DIVERFARMING

Crop diversification and low-input farming across Europe: from practitioners' engagement and ecosystems services to increased revenues and value chain organisation

A TOOLKIT OF INDICATORS FOR CHARACTERISING PRODUCTIVITY AND SUSTAINABILITY

Deliverable D7.1
Version 1.0
Issue date: 04/10/2019
Authors: Silvia Vanino, Roberta Farina, Roman Hüppi, Bruno Pennelli, Johan Six

DIVERFARMING

This project has received funding from the *European Union's Horizon 2020 Research and Innovation Programme* under grant agreement No 728003

European Commission

DIVERFARMING

Document summary	
Document title	A toolkit of indicators for characterizing productivity and sustainability
Authors	Silvia Vanino, Roberta Farina, Roman Hüppi, Bruno Pennelli, Johan Six
E-mail of principal author	roberta.farina@crea.gov.it
Lead beneficiary	ETH
Deliverable No.	D7.1
Work Package	WP7. Data analysis and upscaling to assess farm productivity and sustainability
Dissemination type	Demonstrator
Dissemination level	Public
Deliverable due date	31/07/2019 (month 23)
Release date	04/10/2019 (month 30)
Copyright	© 2019 DIVERFARMING Project and Consortium

DIVERFARMING

List of Diverfarming participants

No	Name	ACRONYM	COUNTRY
1	Universidad Politécnica de Cartagena (Coordinator)	UPCT	Spain
2	Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria	CREA	Italy
3	Agencia Estatal Consejo Superior de Investigaciones Científicas	CSIC	Spain
4	Universita degli Studi della Tuscia	UTu	Italy
5	Asociación Regional de Empresas Agrícolas y Ganaderas de la Comunidad Autónoma de Murcia	ASAJ	Spain
6	Consorzio Casalasco del Pomodoro Società Agricola cooperativa	CCP	Italy
7	Arento Grupo Cooperativo Agroalimentario de Aragón	GA	Spain
8	Barilla G.E.R. Fratelli SPA	Bar	Italy
9	Disfrimur Logistica SL	DML	Spain
10	Universidad de Córdoba	UCO	Spain
11	Wageningen University	WU	Netherlands
12	Firma Nieuw Bromo van Tilburg	NBT	Netherlands
13	Industrias David S.L.U.	InDa	Spain
14	University of Portsmouth Higher Education Corporation	UPO	United Kingdom
15	Universität Trier	UT	Germany
16	Eidgenössische Technische Hochschule Zürich	ETH	Switzerland
17	Weingut Dr. Frey	WDF	Germany
18	University of Exeter	Exeter	United Kingdom
19	Pecsi Tudomanyegyetem - University of Pecs	UP	Hungary
20	AKA Kft	AKA	Hungary
21	Nedel-Market Kft	NMT	Hungary
22	Luonnonvarakeskus	Luke	Finland
23	Paavolan kotijuustola	PK	Finland
24	Polven juustola	PJ	Finland
25	Ekoboerderijdelingehof	Eko	Netherlands

DIVERFARMING

Executive summary

The Diverfarming project has as an important output a toolkit of indicators to comprehensively evaluate the effect of diversification in cropping systems. The toolkit allows to address the different aspects of sustainability: environmental integrity, economic resilience and social well-being. Although there is a common sense that the European agricultural system needs to implement more diversity in crops over space and time, the effects on different ecosystem services but also human activities are variable. The presented list of indicators should be able to capture the opportunities but also shortfalls of a certain diversification option. With such a metrics it will be possible to assess and communicate the interactions of crop diversification with ecosystem services and their contribution towards agroecosystems sustainability. We have used the SAFA guidelines by the FAO to structure the different indicators. They are grouped within the the following themes and sub-themes: Atmosphere (greenhouse gases / climate change), Land (soil quality, land degradation, soil contamination), Water (water quality, water management), Biodiversity (ecosystem diversity, species diversity, genetic diversity), Investment (profitability), Vulnerability (stability production), Human safety and Health (public health) and Participation (stakeholder dialogue). The 32 individual indicators selected within the different sub-themes are designed to effectively put to use the data collected from the Diverfarming case studies. We are working towards a compatible framework with the other Horizon 2020 projects on crop diversification (https://www.cropdiversification.eu/). Finally, the sustainability indicator toolkit will be applied on the SusDiver app to assess the impact of different diversification strategies at the farm level.

Table of Contents

1. Introduction

Modern farming intensification produced significant environmental impacts such as water pollution i.e. nitrates leaching (Addiscott, 2005), contamination by pesticides (Fantke et al., 2012), and heavy metals (Toth et al., 2016), soil degradation by erosion, sealing, contamination, pollution (Lal et al., 1990), biodiversity loss (Kehoe et al., 2017) and greenhouse gas (GHG) emissions (Sanz-Cobena et al., 2017). Moreover, it has caused an increased vulnerability to political, social and climatic risks, for both the large use of fossil fuels mostly coming from countries outside Europe and products and food prices affected by market speculations. As further possible risk, climate change cannot be neglected since it will reflect on the change in temperature and precipitation patterns, with relevant technical issues to the farmers and possible increase of pests and diseases incidence.

1.1. The European agriculture

European agricultural systems are tremendously efficient in terms of productivity and in the past years they have registered increased yields for the most important crops. In fact, from 2007 to 2014 yields of cereals (+27.8 %), green maize (+22.7 %), oilseeds (+30.0 %), sugar beet (+11.7 %) have all increased. However, this increase came with significant environmental costs, causing a considerable alteration of the agro-ecosystems, and, in some cases, impairing the future productive capacity of agricultural lands and their possibility to adapt to changing situations and needs (i.e. increase of fertilizer price, extreme climate events, etc.).

A picture of the agricultural systems in Europe reveal that cereals dominate the arable landscape (approximately 60% of Utilized Agricultural Area-UAA) with a share of 75 up to 100% of the rotations (Figure 1). Root crops (2%), oilseed crops (10%) and green maize (11%) are also present but with a lower share in the rotations. The common length of rotations in arable farming systems is 3-4 years and normally do not include legume crops, sharing only 0.6% of the rotations (EuroSTAT at http://ec.europa.eu/eurostat/data/database). Rotation including legumes are rare, short (2-4 years) and mostly present in humid or oceanic climate. Monocultures are normally limited, and they refer only to some crops such as rice in Italy; cotton in Greece, Spain and Portugal; barley, rye or oat in Northern EU, and durum wheat in Mediterranean regions (http://ec.europa.eu/eurostat/statistics-explained/index.php/Agricultural_production_-_crops).

It is also noticeable the very limited number of cultivated crops: for example, in France 12 crops cover 50% of the cultivated land (EuroSTAT at http://ec.europa.eu/eurostat/data/database). Permanent crops, including fruit trees, vineyards and olives groves, represent the 6.6% of the total UAA.

