How to Integrate Open Data with Local Knowledge in Co-designed ICT Solutions?

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Abstract: Information and Communication Technology (ICT) applications developed without end-users participation may encounter problems in the development and the uptake phase. Bottom-up co-design with end-users and participatory techniques can constitute an approach to direct tools and data infrastructure development overcoming those risks. In this paper, we present two ICT pilots that have been developed in the context of the CAPSELLA research project with farmers' communities from Greece, Italy and Netherlands, starting from their own requirements. Soil health management has been detected as a crucial activity to raise awareness on and to develop ICT tools for. This issue has been addressed at temporal and spatial level: (i) at temporal level, with a pilot that aims to support soil health self-assessment and evaluation of soil organic matter dynamics as result of farmers practices using open data on soil and weather conditions; and (ii) at spatial level, with a pilot that aims to support farmers in precision farming management of organic fertilisation using parcel linked electromagnetic soil scan data. In our case study, farmers showed interest in ICT solutions supporting their activities as well as the need to integrate local knowledge with external information (e.g. coming from open data). Cooperation with farmers as an effort to be concrete with open data use in agriculture brought to tangible results in our case.

Key words: open data, Information and Communication Technology (ICT) tools, co-design, biodiversity based agriculture, agroecology

Introduction

Minimizing the use of external inputs (e.g. mineral fertilizers, herbicides, fungicides) is a leading challenge in sustainable agriculture. The application of ecological principles in farming systems design and management (agroecology) supports the advance towards the development of more sustainable systems (Altieri, 2004). Soil health (meant as the holistic concept of chemical, physical and biological soil fertility) is a fundamental prerequisite for farming when applying agroecological principles (Rojas et al., 2016).

From long-term measurements and experimentation, nowadays several dedicated dataset repositories are available in public and private institutions in EU about soil characteristics. As result of EU policy to open these repositories, more of these data become available and connected with data processing and analysis techniques. These data have most relevance for farmers, when they are connected to their private data and observations. The exploitation of open research and experimental data in combination with the farmers' private ones and the parallel processing of them by targeted Information and Communication Technology (ICT) tools can support farmers in the application of ecological principles and the transition of farming systems towards sustainability.

However, applications developed without end-users participation may encounter problems in the development and the uptake phase (Lindblom et al., 2016; Rossi et al., 2014). As summarized by Lindblom et al. (2016), the main challenges in the uptake phase include the difficulty of capturing the local knowledge, of interpreting the practical needs of farmers, a perceived problem of complexity, lack of observability, level of knowledge of the users, lack of confidence, poor user interface design, tedious data input requirements, low adaptation to the farm situation, no frequent information update, lack of incentive to learn and adopt new practices, and the fear of replacing advisors.

Several studies showed that engaging end-users through a participatory approach enhances the successful uptake of ICT tools (Cerf et al., 2012; Van Meensel et al., 2012; Anastasios et al., 2010, Matthews et al., 2008). ICT tools development needs to be more user-centred, allowing the targeted end-users to co-design the application and to be involved directly in the whole process. The contrast between the tools offered and the way farmers make decisions explains often the low level of use of decision support tools and this is a main driver that conducted several researchers to advocate for participatory design methods (McCown, 2002; Carberry et al., 2002; Breuer et al., 2008; Jakku and Thorburn, 2010). Apart from increasing adoption, these participatory processes are also likely to enhance co-learning process resulting from the development of the application (Thorburn et al., 2011).

For scientists it is difficult to propose concrete cases of solutions based on open data that assist farmers in everyday decisions impacting on the sustainability of the farm and the agroecosystems. Open data are often perceived as not useful by farmers, especially when their objective is to apply agroecological principles to their agronomic practices. The use of open data is often perceived as more beneficial to large scale conventional agriculture than to biodiversity based systems (Palmer, 2012). Kshetri (2014) reports how agriculture firms in the industrialized world have a long history of data production and consumption but on the other hand, how the access to the data and their interpretation is much more difficult for smallholder farmers. For farmers it is difficult to find relevant platforms tailored to their needs, that offers storing and analysis of data. Often, farmers do not trust the available platforms or tools in order to contribute data for building open data repositories. Farmers are also strongly concerned about the potential misuse of information related to their farming activities and the land characteristics by the firms. The general issue regarding who owns farmers' data is also then of high importance (Seppala, 2014). A broader access to open data and data analytic tools for agriculture mediated by public open-access initiatives can help to re-calibrate the power relation between large agribusinesses and farmers and provide the farmers more power in the information management sector (Carbonell, 2016).

