Co-designing innovative cropping systems with stakeholders

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Over the recent decades, farmers have been subject to the impacts of a number of driving forces acting at the global level, which have substantially modified the structure and the organization of cropping systems (van Vliet *et al*., 2015; Holman *et al*., 2017; Luo *et al*., 2020). We can group these drivers into three main categories: i) environmental, ii) economic and iii) social. Firstly, climate change and the dynamics of soil and water degradation (desertification, soil erosion, sea level rise, freshwater overexploitation) are increasingly constraining the design of sustainable cropping systems. Secondly, the market volatility and the consequences of globalization, are impacting price and cost systems. Thirdly, the growing human population and migratory flows (refugees and international migrants, littoralisation, urbanisation) result in a polarisation of few major centres of production and consumption. The effects of these global drivers on agricultural systems are difficult to predict because of the complex interactions with different technical, economic, social and political factors acting at local level. Nevertheless, some main trends can be recognized at larger levels. In Western-European countries, for instance, a reduction of agricultural land use, an increase of irrigated areas and a reduction of the arable land and permanent grassland have been observed (Rabelo *et al*., 2023). In South America, large areas primarily devoted to dry forests and grasslands have been converted to cropland (Piquer-Rodríguez *et al*., 2008), whereas in China many fertile agricultural areas have been consumed for urban expansion and some degraded lands have been reclaimed to balance the loss of cropped areas (Tao *et al*., 2022). Are these changes the result of a resilient strategies adopted by farmer to respond to the impacts of these driving forces or do they simply reflect the outcome of the pressure of these drivers in terms of limitation of options available to farmers? Unfortunately, the second hypothesis seems to be the most likely. A critical point in developing effective implementation guidelines to adapt/mitigate the effects of global drivers and to improve the resilience of agricultural land systems is the limited engagement of farmers in the design of innovative cropping systems. The transition from conventional to agro-ecological cropping systems seems to be a necessity globally, and farmers' participation in this is valuable for each stage of the process. According to Hill and McRae (1995), the transition can be described as a process made of three subsequent stages (ESR framework) in relation to the growing effort required of the farmer in changing the usually adopted practices: i) optimize and integrate the farm-external input to make them more efficient (E-Efficiency); ii) replace the farm-external inputs with nature-based solutions (S-Substitution); and iii) re-design the whole cropping system (R-Redesign). Farmers' input would be crucial in assessing the reliability, consistency, adaptability, practicability and acceptability of the proposed changes and in reducing the number of alternatives to be tested to identify the most promising ones. One major barrier to taking advantage of farmers' knowledge in improving the ESR strategies is the lack of formalization of the processes used, to integrate the technical and scientific outcomes of research activities. This is one of the reasons why the wealth of experience available from farmers has long been neglected when designing new cropping and farming systems.

The emergence of Digital Agriculture (DA) and the increasing availability of affordable digital services, create new perspectives in the use of farm data, even for research purposes. While many researchers argue that this approach is more focused on big data analysis and technology transfer models rather than on promoting an experience-based exchange of knowledge, others contend that DA is a great opportunity to create a shared knowledge base to facilitate dialogue among all actors involved in cropping system design (Gkisakis and Damianakis, 2020). Moreover, the use of digital tools and technologies (mobile phones, IoT, free apps) increases opportunities for information exchange, knowledge-sharing, and co-design, ultimately generating new spaces for social learning. In the context of digital and agro-ecological transitions, farmers are increasingly collaborating with other stakeholders in researching, co-designing and assessing sustainable cropping systems. This reflects a paradigm shift in the understanding of how agricultural knowledge is produced, from a linear model of knowledge production and transfer to a perspective that integrates knowledge generated by multiple actors. This has been enacted in the use of participatory research and extension, supported by increasing policy interest in fostering farmer-led innovation and multi-stakeholder approaches.

