before pineapple crop in Martinique (© P. Champoiseau, 2015)

Figure 9. Association of tropical species *Lablab purpureus* L. intercropped with tomato for industry in Portugal. Tomato rows are irrigated and lab lab rows are not.(© P. Vidigal, 2019)

Use of technology for best crop management

● Field acquisition data:

Measurement and data acquisition devices have become increasingly accessible as their prices have significantly dropped and as farms are getting better internet coverage.

For example, very inexpensive temperature recorders can be used to better plan harvesting for banana and pineapple as these crops require a determined number of degrees x days to ripen. Hourly temperature logs in excel format can be extracted from the temperature recorder and can be fed into a specific software (PREVIRECOLTE® developed by the CIRAD) that predicts the exact harvest date for a crop.
These measurement and planning tools are all the more relevant in a context of climate change.

Small compact weather stations can also accurately record temperatures as well as precipitations, which can be very useful in determining if and when a rain event has occurred during the night and consequently if a pineapple flower induction has to be renewed or not.

Tensiometers can be used to measure soil humidity and determine if and when irrigation needs to be turned on and for how long, thus helping a better use of a drip irrigation system.

Finally, aerial photos taken by drones can help monitor plant growth and also identify growth problems due to, for example, poor drainage in low-lying areas or incorrect terracing resulting in standing water in some areas, etc…Aerial photos also serve as a strong motivator as they witness continuous progress on the farm.

In Madeira in the framework of CASBio, precision technologies are used to quantify the adaptation of crops to climate changes. These technologies involve a network of meteorological stations, soil sensors and drones with multispectral cameras.

Figure 10: Temperature recording in the shade with a LogTag® temperature data logger (© J. Villard, 2021)

Figure 11: Aerial photo helping monitor crop progress (© J. Villard, 2021)

Innovations for commercialization

● Direct sale marketing:

Figure 11: Direct sale marketing in Reunion **Island**, photo S. Baud

Summarising key issues to face climate change

In this section we have listed key issues to favour intensification of agroecology and agroforestry systems to promote climate-smart (sub)tropical food crops in the EU. We have described, for each of them, the challenges and technical issues at farm, landscape or regional levels.

Key issue #1	Grow varieties and or cultivars that can adapt to agroecological conditions in some parts of continental Europe and its outermost regions and meet market demand	
Challenges	Technical issues	Scale
Production of sub(tropical) cultivars and/or valorisation of local crops when available and relevant in continental Europe.	Availability of seeds and/or planting material	Regional
	Dedicated nurseries specialised in (sub)tropical species	Regional
	Cryopreservation of tropical germplasm	Regional
	Germination rates, virus-free and weed contamination	Farm
	Adaptability of sub(tropical) cultivars to various environments	Farm, landscape
	Low temperatures: negative impact on flowering, pollination, fruit set, fruit quality and yield in many tropical tree crops	Farm, landscape
Production of varieties/cultivars adapted to short production seasons in (sub)tropical environment due to climate change	Availability of seeds and/or planting material	Regional
	Selection/breeding of germplasm to photoperiod sensitivity in annual crops: short cycle varieties	Regional
	Selection/breeding and compatibility tests of rootstocks (for tropical fruit trees)	Regional
	Develop experimental facilities for characterization, identification, evaluation of varieties	Farm, landscape
	High temperatures: negative impact on flowering, pollination, fruit set, fruit quality and yield in many legume crops	Farm, landscape
Protection of cultivated crops from climate change in (sub)tropical environment	Sustainable climate-controlled greenhouse cultivation of tropical fruits trees.	Farm
Overcome erratic and/or intense climate events	Optimal regions in mainland Europe where (sub)tropical crops can be produced are in the Mediterranean area where water availability is scarce and the situation could worsen under the climate change scenario	Regional

Key issue #2	Develop alternative and effective solutions to the use of chemical pesticides for pests & diseases management (PDM)	
Challenges	Technical issues	Scale
Avoid the entrance of foreign pests and diseases that could jeopardize agroecological (sub)tropical crop production	Design tools to be prepared to respond rapidly to new pests and diseases	International
Development of effective IPM programs in continental Europe and outermost regions	Uncertainty of pests behaviour and disease epidemiology under distinct climatic conditions: need for understanding surrounding environments and devising agro-climate modelling	Landscape

	Understand vector-diseases interactions under warmer climates	Farm (plant), landscape
Development of biological control and/or natural plant extracts for effective PDM	Identify and evaluate the potential of native/wild plants in outermost regionals as source for PDM	Landscape, regional
	Development of experimental facilities for biological control and/or natural plant extracts to be used as bioprotectants and biostimulants	Landscape, regional
	Develop adapted ways of control (European legislation)	Regional