Taking into account the above considerations, we present two pilots related to soil fertility co-designed with farmers from Greece, Italy and Netherlands in the framework of the H2020 project CAPSELLA (www.capsella.eu). This experience is framed in the general project objective of developing new models of participatory innovation in biodiversity based agriculture working with open software, open data and open hardware. CAPSELLA belongs to the Collective Awareness Platforms for Sustainability and Social Innovation (CAPS) co-financed by the EU for fostering digital innovation in European society. The approach applied in CAPSELLA for supporting the transition to sustainability in agriculture comprised bottom-up co-design of ICT tools based on open data with end-users and participatory validation to drive the tools and data infrastructure development. In our case study we tested the effectiveness of a co-design process with farmers for developing tools that combine open data analysis and local knowledge for soil fertility management. This process is powered by the data infrastructure developed within CAPSELLA.

The specific objectives of the co-design process presented in this paper are: (i) to study the value of participatory methodology for developing ICT tools in biodiversity based agriculture domain; (ii) to define what are the types of ICT and data infrastructure requirements in innovative, diversity-based, food systems.

Methods

The participatory methodology applied in our case study was structured in five steps:

(a) Target community structure definition

The co-design process is conducted with farmers from Greece, Italy and Netherlands. The first step of the process consisted in interviewing the coordinators of the networks taking part to the project. These interviews were conducted with the aim to understand their structure and activities.

(b) Community requirements collection

We used focus-groups and dedicated workshops to collect the requirements and needs of the collaborating farmers communities. The meetings were planned for understanding the challenges that could be addressed with ICT tools. The farmers were asked to share their concerns and difficulties related to data access and use and the programmers helped to translate such issues in concrete topics for ICT tools. Agronomist facilitated the dialog between farmers and programmers.

(c) Tools co-design

The tools properties are designed with a continuous dialog among farmers, agronomists and programmers. The dialog is kept in all phases of the development to be able to combine end-users' needs and technical feasibility.

(d) Feedback from the communities

The tools prototypes are tested with the communities in dedicated field trials. The feedback from the farmers will help to detect the results of the participatory process and the success in integrating Open data with local knowledge in two concrete solutions supporting soil health management.

(e) Feedback from end users that did not take part to the co-design process

The involvement of external farmers in the testing phase will provide an overview on the possible impact of the tool out of the target communities.

Soil health management has been detected as a crucial activity to raise awareness on and to develop ICT tools for in the first two steps. This issue has been the addressed at temporal and spatial level in the following activities: (i) at temporal level, with a pilot that aims to support soil health self-assessment and evaluation of soil organic matter dynamics as result of farmers practices using open data on soil and weather; and (ii) at spatial level, with a pilot that aims to support farmers in precision farming management of organic fertilisation using parcel linked Soil Scan data. The first pilot was named *Soil Health* and the second *Compost in Precision Agriculture*.

The *Soil* Health pilot is composed of four main components:

(i) Farm data. Farmers enter in the platform basic information about their farm through a web interface: location, soil data analysis (if available), crop rotation and agronomic practices;

(ii) Soil health self-assessment. This component includes a guide for doing and registering results of a spade test (qualitative soil status assessment method) through a step-by-step evaluation of the main soil features: structure, layers, biodiversity, crop-soil interaction;

(iii) Soil model. This function of the platform is based on the Rothamsted carbon model (Coleman & Jenkinson, 1996), one of the most widely used and validated models to estimate SOM dynamics in the soil. RothC model has been used to estimate the turnover of organic carbon in the soil at plot, field, regional, national and global scales;

(iv) Open data. Input of soil and weather data from the following sources: the monthly temperature and precipitation from the Worldclim 1 dataset (Hijmans et al., 2005); the monthly potential evapotranspiration from the Global-PET dataset (Zomer et al., 2007 and 2008); the soil data (clay content, organic soil matter, bulk density, erosion risk, compaction risk) will be derived from the European Soil Database v2 (Panagos et al., 2012) and from the soilGrids datasets from the ISRIC — World Soil Information (Hengl et al., 2014).

