WEBINARS 2021

FARMING SYSTEM DESIGN (FSD7) WEBINARS ON CAPACITY DEVELOPMENT IN SYSTEMS RESEARCH FOR THE TRANSFORMATION OF AGRI-FOOD SYSTEMS TO ACHIEVE SUSTAINABLE DEVELOPMENT GOALS UNDER CLIMATE CHANGE

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FARMING SYSTEM DESIGN (FSD7) WEBINARS

ON CAPACITY DEVELOPMENT IN SYSTEMS RESEARCH FOR THE TRANSFORMATION OF AGRI-FOOD SYSTEMS TO ACHIEVE SUSTAINABLE DEVELOPMENT GOALS UNDER CLIMATE CHANGE

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Summary Report

Farming System Design (FSD7) Webinars on Capacity Development in Systems Research for the transformation of agri-food systems to achieve Sustainable Development Goals under climate change

A series of four short and interactive webinars took place, March 22-25, 2021, to foster the **engagement of young scientists in the value and function of systems research** to support the transformation of dryland agri-food systems, and contribute to reaching the UN's Sustainable Development Goal 2 (SDG2) - to end hunger, achieve food security and improved nutrition, and promote sustainable agriculture by 2030 (UN, 2019), and related SDGs under climate change. It is envisaged that the webinars will maintain momentum for the FSD7 Symposium which has been postponed to 20-23 March 2022 due to COVID-19.

The webinars built on abstracts submitted for the FSD7 Symposium and on the outcome of the recent scientific dialogue on "Systemic Transformation of the dryland agri-food systems of Africa and Asia" between the DryArc Initiative of 9 CGIAR centers and Australian Institutions for Research and Development that took place in August and September 2020. The webinars form part of the FSD7 International Course for design and assessment of rainfed farming systems in North Africa and the Middle East held in Tunis in March 2021. While not exclusive, the focus of the webinars was the transformation of agri-food systems in the **dry regions**.

This brief report provides action points from the presentations and discussions to help young scientists start or amplify their research on agri-food systems transformation in the drylands, and allow more involvement in specific sessions during the FSD7 symposium in 2022. More details are provided in the abstracts of presentations given during the webinars.

WEBINAR 1: Systemic transformation of agri-food systems to reach synergies between SDG1 (no poverty) and SDG2 (no hunger) under climate change, water scarcity and planetary boundaries: An insight on the opportunities and pathways for transformation and implementation

Chaired by Jacques Wery (ICARDA, Egypt) and Rabi Mohtar (AUB, Lebanon)
22 March 2021

The webinar's aim was to discuss opportunities and pathways to implement development projects in the drylands of Africa and Asia, recognizing that approaches based on a single technology (e.g. new varieties) a single commodity (e.g. wheat) or a single resource (e.g. water) are not sufficient to achieve a sustainable transformation of agri-food systems and synergies between SDG1 (no poverty) and SDG2 (no hunger) under climate change and within planet boundaries. The role of systems research for a systemic transformation in development projects has been discussed based on examples of action research, systems modelling and participatory research in different regions.

What is at stake for drylands and MENA in particular: Lack of recourses (Infrastructure, Human); lack of investment on transformative R&D; and lack of interest in youth in agriculture, water & food security.

This has resulted in: Import of technology even the one essential for local food production (example, potatoes seed as a staple food), food insecurity and high commodity prices.

What we need:
- Food and Agriculture Systems revolution in the MENA
- More activities and scale up of these activities, influence policy and investment in this area both capital and human.
- Food security and water security are national priorities and all sectors of the economy should be mobilized to achieve security and sustainability of the agri-food systems in dry areas.

Webinar 1 Key messages for the drylands

- Food security in dry regions has implications on water, energy and land. It is possible to improve productivity and income through more efficient use of resource: water, land, energy, etc. We need to reduce Water-Energy-Food interdependencies to improve resilience.
- Water is a catalyst for increased resilience, improved livelihoods, and reduced socio-economic challenges. Alternative water resources (harvested rainwater, treated waste water, saline water) are key to the future of food security.

- Food security must involve stakeholders especially government policy makers across sectors. Engage and empower the targeted beneficiary rural communities including women and youth in the innovation process. Some resources that are particularly difficult to build, like human capital, might be more important for fostering resilience than short term benefits like high profits.
- We need to unlock the potential of water and soils innovations to achieve sustainable development. Recognize the importance of small-scale irrigation farms and provide opportunities for future investments.
- Integrated crop-tree-livestock value chain interventions is the most effective strategy for improving rural livelihoods and food security in vulnerable diverse systems.
- Stakeholders' engagement is crucial to identify trade-offs/synergies for suitable SDGs interventions. Policy coherence among various sectors and consensus building for suitable interventions are needed to achieve a sustainable economic growth and job creation in the dry regions. Effective public private partnerships for scaling should be at the core of development projects.
- Examples of systemic approaches to address these challenges are given in the abstracts of this webinar.

WEBINAR 2: Designing climate smart and resilient cereal-livestock based farming systems for food and nutrition security in the drylands of Africa and Asia

Chaired by Zvi Hochman (CSIRO, Australia) and Lamia Ghaouti (IAV Hassan II, Morocco)
23 March 2021

Webinar 2 discussed issues, challenges and case studies related to co-design of resilient climate smart cereal-livestock farming systems. Farmers design their farming systems by manipulating their crop-livestock balance, cropping intensity, the diversity of their crops and crop types and the level of exogenous inputs within the limits of their land, labor and other resources. Will dryland farming systems that have evolved to be resilient to historical weather patterns and socio-economic circumstance stand the test of time over the next thirty years or will transformational changes be required to adapt to a future climate in 2050 and beyond? Dryland agriculture is both vulnerable to the impacts of global warming and a significant contributor to the greenhouse gas (GHG) emissions that cause it. To be resilient to global change, farming systems need to achieve household food security and nutrition goals while reducing vulnerability to a warmer and increasingly variable climate. To be climate smart, these systems will balance these objectives with the need to reduce GHG emissions and to conserve natural resources.

Webinar 2 key messages

- Adapting rainfed systems for climate change impacts through sustainable practices using winter wheat and maize based on models and SWOT analysis shows promising results for the prediction of adaption strategy using certain agricultural practices. Some practices such as no tillage, early sowing provided the best means for water use efficiency and crop productivity.
- The most common adaptation strategies among farm households in Senegal were crop diversification and change in crop production system, increase in water conservation practices, and adjustment in management of livestock, and increase of irrigation technology use, as well as access to credit. These adaptation strategies are essentially focusing on livestock feed storage, mobility, diversity of economic activities and change in herd composition.
- Given the complexity of factors in farming systems (crop, livestock, water, etc.), the role of policies is crucial in promoting adaptation strategies at system level to strengthen resilience.
- Designing farming systems is an ambitious undertaking. We are still at the stage of studying the different components of the systems and effectiveness of the different adaptation mechanisms and strategies. We are not yet at the stage of designing whole farming systems and coming up with comprehensive solutions, but focusing and understanding of the small components before embarking on the design of complex systems that address challenges for farming systems of Africa and Asia.

Webinar 3: Multi-scale and multi-criteria trade-off analysis in the SDG1-SDG2 nexus, to co-design sustainable and healthy agri-food systems and inform policies

Chaired by Hatem Belhouchette (CIHEAM, France) and Pytrik Reidsma (Wageningen University and Research, The Netherlands)
24 March 2021

The objective of Webinar 3 was to present and discuss case studies that have addressed methodological challenges related to the co-design of resilient and sustainable farming systems in dry areas.

The session initiated a debate on the multiscale, multidisciplinary and trade-offs analysis when faced with the challenges of co-designing innovative farming systems with multifaceted objectives including optimal productivity, conserving natural resources and ensuring household food needs. Presentations were selected to represent a variety of different biophysical and socio-economic contexts, assessment objectives, and methods and tools/models that, in one way or another, engage stakeholders.

Webinar 3 key messages

From research to impact at farm level

- **Scaling up from crop to farm level**: Co-innovation framework was applied to vegetable farm systems sustainability (**Berrueta et al.**). This presentation proposed a methodology targeting the scaling up of cropping practices to increase yield and crop net margin at farm level. The paper also concluded that the redesigning of resilient/sustainable farming systems is not a final step but it should rather be followed with implementation, monitoring and evaluation.
- **Farm research networks:** Farmer research networks for co-designing agro-ecological intensification options in crop-livestock systems of southern Mali (**Descheemaeker et al.**). This presentation shared a success story in mobilizing an adaptive and inclusive co-learning cycles used to promote the adoption of agro-ecological practices by farmers. This experience was based on 3 main principles: integration of diversified farmers, mobilizing of a useful and adapted research and the co-learning of innovations through demonstration plots and early engagement of stakeholders. The main idea of this 6-year experience was to avoid placing risks on farmers in order to facilitate chain negotiations and group sales.

Evaluating scenarios to inform policy

- **Using models to explore impacts of strategies**: The utopia of increasing crop diversity and intensification by increasing access to irrigation water in dry conditions (**Bazzi et al.**). This presentation’s main conclusion is that, in dryland areas, increasing access to irrigation systems or increasing subsidies to legume crops does not lead to legume-crop diversification. The main reason is that legume crops are less profitable and more labour demanding than mechanized legume crops and orchards.

- **Exploring transformative pathways**: Participatory exploration of transformative pathways for the cooking banana value chain in Uganda (**Ronner et al.**). This presentation shared an experience aiming to assess the current and future sustainability of banana-based farming systems in Uganda. By testing several scenarios that combined internal drivers such intensification, socio-economic and climate trends, the study mentioned that a compromise solution could be reached to consulate several objectives: keep enough banana production for self-consumption, increase household farm income, and reduce labour.

Assessing resilience-enhancing attributes

- **Economic, social and natural capital**: A Tri-capital framework for assessing social-ecological systems' resilience in Medenine -Tunisia (**Aribi et al.**). This study highlighted the importance of considering the diversity of socioecological systems (SES) in measuring resilience. For this analysis, an adapted innovative resilience method based on a tri-capital approach (economic, socio-cultural and natural capital) was implemented. The study concluded that every SES has its own specificities allowing it to address, or not, the risks linked with the resilience analysis.
- **Resilience-enhancing attributes in EU farming systems**: In the SURE-Farm project, 22 resilience-enhancing attributes were defined for EU farming systems, and the most important ones were also clearly important for the systems into dryland areas, as reflected in the presentations: reasonably profitable, infrastructure for innovation, production coupled with local and natural capital, socially self-organized, appropriately connected with actors outside the farming system, reflective and shared learning, functional diversity, and diverse policies.

WEBINAR 4: Accelerating and amplifying systemic transformation of agri-food systems with digitalization of research and advisory services to family farmers and decision makers

Chaired by Ram Dhulipala (ICRISAT, India), Thouraya Souissi (IRESA, Tunisia) and Bruno Gerard (CIMMYT, Mexico)
25 March 2021

Webinar 4 brought together examples of and the current thinking on application of ICTs and digital technologies addressing issues at a broader systems and regional scales.

Digitalization has transformed most industries in a fundamental way. From incremental efficiency gains to enabling disruptive business models, the impact of digital technologies has been far reaching. Evidence, however, points to a low integration and use of digital technologies in agriculture despite their immense transformative potential especially in smallholder and resource poor contexts. In some instances, digitalization of agricultural research has led to efficiency gains, for example, faster varietal development, tablet-based surveys, and ICT enabled communication of climate information and precision farming. Impacts on the broader farm system, however, require better transmission of research around crop, livestock, trees, soils and water management to farmers and enhanced connections to the private sector. Facilitating and catalyzing digitally enabled systemic transformation of agri-food systems that touches upon a number of global issues like climate change, GHG emissions, resilience etc. would require a more coherent approach towards the digitalization of agri-food systems from research through to advisory systems that support farmers. Such innovations will find ready users only when agricultural research and extension interfaces with market access, government policy, social setting and a host of other local factors that influence farmer behavior and decisions. The design and provisioning of digital tools and interventions, therefore, need to incorporate elements of user-centered design that consider decisions around technology adoption and behavior.

Webinar 4 key messages

- Digitalization in agriculture can be a game changer, and while most agriculture revolutions of the past were on-farm, the digital revolution happens at multiple points in the value chain and land, food and water systems.
- **In reinventing traditional agronomy to become more facilitative in the context of more knowledge intensive agronomy**, there is a strong message that farming cannot be studied as ‘astronomers study planets’. It is essential to go to farms in order to study and understand farming systems, farmers, and people in order to make sure agricultural practitioners can give service that is informed by hands-on experience. This is important consideration as we shape the training curriculum of future agronomists, agricultural engineers, and other researchers and extension agents. This is also supported by the idea of couching an area of specialization in a broad set of knowledge.
- **Digital augmentation for agri-food systems transformation, and technologies like spatial imagery, remote sensing, systems modelling, mobile apps etc. could be**

combined to create tools to enable data and evidence-based policy making at various spatial and temporal scales. The potential of spatial and temporal research through remote sensing, machine learning, data analytics provide exciting research opportunities with direct implications. The value added of Geo tagging information of research trial sites is very important for several fields of study including for those in Breeding, as well as for economists and others like hydrologists.

- **Crop simulation modelling can create knowledge products that support decision making by farmers.** However, modelling can be data intensive, and validation and calibration can also be labour intensive, and may not be of direct use to farmers. To make the results of modelling more useful would require a level of translation or the use of participatory modelling approaches and the engagement of farmer advisors.
- The Plantix app is used for pest and disease diagnostics through mobile phones and is currently downloaded by over 15 million users globally. The app has evolved to also enable farmer users to purchase inputs through a new feature on the app. Plantix presents a clear example of the potential of crowdsourcing, not only to provide advice to farmers, but also for secondary use of massive data fit in terms of plant disease monitoring. It also provides interesting examples of public private partnerships. Most of the time there are prototypes at the research level that are difficult to scale, and the private sector can play an important role in scaling of tools and innovations.
    - *Question to consider:* Is the solution always pesticides? If partner companies are pesticide companies, how do we manage for bias in making recommendation? There is no clear answer, but it is an important question for researchers.
- Picture-based insurance (PBI) is a means to unlocking improved financial and innovative finance for smallholder farmers. Financial Services is currently under researched among CGIAR Centers and there is a strong potential to scale not only innovations but also financial services.
- Meteorology and climate information for farmers requires some translation with the right analysis and actionable information to be useful.

Question to consider: Webinar 4 presentations focused on South Asia and India, and the question is: Is India more ready that other places to scale digital agriculture? And if there are constraints for adoption of digital agriculture in other places, especially in Africa, what can be done to alleviate them?

Abstracts from the Webinars

FSD7-Webinar 1

Systemic transformation of the agri-food systems under climate, water, and planetary constraints: an insight into the opportunities and pathways for transformation and implementation

Date: 22 March 2021

Chaired by Jacques Wery (ICARDA, Egypt) and Rabi Mohtar (AUB, Lebanon)

Objectives
Webinar 1 aims to discuss opportunities and pathways to implement development projects in the drylands of Africa and Asia, recognizing that approaches based on a single technology (e.g. new varieties) a single commodity (e.g. wheat) or a single resource (e.g. water) are not sufficient to achieve a sustainable transformation of agri-food systems and synergies between SDG1 (no poverty) and SDG2 (no hunger) under climate change and within planet boundaries. The role of systems research for a systemic transformation in development projects will be discussed based on examples of action research, systems modelling and participatory research in different regions.

Program and speakers
- A short introduction of the objectives and expected outcome of the webinar (*Jacques Wery,* 3 min.)
- An introductory statement on “Farming Systems Research and CGIAR’s Research and Innovation Strategy to 2030” (*Marco Ferroni*, Chair, CGIAR System Board, 2 min).
- An introductory statement about the value and challenges of application of systems research in development projects in the drylands: Feedback from ACIAR experience and the DryArc-Australia dialogue (*Andrew Campbell and Julianne Biddle*, ACIAR, Australia, 7 min.)
- Selected presentations of 8 min + 8 min. discussion:
    - Supporting transition in agrifood systems: a toolbox to enhance open innovation (*Marie-Helene Jeuffroy*, INRAE, France)
    - Assessing policy coherence in the Water-Energy-Food-Ecosystems nexus (*Maria Blanco*, Univ. Madrid, Spain)
    - A Water-Energy-Food Nexus approach for evaluating the sustainability of the plant-based Mediterranean-inspired diet: The Case of Lebanon (*Sandra Yanni*, AUB, Lebanon)
    - Using system dynamics for resilience management of farming systems (*Hugo Herrera*, Univ. Bergen, Norway)
    - Co-designing profitable and resilient crop-livestock systems in Niger and Burkina Faso using a household modelling approach (*Shalander Kumar*, ICRISAT, India)
    - Analysis of Options for Enhancing the Large-Scale Adoption of Conservation Agriculture Practices in Small-Mixed-Farming Systems of North Africa: Case of Tunisia (*Aymen Frija*, ICARDA, Tunisia).
- Action areas to strengthen the contribution of agri-food systems research in development projects (*Rabi Mohtar*, 5 min.)
- Wrap-up and conclusion by the Moderator: *Jacques Wery* (2 min.)

Supporting transition in agrifood systems: a tool-box to enhance open innovation

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1. Introduction

To face the numerous and complex challenges addressed to agriculture and food, a huge need of disruptive and systemic innovation is required toward more sustainable agrifood systems. Since a long time, in these sectors, innovation has been considered as linear, from knowledge production by research to design and development by engineers of the R&D sector, followed by spreading of resulting innovations. Yet Akrich et al. (1988) showed that innovation is more a swirling process, with numerous back and forth between the steps of research, design, development, industrialization and launching: innovation is a collective and interactive process. To support the systemic innovation capacity of agriculture and food actors, and to create opportunities for open innovation, specific methods and tools were developed by a group of French researchers, who draw their inspiration from ergonomics, design science, transition theory and agronomy. Indeed, these methods combine three main theoretically grounded principles. 1/Including the users throughout the design process allows to take into account the specificities of the situations in which they are likely to be used (Béguin and Rabardel, 2000), and to consider the design abilities of users (Cerf et al., 2012). 2/A design process can be described in terms of its initial design target, the cognitive reasoning making evolve the formulations of the design target through the process, and its final outcomes. Yet, according to Schön and Wiggins (1992), the designer cannot imagine all the properties of a new object before putting it into action: the design of an object is fed in and through the action in which the object takes place. 3/ The multilevel transition theory emphasizes that innovations emerge and are scaled out within a sociotechnical system (STS), defined as a collective of actors, their networks, their practices, their knowledge, the technologies they use, their representations, and the norms they adopt (Rip and Kemp, 1998). When a sociotechnical system is well established, and involves the incumbent actors, only innovations that fit to their strategies, their networks, and the standards that frame their action have a chance of emerging and scaling out. More disruptive innovations therefore often develop in sociotechnical niches, composed of outsider actors who hold new challenges for the future. Consistently with these principles, nine methods were developed to support open innovation processes. We here briefly describe them, as well as their various combinations when implemented within different design projects contributing to support transitions in agrifood systems towards more sustainability.

2. Description of each method

The nine methods (M) contribute either to identify the diversity of actors to be involved in the design process, as well as to refine the target of the object to be designed (mainly M1, M2), or to structure and share knowledge (mainly M3, M4), or to foster concepts exploration (mainly M5, M7), or to assess the innovations in users' situations (mainly M6, M8, M9).
The diagnosis of the sociotechnical system (M1) aims at understanding the functioning of a STS, in order to adapt the management of the innovation process, by analyzing the obstacles and levers to innovate within networks of actors (Meynard et al., 2018).
The diagnosis of use situations (M2) aims at identifying the diversity of potential users of a targeted innovation, and at characterizing their needs or the difficulties they encounter to perform a task or to reach their target objectives (Cerf et al., 2012)**.**
The open knowledge base (M3) capitalizes scientific and expert knowledge in order to feed workshops or step-by-step approaches to design cropping systems or food products (Soulignac et al., 2017).
The on-farm innovation tracking (M4) aims at unearthing and analyzing innovative farming practices, and capitalizing the derived knowledge in order to stimulate the creative capacity of actors in design workshops or step-by-step design (Salembier et al., 2016).
The design workshops (M5) aim at organizing a dialog between key actors (including targeted users) to collectively explore and imagine innovative solutions to reach a desirable target, through knowledge sharing and exploration (Reau et al., 2012).
The step-by-step design (M6) describes a progressive change of a current system (at field or territory scale), to reach new objectives, fed by learning loops, often ending up with a completely different system (Meynard et al., 2019; Prost et al., 2018).
The scenario building of territories (M7) simulates the spatial organization of cropping systems and agroecological infrastructures addressing new challenges, taking into account individual and collective issues, and local specificities (Chantre et al., 2016).
The test of prototype use (M8) aims at implementing, in real-life targeted situations, a mock-up of the object under design, in order to check its relevance for the target users, and its ability to adapt to the diversity of the targeted use situations (Cerf et al., 2012).
System experiments (M9) consist in implementing, assessing and improving, in a systemic way, crop management routes, cropping systems, breeding systems or even farming systems or mini-landscapes (Debaeke et al., 2009).