On-farm research and participatory approaches have long been advocated to bridge the divide between research and practice by engaging farmers as partners in the research process and including the wide variation in contexts and farm practices (Farrington and Martin, 2018; Carberry, 2018). Farmer-researcher collaboration can take multiple forms to address different topics such as participatory research design and participatory plant breeding. A continuum of approaches are described, from conventional trials on farms led by researchers, to on-farm experiments which are designed, managed

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Received: 22 December 2023.
Accepted: 11 February 2024.

Italian Journal of Agronomy 2023; 18:2213
doi:10.4081/ija.2023.2213

and evaluated jointly by a group of farmers and researchers (Pelzer *et al*., 2020). Whilst farmer-led experiments are more established in the global south, a number of initiatives promoting farmer-centric approaches have recently emerged in the global north supported by public, private and NGO sectors, such as operational groups, farmer field labs, and digitally enabled farmer centric on-farm experimentation (Lacoste *et al*., 2022). The sphere of interest has also expanded to include stakeholders as co-researchers: advisory services, innovation support services, the supply chain, the local environment and rural community. These approaches follow a variety of formats and actor interactions, but are underpinned by common concepts and methodologies such as co-design, co-innovation, living labs, and the multi-actor approach (Toffolini *et al*., 2023). Such concepts acknowledge the capacity and the fundamental role of farmers in the design of site-specific and sustainable cropping systems. Core processes include: jointly framing problems and testing solutions, often through field experimentation, stakeholder engagement, and participatory 'exploration processes' which entail a 'search for new knowledge' (Berthet *et al*., 2016). The benefits of such approaches are well documented and include: sharing knowledge, fostering peer-to-peer learning, generating locally relevant solutions, increasing adaptation capacity, and combining different types of knowledge with local innovations (Ingram *et al*., 2020). All of these are critical to the transition to more sustainable agriculture. However, the benefits accrued depend on the nature and extent of the interaction (who participates, in which phases of the research and extension process, and in what ways). The involvement of farmers can vary depending on the farmer experimentation models (Waters-Bayer, *et al*. 2015). Whilst individual scientist and farmer collaboration can be effective for those involved with some scope for transfer of results, collective experimentation with a group or network (Šūmane. *et al.*, 2018) is arguably more impactful for learning, adaptation and capacity building, albeit more difficult to enact, as this approach requires substantial facilitation efforts. These new approaches inevitably bring new demands, relations and sometimes tensions between scientists/agronomists, and farmers and other agri-food system actors. The stakeholder engagement process often requires facilitation skills, while farmers might need to develop new analytical skills and capabilities. Furthermore, the participation of farmers and stakeholders to co-design approaches remains a challenge due to multiple causes, mainly related to lack of time, transaction costs, lack of trust, farmer age or geographical factors (Fieldsend *et al.*, 2021).

How are researchers in agronomy implementing co-design with stakeholders? Which methods and tools are they using, and for what purpose? Who are they collaborating with?

This Special Issue of the Italian Journal of Agronomy "Co-designing sustainable cropping systems' with stakeholders" collects 8 papers illustrating a variety of methods and strategies to support the transitions towards more sustainable cropping systems designed and assessed with stakeholders.