In *Compost in Precision Agriculture* pilot, we aim to provide a tool (web application) that assists farmers in optimal application of compost. This is an important measure to stop the decreasing organic matter content and related buffer capacity and biodiversity in soils in the cultivation zone. The application is limited by laws that prevent nutrient pollution of soil water.

The tool supports the farmers' decision making for applying compost on the places where it is needed most: on parts of the field where organic matter is minimal. To this end, the tool will help to apply more compost on poor zones in parcels. The compost application works in the following steps:

(i) Farm data. The farmer defines on which parcels the compost will be applied, the maximum quantity according to his experience on soil conditions and his decisions on what crop to plant. The maximum quantity of compost to use in the farm will be selected to comply with local legislation.

(ii) Soil health assessment. The information collected using DualEM soil scan will be used to define 5 zones with different levels of organic matter content are defined, based on 5 levels of electromagnetic conductivity in the field. The tool measures the surface of field zones and shows the result in a map, that the farmer can check with his experience.

(iii) Optimising the application of the planned amount of compost. The application uses the farm data and the zoned defined by the soil health assessment for linking the application rate (kg/m^2) to the total application (kg in total).

(iv) Actuation. The tool produces a task map for the spreading machine to apply the compost as planned.

In a later stage the planning tool will be made available in more circumstances: e.g.. the soil health assessment can be determined by farmers' observations, by exploiting the spade test from the *Soil Health Pilot*, instead of DualEM soil scan.

Results and Discussion

Target community structure definition

Our case study is carried on with the support of farmers from Esapoda association (network of organic horticulture farmers from Veneto) in Italy, Aegilops (Network for Biodiversity and

Ecology in Agriculture) in Greece and ZLTO (Southern Agriculture and Horticulture Organization) in Netherlands. Esapoda and Aegilops are two small organizations with a strong link to the organic agriculture and agroecology movements. About 16.000 farmers in the provinces of Brabant, Zeeland and South Gelderland are members of ZLTO, that represents the interests of agriculture entrepreneurs working in these areas.

From the first step of interaction with the coordinators of the three networks, we have identified five main stakeholders types to take part to the co-design process: farmers, contractors, consultants, researchers and programmers.

Community requirements collection

The topic of soil health (meant as the holistic concept of chemical, physical and biological soil fertility) for the two pilots derived by the initial interaction phase with the communities that involved farmers from Italy, Greece and Netherlands in surveys, focus groups and workshops (Figure 1). The need for a platform for exchanging information about soil health threads, for monitoring the effects of fertilization practices on soil organic matter (SOM) dynamics was highlighted by Esapoda and Aegilops networks. ZLTO showed the interest to have a tool for supporting the precise spread of compost on soil according to the level of SOM in a specific area.

Figure 1 Rich picture produced by the discussion with stakeholders during a focus group in May 2016

The two topics were analysed by the researchers and programmers of the project and from this process derived the concrete pilots covering topics of interest for the farmers and feasible in the content of ICT and open data framework, in combination with farm specific data.

Tools co-design

The target communities participated to the pilots structuring phase and the development of the actual applications with the researchers and programmers of the project.

In the *Soil Health* pilot the focus was on soil fertility in time and we used open data on soil characteristics and weather conditions, together with the information coming from farmers self-assessment, for monitoring soil health as result of agronomic practices.

In the *Compost in Precision Agriculture* pilot, SOM distribution in space was targeted and we used Electro Magnetic soil scan data for determining the organic matter distribution as basis for calculating the optimum spread of compost. The results of this process in both pilots show the bridgeheads for fruitful cooperation between worlds that may look distant (conservation of traditional knowledge, open data use and high tech soil scans).

Soil Health pilot

The result of this activity is a web platform on soil health topic. The core of the platform is a central spatial database storing farm data and spatial datasets (Figure 2).