3. Various combinations of methods in projects allow to support open innovation for sustainable agrifood systems

These methods were differently combined within a dozen of projects (only four are illustrated here), according to the problem to be solved, the target to be reached, existing tools, actors involved, etc…. showing their adaptability in various contexts and their contribution to open innovation towards sustainable agrifood systems.

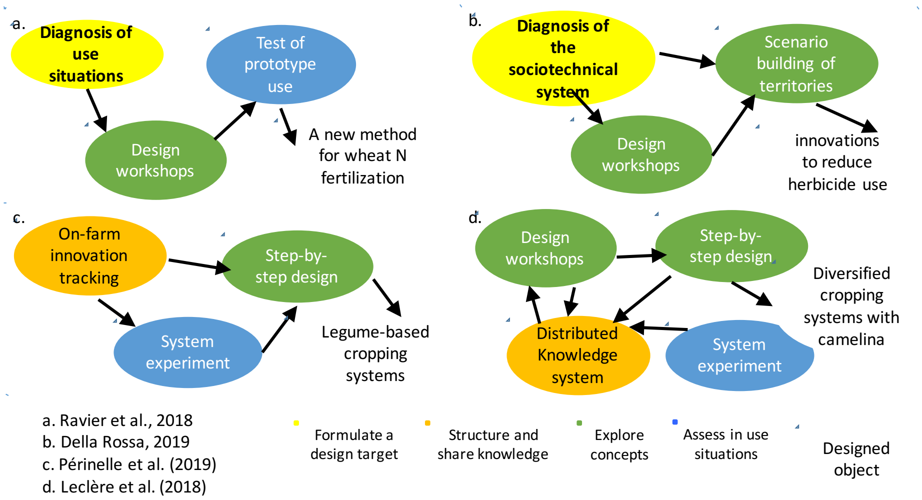

Figure 1: Various combinations of methods supporting open innovation processes for sustainable agrifood systems

Ravier et al. (2018) combined a diagnosis of uses, design workshops and the test of prototype use, to design a completely new method of nitrogen fertilization, resulting in improved performance in terms of the combination of yield, grain quality, and N losses in the environment. Della Rossa (2019) combined a diagnosis of the sociotechnical system, design workshops and scenario building, to develop technical and organizational innovations aiming at reducing the use of herbicides in a catchment area in French West Indies where two main value chains, based on input-intensive systems, dominate (banana and sugar cane). In Burkina Faso, Perinelle et al. (2019) combined on-farm innovation tracking, inspiring farmers to develop their own system, a system experiment to improve some interesting innovative systems, and on-farm step-by-step design, thus developing a diversity of legume—based systems, adapted to each farmer's situation, targeting improving soil fertility. To develop Camelina as a new crop within the cropping systems of a territory, Leclère et al. (2018) combined design workshops (involving farmers, advisors and processors), step-by-step design by farmers-designers, and system experiments, to produce, capitalize and share knowledge, thus supporting systems diversification.

4. Conclusion

As illustrated by their implementation in several collaborative projects, the developed methods and tools allow to support open innovation in agriculture, fostering issue and knowledge sharing, and exploration among various actors from the agriculture and food sectors, but also territories and value chains (Chesbrough et al., 2014). Specifically, the involvement of the "users" of the designed object, throughout the innovation process, was a condition for success of implemented innovations, in all these projects. The proposed resources support several functions, essential in the development of open innovation: embedding actors, sharing common issues to address, enhancing the sharing of knowledge and know-how, supporting exploration, fostering the assessment by implementation in real-life situations.

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Assessing policy coherence in the Water-Energy-Food-Ecosystems nexus

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1. Introduction

How well do policies directed toward the water, energy, food, environment (WEFE) nexus work together to support a resource efficient and low-carbon Europe? Policy coherence is considered a fundamental part of the EU's contribution to achieving the sustainable development goals (SDGs) and calls for addressing the interlinkages between various SDGs; adopting a comprehensive and strategic approach to implement the 2030 Agenda across all policies, and seeking synergies across policies and in close coordination with the implementation of the Paris Agreement on Climate Change (European Union, 2017).
This article presents policy coherence analysis for the case study of Andalusia (Spain). In this article, we extend the policy analysis of the WEF-nexus by adding an environmental dimension focusing on land use and climate policies. The policy analysis, thus, focuses on the WEFE-nexus to provide a better understanding of how relevant policies are linked. Specifically, this article examines and assesses policy (in)coherence at the WEFE-nexus for the particular case of Andalusia (Spain).To design coherent policies and strategies, it is necessary to analyse the interactions beyond simple synergies and trade-offs, which requires up-to-date empirical knowledge of how the goals and interventions of one sector affect another, positively or negatively.
In Andalusia, the degree to which WEFE policy objectives are coherent is questionable. For the Mediterranean region with irregular and dry climate, climate change scenarios predict even higher increases in temperatures and decreases in precipitation in the next decade (BLANCO ET AL. 2017) putting pressure on water and land resources and specifically on irrigation agriculture. Andalusia has a negative water balance and in some areas faces problems of erosion (with risk of desertification). High energy prices have turned into a limiting factor for modernized irrigation systems in particular after the electricity market has been liberalized in 2008 (GONZÁLEZ-CEBOLLADA 2015). In Andalusia, WEFE policies largely aim to boost economic activity while reducing resource use and promoting sustainable water management, climate change mitigation and renewable energy to receive resilience at the nexus. How policy indicators defined in major WEFE policies interact to achieve these goals will be explored in this article.

2. Materials and Methods

A key aspect of this research is the combination of analytical and participatory approaches. In this study, as a first step, we identified the main indicators and the main policy scenarios related to WEFE nexus in Andalusia. These results were introduced in the SDM, which considered as an analytical tool to simulate policy scenarios and to guide the design of sustainability strategies up to 2050. Twelve indictors related to WEFLC nexus were identified to analyse policy coherence in Andalusia (Table 1). Two simulated scenarios were selected related to increase of water price by €0.01 in WP01 and by €0.02 in WP02. Finally, policy coherence analysis conducted based on an analytical framework built by Nilsson et al. (2016) and radar graphs. These efforts help in conducting integrated policy analyses and develop coherent policies and programmes across various dimensions of sustainable development. Furthermore, Pearson's correlation test that has been previously used successfully to identify synergies and trade-offs (Momblanch et al. 2019). In this paper, this methodology has been used to identify the synergies and trade-offs between nexus component indicators, by calculating a correlation matrix which shows the level of consistency between pairs of nexus indicators under each simulated scenario from 2010 till 2050. Positive correlation occurs if the values of the two indicators show similar variation with time. A negative correlation arises if the temporal variability of the indicators is opposing. Statistically significant correlations (Pearson's coefficient higher than 0.5 or lower than −0.5).

Table 1. WEFLC Nexus indicators. Source: Own elaboration.

'Ecological focus area (1000 ha)'	I01
'Irrigated area (1000 ha)'	I02
'Utilised agricultural area (1000 ha)'	I03
'Crops Regional Income (M€)'	I04
'Regional Income Irrigated Crop (M€)'	I05
'Energy productivity in irrigated agriculture (M€/ktoe)'	I06
'Energy used in irrigation (Ktoe)'	I07
'Average gross irrigation (m3 per ha)'	I08
'Irrigation water productivity (€/m3)'	I09
'Irrigation water use (hm3)'	I10
'agricultural global warming potential (1000 t)'	I11
Total production of Irrigated Crops (t)	I12

3. Results and discussion

Based on the radar chart below, generally, we find that synergies between WEFE-nexus indicators far exceed conflicts under the two simulated scenarios (WP01 and WP02). In 2030 and 2050, total production of irrigated crops, irrigated Agricultural area present synergies and positively correlated between them, which means that the increase of water price reduces the total production of irrigated crops and irrigated agricultural area. On the same line, it reduces slightly the crops' regional income and regional income from irrigated crops. Hence, the reduction in total production of irrigated crops and irrigated agricultural area leads to a decrease in irrigation water use, and average irrigation water use. As a result, a reduction in energy used in irrigation is caused. However, this reduction in all these indicators improves irrigation water productivity and the productivity of energy in irrigated agriculture under the two simulated scenarios "synergy". Furthermore, the impact of the increased water price is, to a lesser extent, on the level of crops' global warming potential and the utilised agricultural area. In contrast, the ecological focus area remains virtually unchanged.

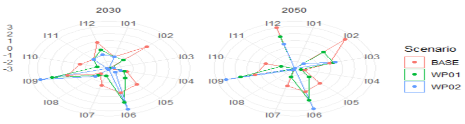
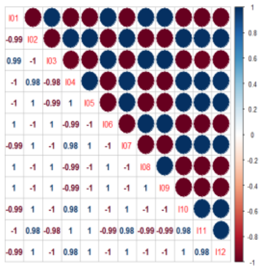


Figure 2: Nexus indicators for the baseline, and the two simulated water price scenarios (WP01 and WP02). Source: own elaboration



From the correlation matrix and under the two simulated scenarios (WP01 and WP02) in 2030 and 2050, tradeoffs and synergies among the twelve indicators mentioned before are shown. The indicators directly affected synergistically by these policies are 'energy productivity in irrigated agriculture (I06)' and 'irrigation water productivity (I09)'because an increase in water price leads to an increase in these two indicators. However, they present trade-offs with the majority of the indicators except for 'average gross irrigation (I08)' and 'utilised irrigated land (I03)'. Furthermore, the two water price scenarios together create synergy between 'total production of irrigated crops (I12)' and 'irrigated agricultural area (I02)' where these indicators show more synergies than tradeoffs with the remaining indicators. Meanwhile, stakeholders pointed out that in this area the reduction of these two indicators can be explained, on one hand, by the substitution of irrigated crops with rain-fed crops (especially, olives for oil) and, on the other hand, by the disappearance of some cereal crops, such as rice. In line with 'total production of irrigated crops (I12)' and 'irrigated agricultural area (I02)', 'irrigation water use (I10)' and 'energy used in irrigation (I07)' present synergies among them as they decrease when the water price increases. This synergy generated by the reduction in 'total production of irrigated crops (I12)' and 'irrigated agricultural area (I02)'. Hence, the increase of water price improves water efficiency, reduces water used by the agriculture sector, and, as results, lesser use of energy for irrigation. Furthermore, as a consequence of the reduction in 'total production of irrigated crops (I12)', 'regional income of irrigated crops (I05)' and 'crops regional income (I04)' decrease and show more synergies with the rest of the indicators except 'energy productivity in irrigated agriculture (I06)', 'irrigation water productivity (I09)', 'average gross irrigation (I08)', and 'utilised irrigated land (I03)'.

4. Conclusion

This study analyses the impacts of the increase of water price on the water-food-energy- environment nexus and uncovers the existing synergies and trade-offs to identify general strategies for sustainable development. Pathways for water simulated from the SDM to achieve sustainable goals in the region of Andalusia (Spain). Hence, to identify conflicts or synergies between simulated policy scenarios obtained from the System Dynamics Model, sustainable indicators and policy goals related to WEFE-nexus are identified through stakeholder engagement. The increase of water price in 2030 and 2050 will lead to improved irrigation water productivity and energy productivity in irrigated agriculture. However, it causes a reduction in the total production of irrigated crops, energy used in irrigation, irrigation water use, irrigated agricultural area, average irrigation water use, to a lesser extent the crops' global warming potential, and the utilised agricultural area in comparison to the baseline. Ecological focus area remains virtually unchanged under the two simulated scenarios. Finally, the increase in water price presents more synergies than trade-offs between the indicators. Meanwhile, it improves the harmonisation between the Nexus 'water, energy, food, land, and climate' and increases the interconnections among them.Overall, this study shows how a combination between systems modelling and participatory approaches helps to analyse policy coherence for sustainability.

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A Water-Energy-Food Nexus approach for evaluating the sustainability of the plant-based Mediterranean-inspired diet: The Case of Lebanon

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1. Introduction

Addressing the food security and water scarcity challenges in Lebanon, and similarly in the MENA region, requires a paradigm shift that acknowledges the nexus between water and energy for food and across sectors (Liu et al., 2017; Giampietro et al., 2013; Howells et al., 2013; Mohtar and Daher, 2016). Problems such as access to clean water, energy, nutritious food, and health care are expected to increase with climate change and changing demographics, and with the current financial and economic collapse in Lebanon. Understanding the interconnectivities between resources will catalyze the tradeoff analysis which is required for the sustainable management of scarce resources (Daher and Mohtar, 2015). A plant-based diet such as the "planetary health diet" proposed by the EAT-Lancet commission, promotes health, and reduces environmental strain (Willet et al., 2019); meat production is the most resource-intensive requiring significantly more land and freshwater resources and generating more GHG per unit of protein than any other food (Ranganathan et al., 2016). The Mediterranean diet is plant-based highly overlapping with the EAT-Lancet recommendation and includes fruits, vegetables and beans, nuts and seeds, whole grains, and seafood omega-3 fatty acids. Therefore, we asked the question: can the Mediterranean diet be produced sustainably in Lebanon and what is the impact on the limited water and energy resources. What are the tradeoffs of water and energy to increase the self sufficiency of Lebanon in the crops that constitute the plant-based diet and how does this impact the environmental footprint? To aid the tradeoffs analysis an excel-based nexus tool will be developed to link the production with the resources used. The tool will be initially developed and tested for Lebanon and will be scaled up to other dryland regions at later stages. The main goal of developing this tool is to evaluate the trade-offs associated with scenarios consisting of different crop choices, water sources, and energy sources.

2. Method

We developed a list of 30 crops commonly used in the Mediterranean and Lebanese diets both of which are consistent with EAT-LANCET recommendations. Current water and energy portfolios for agricultural production include inputs of 1) Irrigation water required to produce one ton of a given crop, equivalent to (evapotranspiration (ET) of crop – rainfall); 2) Land (ha) required to produce one ton of a given crop, calculated using local yield data; 3) Energy (kJ) is considered with two components - energy for water (Ew) and energy for agricultural production (Ea). Ew considers surface and ground water, and treated wastewater as options that require different energy requirements. Ea include the energy required for field operations, and the energy needed for transportation of the crop from farm to market; 4) Financial cost ($), includes two main components: cost of irrigation water, and cost of energy, additional to cost for new infrastructure for water or energy; 5) Environmental impact, CO_2 emissions associated with different scenarios depending on the source of energy used including options of diesel, fuel oil, solar, wind and hydro; 6) Nutrition, The nutritional value of the produced crops is quantified according to the Kcal energy.
To support the scenario evaluation additional to the evaluation produced by the developed tool, a survey of farmers from the Beqaa region, the main agricultural region in Lebanon, will be conducted. The survey will investigate the willingness of the farmers to shift towards more resource-efficient practices and will rank farmers priorities when deciding on resource use such as reducing irrigation water, land requirements, energy requirements, financial costs, environmental impacts and maximizing nutritional value of what they produce.

3. Results

The results from the study will allow for evaluating the sustainability of different scenarios from a resource and nutrition perspective while accounting for the preferences of farmers as they manage their lands into the future. The framework and tool developed in this study could be scaled to other countries in the MENA region. Results and the framework will aid policy making and planning for food security and different levels of self-sufficiency.

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Using system dynamics for resilience management of farming systems

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1. Introduction

Socio-ecological resilience is essentially understood as a system's ability to maintain its functionality even when it is being affected by a disturbance (Folke et al, 2010). While sustainability provides a framework for long-term planning, resilience focuses on adaptive mechanisms that will support a system's functionality in the medium and long-term future. The emphasis on adaptive mechanisms to unpredictable changes has made resilience a compelling forward-looking approach to adaptation (Berkes and Jolly, 2001).
While resilience is a characteristic of the system, resilience management is the active modification of a system with the explicit aim to improve its capacity to absorb and adapt to change (Nettier et al, 2017; Walker et al, 2002). This adaptive capacity depends on the way the system has been organised and the mechanisms embedded in the system structure that drive such response. Resilience management process is not a normative process but a structured and systematic framework that allows stakeholders to adapt to challenges in the environment (Nettier et al, 2017; Holling & Gunderson, 2002).
The aims of resilience management are twofold. First, it seeks to prevent a system from transitioning into undesirable configurations in the face of external shocks. Second, resilience managment aims to develop the enabling conditions that facilitate the system's adaptability (Walker et al., 2002 p. 14).

2. Materials and Methods

In the SURE-Farm project, System Dynamics (SD) is used to understand the feedback loop mechanisms driving systems' responses to external disturbance. SD is a modelling method focused on studying how outcomes of the systems are driven by systems' own internal mechanisms and, in particular, by its circular relationships (feedback loops) between its components (Richardson, 2011).
In this paper we present the results of using a SD model to understand what are the main dynamics that could enable EU farming systems to adapt and bounce back after being affected by an external challenge or disturbance. For this analysis we developed a conceptual SFD representing, at an aggregated level, the main dynamics in EU farming systems. The model is 'conceptual' so that it can be applied to many different contexts and issues (high generality) instead or being problem specific. As Constanza et al., (1993) noted, to achieve high generality, the conceptual models trade off some level of precision and realism. The model was built using description of EU farming systems provided by stakeholders of the case studies investigated in the SURE-Farm project during participatory impact assessment workshops and complemented with the literature.
We use the resulting conceptual SFD to assist our analysis and to identify those feedback loops that are more relevant to the system's response to a disturbance. Since feedback loops are invariably linked to slow variables (like soil resources, biodiversity, etc.), by identifying relevant feedback loops it is possible to identify which slow variables and resources could contribute to resilience improvement (Chapin III et la., 2009). The current status of these particular resources and projections about their future development for a particular scenario can be used to indicate if a system is likely to be able to implement a particular adaptive strategy effectively.

3. Results and discussion

For simplicity in our analysis we focused on challenges that affect directly the production throughput of the farming systems studied. For example, increase in droughts, floods and pests are likely to reduce farming system productivity and hence production throughputs. Lower throughputs will, over time, reduce margins making farming an unattractive economic activity to both new entrants and successors. If EU farming systems are to continue providing its desired outputs (high quality food, jobs in rural areas, ecosystem services, etc.) in the face of such challenges, the systems need more efficient configurations that compensate for temporary losses in productivity.
Using the conceptual model, we identified three potential pathways towards more efficient configurations for EU farming systems. These three alternatives are described using SFD in Figure 1 and can be summarised as:

Alternative 1 Focus on mechanisation and automation: This reconfiguration requires three key resources: farm's capital, farm's cash and workforce availability (to keep costs low).

Alternative 2 Skill based innovation: This reconfiguration requires four key resources: farm's cash, workforce availab*ility*, natural resources (to support high productivity without mechanisation) and human capital.

Alternative 3 Expansion: Increase in size trying to take advantages of economies of scale. This reconfiguration requires three key resources: land, farm's capital and farm's cash.

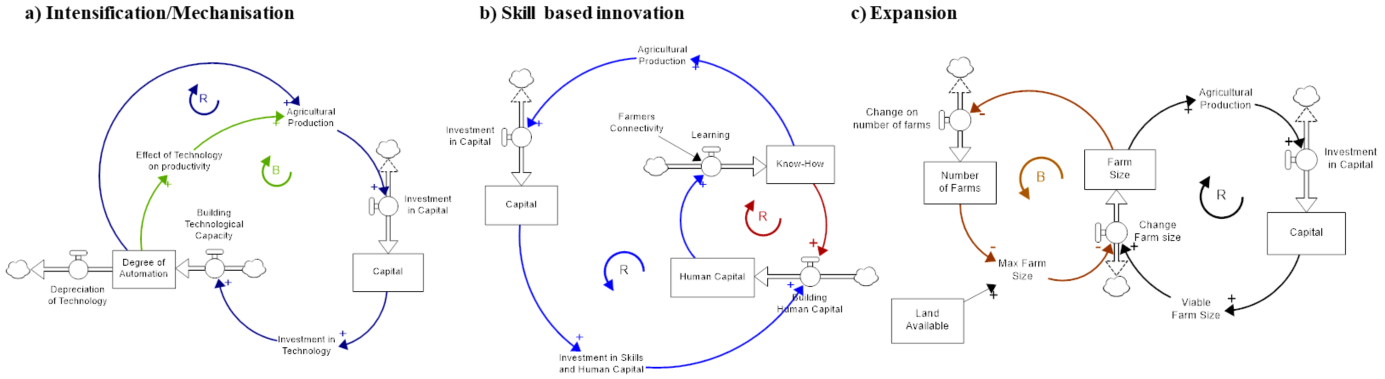

Figure 1: Stock and Flow Diagrams representing the potential adaptation pathways towards more efficient configurations for EU farming systems a) Pathway 1: Intensification/Mechanisation, b) Pathway 2: Skill based innovation c) Pathway 3: Expansion and intensification. ***Note: Actual models are models are more complex that the diagrams shown.***

The resources needed to successfully implement the three pathways presented in Figure 1 are presented in Table 1. Same table shows an assessment of the current status of these resources for the four case studies investigated in this paper. Although it can be argued that all the resources listed are needed for all the pathways, some are closer related to a specific path than others. For example, land available is more important for the 'Pathway 3' (expansion) than for the other pathways.