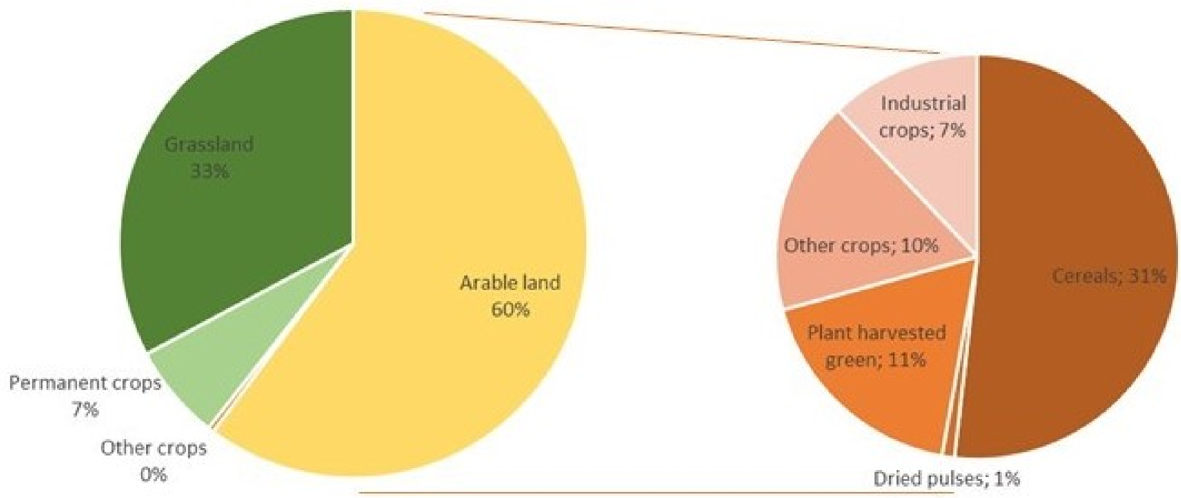

Figure 1*. Agricultural land use in Europe (Total agricultural utilized area is nearly 177 million ha) (from EuroSTAT at http://ec.europa.eu/eurostat/data/database).*

To design farming systems that can, at the same time, ensure farmers income and environmental sustainability is one of the most important challenges for the agricultural sector in Europe and worldwide. Cropping systems like organic, agroecology-based, ecologically-intensive, diversified farming systems all refer to the common concept of new/revised approaches to the issues generated by the intensive agricultural systems as illustrated above.

1.2. Diverfarming strategy

Diversification of crops through rotation, intercropping and multiple cropping favours ecological interactions that contribute to maintain soil fertility, nutrient cycling and retention, water storage, pest/disease control, pollination, to reduce the use of external inputs and the build-up of pests, and to mitigate the effects of and adaptation to climate change (Nicholls et all, 2016). The adoption of crop diversification from intensive and simplified farms represents an important step towards sustainability.

Despite the technical and scientific consensus on the positive impact of diversification, the adoption of “new concept” crop diversification systems are still uneven from the farmers’ side, due to the lack of knowledge on new/underutilised crops, no awareness on the benefits of rotations/multiple cropping/intercropping, the costs of machinery or new labour organization, market uncertainty and lack of reward with higher price for the products. Often, policies and strategies fostering the adoption of diversification and the reduction of inputs failed, because of technical solutions were not affordable or products being out of market.

The H2020 Diverfarming project (Grant Agreement 798003) was therefore designed to empower farmers and agro-industries to implement low-input innovative practices of crop diversification and the related value chains, to remove the barriers that limit their adoption. The project Diverfarming has the aim to promote the diversification and the reduction of inputs in the European farming systems, by proposing adequate agronomic solutions and by removing technical, social and economic barriers. A key step for the promotion of the diversified systems is the implementation of friendly-to-use tools enabling to identify the pros and cons of the diversified systems compared to traditional ones. The tool should allow for the assessment of profitability and agro-environmental impacts of the newly designed agricultural systems respect to reference systems. Recognizing the strategic role that the tools could play for promoting the diversification adoption, one of the project's work-package, the WP7, is completely devoted to the assessment of how diversified cropping systems influence soil-water-atmosphere continuum from farm to regional scale. To draw the most comprehensive picture of the diversification sustainability, three synergistic approaches were foreseen: modelling, geographic information systems (GIS) analysis and indicators-based evaluation.

The WP7's approaches for the agroecosystems sustainability assessment were specifically designed to detect the differences between the traditional systems compared to diversified ones. Moreover, they are designed so that measured data and model output can all be used to perform the evaluation of the agricultural systems (Figure 2). It is true that the economic aspect of sustainability is not included in Figure 2 because this topic is studied within WP8 "Economic assessment at farms and value chains". However, economic indicators have been included in the Toolkit as close collaboration between both WPs in the project.

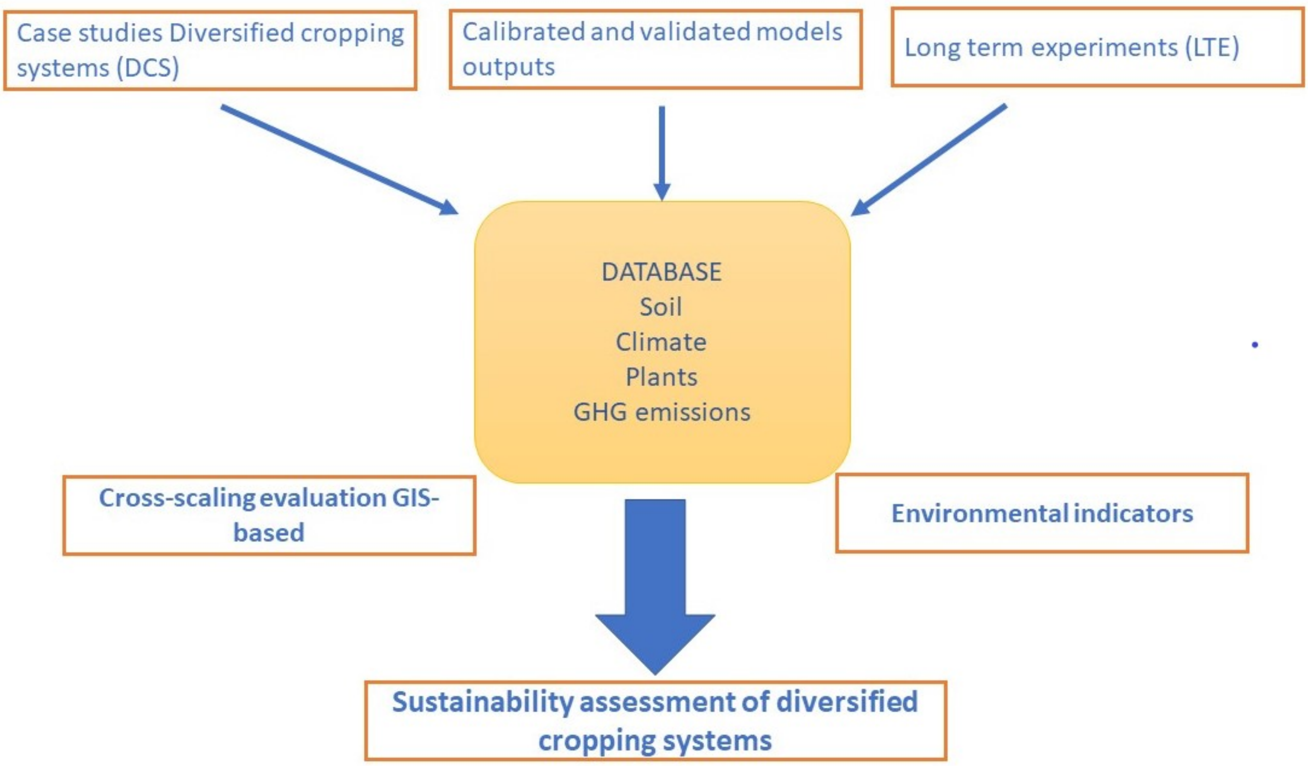

Figure 2. *Scheme of the Work package 7*

The present deliverable D7.1 illustrates the criteria followed for the selection of indicators, their possible aggregation and their validation. Moreover, fiches describing each indicator were prepared and showed as Annex. A methodology to display indicators results using a multi-criteria analysis (MCA) approach was also defined.