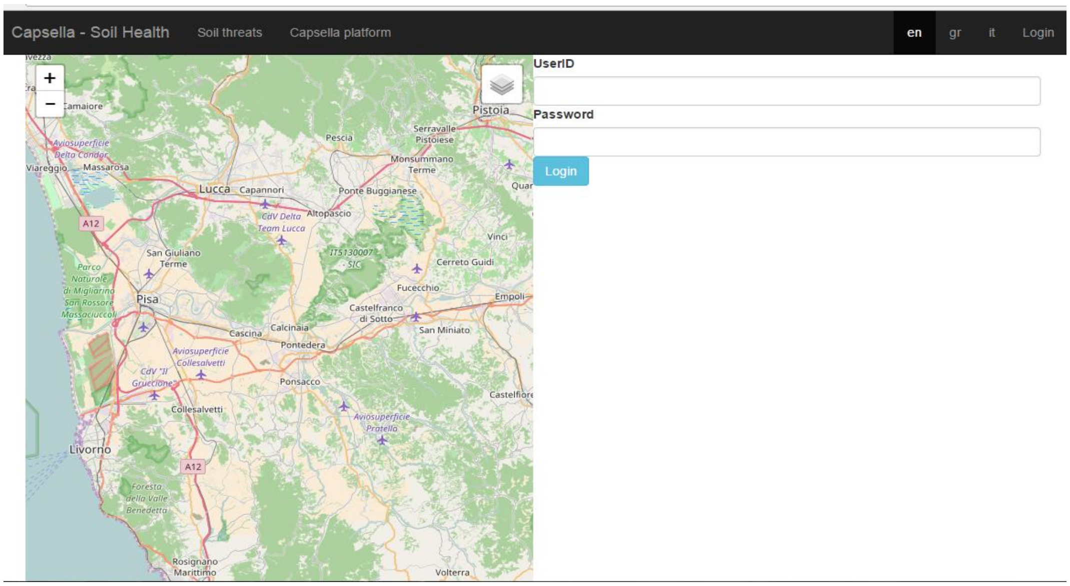


Figure 2 Home page of CAPSELLA platform on soil health

A set of web services are developed and used by the web-app to access data and tools. All the spatial data are available using the Web Map Service and Web Coverage Service standards, allowing the users to request weather and soil data for a specific location. The web service receives all the needed data from the RothC model and results are saved in the CAPSELLA database. A responsive designed web-app is the interface with the tools. The app can be reached online using a web browser from a desktop or a mobile device. The device obtains the user location using geolocation but the user can also click on a map to access a different location. The app queries the soil and climate web services to collect all the available information from the open datasets. The user can confirm a pre-defined scenario or edit the climatic and soil data, and then access two functions: spade test and SOM dynamics. The spade test function guides the user through an easy touch-enabled interface to define the soil features for different layers. At the end, summary results highlighting the positive and negative features are given and shared, eventually adding comments and a short description of farm practices (**Figure 3**).