Table 1. Resource assessment for four farming systems in EU SURE-Farm Project

Alternative	**Resource**	**Mixed farms in the Altmark region Germany**	**Intensive livestock farms in the Bourbonnais, France**	**Hazelnut farms in Viterbo Italy**	**Starch potato production in the Veenkoloniën, the Netherlands**
Intensification/Mechanisation	Degree of automation	Moderate	Low	Low	Moderate
Intensification/Mechanisation	Food market	Moderate	Low	High	High
Intensification/Mechanisation Expansion	Farms' Capital	High	Moderate	High	Moderate
Expansion	Land Available	Moderate	Moderate	Moderate	Low
Skill based innovation	Human Capital	Moderate	Moderate	Moderate	High
Skill based innovation	Natural Resources	Low	Low	Low	Low

4. Conclusion

Our analysis shows that farms are more likely to be resilient in those scenarios where conditions facilitate the development of key resources driving farm potential responses to future challenges. Through understanding of the state of such resources it is possible to make an assessment of how resilient is and might be in the future. Our results show that, in the long-term, some resources that are particularly difficult to build, like human capital, might be more important for fostering resilience than short term benefits like high profits.

Looking at four farming systems in Europe we have observed that expansion and economies of scale are the predominant adaptation pathway with automation and mechanisation being a good viable alternative. We also observed with some concern that more sustainable pathways based on skills and efficient management of natural resources are still lagging behind.

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Co-designing profitable and resilient crop-livestock systems in Niger and Burkina Faso using a household modelling approach

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1. Introduction

The West Africa Sahelian (WAS) countries of Burkina Faso and Niger face serious challenges of water scarcity, frequent droughts, high vulnerability to climate change, food insecurity, gender inequality and widespread unemployment. More than 80% of the population depend on low input- low output rain-fed agriculture and agro-pastoralism for their livelihoods. Prevalence of undernourishment is very high for all section of peoples. Context specific integrated crop-livestock systems are suggested as a key strategy for enhancing resilience of the livelihood systems. The present study therefore undertakes integrated farming system assessment using whole farm modelling to identify the leverage points for achieving higher profitability and resilience under different crop-livestock farm types in the study regions.

2. Materials and Methods

A total of 400 households, 200 from each Niger and Burkina Faso, were surveyed using a detailed survey instrument. These randomly selected households were from Maradi (103) and Tillaberi (97) regions of Niger and Centre-nord (100) and Sahel (100) regions for Burkina Faso. Table 1 describes the basic characteristics of the regions. The cropping systems, agricultural practices and livestock integration differed across regions however both the regions have unfavourable climatic conditions. To develop relatively homogeneous farm typologies, we considered six important livelihood assets (Family size, Number of cattle, Number of small ruminants, Technology adopted, Land size and Access to animal traction). We used principal component analysis (PCA) and k-cluster mean method to categorise households into three relatively homogenous farm types each for both the countries. Afterward using Integrated Assessment Tool (IAT)[1] also known as whole farm modelling tool, the baseline as well as different alternative intervention scenarios were generated.

Country	Region	Characteristics
Niger	Maradi and Tilabery	✓ Mixed crop-livestock systems ✓ More than 41% of the country's livestock are located on the transect Maradi-Zinder ✓ Livestock diseases, seasonal feed shortage and water scarcity particularly during the dry season. ✓ Crop-livestock systems are gradually changing from the traditional extensive system to semi-intensive and intensive system
Burkina Faso	Centre-nord and Sahel	✓ Agro-pastoral activities account for nearly 90% of the labor force ✓ Low availability of labour for agriculture activity ✓ Unfavorable climatic conditions, poor access to improved technologies and market ✓ Seasonal fluctuation in feed resources with acute shortage in the dry season, lack of water for animals, high mortality of animals, problem in livestock services delivery

Table 1. Study locations and basic characteristics

3. Results and discussion

3.1. The Base model

Initially the study considered baseline household situation for the three farm types over a 5-year period (Table 2). It was found that cowpea, sorghum, millet and groundnut are the major annual crops for both locations, whereas tree crops were more important in Niger households for their livelihood. Table 3 describes the average net income and share of different components in details. In Niger the cattle rearing contributed more than one third of household's total income for all farm types. Besides annual crops, the tree crops were also an important source of farm household income in Niger. The small ruminants contribute about 8% to 12%. The share of annual crops to household income in Burkina Faso was much higher at 37 to 49%. The tree crops were not so economically important in the study area in Burkina Faso. The potential impact of different scenarios on households' income is discussed in the following section.

Country	Farm type	Cultivated land (Ha)	Tree crops	Annual crops	Livestock (No)		
					Cattle	Goat	Sheep
Niger	1	1.890	Balanites (Balanites aegyptiaca), Diney (Sclerocarya	Cowpea, Millet, Sorghum	4	3	2

[1] For further details about IAT please go through https://research.csiro.au/livegaps/tools/integrated-analysis-tool-iat/

	2	2.734	birrea), Farou (Lannea acida), Doum palm tree (Hyphaene thebaica), Tokoye (Diospyros mespiliformis)	Cowpea, Millet, Sorghum	5	5	3
	3	6.525		Cowpea, Millet, Sorghum, Groundnut	8	7	6
Burkina Faso	1	4.080	Karité (Vitalaria paradoxa) and Néré (Parkia biglobosa)	Cowpea, Millet, Sorghum	7	4	4
	2	4.661		Cowpea, Millet, Sorghum, Groundnut	6	4	4
	3	6.320		Cowpea, Millet, Sorghum	16	12	10

Table 2. Key characteristics of three farm household types for Niger and Burkina Faso

Country	Particulars	Farm type1	Farm type2	Farm type3
Niger	Tree crop	473 (39)	571 (39)	597 (23)
	Annual crops	192 (16)	286 (19)	597 (23)
	Cattle	444 (37)	512 (35)	1144 (44)
	Small ruminants (SR)	97 (8)	105 (7)	275 (11)
	Total net farm cash flows	1204 (100)	1474 (100)	2611 (100)
Burkina Faso	Annual crops	519 (49)	571 (48)	850 (37)
	Cattle	425 (40)	482 (41)	1190 (52)
	Small ruminants (SR)	120 (11)	128 (11)	270 (12)
	Total net farm cash flows	1062 (100)	1178 (100)	2309 (100)

Table 3. Baseline farming system cash flows under three farm household types in Niger and Burkina Faso (USD/annum)

Note: Values in the parenthesis indicate percentage to household's total farm cash flows

3.2. The scenarios

To find out the most important and feasible strategies for enhancing profitability and resilience as compared to baseline farming system situation, the present study considered thirteen different alternative intervention scenarios for both the countries. We have run the scenarios separately for all three farm groups and the change in profit (%) as compared to the baseline have been depicted in Table 4. In Niger, scenarios 1 to 4 and scenario 13 were the most profitable five best scenarios which would result in highest increase in income. The farm household income is likely to increase by 11% to 80% for farm type-1, 21% to 76% for farm type-2 and 27% to 84% for farm type-3 as compared to base scenario. Scenario 1 to 3, scenario 10 and scenario 13 were the five most profitable scenarios for Burkina Faso. In these scenarios the increase in income as compared to baseline ranged from 30% 45% for farm type-1, 25% to 37% for farm type-2 and 10% to 24% for farm type-3.

Alternative intervention scenarios	Niger farm type			Burkina Faso farm type		
	1	2	3	1	2	3
1. Improved Cattle (replaces the local cattle)	64.6	44.2	44.3	5.0	14.2	4.6
2. Improved (Cattle+Millet)	75.7	72.1	78.8	31.5	25.2	16.4
3. Improved (Cattle+Millet+SR)	76.9	72.0	82.9	31.9	25.6	16.8
4. Improved (Cattle+Millet+SR) + 15% extra price of livestock	80.4	75.8	84.3	44.6	31.4	24.2
5. Improved Millet	9.3	21.2	27.3	24.4	19.9	7.2
6. Improved small ruminants (ISR)	5.8	6.1	3.2	0.4	0.4	0.4
7. Prophylaxis (SR)	1.0	8.1	1.1	2.2	2.0	1.8
8. ISR + Prophylaxis	6.4	9.3	4.5	2.7	2.5	2.2
9. ISR + Prophylaxis + 15% increase in price of ISR	8.6	10.8	6.4	4.8	4.2	4.5
10. 50% local Cattle + 50% improved Cattle	10.1	9.8	8.7	29.7	37.2	14.0
11. 30% legume area shifted to millet	0.0	7.1	1.2	1.7	1.0	-0.8
12. 30% millet area shifted to legumes	-0.7	3.6	-2.5	-3.0	-0.5	1.0
13. 30% legume area shifted to improved millet	10.9	25.8	32.3	30.8	28.4	9.9
14. Improved cowpea	1.6	1.2	8.0	6.5	16.2	1.0

Table 4. Potential impact of different interventions on farm household cash flows (% change from the baseline scenario)

4. Conclusions

The study identifies a number of potential intervention scenarios for enhancing the household cash flows and resilience as compared to their respective baseline scenarios in Niger and Burkina Faso. For specific farm types, the models reveal the most promising crop and livestock value chain interventions. Introducing improved cattle, improved millet cultivars and appropriate allocation of area between legume and millets, prophylaxis in livestock and increased price through market linkages were the most effective interventions to enhance farm household cash flows, however each intervention will not work for all farm types. The study concludes that not only crops but the context specific integrated crop-tree-livestock value chain interventions will be the most effective strategy for improving rural livelihoods and food security in these vulnerable regions.

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Analysis of Options for Enhancing the Large-Scale Adoption of Conservation Agriculture Practices in Small-Mixed-Farming Systems of North Africa: Case of Tunisia[a]

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1. Introduction

Conservation agriculture (CA) has the potential to address long-suffered paradox of financial viability of farms with environmental degradation. CA is characterized by linked principles of minimal (to zero) tillage, mulching and crop diversification (Giller et al. 2011). Though being widely promoted, CA adoption is still low and slow in small, integrated crop-livestock systems of North Africa. In Tunisia, in particular, associated constraints are the small size of farms, the low investment capacity of farmers who are unable to afford Zero Tillage machinery, and the nature of mixed agricultural production systems where an abundance of livestock creates significant demand for feed (Frija, 2017). The latter indicates a dilemma for farmers who are challenged by trade-offs of using crop residues as mulch under CA instead of grazing it during the dry summer periods.
This paper intends to explore the economic feasibility and the effects of some technical packages allowing for better crop-livestock integration under conservation agriculture (CLCA) that can potentially be adopted by mixed farming systems of Northern Tunisia. Specifically, this paper aims to (1) to identify and characterize different farm types in terms of their level of integration between crops and livestock activities, and (2) to build an appropriate farm model for ex-ante impact assessment of some CLCA technical packages on the identified farm types, with focus on the economic performances of farms and trade-offs of biomass use in alternative activities. Results are expected to identify appropriate technical solutions that can enhance the adoption of CA in the studied small, mixed farming systems.

2. Materials and Methods

The methodological framework used in this study entailed a combination of farm typology and farm model simulation. The data used came from a comprehensive survey of 365 farms from the north-eastern part of Tunisia conducted in 2014. The data describes the cropping systems, farming and tillage practices, crop choices, livestock management and feeding strategies, structural and economic variables, and farmer perceptions of the study farms.
First, farm typology was identified to categorize the farms according to their level of crop-livestock integration. Next, farm models were developed for each of the identified farm types to represent the economic and technical attributes of farm production systems. The model used was an optimization model which optimizes an objective function that maximizes farm net income without violating a set of constraints (i.e. land area allocation, number of sheep the farm can maintain, etc.). A calibration technique, namely standard positive mathematical programming approach, was applied to ensure that the farm model exactly calibrates the observed data to avoid over-specialized, unrealistic model solutions. Finally, scenario analyses were carried out to simulate and analyze the effects of CLCA technical packages (TP) in the farming system in terms of farm output (income and available animal feed in terms of fodder units, UF) and activity levels (land allocation and herd size) and to identify which TP would lead to maximum net farm income. TPs that are relevant to increasing biomass resource that can potentially enhance the crop-livestock integration were considered. Specifically, these options were (1) optimized stubble grazing strategies through optimized crop residue retention and (2) increased fodder availability through optimized production of a suitable crop which is barley. These TPs were the basis for elaborating alternative scenarios in farm modelling and were evaluated against the baseline scenario (BAS) which represents a set of 'average' farm activity levels for each farm type. Consequently, three alternative scenarios were simulated. Scenario TP1 examined the effects of optimized crop residue retention through an increase from 10% (BAS) to 30% of crop residue retained in the field as mulch which is the recommended CA-based mulching. This also means a decrease from 90% to 70% of crop residue used as animal feed. Scenario TP2 evaluated the effects of optimized barley production through an increase in barley yield by 30%. Scenario TP3 entailed simultaneously retaining 30% of crop residue in the field and increasing barley yield by 30%.

3. Results and discussion

Farm typology. Three farm clusters were typified according to the level of integration between their crop and livestock activities. Farm 1 cluster (n=133, 36.6%), with an average of 16.5 ha of agricultural land and 17 sheep, was categorized as more-integrated farm type. More than half of its land is left as fallow land, with only 32% allocated for cereal production – the least share compared to the other farms. Its crop and livestock enterprises share almost equally to the total income accounting to 60%. Crop rotation with legumes is only observed in a very small proportion of the total land area. The share of the value of farm-produced feed to total feed cost only accounts for 6.9%, though small, it is the highest compared to the rest of the farms. Farm 2 cluster (61%, n=223) was

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identified as less-integrated farm and the most dominant farm type. On the average, Farm 2 is slightly smaller in land (14.2 ha) and herd size (15 heads) but generated more than double the average farm income of Farm 1. Moreover, crop and livestock enterprises contributed 84% of the total income. With 70% of the its land allocated for cereal cultivation, particularly of wheat and barley, crop production contributes more than half of the total income, making this farm to be considered as crop-producing farm. Crop rotation with legume is practiced in small portion of their land. This existing legume production is a potential source of fodder for livestock. However, the share of value of own-produced feed to total feed cost is relatively lower in Farm 2 compared to Farm 1. Still, they spend lesser in livestock maintenance per head compared to Farm 1. Farm 3 (2.5%, n=9) is considered large-scale and is very different from the rest of the sample farms and thus considered to be an outlier cluster. Model simulation and analysis was not performed for Farm 3.

Farm model simulation. Table 1 summarizes the effects of identified TPs on farm structure (land area and livestock size), animal feed availability (in terms of UF) and farm income in comparison to the baseline level (BAS), per farm type. Simulation results showed that, for both farms, adopting CA-based mulching (TP1) has no income effect though it reduces the available animal feed at the farm-level. The reduction in UF availability is slightly higher in more-integrated farm system, Farm 1 (-17%), compared to farms with lower crop-livestock integration, Farm 2 (-15.3%). Moreover, the reduction of available UF did not affect land allocation and herd size for both farm types. In other words, crop residue retention reduces the available animal feed in the farm-level, but not to a point of posing a threat to the livestock component. This is because crop residues have low nutritive value and only has congestion effect to the animals, and thus used only as supplementary feed. This implies that even with the reduction of crop residue for feed, the farm can maintain its current herd size, given that the animals' minimum nutritional requirements are met from other sources such as concentrates and other grain feed. Results from simulating Scenario TP2, where barley production was optimized, showed a minor farm income increase for both farm types. The income effect is marginally higher in lesser-integrated Farm 2 (1.19%) compared to more-integrated Farm 1 (1.27%). The increase in income is small since the yield level is also very small to begin with. Besides, based on the survey data, only 20% of the barley grain yield is marketed and income-generating, while the rest is used as grain feed for animals. Moreover, the income increase is hardly significant that it did not affect any other farm components or activities. Scenario TP3 led to a minimal income increase as triggered by improved barley production but reduced the available UF at the farm-level caused by crop mulching. Yet, land allocation and herd size remained unchanged. This implies that, when adopted together, mulching and improved barley productivity will bring about the optimal improvement in the objective of the farm, maximizing income, while also enhancing crop-livestock integration of the farms by addressing the needs of both the animal and the soil. With these perceived benefits, CA may be attractive to farmers to adopt. Noteworthy, the overall benefit of the combined CA options is slightly higher among farms with lower crop-livestock integration (Farm 2) compared to the more integrated farms (Farm 1).

Table 1. Summary of simulation results of the effects of CLCA technical packages, per farm type, average (% Δ)

Variables	BAS		TP 1		TP 2		TP 3	
	Farm 1	Farm 2	Farm 1	Farm 2	Farm 1	Farm 2	Farm 1	Farm 2
Durum wheat (ha)	2	3	2 (0)	3 (0)	2 (0)	3 (0)	2 (0)	3 (0)
Soft wheat (ha)	1	1	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)
Barley (ha)	3	4	3 (0)	4 (0)	3 (0)	4 (0)	3 (0)	4 (0)
Oat (ha)	1	1	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)
Fallow Area (ha)	9	4	9 (0)	4 (0)	9 (0)	4 (0)	9 (0)	4 (0)
Grazing Area (ha)	7	5	7 (0)	5 (0)	7 (0)	5 (0)	7 (0)	5 (0)
Sheep (head)	17	15	17 (0)	15 (0)	17 (0)	15 (0)	17 (0)	15 (0)
UF available	23,390	22,980	19,410 (-17)	19,460 (-15.3)	23,390 (0)	19,460 (0)	19,410 (-17)	19,460 (-15.3)
Income (TND)	7,442	9,295	7,442 (0)	9,295 (0)	7,531 (1.19)	9,413 (1.27)	7,531 (1.19)	9,413 (1.27)

Remarks: % Δ is the percentage change against the baseline scenario (BAS); TND 100 = USD 33
Source: Author's computation based on the CLCA Baseline data survey.

4. Conclusion

Results of this study provide two important insights. First, there can be a compromise of using crop residue in the farm to feed the animals while also 'feeding' the soil or practicing CA-based mulching in mixed crop-livestock farms of Northern Tunisia. This implies that the trade-off of crop residue use for animal feeding and soil mulching is not as restricting in CA adoption as previously concluded. Second, to benefit more from crop residue retention, the practice must be partnered with optimizing barley production under CA system. The combined effect of these two CLCA packages would lead to favorable benefits – increased income and enhanced crop-livestock integration by feeding both animals and the soil. These advantages make CA more attractive among small, mixed farming systems. In addition, it can be said that the promotion of CA principles, as a whole, will result to maximum potential benefit, both financially and environmentally, rather than adoption of single technologies.

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FSD7-Webinar 2

Designing climate smart and resilient cereal-livestock based farming systems for food and nutrition security in the drylands of Africa and Asia

Date: 23 March 2021

Chaired by Zvi Hochman (CSIRO, Australia) and Lamiae Ghaouti (IAV Hassan II, Morocco)

Objectives
Farmers design their farming systems by manipulating their crop-livestock balance, cropping intensity, the diversity of their crops and crop types and the level of exogenous inputs within the limits of their land, labour and other resources. Will dryland farming systems that have evolved to be resilient to historical weather patterns and socio-economic circumstance stand the test of time over the next thirty years or will transformational changes be required to adapt to a future climate in 2050 and beyond? Dryland agriculture is both vulnerable to the impacts of global warming and a significant contributor to the greenhouse gas (GHG) emissions that cause it. To be resilient to global change, farming systems need to achieve household food security and nutrition goals while reducing vulnerability to a warmer and increasingly variable climate. To be climate smart, these systems will balance these objectives with the need to reduce GHG emissions and to conserve natural resources. This webinar will discuss issues, challenges and case studies relating to co-design of resilient climate smart cereal-livestock farming systems.