2. The need for diversification

The current agricultural food system causes many environmental problems, often trading-off long-term maintenance of ecosystem services for short-term agricultural production (Ponisio et al., 2014). The project Diverfarming has been funded under the H2020 RUR-06 call, where temporal and spatial diversification were identified as "...drivers for resource-efficient farming systems" allowing also the adoption of low-input agronomic practices. Crop diversification is defined in the call as the practice of growing different crop species on the same land "...in successive growing seasons (i.e. rotation) and within a growing season (i.e. multiple cropping) and growing different species in proximity in the same field (i.e. mixed, row and strip intercropping)".

2.1. Diversification options

As first step of the sustainability assessment process, it is necessary to precisely define the terminology of the study and how this translates in agronomic practices.

Diversified Cropping or Farming Systems (DFS) can be defined as "...the farming practices and landscapes that intentionally include functional biodiversity at multiple spatial and/or temporal scales in order to maintain ecosystem services that provide critical inputs to agriculture, such as soil fertility, pest and disease control, water use efficiency, and pollination." (Kremen et al., 2012).

The diversification concept can be applied at several scales, from plot to landscape. For the objectives of our study and in coherence with the terminology used in the call RUR 06, we focus on the diversification at field scale, identifying three main categories: rotation, multiple cropping and intercropping (Figure 3).

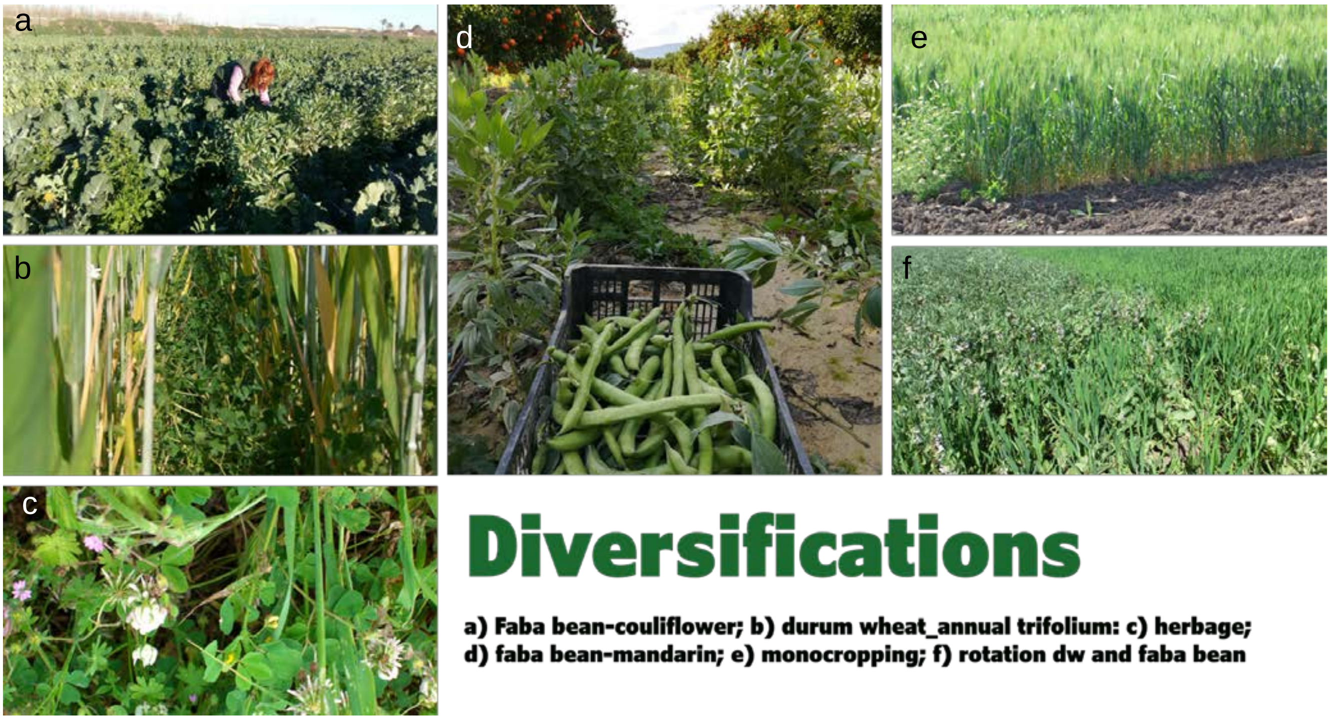

Figure 3. *Examples of rotations, multiple cropping, intercropping in Diverfarming project.*

2.1.1. Crop rotation

Crop rotation is the practice of cyclically growing a sequence of different plant species on the same parcel of land following a defined order of the crop succession with or without a fixed order (Farina et al., 2017). From the agronomic point of view, it consists of managing the crop succession to optimise positive interactions and synergies among crops. Crop rotation is the most traditional way to introduce diversification in a farm. Rotation, one of the oldest practices in agriculture, was adopted since the beginning of sedentary agriculture starting from the empirical evidence that the yields decreased in the case of cropping (monocropping) for many years. From the Middle Age, crop rotation practice evolved as a precise strategy to increase harvestable yields (Ryan et al., 2008). After the Green Revolution, the extensive use of commercial fertilizers and pesticides has somehow hidden the beneficial effect of rotation. However, as stated by Karlen et al. (1994) "...no amount of chemical fertilizer or pesticide can be fully compensated for crop rotation effects". Rotations are now reconsidered as an important mean of sustainability of farms, helping to reduce the use of external inputs, to break crop pest cycles, to avoid weeds become resistant to commonly used herbicides and to enhance the whole resilience of the system (Altieri et al., 2015).

The schemes of crop rotations are various and inherently regional, and a rotation suited for a specific pedo-climatic condition might not applicable to another (Bruns, 2012). In Diverfarming, a large variety of rotations was set up, according to pedoclimatic and socio-economic context.

2.1.2. Multiple cropping

Multiple cropping is the cultivation of two or more crops, more than once on the same field in a year (or growing season). In multiple cropping the plants are not growing together at the same time but in a temporal sequence. Crop diversification in this case is only temporal and the farmer manages one crop at time (Gaba et al. 2015). Multiple cropping has several advantages: (i) the risk of total loss from drought, pests and diseases is reduced; (ii) this method can help farmers cope with economic issues because it gives maximum production and income from small plots; (iii) it improve soil fertility by fixing nitrogen in the soil when legumes were included in the cropping, and ground cover of crops reduces weeds and prevents erosion.