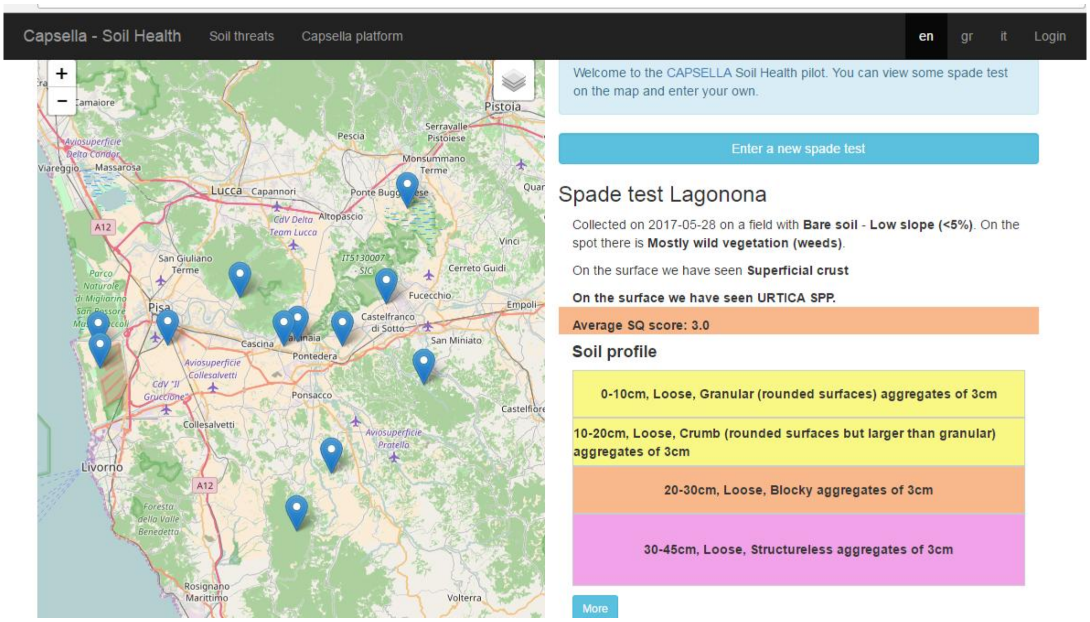


Figure 3 Example of information available of spade test entry saved on the platform

The SOM modelling function allows the user to select predefined crops and farming practices, or edit them with specific data. A preliminary list of scenarios is available in the CAPSELLA database. After choosing the scenario, RothC simulation of the SOM dynamics in the following years is run, showing the charts of SOM content and the nitrogen units available from SOM mineralisations. A map interface allows the users to search across farms, practices, spade tests and soil simulations.

Compost in Precision Agriculture pilot

The compost calculator web application exploits the CAPSELLA infrastructure for storing and retrieving its datasets. The geospatial datasets describing the involved parcels are disseminated through OGC geographical web standards, the Web Map Service (WMS) and consumed by the web application (Figure 4).

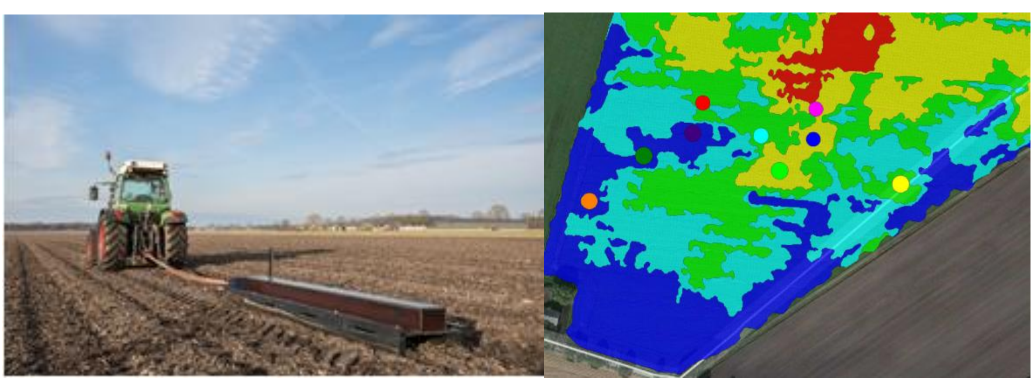


Figure 4 On the left, a tractor scanning the soil with the DualEM sensor. On the right, soil scan result of the pilot field in Netherlands in 2016.

Through a simple to use User Interface (UI) the farmer can provide the required input, as this has been described in the previous section, and automatically get a proposal for the compost application together with the produced task map. The resulted task map is stored into the

CAPSELLA infrastructure and can be later exploited by the user who generated it.

Future releases of the tool are planned to exploit open data related to soil health and the dynamic evaluation of the soil organic matter produced by the soil health pilot so as to be able to provide indication for any parcel on the application of fertilization / compost.

Feedback from the communities and from end users that did not take part to the co-design process

The tools are currently at fine tuning development and testing phase within the target communities and with external farmers. The process loop has not been completed yet, so we cannot discuss the results about the uptake phase. In the development phase, the collaboration of the different stakeholders involved resulted very useful, on one hand to make clearer to the farmers the potential of ICT tools and open data and, on the other hand, to highlight for the programmers the details about how the end-users expect to interact with the tools.