Program and speakers

- A short introduction on objectives and expected outcome of the webinar (*Zvi Hochman*, 5 min.)

- **Selected presentations:** 12 min. presentation and 8 min. discussion
    1. Adapting rainfed farming system to potential climate change impacts through Sustainable practices (*Youssef Brouziyne*, Mohammed VI Polytechnic University, Morocco)
    2. Adaptation to climate change in pastoral areas: determinants and complementarities in Senegal (*Assane Beye*, Université Cheikh Anta Diop of Dakar, Senegal)
    3. Adaptation strategies of oasis agricultural production systems in south-eastern Tunisia to climate change (*Houcine Jeder*, Arid Regions Institute (IRA), Médenine-Tunisia)

- Conclusion and summary (*Lamiae Ghaouti,* 5 min.)

Adapting rainfed farming system to potential climate change impacts through Sustainable practices

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1. Introduction

At a global scale, the potential impacts of climate change on agricultural productivity are an important concern for decision makers, investors, and population. Global farming systems are supposed to support both current and future growing demand for food worldwide; thus increasing productivity, especially for the mid and long term, should be lead through the adaptation of agricultural systems to projected climate change (Brouziyne et al. 2018). Many development international agencies and organizations believe that there is still an opportunity to preserve ecosystem balances and are claiming for nature based and sustainable strategies to prepare farming activities to future climate impacts (Mrabet, 2001). Rainfed agriculture was always playing crucial role in food security and social integrity for many populations around the world. This farming mode is representing around eighty per cent of the global agricultural lands and is characterized by low yield levels and high vulnerability to climate effects (Mrabet et al.2012). Rainfed agriculture in Morocco is particularly vulnerable to the uneven spatiotemporal distribution of rainfall, and is expected to be more vulnerable to the projected climate change especially in arid and semi-arid areas; this problematic will inevitably put the national economy at risks (Zahour et al.2015).
The main purpose of this work is assessing rainfed crops' productivity in a semi-arid watershed, R'dom watershed, under two RCP scenarios (4.5 and 8.5) downscaled from a regional circulation model in the near future (2031 to 2050). Soil and Water Assessment Tool (SWAT) model has been used to simulate a set of sustainable practices to build more resilient farming systems in the area. Results will help to understanding potential climate change impacts on strategic rainfed crops in a typical agro-forestry watershed in the Mediterranean area, and contribute to more adapted agricultural systems in any watershed similar to R'dom.

2. Materials and Methods

Located in the north eastern of Morocco, R'dom watershed is covering an area of 1993km^2 and includes two large plains (Saiss and Gharb). Being a part of one of the largest hydrologic watersheds in Morocco (Sebou basin), R'dom watershed is characterized by a semi-arid climate and has a big socio-economic importance due to the activities held inside it (farming and forestry activities) (table 1).
SWAT soil database was updated by a set of inputs data that have been collected with very high attention: digital elevation model (DEM) of R'dom basin has been extracted from the Shuttle Radar Topography Mission (SRTM) with a resolution of 30 meters, soil map of the study watershed based on findings of a study performed by the Moroccan Minister of Agriculture (1/100,000 scale), Land cover based on two LANDSAT8 satellite images (30m resolution),observed weather parameters including daily temperature (max and min) records from 9 weather stations and daily rainfall from 4 recording stations in and around the watershed (from January 2003 to December 2010).

Table 1. Occupation percentages of major land covers in R'dom watershed

Land use categories		Percentage (%)
Residential centre		3.69
Forest (Oak)		7.98
Pasture & Barren		42.03
Wetlands/Lakes		1.71
Agricultural lands	*Wheat*	*12.23*
	Corn	*9.83*
	Olive trees	*10.59*
	Onion & potatoes	*7.21*
	Sunflower	*4.73*

Table 2. Considered farming patterns for winter wheat and sunflower

Farming Practice	Winter wheat	Sunflower
Sowing date	1st November	20th March
Harvest date	1st June	1st July
Tillage techniques	Chisel plow + Disk harrow	Disc plow + Disc harrow
Fertilization N-P-K (kg/Ha)	90-70-80	110-30-40

Winter wheat and sunflower were chosen as target crops for this study. The conventional practices used are given in Table 2. Farming practices features were amended according to the real agronomic practices held in R'dom watershed, especially the operations that can have an effect on water cycle such as: season calendar, irrigation management, tillage machinery and frequency...etc (Table 2). In this study, optimal fertilization was supplied to crops so as not be considered a limitation factor to plant growth; only heat and water stress (due to potential climate change impact) were taken into account.
The used climate change scenarios in this study were generated from the output of two RCPs (4.5 and 8.5) of the global climate model CNRM CM5 (*Centre National de Recherches Meteorologique*) based on IPCC Assessment Report (AR5). There are 4 different types of Representative Concentration Pathways (RCPs): RCP 2.6, RCP4.5, RCP6.0 and RCP 8.5 that represent different alternatives of global development. Grid size was 12.5 km and the baseline was from January 1981 to December 2005. The future simulation period for both precipitations and temperature (max and min) was from January 2031 to December 2050.

3. Results and discussion

The analysis of the downscaled RCM data revealed that the area will definitely experience rainfall and mean temperature increase in the period 2031 to 2050 for both emission scenarios. In general, a cumulative decrease of annual rainfall by-172.9 mm and -213.6 mm are expected under RCP4.5 and RCP8.5 respectively. Temperature increase is also expected (+1.1°C and 1.7°C respectively for RCP4.5 and RCP8.5).

Table 3. Average values of future crops water productivity and water yield, and their changes to baseline

		Wheat CWP *(kg/m^3)*	Sunflower CWP *(kg/m^3)*	Water yield *(mm)*
RCP4.5	Values average	0.56	0.32	71.17
	Change to Baseline	-18.8%	-15.7%	-20.2%
RCP8.5	Values average	0.54	0.21	65.67
	Change to Baseline	-21.7%	-44.7%	-26.4%

Running SWAT model in R'dom watershed using future climate variables allowed the investigation of future water resources and crops performances in the study area; table 3 represent both values and changes of future crops water productivities and water yield from baseline situation. A clear decline of crop water productivities of both crops (wheat and sunflower) and water yield in the R'dom watershed is expected under both climate change scenarios. The extent of change is clearer under the pessimistic scenario for both crops and for the water resources too.

In order to investigate potential adaptation opportunities of wheat and sunflower to climate change in R'dom watershed, a set of sustainable management strategies were simulated using the calibrated SWAT model over the study area and using the projected climate variables under RCP4.5 and RCP8.5. The selected adaptation strategies were built from the combination of three cropping techniques: No tillage, Early sowing by 10 days and by 20 days from the standard sowing date adopted by local farmers.

In overall, 5 different combinations of adaptations strategies were considered: No tillage (NT), 10 and 20 early sowing days (ESD-10 and ESD-20 respectively), and a combination of no tillage and sowing dates change: NT+ESD-10 and NT+ESD-20. While simulating the adaptation strategies, future total water yield (WYLD) was monitored too as we believe that adapting crops to climate change should not be at the expense of local water resources.

After running SWAT model using the selected adaptation strategies (separately), an analysis of the change to baseline scenario has been carried out; the table 4 represent simulation results.

Based on these results, both adapting wheat and sunflower crops and preserving water resources in R'dom watershed to future climate change is possible. Most of the simulated adaptation strategies gave good results on at least one variable; and some strategies leaded to inconsistent results across the parameters and the scenarios. Generally, the no tillage (NT), sowing earlier by 10 days (ESD-10), and no tillage and sowing earlier with 10 days (NT+ESD-10) gave the most consistent (positive) change over the three parameters and under the both RCPs.

Table 4. average changes from baseline of crops water productivity and water yield after simulation of the adaptation strategies

	RCP4.5			RCP8.5		
	Wheat CWP *(kg/m^3)*	Sunflower CWP *(kg/m^3)*	WYLD *(mm)*	Wheat CWP *(kg/m^3)*	Sunflower CWP *(kg/m^3)*	WYLD *(mm)*
NT	+21.4%	+56.3%	+7%	+16.7%	+57.1%	+5%
ESD-10	+14.3%	+3.1%	+2%	+14.8%	-4.8%	+1.70%
ESD-20	+5.4%	-40.6%	+3.80%	-7.4%	-23.8%	+3.40%
NT+ESD-10	+25.0%	+3.1%	+1.50%	+18.5%	0.0%	+2%
NT+ESD-20	0.0%	-40.6%	+4%	-3.7%	-23.8%	+6.40%

4. Conclusion

This study attempts to investigate potential opportunities to curtail the vulnerability of two of key rainfed crops in Morocco to future climate change impacts. Results showed that SWAT model succeeded in replicating responses of both hydrology processes and crops development occurring in the study area; both processes will undergo significant effects of climate under both scenarios (RCP4.5 and RCP8.5). The simulated sustainable adaptation strategies showed promising results as water resources' preservation and increase of crops water productivity is possible according to our SWAT's simulations over R'dom watershed conditions. Among the simulated strategies, The no tillage one gave the best compromise between crops productivity, water use efficiency and water resources in the watershed. In the meanwhile, sowing 10 days earlier than usually offers good overall effectiveness to overcome the climate change impacts in the future; combining this strategy with no tillage, gives very promising results as well.

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Adaptation to climate change in pastoral areas: determinants and complementarities in Senegal

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1. Introduction

Several empirical studies have shown the importance of adaptation strategies to mitigate the impacts of climate change on rural activities. Rather than assuming independence between the different adaptation options, the multivariate probit model that is used relies on the assumption that adaptation decisions can be made jointly and thus tests independence, substitute or complementary between them (Mengistu & Haji, 2015; Getachew et al., 2014). Second, these studies are more geared towards crop production. Nonetheless, short-term variability or lack of precipitation generally influences livestock activities, either by lowering productivity or by depleting herds with potentially disastrous consequences for the well-being of rural households (Fabricius et al., 2007). The objective of this paper is to investigate the determinants of adaptation strategies; and analyze the joint or independent nature of adaptation decisions.

2. Materials and Methods

The theory of decision-making suggests that decision-makers react differently to risks or threats (Tversy & Kahneman, 1992). Although adaptation is intrinsically local, the identification of its explanatory factors should make it possible to understand the necessary mechanisms and institutions which will allow the transition from simple reactive responses to climate change and extreme events to strategic and sustainable action in socio-economic systems (Agrawal & Perrin, 2009).

A representative household i decides to implement an adaptation strategy if the expected utility, if she adapts U(π_1), is greater than the expected utility if she does not adapt U(π_0) (Di Falco et al., 2011). We note this difference A_i^* so that A_i^* >0 corresponds to the case the benefit of using the adaptation strategy is greater than that of not using it:

$$A_i^* = E[U(\pi_1)] - E[U(\pi_0)] > 0 \qquad (1)$$

where E(.) is the expectation operator based on the subjective distribution of the uncertainty variables facing the decision maker, and U(.) is the von Neuman and Morgenstern utility function representing household preferences.

However, A_i^* is a latent variable that is not observable. What is observed is A_i, which represents the observed behavior of the farmer with regard to the adoption of the technology. The latent variable is specified as follows:

$$A_i^* = Z_i\alpha + \eta_i \quad with \ A_i = \begin{cases} 1 & si \quad A_i^* > 0 \\ 0 & otherwise \end{cases} \qquad (2)$$

The household i chooses to implement an adaptation strategy ($A_i = 1$) to cope with long-term climatic variations if A_i^*>0, otherwise $A_i^* = 0$. Equation (2), called selection, represents a probit model of the implementation of an adaptation strategy, where Z is a vector of explanatory variables; α is a vector of unknown parameters to be estimated, and η_i is a random error term with zero mean and variance σ^2. The error term includes measurement error and unobserved factors.

The analytical approaches commonly used in adoption studies involving multiple choices are the multinomial logit (MNL) and multinomial probit (MNP) models (Tazeze et al., 2012). The MNL model provides a simple form for calculating probabilities without any multivariate integration with the independence of irrelevant alternatives (IIA) assumption which states that the ratio between the probabilities of choosing two alternatives is independent of the attributes of any other alternative in the choice set (Hausman & McFadden, 1984). Specifying the MNP for discrete choice models does not require the IIA hypothesis (Hausman & Wise, 1978). In addition, it takes into account joint decision-making by breeders and the potential correlation between adoption decisions (Marenya & Barrett, 2007). Consequently, the estimated correlation coefficients make it possible to analyze the complementary or substitutable nature between the adaptation strategies. Thus, positive correlation coefficient indicates that the two adaptation options are complementary and can be used simultaneously by the breeder. Negative correlation coefficient means that they are substitutes. The model is specified as follows:

$$Y_i = X_i\beta_i + \epsilon_i$$

where Yi represents the adaptation options which include increasing mobility (distance and frequency), change in water management, storing livestock feed, diversifying activities and changing management of the herd and Xi represents the factors likely to influence the adaptation decision such as climatic variables, the socioeconomic characteristics of the household head, social capital and the household assets.

3. Results and discussion

The results show that 73.7% of the households use at least one adaptation strategy to cope with climate change, the main ones being the storage of animal feed, the increase in mobility which are implemented by 94% and 50% of the surveyed households, respectively. The other adaptation strategies include change in water management (20.9%), diversification of economic activities

(10.9%) and change in the composition of the herd (30.1%). The results also show that the adaptation decisions of pastoral households are therefore taken jointly. While increased mobility is negatively correlated with most adaptation strategies, the storage of livestock feed is complementary to diversification of economic activities.
The identification of the determinants of adaptation provides a profile of the households that use the different adaptation strategies. Thus, livestock feed storage is likely to be used by wealthy households, living in areas with declining rainfall and temperature and which received state support during the last drought in 2014 even though the household head does not belong to breeders' organizations and does not have access to early warning systems. The increase in mobility is likely to be implemented by households located in areas which receive low rainfall, distant from markets where the household head has access to early warning systems but not to credit with a low level of food security. Change in water management is used by households living in areas with low rainfall and temperature, of which the head of household is educated with a low wealth index. Diversification of economic activities tends to be used by households living in vulnerable areas due to the number of droughts suffered since 2000 but with high rainfall and high temperature, the head of the household is young and does not have access to early warning systems.
The high significance of the LR shows that adaptation decisions are taken jointly. Thus, adaptation strategies can be complementary when the correlation coefficient is positive, substitutable when it is negative or independent if the correlation coefficient is not significant. The results show that the change in mobility is not compatible with either the storage of livestock feed, the change in water management, or the change in herd management. They are then substitutes. Thus, pastoral households use either mobility or these other adaptation strategies to cope with climate change. This result can be explained by the fact that, unlike other strategies that are carried out at the farm level, mobility requires a trip outside the farm. There is also a substitutability between the diversification of economic activities and the change in water management. Moreover, the correlation coefficient between mobility and the diversification of economic activities is not significant; they are thus independent. The diversification of economic activities is complementary to the change in water management. In other words, pastoral households that use diversification of economic activities also tend to use livestock feed storage.

Tableau 1. *Estimated correlation coefficients*

	Coef.	Std. Err.	z	P>z
$rho_{Storage\ Mobility}$	-0.55***	0.08	-6.63	0.000
$rho_{Gesteau\ Mobility}$	-0.22**	0.10	-2.24	0.025
$rho_{Diversif\ Mobility}$	-0.18	0.11	-1.59	0.111
$rho_{Gestroup\ Mobility}$	-0.48***	0.10	-4.97	0.000
$rho_{Gesteau\ Storage}$	0.03	0.12	0.26	0.796
$rho_{Diversif\ Storage}$	0.32**	0.16	2.03	0.042
$rho_{Gestroup\ Storage}$	-0.08	0.14	-0.55	0.582
$rho_{Diversif\ Gesteau}$	-0.27*	0.16	-1.69	0.091
$rho_{Gestroup\ Gesteau}$	-0.12	0.11	-1.02	0.306
$rho_{Gestroup\ Diversif}$	0.10	0.13	0.77	0.443

Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho32 = rho42 = rho52 = rho43 = rho53 = rho54 = 0; chi2(10) = 63.5566 Prob > chi2 = 0.0000

4. Conclusion

This paper analyzes the socio-economic determinants of adaptation options in pastoral areas and investigates whether adaptation strategies are used jointly as complements or substitutes. Multinomial probit model is used to analyze adaptation options, using primary data collected from 410 herders in Senegalese drylands. Moreover, the results show that the adaptation decisions of pastoral households can be taken jointly. Actually, the increase in mobility is negatively correlated with most adaptation strategies, whereas the storage of livestock feed is complementary with the diversification of economic activities. The diversity of factors explaining adaptation choices calls for targeting policies to promote adaptation strategies to strengthen the resilience of pastoralists.

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Adaptation strategies of oasis agricultural production systems in south-eastern Tunisia to climate change

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1. Introduction

In south-eastern Tunisia, The oases of Gabès have been known in recent decades, an accentuated degradation of their natural resources and their plant heritage (overexploitation of water and soil resources, urbanization and transformation of the characteristics of agricultural production systems). We can deduce that the climate change remains the main factor behind this degradation. For this, the purpose of this paper is to identify the determining factors of adaptation strategies in agricultural households in the oases of south-eastern Tunisia to climate change.

2. Materials and Methods

Case study: The Métouia oasis is one of the coastal oases of the governorate of Gabès. It is located 12 km north of the city of Gabes (south-eastern Tunisia) and covers an area of approximately 270 ha (Figure 1). The oasis farms cover very small areas of around 1.5 ha on average (Grira *et al*., 2002; Hatira *et al*., 2002).

Data type and sources**:** Data used in this analysis were collected from a 50 household farms survey conducted in Métouia oasis. Data were gathered at the household level on socio-economic characteristics, agricultural production system and extension institutions.

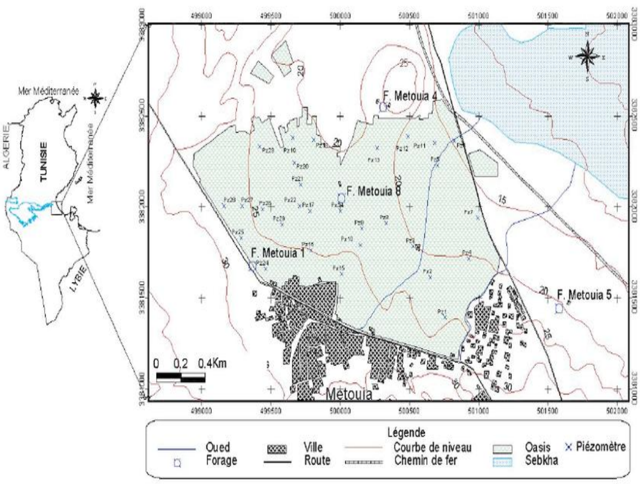

Figure 1 - Location map of the Métouia oasis, south-eastern Tunisia

Binary probit models*:* Binary probit models can also be motivated by an underlying continuous latent variable yi * which depends on β‘xi and an error term εi (for i = 1… n) as in the case of equation 1(Agossou, S. 2008). However, latent variables are not observable. But they can be related to the observed binary dependent variables yi:

$$y\ (Farmer's\ strategies) = \begin{cases} 1\ if\ \ y_i^* \ \geq 0\ , adopt\ strategies\ j \\ 0\ if\ \ y_i^* \ < 0\ , not\ adopt\ strategies\ j \end{cases} \qquad (1)$$

Where $Y* = \ \beta_0 \ + \ \beta_1 x_1 + + \beta_2 x_2 + \ \beta_3 x_3 + + \beta_3 x_3 + \ \beta_4 x_4 + + \beta_5 x_5 + + \beta_6 x_6 + \ \beta_7 x_7 + \ \beta_8 x_8$

Y* (Farmer's strategies) = 1 (adopt strategies j), 0 (not adopt strategies j). ; x_1 = Ages of farmer (years), continuous (in number) ; x_2 = Level of education (ordered), 1 (literate), 2 (primary), 3 (secondary), 4 (university); x_3 = Main agricultural activity, binary (1 if agriculture, 0 other); x_4 = Place of residence, binary (1 if on the farm, 0 outside); x_5 = Farm size, continuous (in hectare); x_6 = Type of agricultural production system, ordered (3-stage system, 2 classic system, 1 otherwise); x_7 = Agricultural land owner, binary (1 if farm owner, 0 other); x_8 = Membership of the Agricultural Development Group, binary (1 if yes, 0 no)

3. Results and discussion

Based on the main component analysis, three adaptation strategies practiced by farmers in the oasis of Methouia: Strategy 1: ***Adaptation strategy in terms of water saving policy***; Strategy 2: ***Autonomous adaptation strategy***; Strategy 3: ***Technical strategy and production system***. The Binary probit models application on all farmers in the region shows the determining factors which contribute positively and significantly in these strategies (Table 1).