2.1.3. Intercropping

Intercropping consists of growing several crops (annual or perennial) simultaneously in the same field for a significant amount of time, each crop developing and growing according to its physiology (Brisson et al., 2004). Intercropping can be view as an eco-functional intensification practice, aiming to take advantage of the association between crops. The association might improve productivity per unity of land, increase the land equivalent ratio (LER), and optimise the available resources (Gao et al., 2009). The cultivar or plant species can be totally mixed (mixed intercropping) or arranged in strip (row intercropping). Grass–legume intercrops are common in natural ecosystems and are often used in herbages to improve the quality of hay. Intercropping is very common in the tropics and was common in the past, while they are rarely used in developed countries (Lithourgidis et al., 2011). However, they are now reconsidered in a framework of external inputs reduction and better use of resources. They are of interest in organic farming, also for the possible weed- and soil-borne diseases suppressive effects (Bilalis et al., 2008). Intercropping can include growing two or more crops only during a part of each crop life cycle. Numerous arrangements of intercrops exist: strip intercrops, alley crops, mixed intercrops or even wind-breaks, which exhibit more or less spatial heterogeneity (Pelzier et al., 2012).

2.2. Inputs reduction

Diversifying simple cropping systems often entails altering other management practices, such as tillage regime or nitrogen (N) source fertilizers. Single-species cropping systems are based on individual plants, all using the same resources in the same way. In such system the competition among plants is reduced and managed by external inputs use. In multi-/ inter-cropping systems the interaction among plants is used to increase the production, with a reduced use of water and nutrients and strategies are needed to reduce competition among species.

2.2.1. Mineral fertilizer reduction

Mineral fertilizers, especially N, are among the major responsible for the impressive crop yield increases realized since the 1950s (Robertson and Vitousek, 2009). Prior to the massive utilization of mineral N fertilisers, the addition of N to ecosystems resulted only from biological N fixation. Since the introduction of N mineral fertilisers, the rate of N inputs into terrestrial N cycle have doubled, with consequences on N_2O emissions increase, acidification of soils and water (Vitousek et al., 1997). Furthermore, because the rates of fertilizer applied often exceed plant requirements, unintended environmental consequences, such as leaching of nitrates and emission of nitrous oxide and ammonia, are caused.

About 16 to 20 Tg N_2O-N is emitted annually to the atmosphere and agriculture accounts for 20-30% of the emissions (67–80% of the anthropogenic N_2O emissions) (Ussiri and Lal, 2013). About half of the anthropogenic N_2O emissions originate from cultivated soils (Stehfest and Bouwman, 2006).

In conventional agricultural systems, N management focus on soluble, inorganic plant-available pools. On the contrary, in diversified cropping systems, the management of N optimize both organic and mineral pools, by microbial- and plant-mediated processes. This approach implies the deliberate use of different nutrient sources and the exploitation of the plant diversity.

Strategies to optimise, reduce or avoid the use of fertilisers in diversified cropping systems compared to actual mineral N-based systems, are reported in Table 1.

Table 1. Characteristic of the nitrogen management framework in current and diversified cropping systems (adapted from Drinkwater, 2004)

Agronomic framework	Current agronomic framework	Diversification framework
Goals	Maximize crop N uptake and yield	Optimal yield while balancing N addition and exports
Nutrient management strategy	Aimed to increase mineral N crop uptake, by removing all growth limiting factors	Aimed to increase internal N cycling capacity to (1) maintain N pools that can be accessed through plant- and microbially mediated processes and (2) conserve N by creating multiple sinks in time and space for inorganic N
N pools actively managed	Inorganic pools	Organic and inorganic pools
Processes targeted by nutrient management	Crop uptake of N	Plant and microbial assimilation of N, C cycling, N and C storage
Strategy toward microbially-mediated N transformations	Reduce as much as possible	Manage to promote N transformations that conserve N, reduce transformations that lead to losses by maintaining small inorganic N pools
Strategy for reducing N leaching	Increase crop uptake of mineral N, use of nitrification inhibitors	Minimize inorganic pool sizes through management of multiple processes
Assessment of NUE	Fertilizer uptake of the crop. Time step is one growing season	Apparent budget. N balance and yield, time-step according to the cropping system cycle

2.2.2. Deficit Irrigation

Irrigated agriculture is the biggest consumer of freshwater. In Southern Europe irrigation accounts for more than 60% of water use (EIIE, 2000). Irrigation is used to stabilize yields in temperate/cold climates and is essential to cultivate summer crops (vegetables, maize, etc.) in Mediterranean regions. Improving management is most likely the best option in most agricultural systems for increasing the efficiency of water use (Steduto et al., 2007).

Deficit irrigation (DI) is a method of irrigation where the quantity of water used is maintained below the maximum level and the stress that is generated has minimal effects on the yield (Jensen at al., 2010). Objective of full irrigation (FI) is to meet crop water requirements to maximize crop yield. On the opposite, in deficit irrigation (DI) water use is optimized in relation to crop yield per volume of water consumed (Francaviglia et Di Bene., 2019). Deficit irrigation is an optimization strategy in which irrigation is limited to the periods where a crop is in a drought sensitive physiological stage. Water restriction is limited to drought-tolerant phenological stages, often the vegetative stages and the late ripening period (Geerts and Raee, 2009).

In Mediterranean regions, side effects of irrigation include a stimulation of soil microbial activity with consequent faster mineralization of soil organic matter that, in many Mediterranean systems, is not compensated by the C inputs. Nuñez et al. (2007), analyzing soil profiles in Spain, found that in irrigated soils, soil organic matter was always lower than in the rainfed ones. This is confirmed by studies of Zornoza and collaborators (Zornoza, 2016; Muñoz and Zornoza, 2017) that found a significant decrease in CO_2 emission rates, compared to that of FI during the period when deficit was applied. Results of previous research were quite variable and site- and crop- dependent and the need to further research was highlighted (Jensen, 2010).

2.2.3. Tillage reduction

Many authors have demonstrated how the adoption of an intensive soil management led to a depletion of soil organic matter level with negative ecological effects: reduction of soil biodiversity and soil water storage capacity (McVay et al., 2006), compaction, creation of waterproof layers that reduce the penetration capacity of roots and the percolation of water (Doran, 1994, Dick, 1994). The adoption of reduced or no tillage, characterised by the least disturbance of soil, has been proved to have a positive effect on soil C conservation (West and Post, 2001, Lopez Bellido et al., 2010), soil water retention (De Vita et al., 2007), soil aggregation stability (Hernanz, 2002). It has also been shown a positive effect on C sequestration in the top layer (Six et al., 2000). The reduction on tillage intensity normally improved the biological and biochemical processes in soils (Alvarez and Alvarez, 2000; Acosta-Martínez and Tabatabai, 2001).

3. Ecosystem services from diversified cropping systems

Ecosystem services (ESs) are benefits that humans obtain from ecosystems that support, directly or indirectly, their survival and quality of life. The Millennium Ecosystem Assessment (MEA, 2005) categorizes ecosystem services into four different classes (Figure 4):

- **Provisioning services**, the products obtained from ecosystems, including food, fiber, fuel, genetic resources, ornamental resources, freshwater, biochemical, natural medicines and pharmaceuticals.
- **Regulating Services**, the benefits obtained from the regulation of ecosystem processes including air quality, climate, water, erosion, water purification and waste treatment, disease, pest, pollination and natural hazard.
- **Cultural Services**, the non-material benefits people obtain from ecosystems including cultural diversity, spiritual and religious values, knowledge systems, educational values, inspiration, aesthetic values, social relations, sense of place, cultural heritage values, recreation and ecotourism.
- **Supporting services**, necessary for the production of all other ecosystem services. Some services, like erosion regulation, can be categorized as both a supporting and a regulating service. These services include soil formation, photosynthesis, primary production, and nutrient and water cycling.