In particular, three articles deal with the redesign of cropping systems with farmers in on-farm experiments with different goals (crop diversification, cultivar choice, adoption of Integrated Pest Management practices) for different cropping systems (cereal-based or vineyard). All three articles underline the added value of these research practices for co-creation of knowledge, which in turn can support the adoption of innovations at the farm level. For example, Leoni *et al*. (2023) focus on the intercropping of lentil with wheat as a strategy for stabilizing crop yields and improving weed control. There is still limited knowledge about the on-farm feasibility of intercropping solutions; therefore, the authors propose a participatory methodology in three steps with increasing involvement of farmers, starting from an evaluation of the most promising solutions tested at the experimental station, to their active engagement in co-designing on-farm experiments tailored to their specific local contexts. Each step allowed a piece of information to be added to address the central question, i.e. the on-farm feasibility of the technical solution tested in the experimental farm or the actual benefit for the farmer of the designed solution. Bosi *et al*. (2023) conducted a participatory breeding on-farm experiment to replace cereals with underutilized varieties in organic farming in marginal areas for the creation of tailor-made solutions. The collaboration between farmers and researchers on two on-farm experiments resulted in a win-win solution for the preliminary identification of the most adapted genotypes in each farm and provided a set of relevant indicators for varietal choice in marginal areas. Perez *et al*. (2023), in an experiment with farmers from the same cooperative, focused on the redesign of vineyard-based systems to find sustainable alternatives to reduce the use of agrochemicals. Three different solutions were proposed to farmers and the cooperative advisors who collectively identified the main technical levers. Afterward farmers implemented the designed solutions and made tests on small vine areas. The authors, by analysing the different steps developed, discussed the enabling and constraining factors that can have an impact on the adoption of solutions on a wider agricultural area. These factors are multi-scale and multi-sectoral, from the farm organisation and farmer knowledge, to the trust in the group and belonging to the same cooperative. This showed that this process is neither simple nor fast but requires trust, time and commitment from all the stakeholders involved. More broadly, Giannini and Marraccini (2023) highlighted the importance of on-farm experimentation in the set-up of the different agronomic experimental methods, by reviewing Italian literature on the recent developments in this field, as well as discussing the main constraints and challenges for future research.

Another three articles focus on the design of cropping systems supported by tools (indicators, models or serious games), often involving farmers and other stakeholders, beyond the farm level. All authors observe that supporting the design activities with the above-mentioned tools can facilitate the discussion among different stakeholders when dealing with complex issues and the exploration of different alternative futures. For example, Darmaun *et al*., (2023) tested in Senegal a prototype tool based on indicators to assess agroecological transitions at different levels; i.e. the village, the household and the individual. The stakeholders, all belonging to the same village, participated in building, testing and validating this prototype over a long-time span, from 1994 until 2021. The prototype used indicators already defined in other tools, until achieving a final multi-criteria multidimensional assessment and end-user validation with local actors. Barbier *et al*. (2023) examined the threats posed by climate change to wheat and lavender based farms in a small agricultural region of Southern France, organising workshops with local stakeholders over a two-year period to discuss alternative cropping systems. Supported by a multi-agent model, the authors show how multi-agent modelling sustained the interaction among stakeholders and knowledge co-construction about desirable future options for the concerned farms. Moreover, issues of participation and representation of different points of view during the research project were also addressed. Finally, Renaud-Gentié *et al*. (2023) group different stakeholders of the Cognac PDO (Protected Designations of Origins) to discuss strategies to reduce the environmental impacts of the vineyard production in the area, with a focus on the vineyard soil management and herbicide reduction. The discussion was supported by a serious game and an LCA (Life Cycle Analysis) calculator, leading to a decrease of up to 51% of environmental impacts with respect to a business-as-usual scenario and introducing new relevant questions for the PDO strategic planning.

Finally, Baratella *et al*. (2023) propose a methodological framework developed to integrate stakeholder analysis and participatory tools for exploring environmental issues and related stakeholders in a pilot area in Central Italy. Several participatory tools were used to strengthen stakeholder engagement such as stakeholder analysis and mapping, learning and action alliance or participatory system dynamic modelling. This led to the drawing of a conceptual map of the causal relationships between issues, social and environmental processes, and possible actions and local policies. This conceptual map can support further farming system design activities in the area at territorial level, representing an example of pre-design study.

In conclusion, the articles in this Special issue demonstrate that a variety of tools and methods are already being used to co-design innovative cropping systems with stakeholders to support transitions in agriculture, with a focus on agro-ecological transitions. The articles explore different strategies, which can be aligned to the steps of the ESR framework, with a panel of different solutions tailored to local contexts and stakeholder needs.

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