Table 1. Binary probit models results

	Strategy 1		Strategy 2		Strategy 3	
	Coef.	P>|z|	Coef.	P>|z|	Coef.	P>|z|
X1 : AGE	**.2594575*** **	**0.003**	.0657398	0.250	**.155476** **	**0.027**
X2 : EDUC	.5832071	0.147	.5041755	0.114	.3956855	0.380
X3 : AGR	**1.863913** **	**0.045**	**1.299478** **	**0.047**	**1.747972*** **	**0.008**
X4 : RESID	1.828314	0.191	-1.177553	0.430	-2.879703	0.060
X5 : SIZE	.0507614	0.795	.0446131	0.854	.0756938	0.755
X6 : SYSTEM	-1.033163	0.186	**1.767906 *** **	**0.003**	**1.731461*** **	**0.001**
X7 : OWNER	**2.345358*** **	**0.001**	**1.366003***	**0.069**	.8416214	0.249
X7 : MEMBERSHIP	**2.47279** **	**0.016**	**1.617083***	**0.079**	**2.051047** **	**0.034**
CONST	-19.64239	0.002	-8.700323	0.052	-13.74039	0.015
	Wald chi2(8) =16.15 Prob > chi2 = .0403 Pseudo R2 = .3881		Wald chi2(8) = 23.02 Prob > chi2 =0.0033 Pseudo R2 = 0.4138		Wald chi2(8) = 30.83 Prob > chi2 =0.0002 Pseudo R2 = 0.4689	

Notes: *** significant at 1%, ** significant at 5%, * significant at 10%

The results of ordered binary probit models show that the overall significance of a level (Prob> chi2) of 5% for the strategy 1 and strategy 2; at a level (Prob> chi2) of 1% for the strategy 3 reflecting acceptance of the choice of adaptation variables to describe the strategies identified. The results also show the significant contribution of certain variables to express adaptive behaviour among farmers in the oasis of Methouia. Finally, a significance at the 1% and 5% level for the variables age, main agricultural activity, production system, owner of agricultural land and membership of the agricultural development group confirm the consistency between these variables and the choice of adaptation in the region which are based on experience and technicality in this type of production system, credit access for investment in water saving as well as membership of the agricultural development group for access to water and extension.

4. Conclusion

Adaptation of agriculture to climate change in Tunisia and in particular an oasis production system is not only a political question of adaptation strategy but also a question of farmer behaviour. Being a lover of agricultural activity with experience or sophisticated technical skills play an important role in mitigating the impacts of climate change. The behaviour of the farmer in terms of adaptation is necessary but insufficient; it must be accompanied by policies of subsidy, encouragement, supervision and training.

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FSD7-Webinar 3

Multi-scale and multi-criteria trade-off analysis in the SDG1-SDG2 nexus, to co-design sustainable and healthy agri-food systems and to inform policies

Date: 24 March 2021

Chaired by Hatem Belhouchette (CIHEAM-IAMM) and Pytrik Reidsma (WUR)

Objectives

The objective of this session is to present and discuss case studies that have addressed methodological challenges related to the co-design of resilient and sustainable farming systems in dryland areas. More particularly, this session should initiate a debate on the multiscale, multidisciplinary and trade-offs analysis when faced with the challenges of co-designing innovative farming systems with multifaceted objectives including optimal productivity, conserving natural resources and ensuring household food needs. The presentations are selected in order to represent a variety of different biophysical and socio-economic contexts, assessment objectives, and mobilized methods and tools/models that associate, in one way or another, local stakeholders. A final session will be reserved to utilize the former presentations and debates to explore possible areas of action to be promoted in development projects and agricultural policies.

Program and speakers

- A short introduction on objectives and expected outcome of the webinar (*Hatem Belhouchette*, 5 min.)
- An introductory statement by a representative of a development agency, donor or country representative, about the value and challenges of application of system research: Addressing climate change challenges to food systems (*Theresa Wong*, *Mohamed Abdel Monem* and *Rachid Serraj*, FAO, 7 min.)
- **Selected presentations:** 10 min. presentation and 10 min. discussion
    1. Scaling up from crop to farm level: co-innovation framework applies to vegetable farm systems sustainability (*Cecilia Berrueta* et al., INIA-Uruguay)
    2. Farmer research networks for co-designing agro-ecological intensification options in crop-livestock systems of southern Mali (*Katrien Descheemaeker* et al., WUR-Nederland)
    3. The Utopia of Increasing Crop Diversity and Intensification by Increasing Access to Irrigation Water in Dry Conditions (*Hassan Bazzi*, INRAE-CIHEAM-IAMM-France)
    4. Participatory exploration of transformative pathways for the cooking banana value chain in Uganda (*Esther Ronner* et al., WUR-Nederland)
    5. A Tri-capital framework for assessing social-ecological systems' resilience in Medenine-Tunisia (*Fatma Aribi, Mongi Sghaier*, ERA-Tunisia)
- Action areas to strengthen the contribution of agri-food systems research in development projects and agricultural policies, based on presentations and findings from the European context (*Pytrik Reidsma*, 7 min.).
- Conclusion: next steps (*Hatem Belhouchette*, 3 min.)

Scaling up from crop to farm level: co-innovation framework applies to vegetable farm systems sustainability

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1. Introduction

Successful scaling up from crop level research to application by farmers depends on its practitioners being aware of the constraints that arise during this process. Promising ideas from crop level research are not adopted by farmers in many cases. Berrueta et al. (2019, 2020) identified strategies to reduce the distance between under-performing and best-yielding greenhouse tomato crops in the south region of Uruguay. Results and conclusions of this study allowed better targeting of recommendations to improve crop performance. However, crop yield maximization sometimes contradicts other farmers' concerns like the increase of earns and profitability and reduction of risks or stability of incomes (Guilpart et al., 2017). Therefore, recommendations resulting from yield gap analysis are only relevant if the improvements suggested by agronomists for cropping systems are compatible with the way the farmers make their technical decisions (McCown, 2002). This, depends on farming system characteristics and functioning, farmers objectives and socio-economic context (Milleville, 1993). Thereby, further analysis is needed to understand and quantify the economic and agronomic trade-offs associated with management changes in farm systems. Scaling up is explored here, aimed to analyze re-design process at crop and farm level focusing on: synergies and trade-offs between crop yield and farm system improvement and how critical crop constraints could be solved at farm level.

2. Materials and Methods

We selected 5 vegetable family farms in south Uruguay where tomato production was one of the main sources of income. Co-innovation process at farm level was conducted between 2015 and 2018 followed the methodology of Dogliotti et al. (2014) which includes three phases: 1) characterization and diagnosis of sustainability, 2) re-design and 3) implementation, monitoring and evaluation of system evolution. Re-design at farm level included a multi-year plan, defining crops choice, crops area and allocation of fields to crops, to match resource demands to supply, especially for labour. Improved crop management practices were proposed following yield gap analysis recommendations developed by Berrueta et al. (2019, 2020), aiming to maximize crop yield and inputs use efficiency.

3. Results and discussion

Despite differences in farms structure, similar main problems were identified in all farms, associated with low family income, labour productivity and leisure time, added to erosion problems, low system diversification and fragility. Redesign plans varied according to farm diagnosis, but all aimed to increase production by improving crop yields, crop diversification, increasing greenhouse area while reducing eroded and unirrigated field crops area, with low yields. Soil solarization, green manures, compost and animal manures were proposed for intercrop periods. Re-design plans were implemented for one year, with 66% of re-design activities adopted at farm level and 86% at crop level.

The magnitude of economic productivity changes relative to base year was different between levels of analysis (crop and farm) (Fig. 1). Impact on family income was larger than improvement on crop net margin, indicating that re-design at farm level exceeded the effect of re-design of crop management. Farm 1 and 2 showed a larger increase in family income compared to crop net margin explained by: (1) increase in inputs use efficiency, (2) reduction of open field crop area, (3) increase in mechanization level (e.g. sorting machine and automatized fertigation in farm 1), and (4) increase in main crop and greenhouse area for farm 1. 20% of family income increase was obtained in farm 3 despite of unchanged main crop net margin. This was due to an increase in greenhouse area and the reduction of open field crops with poor results in base year. In farm 4, family income decreased despite of main crop net margin increased, explained by the importance of swine production in family income (78%) and the replacement of tomato crop with good net margin with high prices by sweet pepper. Net margin of tomato crop and family income decreased 64% and 36% respectively in farm 5. Family income decreases was lower compare to crop net margin due to a reduction in greenhouse area due to impact of a strong windstorm and a reduced tomato area.

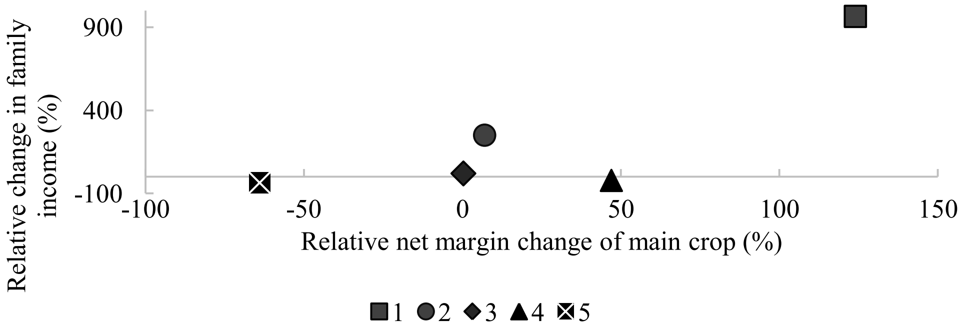

Fig. 1. Relative changes in net margin of main vegetable crop and family income after re-design plan implementation compared to the base year (2015/16) for each farm (1, 2, 3, 4 and 5).

We found examples where improving farm system performance did not align with yield maximization of the main crop. Longer growth periods and earlier transplanting dates in tomato maximize potential yield (Berrueta et al., 2020). However, most farms' strategies consisted in several transplanting dates to distribute harvests, incomes and labor, despite lesser potential of many of the chosen crop cycles (short autumn crops). Matching labour availability with demand was essential as most farms depend on limited family labor and many of them had high workload. Longer harvest periods, achieved by diversity in transplant dates, ensures more even supply of customers along the season, and cash flow for family needs during most of the year. In greenhouses affected by soil-borne diseases and nematodes, two short cropping cycles per greenhouse per year allow implementation of soil solarization during middle of summer, when it is most effective. These examples showed how general recommendations obtained from yield gap studies of a given crop could not be always adopted by farmers in their fields mainly because: (1) application require adjustments of other farming system components or a cropping plan for many years (e.g. soil solarization, transplanting dates and cycles length), (2) crop performance improvement is not aligned with other farmer objectives (e.g. labour or income distribution along the year) (Giller et al., 2006).

We found also constraints prioritized as bottlenecks for crop yield improvement, that require solutions at farm level. For instance, fertigation problems (quantity and timing) explained yield gap in tomato. Overcoming these constraints requires farm system settings, e.g. adjustment of cropping surface to water availability, development of suitable water reservoirs and infrastructure for water distribution and fertilizers injection, besides adjustment of fertigation plan according to crop demand and soil fertility. Another bottleneck to yield improvement was plant losses during crop growth period. This constraint was also solved at farm level, by designing crops sequences, soil solarization and green manures that contribute to diseases inoculum reduction. The main tool to address this problem was multi-year planning of the entire farm. Whitefly incidence was highlighted as another factor reducing tomato yields. To improve control of this polyphagous pest is necessary to consider the whole farm and all hostage crops. Crops sequences, neighboring crops and surrounding vegetation affect whitefly dynamics. If farm is nearby to other farms with high incidence of whitefly, the problem should be addressed at zone or regional level.

4. Conclusion

The overall consideration of farm systems showed greater economic impact than focusing only on the main crop due to synergies and trade-offs among farm system components. However, crop yield limiting factors obtained through yield gap analysis, considered inside a farm system re-design process, could be a powerful tool to better targeting crop management recommendations to overall farm performance improvement.

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Farmer research networks for co-designing agro-ecological intensification options in crop-livestock systems of southern Mali

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1. Introduction

Farming systems in southern Mali face difficulties and opportunities linked to changing climate and market conditions, demographic growth, but also resource degradation. Agroecological intensification (AEI) is seen as a promising way to increase agricultural productivity and nutritious food production, while maintaining healthy ecosystems and equitably improving livelihoods. Yet, given the diverse contexts in which farmers operate, tailoring solutions and bringing them to scale is challenging. We are exploring how farmer research networks (FRNs), defined as a collection of farmer groups that engage in research together with researchers and development organizations (Nelson et al., 2019), can address this challenge by co-designing technical innovations, and fostering co-learning through social and organizational innovations.

2. Materials and Methods

Since 2012 an interdisciplinary project team works with local farmers and other stakeholders of the Koutiala district in adaptive co-learning cycles (Descheemaeker et al., 2019; Figure 1) that are inspired by a combination of the DEED research cycle (Describe, Explain, Explore and Design; Giller et al., 2008) and the learning cycle of Kolb (1984). The year 2020 marks the start of a third phase of participatory farming systems research, continuing for another four years.

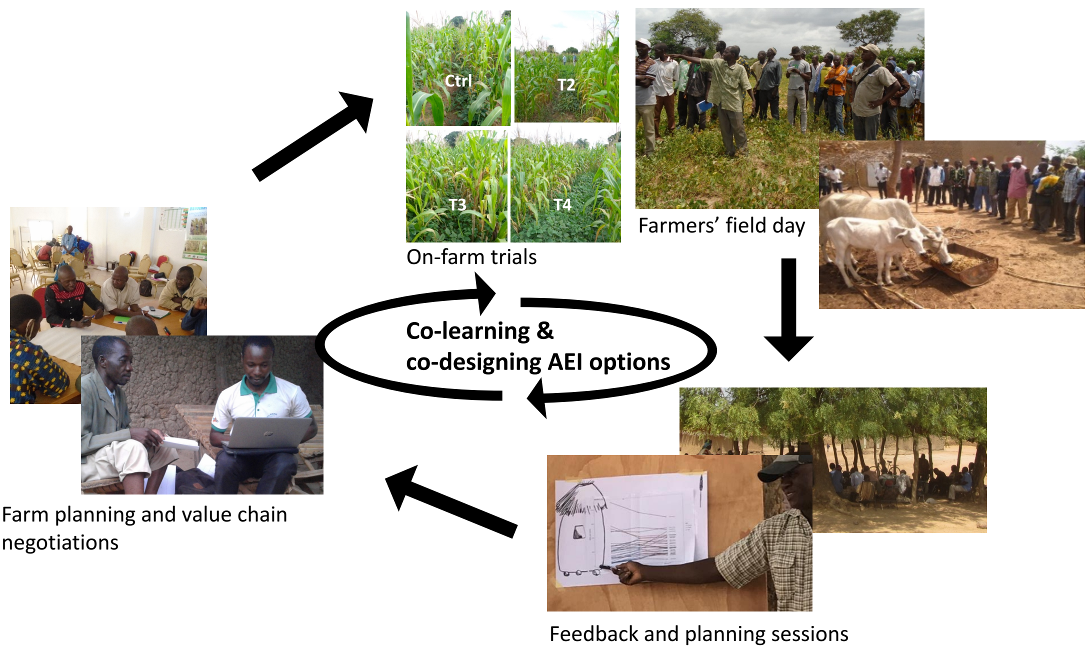

Figure 1: Iterative co-learning cycles with activities allowing the co-design of AEI options for farming systems in southern Mali

Following three principles (Nelson et al., 2019), the project established an FRN that enables farmers, representing the diversity in socio-economic and biophysical contexts of six project villages (principle 1), to participate in rigorous, democratized, and useful research (principle 2), and to exchange knowledge and co-learn with other stakeholders (principle 3). The FRN conducts on-farm experiments on technical AEI options, and evaluates them based on various indicators. The experiments comprise small agronomic plot and animal feeding trials, facilitated by the project, larger field- and herd-scale try-outs, managed by farmers, and specific activities for female farmers. The experimental work is complemented with model explorations on the effects of AEI options on farm-level performance, including risk mitigation; scenario analysis to explore pathways towards a shared vision of sustainable farming systems; value chain analysis, feeding into the co-design of institutional innovations for increased bargaining power of farmers; and the development of decision support tools for improved farm planning and budgeting (Figure 1). Annual research cycles comprising field visit days, mini-workshops, focus group discussions and feedback sessions in the villages allow the continuous evaluation and adaptation of the technical and institutional AEI options. We strongly rely on visualization in communication and information sharing among diverse stakeholders.

3. Results and discussion

The FRN was initiated with 12 farmers in 2012 and successfully established in full swing in 2013 with 36 farmers. The number of participating farmers increased since then to over 300 male and female farmers representing different resource endowment groups in 2020. Baskets of AEI options were developed containing crop, animal and farm management options for the specific contexts of farms with different resource endowment. For example, for better resource endowed farms with animals, a promising option was intercropping maize with cowpea. The haulms from a dual-purpose or fodder cowpea variety produced much-needed high-quality forage, without compromising maize yields (Falconnier et al., 2017). Experiments with stall feeding of cows demonstrated that improved feeding could significantly increase milk production (Sanogo et al., 2019) and better manure management had soil fertility and environmental benefits. Composting trials, closing the cycle of crop-animal-manure-soil interactions, showed the benefit of nutrient recycling but also the high labour requirements. Promising options for medium resource endowed farms included the partial replacement of sorghum with soybean, which raised farm profit, diversified diets and brought nitrogen into the system. Farmers appreciated getting to know different varieties of this relatively new crop. Similarly, farmers were interested in the nutritional benefits of a new iron-enriched millet variety. This variety was tested with different soil fertility management options, including the concentrated application of animal manure. For farmers with small herds that produce limited manure amounts, this practice was promising from the perspective of resource use efficiency, but high labour requirements hampered the implementation by farmers on their larger fields. The FRN also included six groups of female farmers, typically a disadvantaged group due to limited access to production assets. Since several seasons, the women experimented with fattening sheep for selling at the time of the religious festival of Tabaski, which coincides with remunerative prices (Sanogo et al., 2020). Through a system of revolving funds, access to fodder and veterinary care was assured, and capacity building in group organization and joint selling helped to increase the bargaining power of the women's groups. By engaging the farmers who are experimenting on their farms also in value chain activities, the farming systems analysis conducted by the FRN was embedded in broader efforts aimed at transitioning towards more sustainable food systems. A key element of the shared vision for the future was to avoid placing the burden of the production risks completely on the back of the farmers. This was aimed for through facilitating value chain negotiations and group sales. We believe that such engagement in commercialisation will be a key factor to sustain FRN activities beyond the project's life time.

4. Conclusion

The scaling potential of the FRN approach is derived from two complementary aspects. Firstly, it is an approach that thrives through the engagement of large numbers of farmers in research prioritization, experimentation, data collection and result interpretation. Secondly, the three principles of the FRN approach help to generate solutions and guidelines that can be scaled to similar contexts because they have been obtained through relevant, credible and legitimate research. Indeed, relevance was achieved by conducting research in diverse socio-economic and biophysical conditions and retaining AEI options that performed in those contexts according to famers' criteria. Credibility was ensured through rigorous observational and experimental data collection, statistical and modelling analysis. Here, the added value of the FRN is the possibility to experiment in a large variety of contexts, thus allowing to generate systematic insights on why, how, where and for whom the tested options work. Finally, legitimacy is obtained by involving farmers who differ widely in resource endowment and ensuring marginalized groups are included. The inclusive co-learning process that we establish through adaptive cycles of research is empowering farmers in setting the research agenda and driving the development process. As this is a slow process, the long-term engagement (since 2012; continuing to 2024) is essential.

Acknowledgement

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The Utopia of Increasing Crop Diversity and Intensification by Increasing Access to Irrigation Water in Dry Conditions

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1. Introduction

With changing climatic conditions, the agricultural sector in the Mediterranean region face major challenges to reduce the undesirable effect of the climate change on crop production and food security. The main hypothesis supposes that improving the farm resilience and adapting to climate change necessitate more crop diversification. Among several diversification strategies, increasing the irrigation amounts and efficiency are considered as key requirement for agricultural productivity.
This study describes first the diverse farming systems in the Mediterranean and presents a preliminary assessment of the impact of increasing water available for irrigation over the Mediterranean region by considering a wide range of farm dataset collected over five different countries of the South and the North of the Mediterranean region. A bio-economic model has been run to simulate the farms' performance towards increasing water available for irrigation.