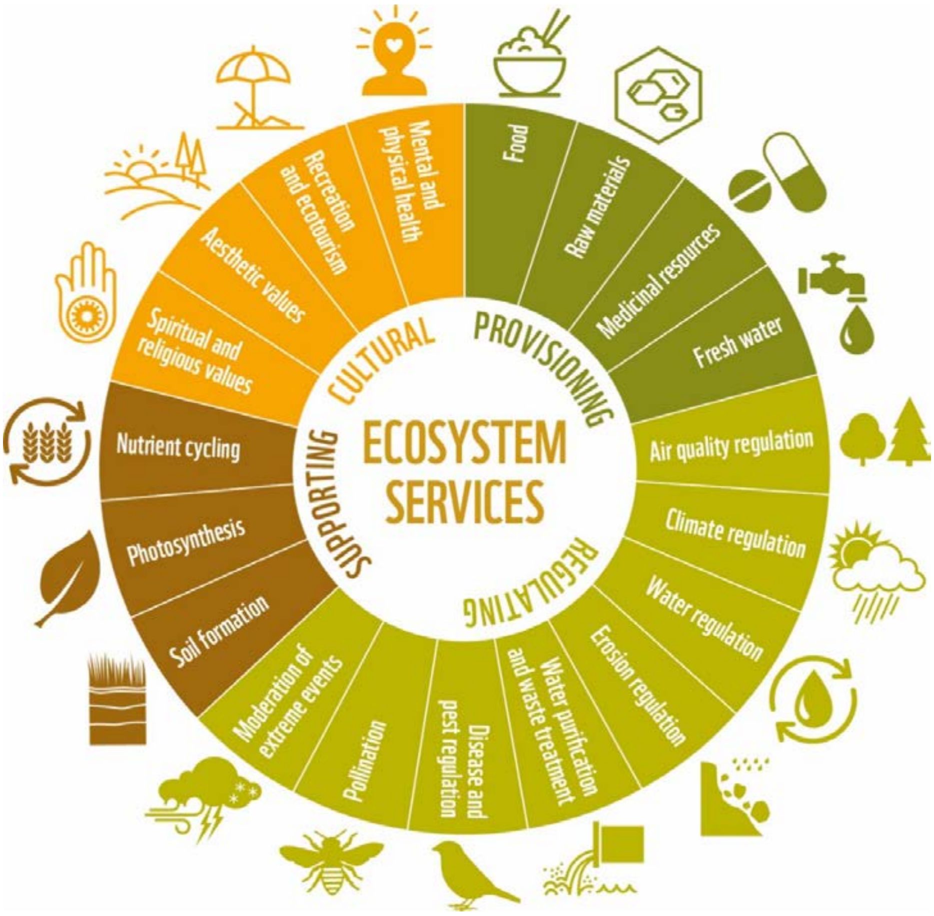

Figure 4. *Ecosystem services (from WWF, 2018).*

Diverfarming proposed the following set of farming practices with the assumption that they can improve the delivery of ecosystem services:

- Diversification of plants in the field/farm through rotation, intercropping and multiple cropping;
- Novel machinery for reducing tillage intensity or zero-tillage,
- Optimisation of fertiliser applications, use of alternative organic amendments, functional composts, integrated pest management;
- Irrigation management through regulated deficit irrigation and use of alternative water resources,
- Management of native vegetation,
- Precision farming and nutrient management,
- Conservation agriculture (cover crops, mulching, incorporation of crop residues, erosion barriers), cross-slope farming.

During the project, the effective delivery of ecosystem services (soil fertility, prevention of soil and water contamination, water availability, reduced greenhouse gas (GHG) emissions, carbon sequestration, erosion prevention, above and belowground biodiversity and pest and disease control) by the diversified cropping systems will be assessed.

Agro-ecosystems are 'functional units, producing agricultural products and providing rural services'. Their spatial extent ranges from a single field to the global scale. Agro-ecosystems are clearly distinct from other ecosystems in that the agricultural production is an integral part of the ecosystem maintenance. Consequently, sustainability of agro-ecosystems needs to be ecologically as well as economically viable.

Diversified cropping systems can produce marketable yields and ecosystems services at the same time. Nine major ecosystem services that the proposed diversified cropping systems could potentially provide were identified, as reported in Table 2.

Table 2. Ecosystem services influenced by diversified cropping systems

Ecosystem services	Rotation	Intercropping	Multiple cropping	N min inputs reduction	Tillage reduction	Irrigation reduction
Nutrient cycling	X	X	X	X	X	X
Soil conservation, structure, fertility	X	X	X	X	X	
Water provision, quality, quantity	X	X	X		X	X
Pollination	X	X	X			
Pest & Disease control	X	X	X			
Weed control	X	X	X			
Erosion control	X	X	X			
Climate regulation: soil carbon sequestration	X	X	X	X	X	X
Climate regulation: GHG emissions	X	X	X	X	X	X
Productivity	X	X	X	X	X	X

4. How to evaluate the sustainability of diversified cropping system: the toolkit of indicators

To make the concept of ecosystem services operational with respect to agro-ecosystems sustainability evaluation, ESs must be quantified to detect changes as a function of changing conditions. However, measuring the ESs is not always practically attainable, given the nature of some of them and the limitations in the number of measures that can be realistically carried out in experiments/farms. Metrics and indicators are essential to assess and communicate the current status and interactions of ecosystem services and their contribution towards agroecosystems sustainability. They allow to understand if the trend of services is favourable or not and if proposed alternative farming systems are increasing or decreasing the overall sustainability. This will help to design management and policies that ensure the sustainable flow of services to support human welfare and maintain biodiversity.

Despite wide consensus on the relevance of the sustainability concept and its practical application, a high grade of variability exists on how sustainability in agriculture is defined and how it is practically implemented. FAO and the European Union have adopted multidimensional (i.e. social, economic and ecological) and multi-functional (e.g. food security, biodiversity and natural resources conservation, maintenance of the landscape) perspectives for sustainability in agriculture, following chapter 14 of Agenda 21 on sustainable agriculture and rural development.

4.1. Selection of indicators

Indicators are useful for informing about the status of a system, for interpreting and summarizing complex processes, and for communicating effectively with stakeholders. In general, the term 'indicator' refers to quantifiable and measurable attributes of a system and might supplies information on other variables or processes that are difficult to access or to describe. Indicators should respond to the following characteristics:

1. **Intuitive**. Indicators point out information about ecosystem services clearly without ambiguity. It is of particular importance that indicators are easily understood by policy-makers and other non-technical audiences.
2. **Sensitive**. Indicators are able to detect changes timely in order to give early warnings of undesirable changes.
3. **Accepted**. They are scientifically-based and transparent in terms of calculation methodology, data availability and evaluation (Layke et al., 2012)

Since a single indicator cannot meet all the requirements, **a set of indicators (toolkit)** is needed to describe key attributes of ecological systems of interest (Dale et al., 2004). A first analysis of the studies conducted so far on the selection and application of indicators to assess farming systems sustainability have shown that, there has been an important effort to design comprehensive or targeted set of indicators.