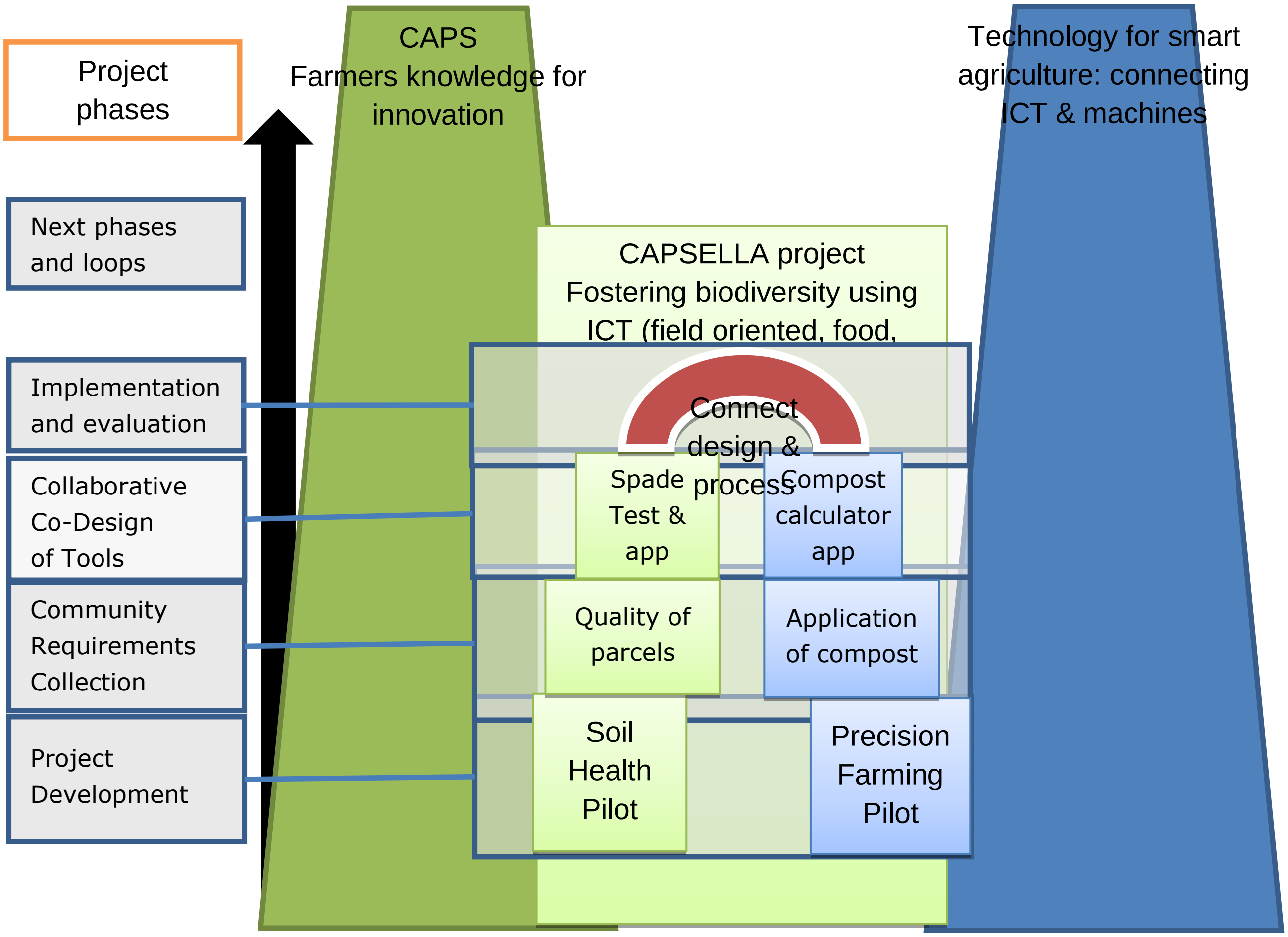
Bridging two development lines, phase by phase. How the case study contributes to the discussion on open data use in agriculture

The project was developed in the framework of Collective Awareness Platforms for Sustainability and Social Innovation (CAPS). Having as challenge the sustainability of agriculture, CAPSELLA was designed to create bridges between the biodiversity based agriculture domain and the ICT world. The *Soil Health Pilot* was developed with two farmers associations strongly grounded in the domain of organic agriculture and agrobiodiversity conservation (Figure 5).