2. Materials and Methods

From the Mediterranean basin, data of existing representative 10 farming systems (representing more than 10,000 real farms) were selected by using the PCA over six distinct study sites existing in Lebanon, North Tunisia, South Tunisia, Algeria, Morocco and France. Interviews with farmers, over all study sites, were conducted to collect a set of biophysical, socioeconomic and nutritional data describing their farms. This wide range of collected data allowed covering different Mediterranean contexts as a function of several variables such as the climate (arid to semi-arid regions), resource endowment (irrigated area per farm, farm income …), intensification production (as a part of production cost) and production goal (crop orientation, self-consumption…) (El Ansari et al. 2020). Since the main objective is to increase diversification and improve the farm performance, the main hypothesis suggests that adding more water for irrigation should lead to more intensification and diversification and eventually increase the farm income. This scenario is also in line with the farmers' desire, acquired from local interviews, to have better access to water. For this reason, a static bio-economic model (Belhouchette et al. 2012) was developed in order to assess the farm behaviour in response to the strategical scenario of increasing water dedicated for irrigation in the Mediterranean region.

3. Results and discussion

Figure 1 presents a general description of the current situation for all the studied farm systems over all the countries. In almost all farms in Mediterranean region, the average income per capita is lower than the national revenue unless for the intensive ones which represents only 25% of the total number of farmers. This high revenue is ensured mainly by a high productivity (income/ha) rather than the average area per farm. For some particular cases, the intensive specialized system in Lebanon shows a significant income per capita ensured by premiums provided for tobacco farms. Another particular case is found in Algeria where such intensive farms profit from very important livestock that ensures the increase of the farm income.
The semi-intensive system generally provides good income per capita. However, the good income is mostly related to the large cultivated area per farm compared to the intensive system or the presence of important livestock (Algeria). However, the low productivity of the SI system indicates that these farmers have the desire to intensify but are consuming many resources, which makes their productivity even lower than that of the extensive system. Finally, the extensive system is the most dominant system in the Mediterranean region (60%) and are characterized by the least productivity compared to other systems and low income per capita. This largely explains the deficiency of these farms that are most often managed in dry conditions.

The simulation of adding more water for irrigation shows different impact on each system and leads to several significant conclusions. The first remarkable issue is that supported farming systems could be restrictive for promoting diversification as it is addressed only for strategic crops. For example, the intensive system in Lebanon, dominated by highly supported tobacco crop, show no significant change regarding its performance when more water is added for irrigation. These farms insisted on maintaining their rained tobacco crop. This could be the same case for supported cereals and sugar cane in other Mediterranean countries. Indeed, in the presence of high premiums, the desire to intensify the existing system can prejudice the system since premiums already guarantee high income for farmers, which does not encourage them to take risks with alternative strategies.
Another major observation is that intensification using more water can only lead to the specialization of existing profitable crops and thus unchangeable diversity especially for intensive and semi-intensive systems. For example, in the specialized intensive system in North Tunisia, 48% of the farmland benefited from the additional water quantity, which was mainly used to irrigate existing orchards and vegetables. Despite of the increase in the farm income by 19% for such farms, the results demonstrate that additional water will encourage these intensive farms to intensify existing profitable crops (vegetables and orchards) with more specialization degree. Additional water in the SI systems also pushes toward more specialization in the existing profitable crops as

the SI farm of North Tunisia showed that 15% of the farmland profited from the additional water to irrigate existing vegetables. This validates that adding water can only lead to higher specialization rather than diversification.

In extensive system, generally, all farms profit from the additional water for irrigation as the percentage of irrigated area generally increases (Table1). Regarding the farm income, adding more water for irrigation marginally changes the farm income. Nevertheless, this slight change does not allow reaching the national average income per capita and thus fails to improve significantly the farm's performance. Concerning the farm diversity, adding water produces slight change in diversity level depending on the initial diversification level. Similar to what was observed in the intensive systems, the additional water in the extensive diversified farm (Lebanon) was used to irrigate existing vegetables and orchard trees to insure higher profitability with no change in the crop pattern. On contrary, the diversity increased for the Moroccan and Algerian case due to a slight increase in vegetables and legumes areas. However, this increase was at the expense of cereals and livestock. The results thus validate that the extensive system seems to invest the additional water in the profitable crops (mainly vegetables) to insure high profitability regardless of the environmental impact. The most hazardous effect could be the decrease in the rain fed cereals. This decrease could affect the food security in the Mediterranean, which is directly related to the cereal production.

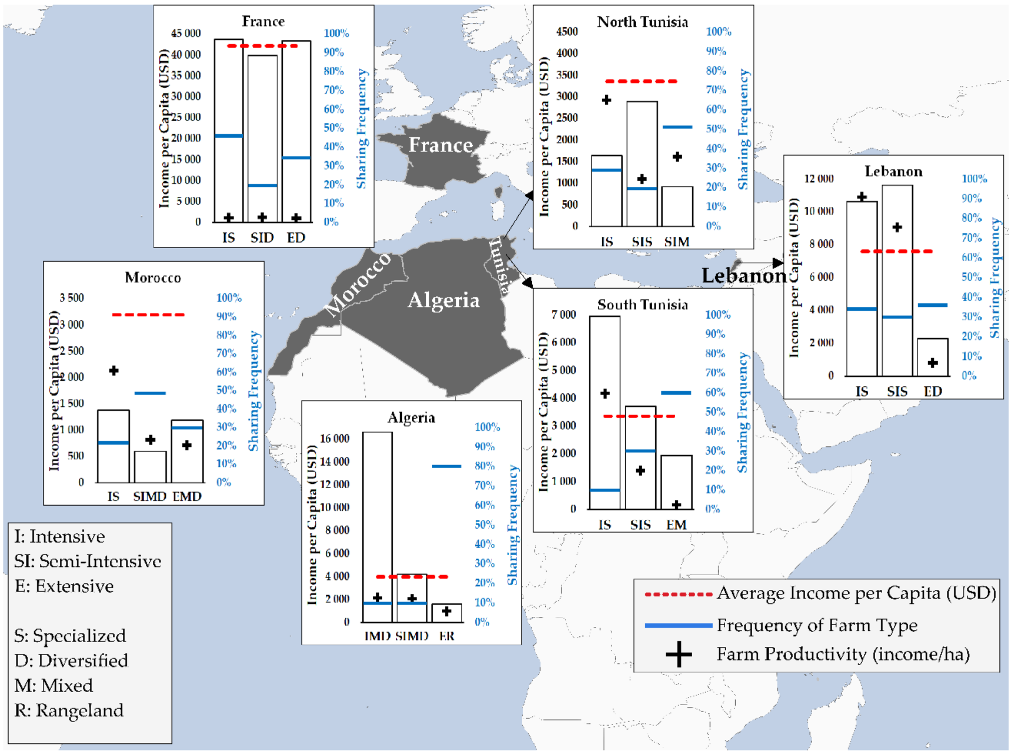

Figure 1: Distribution and characteristics of the surveyed farms in the six studied sites over the Mediterranean region. Vertical bars represent the average income per capita, red dashed line symbolises the national average income per capita, blue solid line shows the sharing percentage of each farm and the "+" sign displays the farm productivity.

	Irrigation Scenario vs Base Scenario		
Extensive Systems	**Income Variation (%)**	**Irrigated Area Variation (%)**	**Diversity Variation (%)**
ED – Lebanon	+19%	+22%	0%
EMD – Morocco	+30%	+10%	+17%
ER – Algeria	+30%	+10%	+46%

Table 1: Variation of the farm income, irrigated area and diversity between irrigation and base scenario for three extensive farms

4. Conclusion

In order to reply to the main objective of increasing the farm diversification and income, this study will continue exploring different alternative levers and scenarios that could help encourage the diversified system over the Mediterranean region. The study will concentrate on combining a set of scenarios representing different interventions that could create diversification while preserving natural resources and increasing the farm income. The idea behind the combined scenario is that employing only one measure (e.g. irrigation) can be partially effective and would not lead to significant change in the diversification level. Thus, acting on several components of the farming systems, economically such as price, premiums and water and environmentally such as crop innovations (e.g. more rotations, productive crops less sensitive to water stress…) could help achieve the desired farm diversification without jeopardizing natural resources.

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Participatory exploration of transformative pathways for the cooking banana value chain in Uganda

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1. Introduction

Cooking banana is one of the main staple foods in Uganda. Over the past decades, intensified banana cultivation has concentrated in southwestern Uganda. Farmers value the commercial importance of the crop, but with declining soil fertility, dwindling natural resources and increasing drought incidence in the face of climate change, the sustainability of the system is questionable. In western Uganda, which is endowed with better rainfall and soil fertility, banana is part of a more diverse farming system. However, also here increasing population pressure and developing markets are driving a transformation of the system. To unpack the uncertainties in future developments we conducted a scenario analysis to assess current and future sustainability of these contrasting systems and explored synergies and trade-offs across four sustainability domains.

2. Materials and Methods

Multi-stakeholder, participatory visioning and back-casting workshops were held in southwestern (SW) and western (W) Uganda. A vision for the banana value chain, obstacles for reaching the vision and opportunities to overcome the obstacles were identified, together with important trends that influence farming and the banana value chain. Outputs were translated into four plausible scenarios for the near future (2040): marginalisation (*Marg*), business as usual (*BaU*), adaptation (*Adap*) and transformation (*Transf*). The scenarios range from no action to current negative trends (climate change, population growth) and little advancement in technology or value chain development, to a more and more active and cooperative approach to adapt and transform the agricultural sector towards a desirable future (Table 1).

Table 1: Overview of trends and scenarios influencing banana value chains and farm households in Western and Southwestern Uganda

Trends / Scenarios	Population growth/ urbanisation/ job opportunities	Climate change: rainfall - 10% and temperature +1.5°C	Agricultural technology development	Value chain development
1: Margina-lisation	All male children inherit land. Urbanization outweighs population growth, but urban people keep their land. Farm sizes decrease.	No action. Most crop yields decrease, some increase. Banana: yield reduction due to increased water shortage	Modest improvements in low-cost agricultural practices: better weeding, plant spacing, etc. Limited mulch and manure application in banana.	Market price information improves, but sales remain individual. No changes in market access. No value addition.
2: Business as usual	Urbanization outweighs population growth. Some people keep, some people sell their land. Farm sizes remain the same.	Drought tolerant and disease tolerant varieties. Certain crop areas become unsuitable.	Low-cost practices and some action to improve soil water holding capacity. All apply mulch in banana, limited manure application.	Market price information improves, but sales remain individual. Modest improvement in market access (infrastructure, farmer cooperation). Small-scale, individual value addition.
3: Adaption	Urbanization outweighs population growth, and urban people sell their land. Farm sizes increase.	Drought tolerant and disease tolerant varieties; intercropping, crop diversification, water harvesting.	Investments in soil fertility improve yields and reduce drought stress. All apply mineral N+K-fertilizer in banana, limited manure application.	Farmer groups negotiate reduction on input costs. Farmer groups cooperate in value-addition (market expansion + prices).
4: Transfor-mation	Off-/non-farm employment is actively promoted, fewer people in agriculture with larger farms.	Drip irrigation in banana to reduce water deficit, transformation to other crops.	Investments in soil fertility to improve yields, mechanization (economies of scale). All apply mineral N+K-fertilizer & manure in banana.	Full-fledged cooperative (negotiate input and output prices, insurance, marketing of value-added products).

A selection of indicators in the four sustainability domains (economic: farm gross margin; food security: food self-sufficiency; environment: partial nutrient balances of banana fields; social: farm labour demand) were assessed under the current situation (*Base*), and under each of the scenarios. A socio-economic and biophysical survey among households in the study sites (n=171) served as the basis for the explorations. Assumptions on effects of climate change and agricultural development on crop yields and development of world market prices were largely based on Thomas and Rosegrant (2015), and effects of water availability and nutrient application in banana on Calberto et al. (2015); Taulya (2015).

3. Results and discussion

Farm gross margin (FGM) from the production of banana and other crops (incl. maize, beans, groundnuts, millet, sweet potato, rice) was larger than the poverty threshold (1.90 USD/capita/day) for about 60% of households in *Base* and *Marg*, and increased to 85% in *Transf* (Fig. 1A). Returns on investments in soil fertility improvements in banana were generally positive. In *Base*, *Marg* and *BaU*, 80-90% of households would not be able to earn a living income (4.65 USD/adult equivalent/day; www.wageindicator.org) from crop production. In *Transf* this would reduce to 40% (Fig. 1A).

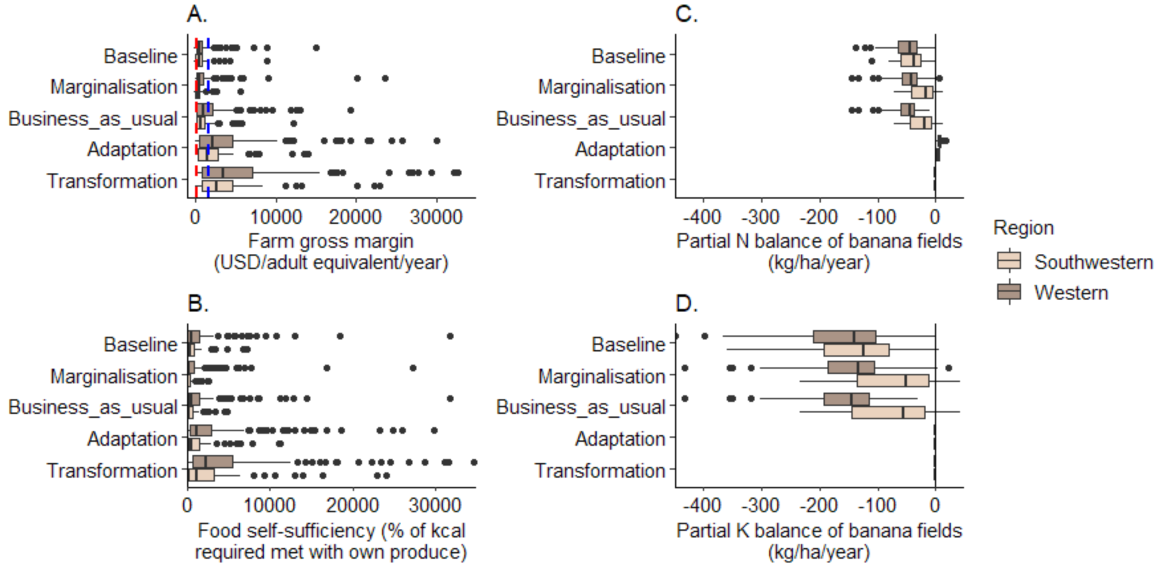

Figure 1A-D: Food self-sufficiency (A), farm gross margin from crop production (B), and partial nitrogen (C) and potassium (D) balances. Red dashed line in A represents the poverty threshold (1.90 USD/adult equivalent/day), and blue dashed line the living income threshold (4.65 USD/adult equivalent/day).

Food self-sufficiency (FSS) was well above 100% of household requirements for nearly all in *Base*, and even in *Marg* (Fig. 1B). FSS was larger in all scenarios in W than SW Uganda, reflecting more favourable agro-ecological conditions. The high FSS emphasizes the commercial nature of banana production in both regions. Nutrient balances for both N and K in banana fields were strongly negative in *Base* (Fig. 1C&D), resulting from the current limited use of external inputs like mulch or manure. Improvement in *Marg* resulted from reduced nutrient offtake with lower yields, while in *BaU* farmers used mulch to mitigate negative climate change effects, and at the same time adding nutrients to the soil. In *Adap*, mulch and manure application from *BaU* were maintained, but a neutral K-balance was aimed for by compensating the remaining K-offtake in the form of mineral fertilizer. K improves soil fertility, while simultaneously reducing drought stress (Taulya, 2015). Mineral N was supplied in a ratio of 1:3 to K (recommended for banana). In *Transf*, N-requirements were assumed to be met with manure application, topped up with mineral K-fertilizer. Labour for banana cultivation only would increase from an average of 140 mandays/ha/year in *Base* with 24 days for mulching in *BaU*, and another 16 + 18 days for manure/fertilizer application and irrigation respectively in *Transf*.

The scenario analysis showed synergies between FSS, FGM and nutrient balances, but trade-offs with labour demand. Additional trade-offs on different criteria and scales included: 1) Most households were highly food self-sufficient, yet 90-97% of the total energy from crop production was supplied by bananas in W, and SW Uganda, reflecting vulnerability to any yield loss in banana and a high dependency on food produced in other regions to ensure a diverse diet. 2) Negative N and K balances at the field level are exacerbated at the farm level: application of maize and bean residues as mulch on banana fields from different fields/ farms depletes soil fertility of these fields, unless external inputs are used. 3) The neutral N-balance in *Transf* would require an average of 28 t/ha fresh manure; three times as much as current mean application rates. As SW and W Uganda already face manure scarcities, a substantial increase in manure production from intensified livestock-keeping would be required, along with manure transfer to banana-growing areas. 4) Intensified production in *Adap* and *Transf* depends on larger organic or mineral fertilizer inputs, inevitably resulting in environmental trade-offs (increased greenhouse gas emissions, other nutrient losses to the environment).

4. Conclusion

The study provides insight in synergies and trade-offs that occur between indicators in four sustainability domains, as well as differential effects across the farm population. The implications of following a certain pathway serve as input for discussions with stakeholders and policy makers as basis for decision-making towards a sustainable banana value chain.

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A Tri-capital framework for assessing social-ecological systems' resilience in Medenine-Tunisia

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1. Introduction

Resilience requires an assessment in order to identify the necessary strengthening measures and define sustainable development trajectories. Folke et al. (2010) define the resilience as "The capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure and feedbacks, and therefore identity, that is, the capacity to change in order to maintain the same identity". Resilience assessment is largely based on the concept of socio-ecological system (SES). The SES is a system that integrates social (human) and ecological (biophysics) subsystems in mutual interaction (Gallopin, 2006). SESs are dependent on an economic, ecological, and social environment characterized by permanent changes and deep uncertainties. Thus, SESs are diverse and heterogeneous in regards to the complexity of interactions between subsystems and the dissimilarity within those subsystems.
Medenine governorate, which belongs to southeast Tunisia, has diverse farming systems that are integrated under more global SESs. The SESs in Medenine are reputed by their resilience, which allowed their viability until today, but in view of the pressures and increasing risks because of socio-economic and environmental changes, they become more and more vulnerable. Despite these facts, few attempts have addressed the question of SESs resilience in Medenine. Therefore, this study aims to fill this gap. At a first level, it suggests a typology of SESs. Then, it proceeds to assess precariousness indicator (Pr), for each SES identified through the typology, while adopting an innovative resilience framework and testing its applicability to our context.

2. Materials and Methods

The analysis of SESs resilience in Medenine governorate was carried out using three steps following a progressive approach:
In a first step, we carried out a typology of SESs. With the last national survey database on farm structure (relevant to 2185 farms), carried out in 2004-2005, we applied the Principle Component Analysis (PCA) method. The PCA was used to reduce massive variables to a limited set of factors. The generated factorial coordinates allowed us to proceed to the hierarchical ascending classification (HAC) which is employed to classify SESs according to the significance of the considered variables (Köbrich et al. 2003). These two methods led to a typology whose groups are very heterogeneous with one another and their elements are very homogeneous. This step is performed with Tanagra, which is an open source software available on the web (http://eric.univ-lyon2.fr/~ricco/tanagra/). Further, we gathered field survey data using a monitoring system of 40 reference farms identified by the already carried out typology. The collected data were used to carry out a comparative assessment of SESs' resilience.
In a second step, we used a tri-capital approach to assess the resilience of each identified group. Based on our previous experience and on a deep literature review, we adapted a set of indicators relevant to economic, natural, and socio-cultural capital to our context specificities (Table 1). The selected indicators are either quantitative or qualitative. Quantitative capital were scored according to a 0-4 scale; with 4 represents the upper limit indicating a robust capital. For qualitative scores we used the following scale: 0 for weak or absent, 1 for moderately weak, 2 for moderate, 3 for moderately strong, and 4 for strong (Ifejika Speranza et al. 2014). Equations for calculating the scores of each capital are shown in Table 1. These scores were calculated for each group of farms identified by the typology. Scores for each capital for each group constitute the median value, which is considered more representative of the central tendency of a set of values and it is resistant to outliers.
In a third step, we used capital median values to calculate Pr-values, which express the resilience of each household and each SES. The Pr determine the distance of each group to the possible collapse or transformation point (Figure 1) (Jarzebski et al., 2016). The Pr-values of each farm household and SES were calculated using the following formula: $\boldsymbol{Pr = \sqrt{(EC^2 + SSC^2 + NC^2)}}$ (Leung and Suen 1994).