Key issue #3	**Proceed to economic viable substitution of chemical to organic fertilisation**	
Challenges	Technical issues	Scale
Use organic fertilisation	Develop optimized fertilisation plans based on organic fertilisation to ensure commercially acceptable yields	Farm
Use on-farm organic fertilisation sources	Identification and characterisation of locally available organic fertilisation sources	Farm
	Develop on farm production facilities to transform local organic matter (farm biomass and wastes) to organic fertilisation sources	Farm
	Identify (sub) tropical species (crops, weeds, trees) for on farm biomass production	Farm
Optimize organic mineralisation and plant assimilation,	Identify, develop mycorrhizal plants in association with crops	farm
	Develop pre-mycorrhization of plantlets in orchards	Farm, landscape
	Develop growth-promoting micro-organisms	Farm, landscape

Key issue #4	**Restore and/or maintain soil fertility by using permanent cover crops, associated crops and simplified cultural techniques**	
Challenges	Technical issues	Scale
Predict sustainability of soil fertility	Evaluate impact on cultivated species of soil evolution under warm climate (e.g. by comparison of soil quality between French Antilles and Madeira (volcanic soils) and Mediterranean region	Regional
Mechanisation of planting/harvesting of cover crops	Develop adapted sowing/seeding and harvesting machinery: adaptation of machinery and other tools to cope with crops seldomly mechanized	Farm
Management of cover crops	Develop economically accepted solutions for cover-crops management (i.e. in the absence of herbicides)	Regional
Generalize soil permanent coverage (intercropping)	Identify and characterize locally adapted species (crops, weeds)	Landscape, regional
	Availability of seeds/planting material	Regional
Reduce soil impact, develop simplified cultural techniques	Develop adapted sowing/seeding and harvesting machinery	Farm, landscape
	Develop limited tillage	Farm, landscape

Key issue #5	Develop functional biodiversity in aerial and soil compartments	
Challenges	Technical issues	Scale
Understand variations in functional biodiversity in relation to climate change	Identify and characterize aerial and soil biodiversity on various environments	Farm, landscape, regional
	Develop models to understand variations in functional biodiversity	Farm, landscape, regional
Restore aerial biodiversity	Identification and implementation of species adapted for hedges or grass strips	Farm, landscape,
Restore soil biodiversity	See technical issues from key issue #3 and 4	
	Develop mulching strategies	Farm

Key issue #6	Develop innovative and functional crop-farming systems	
Challenges	Technical issues	Scale
Develop innovative cropping systems	Explore possibilities for underexploited intercropping (mixed cropping, row intercropping, strip intercropping, relay intercropping) and alley cropping	Farm, landscape
	Develop adapted sowing/seeding and harvesting machinery: adaptation of machinery and other tools to cope with crops seldomly mechanized	Farm
Develop innovative crop-farming systems	Explore possibilities for underexploited farm-cropping systems	Farm, landscape

Key issue #7	Use of technology for best crop management	
Challenges	Technical issues	Scale
Reduce/optimize water use	Develop water management tools particularly in orchards	Farm, landscape
Manage intensive frost climatic events	Develop automated and remotely controlled systems based on sensors and models ((e.g. anti-frost water aspersion)	Farm, landscape
Manage intensive drought climatic events	Develop automated and remotely controlled systems based on sensors and models (e.g. localized water irrigation)	Farm, landscape
Monitor plant growth and physiological disorders	Use of drones, climatic stations, data recorders	Farm, landscape
Develop decision tools to optimize crop management	Increase data records to develop decision tools	Farm, landscape

Key issue #8	Commercialisation of tropical crops	
Challenges	Technical issues	Scale
Optimize postharvest storage and handling	Manage chilling and heat injury in tropical fruits (storage and transportation)	Regional
Commercialisation and marketing	Information and Communication Technologies: to assist acceptance of new foods by consumers and farmers, to advocate health and environmental benefits (including shorter supply chains) to avoid negative perceptions from the public opinion (e.g. water consumption in avocado growing in southern Europe)	Regional

Key issue #9	Transversal items	
Challenges	Technical issues	Scale
Communicate on climate and environment-friendly techniques and practices	Having "open-public" access data and information/user friendly tools (e.g. how to calculate irrigation needs in relation to climatic conditions, or how to calculate carbon or water footprint of farm productions	Regional, National and international

CONCLUSIONS

Summary: lessons learnt on the key issue

Outermost regions are precious germs on the EU palette with a variety of physical environments. They have common problems but also common potential to switch these problems to opportunities. Some of the common problems include the difficult access to major markets since the high transportation and packaging cost, among other, decrease farmers' net profit. Other problems include the lack of political support, in particular to implement sustainable but less intensive options such as agroforestry. In this context, the risks taken and the technical tests carried out in isolation for several years slowed down the development of this agricultural model and the "pioneer" farmers lacked adapted effective support.