The techniques and network in the *Compost in Precision Agriculture* pilot originated from the projects on technology for smart agriculture, connecting ICT and machines. Examples in this line are Future Internet, Smart Agrifood and Internet of Farm and Food 2020. Precision Agriculture techniques can support agrobiodiversity and soil health management, therefore the *Compost in Precision Agriculture* pilot was incorporated in CAPSELLA (Figure 5).

As described before, the communities determined the lines of pilot development, within the objectives and scenarios of the project. In the *Soil Health Pilot*, soil quality at field level was central; in the *Compost in Precision Agriculture* pilot, the application of compost was chosen. Both pilots actually focussed on improving quality of soil at field level looking one at its spatial and the other at its temporal dimension. In the design and programming of tools, the *Soil Health Pilot* started with retrieving data on individual fields from open data, detailing them with observations (spade test) for specific fields. The *Compost in Precision Agriculture* pilot started from sensor data, combining them with open data like field boundaries, and introducing both in a calculating tool. Together, we realised tool prototypes that have similar functions and design. At the same time, we worked on the realisation of CAPSELLA ambition to share open data structures and interfaces and to promote their usefulness among farmers. In this way, connectivity between the precision compost calculator and soil health tool was relatively easy to accomplish. For the later loops in development, integration has concrete advantages: the open soil data and spade test are interesting additions to the *Compost in Precision Agriculture* pilot, and the calculating tool and other parcel data are interesting for the *Soil Health* pilot.

Figure 5 Schematic representation of how CAPSELLA contribute to the discussion about social innovation in CAPS (Collective Awareness Platforms for Sustainability and Social Innovation), open data infrastructures and technology for smart agriculture



Our case study contributes to the current discussion on how public initiatives can enhance the positive exploitation of open data, when we are able to engage farmers in a practical way on a challenge that they identify as important. This means striving for data oriented tools that farmers can really use and appreciate. Because of this, from the start of the project, we asked farmers to collaborate in requirements collection, co-design and implementation/evaluation.

When the first loop of interaction with the communities will be completed and the feedback on the tools developed harvested, we will be able to understand the effectiveness of the participatory process. The appreciation of the communities will determine if our case study can be used as a practical proof of effectiveness of co-design processes both for avoiding uptake problems of ICT tools and for supporting collective awareness mediated innovation in biodiversity based agriculture. Looking at the process until the development phase, we can highlight a good integration among the stakeholders involved and a continuous interaction that is promising.

Conclusion

Farmers showed interest in ICT solutions supporting their activities as well as the need to integrate local knowledge with external information (e.g. coming from open data). Information coming from open data in the CAPSELLA application is complementary to the existing knowledge and practices of the farmers, and do not substitute farmers decision taking process. This information rather improves their decisions and empower the local knowledge with additional information coming from external sources. Cooperation with farmers as effort to be concrete with open data use in agriculture brought to tangible results in our case.

References

Altieri, M.A. 2004. "Linking Ecologists and Traditional Farmers in the Search for Sustainable Agriculture." *Frontiers in Ecology and the Environment* 2 (1): 35–42.

Anastasios, M., Koutsouris A., and Konstadinos M.. 2010. "Information and Communication Technologies as Agricultural Extension Tools: A Survey among Farmers in West Macedonia, Greece." *The Journal of Agricultural Education and Extension* 16 (3).

Breuer, N. E., Cabrera V. E., Ingram K. T., Broad K. , and Hildebrand P. E. 2008. "AgClimate: A Case Study in Participatory Decision Support System Development." *Climatic Change* 87 (3–4): 385–403.

Carberry, P., Gladwin, C., and Twomlow, S. 2004. "Linking Simulation Modelling to Participatory Research in Smallholder Farming Systems." In *ACIAR PROCEEDINGS*, 32–46. ACIAR; 1998.

Carbonell, I. 2016. "The ethics of big data in big agriculture." *Internet Policy Review* 5(1)

Cerf, M., Jeuffroy M., Prost, L. and Meynard, J. 2012. "Participatory Design of Agricultural Decision Support Tools: Taking Account of the Use Situations." *Agronomy for Sustainable Development* 32 (4): 899–910.