Agriculture is a key sector, strictly linked with environment, economy and policy. For instance, agriculture can have significant impacts on the environment: while negative impacts are relevant, and can include pollution and degradation of soil, water, and air, agriculture can also positively impact the environment, for instance by trapping greenhouse gases within crops and soils or mitigating flood risks through the adoption of certain farming practices. For this reason, the toolkit of indicators proposed in this study was designed to monitoring the linkages between crop diversification and agro-environmental, political and social aspects. The toolkit of indicators proposed in this project was defined based on the sets already used for international and European statics and surveys (i.e. OECD and FAO, Eurostat, etc.). Particular focus has been given for tracking the integration of environmental indicators into the Common Agricultural Policy (CAP) at EU level, and other international frameworks and guidelines (i.e. SAFA, FAO 2014). We have also exploited the results of previous and ongoing EU projects (i.e. H2020 projects Fatima and DiverIMPACTS).

As for the specific choice of indicators, the preference was given based on their applicability to farming systems diversification context. For a better reading of the results of the indicators, they were subdivided in Macro-themes, Themes and Sub-themes as described in Table 3.

Table 3. Subdivision of indicators in Macro-themes, themes and sub-themes and number of indicators in each sub-themes considered in the project.

Macro-theme	Themes	Sub-themes	Num. indicator
Environmental sustainability	Atmosphere	Greenhouse Gases/ Climate Change	4
	Land	Soil quality	5
		Land degradation	1
		Soil contamination	2
	Water	Water quality	2
		Water management	2
	Biodiversity	Ecosystem diversity	3
		Species diversity	3
		Genetic diversity	1
Economic sustainability	Investment	Profitability	3
	Vulnerability	Stability of production	3
Social sustainability	Human safety and Health	Public health	2
	Participation	Stakeholder dialogue	1

4.2 Toolkit of indicators

The indicators presented below try to highlight the effects of diversification on the themes above. Crop diversification is expected to positively affect moisture conservation and water infiltration, run-off of pesticides and fertilizers, consumption of fuel, organic matter content with associated carbon sequestration, diversity of soil, flora, and fauna, wildlife habitat, soil structure, wind and water erosion, labour and investment in equipment.

Indicators will be subdivided in the following sub-theme and described in Annex1:

Sub-themes	Indicators	Code	Description	WP interested
Greenhouse Gases/Climate Change	Change in SOC stock	CC1	Impact on soil organic carbon (SOC) stocks. SOC indicator is important for land and soil degradation monitoring.	WP5
	Nitrous oxide emission	CC2	Change in nitrous oxide emissions by the diversified cropping systems.	WP5
	Methane emission	CC3	Change in soil methane emissions by the diversified cropping system	WP5
	GHG balance	CC4	This indicator includes soil GHG emissions but also emissions from management (machinery), pesticide use and fertilisation.	WP5
Soil quality	Nutrient availability	S1	Complex indicator that considers mineral nitrogen, potentially mineralizable nitrogen, soil nitrate, soil test phosphorus, potassium, sulphur, calcium, magnesium, boron, zinc and soil pH.	WP5
	Nitrogen Balance	S2	A nitrogen balance calculates the balance between nitrogen added to an agricultural system and nitrogen removed from the system per hectare of	WP5

			agricultural land.	
	Phosphorous balance	S3	A phosphorus balance calculates the balance between added and removed phosphorus to an agricultural system per hectare of agricultural land.	WP5
	Organic matter	S4	Soil organic matter quality is one of the most important factors for soil fertility and is dependent on soil management.	WP5
	Soil compaction	S5	Bulk density and air-filled pore volume at a specified suction	WP5
Land degradation	Soil erosion by water and wind	L1	The role of cover crops and crop residues is crucial in mitigating the impact of atmospheric agents (rain and wind) on soil particles; moreover, their presence slow down the water flow that does not infiltrate into the soil, reducing the removal possibility of soil particles.	WP5
Soil contamination	Heavy metal contents in soil	SC1	Amount of heavy metals in soil.	WP5
	Consumption of pesticides	SC2	The amounts of different pesticides used for the whole crop rotation.	WP8
Water quality	Water quality	W1	Nitrate loss by leaching, potentially polluting water bodies.	WP5
	Available water capacity	W2	Available water capacity is the maximum amount of plant available water a soil can provide. It is an indicator of a soil's ability to retain water and make it sufficiently available for plant use.	WP5

Water management	Water use efficiency	W3	This indicator provides information on the water efficiency of crops related to crop productivity.	WP5
	Water scarcity	W4	In crop diversification, water management mainly depends on the irrigation system, but the water requirements are lower and it is easier to obtain good yields in non-irrigated conditions or water scarcity.	WP5
Species diversity	Earthworms diversity	SD1	Earthworm species collected.	WP4
	Crop rotation diversity	SD2	Number of elements in the crop rotation.	WP3
	Plant species richness	SD3	Counting of different plant species (Margalef index).	WP4
Genetic diversity	Soil microbial diversity	GD	Soil bacterial and fungal diversity measured by metagenomics and Next Generation Sequencing.	WP4
Ecosystem diversity	Annual/vegetative cover	ED1	Average covered soil surface in percent per year.	WP3/WP4/WP5
	Main crop surface	ED2	What fraction of the field does the main crop occupy.	WP3/WP4
	Land equivalent ratio	ED3	ED3 compares the yields from growing more crops together (intercropping) with yields from growing the same crops in pure stands or in monocultures.	WP3
Profitability	Total costs	P1	Full costs associated with the productive process, i.e. productive factors (i.e. labour cost, fuel cost, input cost etc.).	WP8
	Crop Gross Margin	P2	Assessment of profitability of crops at diversified level by calculating a gross margin, i.e. the difference between revenues and costs.	WP8

	Workload	P3	Change in workload for the farmer due to diversification.	WP8
Stability of production	Product diversification	SP1	Number of different crops sold yearly.	WP8
	Variability of Yield	SP2	Variability of yield measured by the coefficient of variation (CV) over the years.	WP3
	Food chain stability	SP3	Number of elements in the food chain and geographical distance in the distribution network.	WP6
Public health	Public health	PH1	Exposure of farm workers and local community to pollution by pesticides, soot (machinery), ammonia (fine dust), etc.	WP8
	Micronutrient productivity	PH2	Amounts of important micronutrients are available in the products.	WP3
Stakeholder dialogue	Effective participation	SD1	Number of active stakeholder and total number of stakeholders.	WP10

Indicators and composite indicators are useful tools for science, policy making, decision making, advisors and consumers to assess the environmental, economic, and societal impact of cropping systems. The main characteristic of indicators is their ability to summarise, focus and condense the complex information arising from research to understandable and manageable concepts. The Toolkit of indicators proposed in Diverfarming includes, in a coherent framework, the most relevant indicators particularly suitable for a comprehensive assessment of the sustainability of diversified cropping systems.

The toolkit is not suitable for evaluating a single agricultural system. In fact, for most of the indicators that are included in it, neither maximum or minimum values or thresholds have been indicated, unless these are required by mandatory regulations. Instead, more properly, the indicators must be used for the comparison of different cropping systems in order to highlight the effects of the introduction of new agricultural practices compared to the current ones. Hence, a single value of an indicator provides meaningless information if it is decontextualized with respect to comparable situations. The toolkit, according to data availability, can be used in a full mode, i.e. by calculating all the indicators, or in a limited mode, if data for calculation are not present, and data should be conveniently displayed as differences among the two or more systems in comparison. A nice way to display the results is through web graphs.