EC: Economic capital= (FC+PC)/2	FC: Financial capital=(FC1+FC2+FC3+FC4+FC5)/5 FC1: Share of the non-farm income to the total income FC2: Income diversification: Simpson diversity index FC3: Amount of savings per year FC4: Value of subsidies per year FC5: Migratory money transferred
	PC: Produced capital=(PC1+PC2+PC3+PC4+PC5)/5 PC1: Agricultural equipment PC2: Vehicle ownership PC3: Buildings value PC4: Herd size PC5: Number of olive trees
	HC: Human capital=(HC1+HC2+HC3)/3 HC1: Age of the household head HC2: Dependency ratio

SCC : Socio-cultural capital= (HC+SC+CC)/3	HC3: Household size
	SC: Social capital= (SC1+SC2+SC3)/3 SC1: Number of assistance received from extension services SC2: Membership in any organisation SC3: Distance to the market
	CC: Cultural Capital= (CC1+CC2+CC3)/3 CC1: Number of years of experience in agriculture CC2: Number of training performed per year CC3: Number of years of education of household heads
NC : Natural Capital= (NC1+NC2+NC3+NC4+NC5)/5	NC: Natural capital NC1: Total agricultural area NC2: Share of the useful agricultural area to the total agricultural area NC3: Share of the irrigated area to the total area NC4: Water quality NC5: Soil quality

Table 1. Capital indicators used in assessing the SESs' resilience

3. Results and discussion

Through the PCA, thirteen variables are retained as being relevant for classifying farming systems. These variables reflects the household livelihoods and the resilience determinants. Results of the PCA provide five categories of factorial axis explaining 76 % of the total variance. The HAC on the coordinates of the five factorial axes resulted in the identification of four farm groups: SES1 named "livestock farming with family labour" consists of 266 farms, SES2 named "livestock farming with waged labour" consists of 366 farms, SES3 named "crop production with family labour" consists of 694 farms, and SES4 named "crop production with waged labour" consists of 859 farms.

Results of assessment of Pr and capital median values by SES are shown in figure 2. The Pr-values recognize the contribution of each capital to sustain the stability of the SES. Our results revealed Pr-values ranged between 2.5 and 6. If 2.5<Pr<4, the SES is weakly resilient, if 4<Pr<5.66, the SES is moderately resilient, and Pr>5.66, the SES is strongly resilient. SES4 is strongly resilient, due to crop high contribution to income in addition to livestock income, which led to high-income diversification and therefore higher financial capital. Moreover, this group have a higher produced capital compared to other groups thanks to the importance of agricultural equipment and the prominence of herd size and olive trees. Most SES1 households are weakly resilient (Pr<4), they have a lower social-cultural score due to less social interaction and lack of experience in agriculture. They also have experienced a financial shortage, which reveals a low management capacity. SES2 households are moderately resilient. The livestock production enhanced the produced and the financial capital scores, the water availability enhanced the natural capital score, and the good social capital have resulted in a balanced contribution of three capitals which led to moderately resilient households. Households of SES3 are also moderately resilient. They have good social-cultural scores such as number of years of experience in agriculture and number of assistance received from extension services. Further, they have a high natural capital due to good agricultural area ownership. SES2, SES3, and SES4 are therefore distant from the breakdown situation due to good capital endowments.

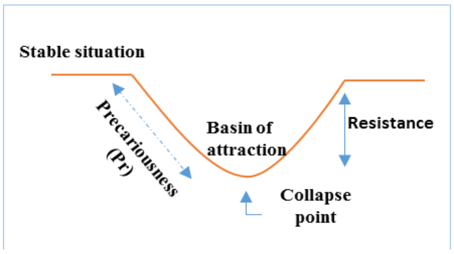

Figure 1. Aspects of the resilience of SES.

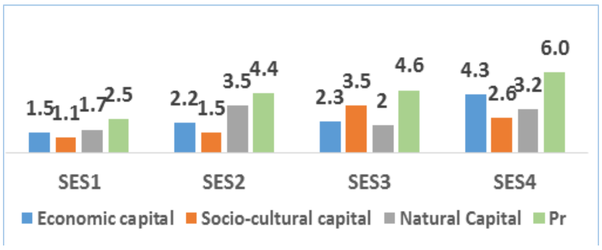

Figure 2: EC, SCC, and NC median values by group of SES.

4. Conclusion

The tri-capital framework enables the resilience assessment and allows the determination of difficulties facing the SES. Our findings suggests some interventions especially for SES1: institutional support, credit and subsidies facilities…The findings of such a study could help policy-makers in designing specific measures to enhance the SES's resilience.

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FSD7-Webinar 4

Accelerating and amplifying systemic transformation of agri-food systems with digitalization of research and advisory services to family farmers and decision makers

Date: 24 March 2021

Chaired by Ram Dhulipala (ICRISAT, India), Thouraya Souissi (IRESA, Tunisia) and Bruno Gerard (CIMMYT, Mexico)

Objectives

The objective of this session is to explore the exciting prospects of the use of digital tools and technologies in agriculture and the consequent impact at a broader systems and regional scales. Facilitating and catalyzing digitally enabled systemic transformation of agri-food systems that touches upon a number of global issues like climate change, GHG emissions, resilience etc. would require a more coherent approach towards the digitalization of agri-food systems from research through to advisory systems that support farmers. Such innovations will find ready users only when agricultural research and extension interfaces with market access, government policy, social setting and a host of other local factors that influence farmer behavior and decisions. The six presentations that are part of this webinar are a mix of real world case studies and research projects that offer promising models to embed science into decision support tools for farming. The case studies and the presentations will showcase examples of the use of ICTs in thematic areas like pest and disease diagnostics, climate information services, financial services etc. The session chairs will strive to also examine issues of low integration and use of digital technologies in agriculture despite their immense transformative potential in the smallholder and resource poor contexts during session Q&A. The importance of user-centered design, digital literacy, role of research and public private sector partnerships (PPP) will also be examined in the discussions.

Program and speakers

- A short introduction on objectives and expected outcome of the webinar (*Ram Dhulipala*, *Thouraya Souissi, Bruno Gerard* 5 min.)
- **Selected presentations:** 10 min. presentation and 8 min. discussion
    1. Reinventing traditional agronomy to facilitate systems-based learning for extension (*Wallau Marcelo*, University of Florida)
    2. Integrating Systems modelling tools as decision support for promoting sustainable intensification under smallholder farming systems in semiarid tropics in India (*Shalander Kumar*, ICRISAT, India)
    3. Digital augmentation for accelerating agri-food system transformation (*Chandrashekhar Biradar*, ICARDA, Egypt)
    4. Plantix : A digital end-to-end solution to support sustainable smallscale farming (*Simone Strey*, Plantix, Germany)
    5. Digitalization for innovative financial instruments to unlock investments in agriculture (*Samyuktha Kanna*, IFPRI, India)
    6. The development of an intelligent ICT-based weather advisory to help Indian farmers manage climate risk (*Andrew Smith*, ICRISAT, India)
- Conclusion and summary (*Thouraya Souissi, Bruno Gerard*, 5 min.)

Reinventing traditional agronomy to facilitate systems-based learning for extension

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1. Introduction

As agricultural systems face increasing challenges from climate change and other environmental pressures, global market demands, and urbanization, new approaches in research, teaching and extension are needed to keep up with real world issues. Increasing our understanding of farming systems requires an interdisciplinary approach to address technical, social, economic, and environmental issues (Darnhofer et al., 2012). However, agricultural training trends over the past several decades have resulted in increased specialization and fragmentation of agricultural systems training and career options (Grant et al., 2000; Hansen et al., 2007). This results in students and faculty "partially trained" and not always capable of conceptualizing the interconnectedness of the agricultural system components in order to accurately assess viability of proposed practices for study or implementation, nor how to systematically improve existing systems. The current situation is fomented by funding sponsors who encourage grant-pursuing strategies focused on addressing highly specific topics. Inevitably, it has led to different silos of expertise that when combined as multidisciplinary teams often lack true system-level integration and understanding of system function.

Extension personnel are responsible for compiling, assimilating and disseminating a large array of information provided by researchers, particularly in subject matters different from their formal education. While a system's approach to farm consulting is needed to expand research into real world practice, current training offered by most higher education institutions is narrowly focussed on specific topics within agricultural sciences (Grant et al., 2000). As the breadth of information continues to expand, college courses are narrowing their scope and training towards more specialized skills. Additionally, formal education is limited by time and financial resources. Since the mid-1950's, the U.S.A. has adopted a more reductionist and productivity-based mindset (Darnhofer et al., 2012) and this early research and training approach resulted in great advances in technology and production (Parr et al., 2007). However, it also increased fragmentation of more encompassing departments and detachment (specialization) of research faculty (Grant et al., 2000). The decline in teaching generalized curricula in agronomy and development of more specialized, passive (i.e. teacher-dependent, distance learning) and less practical (i.e. experience-based learning) teaching programs, our capacity for understanding agricultural systems and integrating across disciplines declined (Parr et al., 2007; Darnhofer et al., 2012).

How is this affecting new generations of extension agents and agricultural consultants, particularly when it comes to translating systems-based research findings to producers? How might the state-sponsored extension systems overcome lack of experience and narrowly focussed technical training of new agents? In this paper, we present a brief assessment of what effects the specialized agricultural training approach has had on agricultural extension in the U.S.A. and offer potential mitigation strategies. To help illustrate the current situation, we provide examples of two recently conducted surveys of agricultural extension agents addressing skill sets and perceived knowledge required for performing their jobs.

2. Current needs in agricultural education

Despite the importance of agriculture in the U.S.A., interest in agricultural careers has been consistently decreasing over the past few decades (McCallister et al., 2005). Hensen et al. (2007) reported that beyond the sharp decline in undergraduate enrolment in soil and crop science related courses, traditional agronomy-focused majors are offered by only six of the fifty land grant universities, with most majors being related to horticulture, landscape and turf. Furthermore, a diminishing minority of undergraduate enrolment in soils and crop science majors is represented by students with farming background (Hansen et al., 2007). Although Cooperative Extension is present in all 50 states, only 19 land grant universities offer academic programs specialized in extension teaching (Harder et al., 2018). Extension careers require a broad range of knowledge as the number of commodities and production systems increase.

Halbritter (2020, unpublished) conducted a survey with agricultural and horticultural extension agents in the Florida Cooperative Extension system, asking what types of skills do new agriculture/horticulture agents need when they begin their job as an extension agent. Out of 124 responses, 58.1% (N=72) identified hard skills related to basic agricultural training as main needs for new extension agent development. Those skills included soil sampling and interpretation of results, plant and pest identification, and general agronomic practices. Conversely, it was assumed that upon hire, those professionals already had this basic knowledge, as required by the position description. Other more job-specific skills and knowledge, such as "extension program development and evaluation" were regarded as less important (N=16, 12.9%). Furthermore, multiple responses (N=6) identified "experience" as a required "skill". While not necessarily a "skill", it corroborates with the hypothesis that our educational strategy/curriculum is inadequately preparing our students for real-world issues.

A second survey was distributed at the same institution, specifically to identify competence needs and assess ability levels related to integrated pest management (IPM; Benge et al., submitted). Respondents of this survey all had IPM responsibilities in their extension programs. Sixteen categories of competency were identified, four of them perceived as essential for IPM: 1) implementing pesticide rotation and use, 2) identifying damage caused by diseases/pathogens, 3) scouting and thresholds for management, and 4) developing and implementing basic IPM plans. Although identified as *basic* IPM principles, those same categories also rated lowest for ability level, indicating that agents are not entering extension with the necessary background needed for executing the jobs they are being hired for. From interaction with newly-hired agents, we also observe a lack of problem-solving skills and an ability to assess production system function based upon its components, in order to arrive at practical recommendations for producers. Furthermore, inadequate agent preparedness adds to the workload of state specialists responsible for agent professional development and in-service agent training, by having to provide additional basic/core training.

A significant proportion of the agents surveyed had gone through University of Florida's undergraduate or graduate schools. Given that those newly-hired professionals were recent graduates of our formal training, there clearly were pieces missing in agent preparedness outside of academia. In other words, beyond the narrow spectrum of training offered, there seems to be a gap between the technical knowledge gained and how it translates into practical, case-specific information for our clientele.

3. Alternative strategies on agricultural agent training

Concern over the effects of increasing specialization on agricultural education and training is not recent (see Grant et al., 2000; Parr et al., 2007). An alternative curriculum proposed by Parr et al. (2007) included a strong component of interdisciplinary and applied sciences (i.e. practical knowledge), along with training in ecology and soil sciences. However, more practical courses and experience-oriented learning require greater investment in infrastructure and personnel, and increased liability issues if farm equipment operation is a component. Going further, we should consider reinstituting "traditional" agronomy courses or integrating practical, systems based learning into existing courses. Field trips, conversations with farmers and internships can be incentives for overcoming lack of experience by increasing agent exposure to real-world problems. Capstone projects can be developed based on real scenarios or include an internship component. Producers are generally supportive of creating opportunities at their operations for training students. According to Parr et al. (2007) stakeholders emphasized the need for learning from experience and to link classroom to field work. Moreover, internships within our extension system can offer practical and technical training, increase awareness about extension careers, and help solving reduced staff issues form recurrent budget cuts.

Graduate degrees specialized in agricultural extension is another option. For example, most options for graduate degrees at the University of Florida (representative of a U.S.A. land-grant university), are more heavily basic science oriented, which do not necessarily fulfil all the preparatory needs of new agricultural extension agents. On the other hand, graduate degrees in Extension Education generally focus on the communication and pedagogy; not offering further knowledge in the agricultural sciences. The Florida Cooperative Extension system requires all agents obtain a Master of Science (MS) degree within 6 years of hire. There may be an opportunity for adapting or developing an interdisciplinary MS degree dedicated to complementing the science-based needs of new agents by providing skills in agriculture (plants, soils, IPM, etc), economy, sociology and pedagogy. Currently, the majority of new agricultural extension agent training comes via in-service trainings (IST) by state extension specialists. However, it is challenging and sometimes inefficient (low demand) to tailor a short program to the needs of a few individuals at a time, especially when competing against more complex and specific training demands. The general purpose of ISTs is to update and further build upon core concepts. Alternatively, our extension hiring services will need to better accommodate new agents over their first career year or two with additional core training and apprenticing under an experienced agent.

4. Conclusions

While new developments in interdisciplinary research contributes to the evolution of more productive and sustainable farming systems, we are not prepared nor are we preparing our next generation of agricultural extension agents to disseminate that data and successfully assist their clients, at least in the U.S.A. In short, our students are often not adequately qualified for the jobs we offer, even within our own institution. As we continue to develop educational curricula to accommodate the needs of sustainable agriculture, we also need to encourage greater interdisciplinary collaboration and include some broader, generalist views of agricultural systems, encouraging critical thinking, problem-solving methods, and provide tools for understanding both, technical and practical issues (Parr et al., 2007; Monfared and Far, 2016). Moreover, we need to find alternatives to increase student exposure to real-world situations via visits, internships, and participation in extension events. While this might seem a challenge, it represents a great opportunity for reconciliating teaching and extension to real agriculture, and attract more students to extension careers. and increase labour force in diminishing-budged extension systems.

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Integrating Systems modelling tools as decision support for promoting sustainable intensification under smallholder farming systems in semiarid tropics in India

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1. Introduction

Smallholder farming systems which constitutes about 90% of total farm holdings in semiarid tropics (SAT) in India are characterized by severe land degradation, increasing climatic and market risks, low and unstable crop-livestock productivity and low levels of profitability leading to persistent poverty. Extreme vulnerability of smallholder farmers threatens food security and overall sustainability of the farming systems and associated livelihoods. Multiple improved technologies/practices are being suggested to enhance the performance of these complex multi-objective smallholder systems. However, the inability of the farmers, extension actors and policymakers to visualize the potential impact of different agricultural development strategies hinders decisions on investments on improved options for achieving increased adaptation, food production, farm profitability and other related objectives both over short and long time horizon. An alternative approach is being piloted by ICRISAT and ICAR for informed decision making at farm household level derived through system modelling tools known as whole farm modelling which integrate crops, tree and livestock, climate, natural resource management and markets. The major aim of this study was to analyse different intervention scenarios being assessed by using whole farm modelling to achieve increased profitability and resilience through various interventions and build capacity of Extension agencies by collaboratively piloting these systems tools.

2. Materials and Methods

The study uses Integrated Assessment Tool (IAT)[1] which is a whole farm model to capture key economic and biophysical processes and their interactions in the smallholder farming system over time (Komarek et al., 2012; McDonald et al., 2019; Kumar et al., 2017). The IAT is an integrated crop–livestock-household model, with dynamic linkages among crop, livestock, and socioeconomic components. The model allows us to understand as to how to enhance food and nutritional security and systems resilience through promoting appropriate integration of livestock-cropping systems using improved technologies, improved value chains, resource management and climate in the context of household preferences and resources. The primary household's data collected from the adopted villages of 2 farm science centres known as Krishi Vigyan Kendras (KVKs) located in Suryapet district (Gadipally KVK) of Telangana state and Chittoor district (Tirupati KVK) of Andhra Pradesh state. Farming systems data were collected from 50 households from each district using a detailed questionnaire. The selected households of each district were grouped into three relatively homogenous farm types considering variables like household's head age and years of education, land ownership, access to irrigation, credit access, availability of family labour and ownership of livestock. The household farm types were constructed applying k-cluster mean technique. Finally, various technology options were assessed in participatory mode with KVKs for a five years' time horizon using whole farm IAT model for each farm household type to generate scenarios for informed decision making.

3. Results and discussion

3.1. Household characteristics

Table 1 represent some basic characteristics of the selected farm households. The average landholding across farm types and districts ranged from 1.31 ha to 3.92 ha. In Chittoor mango tree crops was very important whereas other major horticultural crops were chilli and tomato for Chittoor, and chilli in Suryapet district. Annual crops in Suryapet was more diverse compared to Chittoor. In case of livestock the households in Chittoor area had only large ruminant dairy cows whereas in Suryapet farmers had both large as well small ruminants.

District (KVK)	Farm household type	Average land holding (Ha)	Tree crops	Annual crops	Horticultural crops	Average livestock holding (No)	
						Dairy cows	Small ruminants
Chittoor (Tirupati)	Farm type 1	1.31	Mango	Paddy, Groundnut	Chilli, Tomato	4	None
	Farm type 2	3.87				9	
	Farm type 3	2.11				5	
Surya pet (Gadipally)	Farm type 1	2.08	None	Paddy, Cotton, Pigeonpea, Sorghum	Chilli	5	7
	Farm type 2	2.19				6	3
	Farm type 3	3.92				6	3

Table 1. Land, livestock holding and crops cultivation of the sample households

3.2. The Base model cash flows and potential impacts of different interventions considering impact on riskiness

Initially the study considered baseline household situation and practices (Table 2) and run the model for five-year time periods for all the three farm types. The outputs of the base IAT whole farm model for Suryapet and Chittoor districts have been depicted in

[1] For further details about IAT please go through https://research.csiro.au/livegaps/tools/integrated-analysis-tool-iat/

table 2. In Chittoor the farmers have a good market orientation. The mango tree crop was a major source of farm households' cash flows and its share in household's total cash flow ranged from 50% to 62% across three farm types. Horticultural vegetable crops and livestock were other important contributors to the household cash flows, whereas share of annual crops in household total farm income was relatively low contributing about 4 to 8 percent across different farming systems. The farm households in Chittoor had only dairy cows but no small ruminants. In Suryapet the annual crops like Paddy, Cotton, Pigeonpea, Sorghum; vegetable crops and dairy cows contributed dominantly to households' total farm cash flows. The share of annual crops varied from 34% to 44%, horticultural vegetable crops from 17% to 29% and the share of dairy cows ranged from 24% to 43% of the household's cash flows across farming systems. The small ruminants also made an important contribution of about 4% to 10% share in total household cash flows across farm types. Potential impact of selected interventions being promoted by KVKs on the farm households' cash flow in comparison to base existing farming practices have been presented in table 3. Three different feasible interventions were evaluated for each region. In Chittoor intervention 1 on rainwater harvesting and 2 on increased area under mango were more profitable compared to the intervention 3 on chilli cultivation. In Suryapet the supplemental irrigation through rainwater harvesting was more profitable for farm type 3, whereas for farm type 1 and 2, the intervention 2 was most profitable. Table 4 reveals the riskiness of different scenarios by measuring coefficient of variation (CV) of respective net cash flows. The farming activity in Suryapet was riskier compared to Chittoor. In Suryapet the different intervention scenarios also resulted in reduction of risk, however in case of Chittoor all the interventions scenarios did not result in reduction of risk along with increase in net cash flows.