Coleman, K. & Jenkinson, D.S. 1996, "Rothc-26.3 - a model for the turnover of carbon in soil", in DS Powlson, P Smith, & JU Smith (eds.), Evaluation of Soil Organic Matter Models, NATO ASI Series, Springer Berlin Heidelberg, pp.237–246

Hengl, T., Mendes de Jesus, J. MacMillan, R.A. Batjes, N.H., Heuvelink, G.B., Ribeiro, ME, Samuel-Rosa, A. et al. 2014. "SoilGrids1km — Global Soil Information Based on Automated Mapping." *PLOS ONE* 9 (8)

Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G., and Jarvis, A. 2005, "Very high resolution interpolated climate surfaces for global land areas", *International Journal of Climatology* December 1, vol. 25, no. 15, pp. 1965–1978.

Jakku, E., and P. J. Thorburn. 2010. "A Conceptual Framework for Guiding the Participatory Development of Agricultural Decision Support Systems." *Agricultural Systems* 103 (9): 675–82.

Kshetri, N. 2014. "The Emerging Role of Big Data in Key Development Issues: Opportunities, Challenges, and Concerns." *Big Data & Society* 1 (2)

Lindblom, J., Lundström, C., Ljung, M. and Jonsson, A. 2016. "Promoting Sustainable Intensification in Precision Agriculture: Review of Decision Support Systems Development and Strategies." *Precision Agriculture*, December, 1–23.

Matthews, K. B., Schwarz, G., Buchan, K., Rivington, M and Miller, D. 2008. “Wither Agricultural DSS?” *Computers and Electronics in Agriculture* 61 (2): 149–59.

McCown, R. L. 2002. “Locating Agricultural Decision Support Systems in the Troubled Past and Socio-Technical Complexity of ‘models for Management.’” *Agricultural Systems* 74 (1): 11–25.

Palmer, N. (2012) ICT for data collection and monitoring and evaluation. *Eagriculture, June*.

Panagos, P., Van Liedekerke, M., Jones, A., and Montanarella, L.. 2012. “European Soil Data Centre: Response to European Policy Support and Public Data Requirements.” *Land Use Policy* 29 (2): 329–38. doi:10.1016/j.landusepol.2011.07.003.

Rojas, R.V., Achouri, M., Maroulis, J., and Caon, L. 2016. “Healthy Soils: A Prerequisite for Sustainable Food Security.” *Environmental Earth Sciences* 75 (3).

Rossi, V., Salinari, F., Poni, S., Caffi, T. and Bettati T. 2014. “Addressing the Implementation Problem in Agricultural Decision Support Systems: The Example of Vite.net®.” *Computers and Electronics in Agriculture* 100 (January): 88–99.

Seppala, T.J. 2014 Monsanto pushes Big Data-driven planting but farmers are skeptical. Available at: https://www.engadget.com/2014/02/26/monsanto-prescriptive-farming/

Thorburn, P. J., Jakku, E., Webster, A J., and Everingham,Y. L. 2011. “Agricultural Decision Support Systems Facilitating Co-Learning: A Case Study on Environmental Impacts of Sugarcane Production.” *International Journal of Agricultural Sustainability* 9 (2): 322–33.

Van Meensel, J., Lauwers, L., Kempen, I., Dessein, J. and Van Huylenbroeck, G. 2012. “Effect of a Participatory Approach on the Successful Development of Agricultural Decision Support Systems: The Case of Pigs2win.” *Decision Support Systems* 54 (1).

Zomer R.J., Trabucco A., Bossio, D.A., van Straaten, O., Verchot, L.V. 2008. “Climate Change Mitigation: A Spatial Analysis of Global Land Suitability for Clean Development Mechanism Afforestation and Reforestation.” *Agric. Ecosystems and Envir.* 126: 67-80.

Zomer, R.J., Bossio, D.A., Trabucco, A., Yuanjie, L., Gupta, D.C. & Singh V.P. 2007. Trees and Water: Smallholder Agroforestry on Irrigated Lands in Northern India. Colombo, Sri Lanka: International Water Management Institute. pp 45. (IWMI Research Report 122).