As for the specific use of the toolkit in Diverfarming, the indicators will be calculated using the data collected in WPs 3, 4, 5 and 8 at beginning and end of the project in all case studies (short-term and long-term). The indicators will be used as follows:

- Providing information on agro-environmental and socio-economic aspects of the different diversified cropping systems applied within the project in an easy and accessible manner while considering several critical aspects (i.e. agro-environmental and economic information) of cropping management.
- Providing information on the change of the indicators at different times, by using data collected at the beginning and at the end of the project. In this way it will be easy to evaluate if the sustainable diversified cropping management will have positive or negative impact on farms.
- Values of selected indicators, i.e. CC1 (Change in SOC stock), S2 (Nitrogen Balance), W1 (Water Quality) will be calculated also from ECOSSE modelling outputs (Task 7.1). ECOSSE will be run for each spatially explicit point in the case studies and using data from the geodatabases produced Task 7.3 for twenty years, with and without crop diversifications. The indicators will be linked in a GIS layer and interpolated at farm and landscape level. Relevant maps at farm and landscape level will be produced.

The tool will be tested in selected pilot areas, with and without crop diversification and/or inputs reduction, and used to evaluate the different cropping systems applied within the project. This exercise will allow us to test the discriminatory capacity of the indicators in relation to the purpose of assessing diversification effects. Moreover, it will allow to identify a minimum set of parameters defined to be applied for future assessments. The work performed allows extrapolating and possibly inserting in the decision support system the indicators that can be applied in different parts of Europe to evaluate the impact of cropping systems redesign by rotations, multiple cropping and intercropping through the advancement of multicriterial approaches, and to assess negative and positive effects of crop diversification on agri-food systems.

The WP7 results will be also valorised in the frame of the “Multicriteria analysis and Sustainability Indicators working group (MCA&SI) created within the Crop Diversification Cluster (www.cropdiversification.eu) to: identify similarities in indicators among the projects; to compare the different approaches; to identify the overlaps, the complementarities and the potential synergies that can be exploited.

5. References

Acosta-Martinez, V., Tabatabai, M., 2001. Tillage and residue management effects on arylamidasearylamides activity in soils. Biol Fertil Soils 34, 21-24.

Addiscott, T. M., 2005. Nitrate, agriculture and the environment. CABI.

Altieri, M. A., Nicholls, C. I., Henao, A., & Lana, M. A., 2015. Agroecology and the design of climate change-resilient farming systems. Agronomy for sustainable development, 35(3), 869-890.

Alvarez, C.R., Alvarez R., 2000. Short-term effects of tillage systems on active soil microbial biomass. Biol Fertil Soils 31, 157–161.

Arnold Bruns H., 2012. Concepts in Crop Rotations, Agricultural Science, Dr. Godwin Aflakpui (Ed.), ISBN:978-953-51-0567-1, InTech, Available from: http://www.intechopen.com/books/agricultural-science/conceptsin-crop-rotation.

Bilalis D., Papastylianou, P., Konstantas A., Patsiali, S., Karkanis, A., Efthimiadou, A., 2010. Weed-suppressive effects of maize–legume intercropping in organic farming, International Journal of Pest Management, 56:2, 173-181, DOI: 10.1080/09670870903304471.

Brisson N., Bussière, F., Ozier-Lafontaine, H., Tournebize, R., Sinoquet, H., 2004. Adaptation of the cropmodel STICS to intercropping. Theoretical basis and parameterisation. Agronomie, EDP Sciences 24 (6-7), 409-421. 10.1051/agro:2004031.hal-00886023.

Dace, E., Blumberga, D., 2016. How do 28 European Union Member States perform in agricultural greenhouse gas emissions? It depends on what we look at: Application of the multi-criteria analysis. Ecological indicators 71, 352-358.

Dale, 2004. Dale, V. H., Mulholland, P. J., Olsen, L. M., Feminella, J. W., Maloney, K. O., White, D. C., Peacock, A., Foster, T., 2004. Selecting a suite of ecological indicators for resource management. In Landscape Ecology and Wildlife Habitat Evaluation: Critical Information for Ecological Risk Assessment, Land-Use Management Activities, and Biodiversity Enhancement. ASTM International.

De Vita P., Di Paolo E., Fecondo G., Di Fonzo N., Pisante M., 2007.No-tillage and conventional tillage effects on durum wheat yield, grain quality and soil moisture content in southern Italy. Soil tillage Res 92, 69-78.

Dick, R. P., Doran, J. W., Coleman, D., Bezdicek, D., Stewart, B., 1994. Defining soil quality for a sustainable environment. Soil enzyme activities as indicators of soil quality. Madison (WI): Soil Science Society of America 104-124.

Dick, R.P., Pankhurst, C., Doube, B.M., Gupta, V.V.S.R., 1997. Soil enzyme activities as integrative indicators of soil health. In: C.E. Pankhurst, B.M. Doube, V.V.S.R. Gupta, Eds., Biological Indicators of Soil Health. CAB International, Wallingford, UK, pp. 121–156.

Doran, 1980. Doran, J.W., Parkin, T.B., 1994. Defining and assessing soil quality. In: Doran, J.W., Coleman, D.C., Bezdick, D.F., Stewart, B.A. (Eds.), Defining Soil Quality for a Sustainable Environment. Soil Sci. Soc. Am, 35, pp. 3–21. Special Publication.

Drinkwater, L.E., 2004. Improving fertilizer nitrogen use efficiency through an ecosystem-based approach. Agriculture and the nitrogen cycle: assessing the impacts of fertilizer use on food production and the environment 65, 93-102.

EIIE (Environmental Impacts of Irrigation in the European Union), 2000. A report to the Environment Directorate of the EC, March 2000.

Fantke, P., Friedrich, R., Jolliet, O., 2012. Health impact and damage cost assessment of pesticides in Europe. Environment international 49, 9-17.

Farina R., A Marchetti, R Francaviglia, R Napoli, C. Di Bene, 2017. Modeling regional soil C stocks and CO_2 emissions under Mediterranean cropping systems and soil types. Agriculture, ecosystems & environment 238, 128-141.

Francaviglia, R., Di Bene, C., 2019. Deficit Drip Irrigation in Processing Tomato Production in the Mediterranean Basin. A Data Analysis for Italy. Agriculture 9, 1-14

Gaba, S., Lescourret, F., Boudsocq, S., Enjalbert, J., Hinsinger, P., Journet, E. P., Pelzer, E., 2015. Multiple cropping systems as drivers for providing multiple ecosystem services: from concepts to design. Agronomy for Sustainable Development 35(2), 607-623.

Gao, Y., Duan, A., Sun, J., Li, F., Liu, Z., Liu, H., Liu, Z., 2009. Crop coefficient and water-use efficiency of winter wheat/spring maize strip intercropping. Field Crops Research 111(1-2), 65-73.

Gasso, V., Oudshoorn, F. W., De Olde, E., Sørensen, C.A.G., 2014. Generic sustainability assessment themes and the role of context: The case of Danish maize for German Biogas. Ecological Indicators 49, 143–153.http://dx.doi.org/10.1016/j.ecolind.2014.10.008

Geerts A, Raes D., 2009. Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. Agricultural Water Management 96, 1275–1284.