	Chittoor Farm household types			Suryapet Farm household types		
Particulars	**Type 1**	**Type 2**	**Type 3**	**Type 1**	**Type 2**	**Type 3**
Mango tree crops	3261 (64)	9783 (49)	6522 (64)	--	--	--
Annual Crops	220 (4)	1612 (8)	425 (4)	979 (24)	1026 (30)	1562 (33)
Horticultural vegetable crops	1162 (23)	6107 (31)	2249 (22)	1024 (25)	621 (18)	1403 (29)
Dairy cows	487 (9)	2270 (11)	1072 (10)	1388 (34)	1461 (42)	1126 (24)
Small ruminants	--	--	--	453 (11)	165 (5)	171 (4)
Gross Income	5130 (100)	19772 (100)	10269 (100)	4055 (100)	3450 (100)	4792 (100)
Net Income	4986 (97)	18963 (96)	9833 (96)	3875 (96)	3205 (93)	4275 (89)

Table 2. Baseline farming system cash flows under three farm household types in Suryapet and Chittoor (in USD)

Note: i) Values in the parenthesis indicating percentage to gross income, ii) The exchange rate was 1 USD = 69 INR at the time of survey

Regions	Intervention scenarios	Farm type1	Farm type2	Farm type3
Chittoor	1. One supplemental irrigation through rainwater harvesting	10	11	9
	2. 10% increase under mango crop area	13	10	13
	3. 10% increase under chili crop area	2	3	2
Suryapet	1. One supplemental irrigation through rainwater harvesting	8	7	15
	2. Replacing 20% cotton area with horticultural crop (chili)	15	21	14
	3. Improved cow replace existing local cow	6	10	4

Table 3. Potential impact of different interventions on household cash flows (% change from the baseline scenario)

		Coefficient of variation (%)		
Regions	**Intervention scenarios**	**Farm type1**	**Farm type2**	**Farm type3**
Chittoor	0. Base-farmers practice	5.71	4.34	3.29
	1. One supplemental irrigation through rainwater harvesting	5.14	3.92	3.00
	2. 10% increase under mango crop area	5.06	3.94	2.91
	3. 10% increase under chili crop area	5.59	4.21	3.21
Suryapet	0. Base-farmers practice	13.90	23.34	19.42
	1. One supplemental irrigation through rainwater harvesting	12.95	21.95	17.20
	2. Replacing 20% cotton area with horticultural crop (chili)	11.78	18.82	16.33
	3. Improved cow replace existing local cow	9.26	15.85	14.85

Table 4. Riskiness in farm net cash-flows under base and alternative intervention scenarios

4. Conclusions

The present analysis evaluated impact of different intervention scenarios integrating both crops and livestock on households' cash flows using whole farm IAT model. The analysis demonstrates that the context specific integrated interventions considering annual crops, fruit trees, vegetable crops, livestock, rainwater harvesting and others are key to achieve increased farm profitability and resilience. The net cash flows generated through whole farm model over time also enable in estimating the riskiness or resilience of various intervention scenarios. The analysis clearly suggested that different farm household types even in the same village need different interventions. The whole farm IAT model could prove very useful tool to co-design context specific profitable and resilient farming systems. The piloting of household modelling as decision support was successful in the present case study. Nevertheless, there is need to build greater capacity of extension agencies in using simplified versions of these systems modelling tools as decision support for promoting large scale adoption of sustainable agricultural intensification options.

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Digital augmentation for accelerating agri-food system transformation

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Abstract

Digital technologies are penetrating the agriculture sector rapidly but lack dynamics, granularity, and demand-driven advisory. At the same time, agri-food systems transformation marching towards economically viable and ecologically sustainable options for healthy people and a healthy planet. Such transformation requires a systematic quantification and characterization of farming system dynamics and farm typology at much higher spatial and temporal granularity with real-time analytics and advisory. The data-driven digital augmentation to quantify farming systems and site-specific recommendation on a real-time basis (in-season) is made possible by recent advances in GeoAgro driven big-data analytics in deep learning intelligence, cloud computing along with smartphone-enabled citizen science making precision decisions at the farm-level much smarter, efficient, economical and much more useful than ever before. Such a digitalization level helps to address the gaps at multiple levels (e.g., data, soil health, yield, ecology, economy, resilience) for demand-driven agro-ecological interventions across the scale (e.g., space, time, and package). Here we are presenting ongoing efforts of GeoAgro driven precision-agriculture made simple and affordable to smallholders for accelerating agro-ecological transition through on-demand analytical services aiming at quantifying functional domains (farming systems, farm typology, crop rotations), soil and water resources (irrigation, soil moisture, nutrients, carbon sequestration), and drivers (climate, access, diet pattern, socio-economics) to target site-specific interventions for accelerating agri-food system transformation. It also aims to identify a potential niche for scaling across the regions and discuss foster development in the agro-ecology context to provide a comprehensive decision support system for transforming agroecosystems for better food, nutrition, soil, and planetary health. It also enables vital services to policymakers by providing quantitative and spatially distributed information about impacts and tradeoffs for different policy and technological development options.

Keywords

GeoAgro Digital Augmentation, Agro-ecology, Resource Use Efficiency, Family Farming, Precision Decisions

A digital end-to-end solution to support sustainable small-scale farming

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1. Introduction

Direct and indirect crop losses on account of pests and disease attacks during crop production cycles are up to 40 percent annually (FAO, 2019). In extreme cases, the entire crop is lost leading to adverse outcomes like loss of livelihoods, famines, and food inflation, which impacts the food and nutrition security of communities. Crop losses due to pests and diseases can be minimized through science-based interventions that can be undertaken by farmers. These farmers, especially in developing parts of the world like India, are largely dependent on traditional physical extension services supported by Governments. However, the traditional human agent-based extension systems are unable to disseminate and provide such advisories to support farmers in real-time. The public sector extension system is designed to hire one agricultural extension staff to support up to 20,000 farmers in some states (Rupavatharam, 2017). This has led to farmers using products that are not suitable in addressing their needs, making farming non-profitable and having adverse effect on soil and water environments. The goal is to make small-scale farming economically and environmentally sustainable to feed the generation to come. Plantix has evolved into a digital data-driven smart agri-ecosystem in India through the participation of all the stakeholders like farmers, extension experts, input dealers/distributors and producers/ manufacturers of agri-inputs (Rupavatharam, 2020).

2. Materials and Methods

Progressive Environment and Agriculture Technologies (PEAT) Gmbh is an Indo-German start up that developed an AI and deep neural network (DNN) powered Android application called Plantix that helps farmers with disease diagnostics, control, and crop management. Plantix acts like a plant doctor by providing accurate diagnosis and advisory on crop protection leading to reduced use of agrochemicals to manage pest and disease attack on their crops. This directly affects the cost of production with lower input costs for managing pest and diseasesPlantix uses images captured by mobile phone camera to detect crop disease and recommend crop treatment solutions. The App can be downloaded free of cost from Google Play Store and users can upload a picture of the affected plant which is processed by machine learning and artificial intelligence. The image processing software gives the user insights into the most probable disease, nutrient deficiency, and pest infestation. This insight is coupled with actionable instructions that help farmers treat the affected plants, minimize damage, and thereby improve the overall yield. Plantix recognised that disease diagnosis alone is not solving the problem of reaching out recommended products and hence on boarding local retailers in an integrated way was a solution. Farmers are suggested retail outlets near to their location (based on GPS location of user) and also asked if they would be interested to receive further help from the Plantix team. Local call centres of Plantix then connect the requirements of farmer with the retail outlets which have recommended agro-inputs. To make ecosystem functional, Plantix partnered with multiple retail outlets of agri-input stores and has associations with producers/manufacturers around India. Plantix connects retailers through its partner application and completes the loop of making the agro-advisory as a lead to input retailer. A flow chart of digital data-driven ecosystem developed by Plantix is shown in Fig 1.

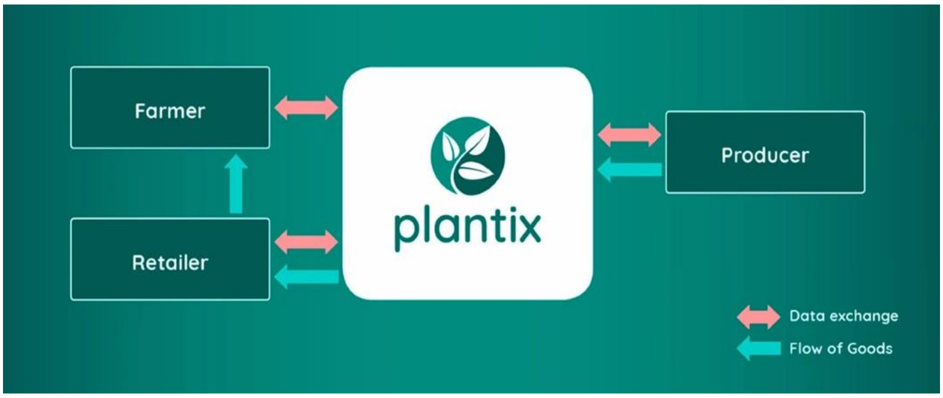

Fig. 1 Plantix: A Digital Data-Driven Agri-ecosystem'

Additionally, the app enables users/farmers to communicate with their peers, scientists, subject matter experts in real-time to seek crop-related advice. Not only does the platform provide access to a large repository of solutions, but also provides farmers alerts on the disease, weather, and pesticide application. Using the Crop Calendar feature, farmers receive customized crop management recommendations based on their sowing dates. Plantix is fully digital, can scale fast and is able to generate unprecedented data-driven insights for the entire value chain of agri-inputs. Wang et al., (2020) has more details on image processing and the use of crowdsourced ground data from Plantix to map rice and cotton crop at 10 m resolution during kharif 2018 season in southeast India.

3. Results and discussion

Plantix partnered successfully with local SAUs, agriculture departments, private sector, and other agencies to expand the use of its app. Plantix has a very strong collaboration with ICRISAT since 2016 with an objective of improving the app and also expand its usage amongst farmers and agricultural extension services. Plantix's farmer outreach in new geographies commenced with focus group discussions and workshops. A field demonstration is done during focussed group meets with farmers where they are taken to a nearby field and a picture of any affected plant is taken (Fig 2). Once the image is uploaded, the AI image recognition system powered by deep learning models identifies the picture and instantly provides the name of the disease or problem in the local language and provides suggestions on what agrochemical ie pesticide/fungicide needs to be used to address the identified problem. Farmers can also use the app to post their queries along with an image in the community space where other farmers, experts, and Plantix team members provide responses in the farmer's local language.
Plantix has taken this forward to extend the agro-input needs of the farmer as an opportunity to the nearest retail outlet and completes the advisory support. A push notification is sent to the user to seek their consent if they would like Plantix team to contact them individually for further support of their specific problem. Call centres established initially in telugu and hindi speaking regions of India hand-hold the last mile of personalised support to the farmer by connecting them to the nearest retail outlet to fulfil the requirement of agro-advisories. Plantix has the largest network of retailers through whom the distribution of agri-inputs are made to farmers. This activity is well coordinated through Plantixs' base station from Indore.

Fig.2 Farmer using Plantix app to take a picture of damage during field demonstrations

4. Conclusion

Plantix is the first of its kind end-to-end digital support system for sustaining smallholder farming in India. The data-driven inputs involve all stakeholders in the ecosystem of plant protection. Plantix has become the largest agricultural application in India and used by farmers, retailers and agricultural extension experts. Scaling up of digital ecosystems like Plantix will enhance opportunities to lower crop losses, improve pesticide and fertilizer use and sustain environment and livelihoods of smallholder farmers. It will be good if government departments disseminate Plantix and help farmers and other ecosystem players in the digital era.

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Digitalization for innovative financial instruments to unlock investments in agriculture

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Abstract

Digitalization, and in particular remote sensing and ICTs, have provided an opportunity to improve the monitoring of crop growth and farming practices. This has applications not only in agricultural extension, but also in improving financial access for smallholder farmers and relaxing risk and credit constraints that hamper agricultural investments and adoption of recommended practices. We share experiences from India, Kenya and Ethiopia, where we leverage remote sensing and smartphone camera data to improve crop insurance and credit services. We discuss to what extent the availability of high frequency and disaggregated field-level data can help reduce problems that affect traditional credit and crop insurance markets, such as moral hazard, adverse selection and basis risk in insurance products. We also present early findings on the effectiveness of these innovations in improving agricultural knowledge, practices and investments.

The development of an intelligent ICT-based weather advisory to help Indian farmers manage climate risk

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1. Introduction

Many farmers in India struggle to produce agricultural commodities in the face of an increasingly variable, and at times, adverse environment. The semi-arid and sub-humid tropics of India in particular can be risky environments for the production of crops and fodder. Here farmers are being continually challenged to respond to changes in weather, market forces, and availability of labour and inputs. As much as this constitutes the profession of farming and whilst traditional farmers learnt to cope with these variations, with the increasing incidence and severity of extreme weather events such as rainstorms, drought, floods, cyclones, dry spells, drought, heatwaves, the riskiness of the food-systems has increased. The implications are that these erratic conditions challenge the timeliness of farm operations and create difficult conditions for plant growth, and the well-being of animals and farm labour.

India has a long history of climatic advisory services for agriculture commencing in 1976. In addition to weather, agricultural advisories include information on the selection of crops, varieties and allocation of land to crops at the start of the season and in planting, water, nutrient, pests and disease management decisions during the season, and post-harvest management. The Agriculture Advisory Services (AAS) is housed as a division within the India Meteorological Department (IMD) and works collaboratively with Indian Institute of Tropical Meteorology (IITM) and Indian Council for Agriculture Research to generate district and crop specific advisories twice a week. IMD has also created a network of multidisciplinary institutions called Agro-Meteorological Field Units (AMFUs) established nationwide in 2008 which integrate weather and climatic information with agro-meteorological information to prepare these advisories.

In the past, this information was distributed through traditional extension services that included local networks such as extension agents, farmer networks, local radio *etc*. Although informative, the information was provided and at large scale and therefore generic, and not related to the actual climatic year. Also, there could be significant delays between when climatic agricultural advisories are made and arrive at the small holder. Indian extension systems have not been able to keep pace with the demands from huge numbers of smallholder farmers and the diverse agricultural systems they practice. These extension systems are increasingly under resourced and limited in their capacity to reach all farmers in their target area. Therefore, advisories do not always reach the intended audience in time to adjust farm operations and schedule inputs, and this information was often ineffective. It has been estimated that only about 24% of the 90.3 million households have access to these climate information systems. Consequently, farmers are not always able to realise the full potential of a climate information system to manage production risk.

Progressively with the expansion of information and communications technology (ICT), the accessibility of the advisories increased however, stakeholders continue to indicate that the generic and fragmented nature of current advisories is a major reason for low levels of their use. Small holder farmers often have additional requirements from an information service that relate to language, literacy, ability to interpret complex information, access and connectivity.

The penetration of affordable mobile networks and phones throughout India has been driven by rising smartphone penetration and inexpensive mobile data. This has presented some opportunities to link data sources and use modern technology to rapidly disseminate information to the farming population. Therefore, we aimed to create a mobile application that would link key current information services in a manner which increases the possibility for farmers to value and use the information in their decision making in the short term to deal with climate risk.

2. Materials and Methods

During stakeholder consultations at the start of the process, several data sources were identified that could be connected using smartphone applications. AMFUs established are devising agricultural advisories based on weather in India's 130 agro-climatic zones. The AMFUs issue contextualized crop wise advisories every Tuesday and Friday relevant to the district level (~5000km2). To give best possible services to the farmers, IMD started issuing experimental block level weather forecast since 2018 for preparation of experimental Block level AAS bulletins. Over the past few years, IITM and IMD have made significant investments in computing infrastructure and models to improve the resolution and timeliness of its weather information and forecast products. To improve the linkages across the AAS information chain, a platform called AgroDSS was designed to link the 130 AMFUs with various information products from IITM and IMD. The AgroDSS facilitated aggregation and presentation of various weather information products from different divisions/groups of IMD and IITM to a single platform. Based on this data, AMFUs manually draft agrometeorological advisories and input them back into the AgroDSS portal. A key distinction between the AgroDSS and the iSAT is the level of automation in the preparation of advisories. iSAT system has been able to encode the process of generating crop advisories based on weather information and forecasts into a nested decision tree notation. In the case of AgroDSS however, the process of generating these advisories is manual.To improve the comprehension and linkage of farmer users with the AAS, Meghdoot mobile app was conceptualized and developed. The app also facilitates feedback collections and aims to deepen the engagement with farmer users on the uptake on agro-meteorological advisories of AAS. The design and technical architecture that evolved from the SowingApp (Rao et al., 2019) and iSAT (Rao et al., 2019) pilots of ICRISAT were the reference architecture for the design of Meghdoot and the backend application program that interfaces with AgroDSS and other databases of IMD and IITM.

3. Results and discussion

The mobile phone application called Meghdoot (Hindi for ‘cloud messenger’) was developed and released in the Google Playstore and iOS AppStore. The app brings together the weather observations and forecasts from IMD, IITM with agro-advisories generated by AMFUs as shown in Figure 1.

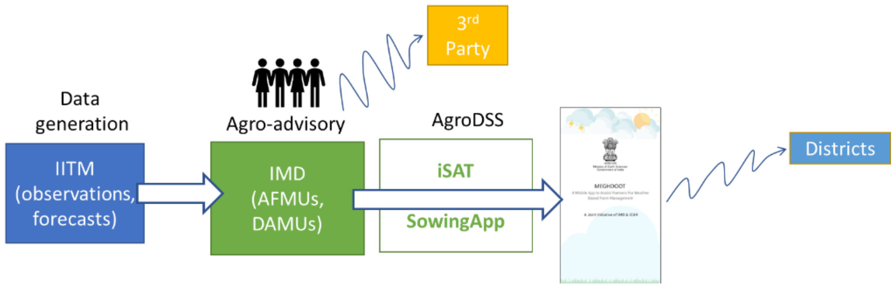

Figure 1: The development of Meghdoot from SowingApp and iSAT based on IMD agroadvisories and IITM forecasts.

All the information is aggregated district and crop wise for better comprehension of the user. An important feature is that the information – in particular the advisories, are disseminated in local language to suit the user needs. Since being released in 2019, the app is now on it first version and has been downloaded by over 135,000 users as of 30th June 2020.

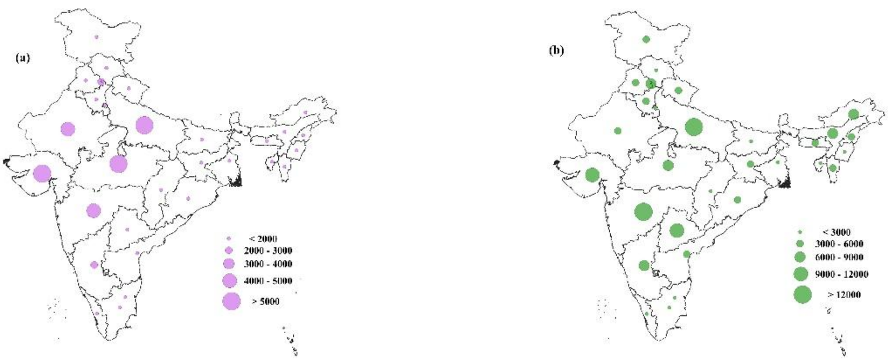

Figure 2: The uptake of Meghdoot and delivery of advisories in India since 2020

Feedback continues to be largely positive however users repeatedly express a desire for finer scale information and more targeted information that is specific to crops, soil types and location. This will require an automation to be incorporated within AgroDSS on the lines of iSAT developed by ICRISAT. Meghdoot can now potentially be expanded to incorporate more information streams. For example, to include finer scale agro-meteorological advisories which will draw on forecasts that are currently generated at the tehsils or block level (~500km^2). Other areas of refinement include a personalised service based on gender and a need to connect with different age groups in population or those without literacy.

4. Conclusion

With timely information on current and impending weather together with agricultural advice, farmers are better able to make informed decisions for better management of down-side and up-side risks. Meghdoot has filled a niche which was previously lacking: to connect the weather and agricultural advisory information to users in a timely and structured manner. The reference architecture which was made possible based on experience from previous decision support systems forms the foundation of the application which for the moment is a focussed-on information delivery.

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