However, some technical solutions and tools, as well as mixed farming systems such as agroforestry, have shown to be effective to achieve an agroecological transition and ensure a resilient and sustainable agriculture, but they are still very limited to some crops and/or geographical areas.

It is our believe that with appropriate political support and with effective Operational Groups gathering each actor of the research-production chain from outermost and continental regions of the EU, the development of climate-smart (sub)tropical food crops will overcome the new reality and the threats of a changing climate.

RESEARCH NEEDS

Gaps and research needs from practice

Gaps	Research needs
- Limited information on research conducted on farming systems of the outermost regions - Limited knowledge on effectiveness of plant extracts (commercially available and from traditional knowledge) - Cost-effectiveness of innovative practices - Diversity of innovative products (eg oils, cosmetics,…) - Non-adapted or insufficient technical support in many outermost regions - Insufficient knowledge in understanding functional biodiversity in agroecological and agroforestry systems under (sub)-tropical environments	- Understand cultural, socio-economic limits for the adoption of research outcomes available - Production and evaluation of well-adapted healthy propagating material in diverse environments - Demonstrate effectiveness of alternative solutions to the use of chemicals for pest and disease control (such as plant extracts, biostimulants, etc…) - Technical-economic studies will be crucial along with the evaluation of innovative solutions and tools to analyse feasibility and sustainability of agroecological and mixed farming systems - Develop cost-limited innovative products to create added-value - Develop alternative, innovative (but yet traditional?) practices such as agroforestry under the specific pedoclimatic conditions of each region.

	- Develop, analyse and experiment innovative technical support organization. - Develop knowledge in entomology, botany, ecology and agronomy to understand functional biodiversity - Need for a deeper knowledge of agrodiversity and genetic resources of crops used in the AF systems, with evaluation of the traits promoting their resilience to climate changes. - Need for knowledge of the pests and diseases of the most important tropical crops and the inclusion of IPM strategies to control them and preventive strategies to avoid the entrance of new pests and diseases.

IDEAS FOR INNOVATIONS

Ideas for innovative solutions or recommendations

A variety of innovations have been proposed by the authors of this mini-paper. They are listed below. The authors point out the fact that success for development and adoption of technical practices and innovative solutions has to go along with well-adapted training, organisation and support. This will be discussed in other minipapers.

1. Survey and evaluation of sustainability and multifunctionality of different AF systems in different regions.
2. Testing of traps and attractions to implement strategies to deal with various pests without the application of pesticides.
3. Implement biotechnological and biological control strategies to reduce the application of chemicals
4. *Short supply chains* – Institutional arrangement across links in the value chain. New business models for local/regional actors and development of innovative products using the subproducts of AF systems
5. Certification schemes for environmental(climate)-friendly production
6. Develop innovative communication tools to enhance sharing of innovative practices and solutions
7. Provision of products directly to consumers (no formation of the prices from intermediary)
8. Diversification in products since this allows for income spread throughout the year, less risky than a monoculture
9. Application of sustainable agricultural models such as agroforestry that allow savings on: seeds, fertilization and phytosanitary

Ideas for potential EIP Operational Groups

Operational Group to test and monitor biological and biotechnical control strategies for the major phytosanitary problems that affect tropical crops.

Operational Group to test the application of the residues of animals and the tropical crops to obtain compost as a way to reduce or stop the utilization of chemical fertilizers on these cultures.

Operational Group to test the production of new (sub)tropical crops in outermost regions and mainland EU.

Operational group to learn how farmers use the residues of animals and the tropical crops to obtain compost and use it as a way to substitute the utilization of chemical fertilizers on these crops

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Research projects:

INTERREG projects: CABMEDMAC; CUARENTAGRI; BIOMUSA; INTERFRUTA; VERCOCHAR; FRUTTMAC; APOGEO.

FEADER Projects in Guadeloupe: PARADE-HLB, IntensEcoPlantain, Plan Banane Durable II, PRODIMAD, PAD

FEADER Projects in Martinique: RESYMAR

FEDER projects in Guadeloupe: CAVALBIO **https://cavalbio.cirad.fr/**, MALIN **https://www.projet-malin.fr/**

H2020 Projects: TropicSafe **http://www.tropicsafe.eu/fr/**

Life Project: Citrus for vida **https://lifevidaforcitrus.eu/**, pre-HLB **https://www.prehlb.eu/**

Operational groups: Aguacate Spain: **https://goaguacatespain.com**, CARISMED (Spain): **https://gocarismed.es**

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