Hernanz J.L., Lopez R., Navarrete L., Sanchez G.V., 2002. Long-term effects of tillage systems and rotations on soil structural stability and organic carbon stratification in semiarid central Spain. Soil Till. Res. 66, 129-141.

Jensen, E. S., Peoples, M. B., Hauggaard-Nielsen, H., 2010. Faba bean in cropping systems. Field crops research 115, 203-216.

Karlen, 1994. Karlen, D. L., Varvel, G. E., Bullock, D. G., Cruse, R. M., 1994. Crop rotations for the 21st century. Advances in agronomy 53 (1.45).

Kehoe, L., Romero-Muñoz, A., Polaina, E., Estes, L., Kreft, H., & Kuemmerle, T., 2017. Biodiversity at risk under future cropland expansion and intensification. Nature ecology & evolution 1(8), 1129.

Kremen, C., Iles, A., Bacon, C., 2012. Diversified farming systems: an agroecological, systems-based alternative to modern industrial agriculture. Ecology and Society 17(4), 44. http://dx.doi.org/10.5751/ ES-05103-170444

Lal, R., Stewart, B.A., 1990. Soil degradation: A global threat. Advances in Soil. Springer Verlag, New York, 344 pp.

Layke C., A. Mapendembe, C. Brown, M. Walpole, J. Winn, 2012. Indicators from the global and sub-global Millennium Ecosystem Assessments: an analysis and next steps. Ecol. Ind. 17, 77-87.

Lichtenberg, E.M., Kennedy, C.M., Kremen, C., et al., 2017. A global synthesis of the effects of diversified farming systems on arthropod diversity within fields and across agricultural landscapes. Glob Change Biol. 23, 4946–4957. https://doi.org/10.1111/gcb.13714.

Lithourgidis, A.S., Vlachostergios, D.N., Dordas, C.A., Damalas, C.A., 2011. Dry matter yield, nitrogen content, and competition in pea–cereal intercropping systems. European Journal of agronomy 34(4), 287-294.

López-Bellido, R.J., Fontán, J.M., López-Bellido, F.J., López-Bellido, L., 2010. Carbon sequestration by tillage, rotation, and nitrogen fertilization in a Mediterranean Vertisol. Agron. J. 102, 310-318.

McVay, K.A., Budde, J.A., Fabrizzi, K., Mikha, M.M., Rice, C.W., Schlegel, A.J., Peterson, D.E., Sweeney, D.W., Thompson, C., 2006. Management eff ects on soil physical properties in long-term tillage studies in Kansas. Soil Sci. Soc. Am. J. 70, 434-438.

MEA., 2005. Millenium ecosystem assessment. Ecosystems and human well-being: biodiversity synthesis. Washington, DC: World Resources Institute.

Mitchell, G., May, A., McDonald, A., 1995. PICABUE: a methodological framework for the development of indicators of sustainable development. The International Journal of Sustainable Development & World Ecology 2(2), 104-123.

Muñoz, M.A, Zornoza, R., 2017. Soil Management and Climate Change: Effects on Organic Carbon, Nitrogen Dynamics, and Greenhouse Gas Emissions. London: Academic Press.

Nicholls, C.I., Altieri, M.A., Vazquez, L., 2016. Agroecology: Principles for the Conversion and Redesign of Farming Systems. J. Ecosys. Ecograph. S5:010. doi:10.4172/2157-7625.S5-010.

Nunes, J.M., López-Piñeiro, A., Albarrán, A., Muñoz, A., Coelho, J., 2007. Changes in selected soil properties caused by 30 years of continuous irrigation under Mediterranean conditions. Geoderma 139, 321–328.

Pelzer, E., Fortino, G., Bockstaller, C., Angevin, F., Lamine, C., Moonen, C., Vasileiadis, V., Guérin, D., Guichard, L., Reau, R., Messéan, A., 2012. Assessing innovative cropping systems with DEXiPM, a qualitative multi-criteria assessment tool derived from DEXi. Ecol. Ind. 18, 171-182, 10.1016/j.ecolind.2011.11.019.

Ponisio, L.C., M'Gonigle, L.K., Mace, K.C., Palomino, J., de Valpine, P., Kremen, C., 2015. Diversification practices reduce organic to conventional yield gap. Proceedings of the Royal Society B: Biological Sciences, 282(1799), 20141396.

Robertson, G.P., Vitousek, P.M., 2009. Nitrogen in Agriculture: Balancing the Cost of an Essential Resource. Annual Review in Environmental Resources 34, 97-125. http://dx.doi.org/10.1146/annurev.environ.032108.105046

Ryan, J., Pala, M., Masri, S., Singh, M., Harris, H., 2008. Rainfed wheat-based rotations under Mediterranean conditions: crop sequences, nitrogen fertilization, and stubble grazing in relation to grain and straw quality. European Journal of Agronomy 28(2), 112-118.

Sanz-Cobena, A., Lassaletta, L., Aguilera, E., Del Prado, A., Garnier, J., Billen, G., Plaza-Bonilla, D., 2017. Strategies for greenhouse gas emissions mitigation in Mediterranean agriculture: A review. Agriculture, ecosystems & environment 238, 5-24.

Six, J., Elliott, E.T., Paustian, K., 2000. Soil macroaggregate turnover and microaggregate formation: a mechanism for C sequestration under no-tillage agriculture. Soil Biol. Biochem. 32, 2099-2103.

Steduto, P., Hsiao, T.C., Fereres, E., 2007. On the conservative behavior of biomass water productivity. Irrigation Science 25, 189–207.

Stehfest, E., Bouwman, 2006. N_2O and NO emission from agricultural fields and soils under natural vegetation: summarizing available measurement data and modeling of global annual emissions. L. Nutr. Cycl. Agroecosyst. 74, 207. https://doi.org/10.1007/s10705-006-9000-7.

Tóth, G., Hermann, T., Da Silva, M.R., Montanarella, L., 2016. Heavy metals in agricultural soils of the European Union with implications for food safety. Environment international 88, 299-309.

Ussiri, D., Lal, R., 2013. The role of fertilizer management in mitigating nitrous oxide emissions. In Soil emission of nitrous oxide and its mitigation (pp. 315-346). Springer, Dordrecht.

Vitousek, P.M., Aber, J.D., Howarth, R.W., Likens, G.E., Matson, P.A., Schindler, D.W., Schlesinger, H. Tilman, D.G.,1997. Human alteration of the global nitrogen cycle: sources and consequences. Ecological applications 7(3), 737-750.

Zornoza R., Rosales, R.M.. Acosta, J.A., de la Rosa, J.M., Arcenegui, V., Faz, A., Pérez-Pastor, A., 2016. Efficient irrigation management can contribute to reduce soil CO_2 emissions in agriculture. Geoderma 263, 70-77. https://doi.org/10.1016/j.geoderma.2015.09.003.

DIVERFARMING

ANNEX 1: Fiches of indicators for characterising productivity and sustainability of crop diversification

DIVERFARMING

Change in SOC stock (CC1)

Dimension: Environment
SAFA Theme and Sub-Theme: Greenhouse Gases / Climate Change
Project internal reference: WP5

Short description
Impact on soil organic carbon (SOC) stocks. SOC indicator is important for land and soil degradation monitoring.

Object:
Estimation of soil organic carbon (SOC) stocks requires estimates of the carbon content, bulk density, rock fragment content and depth of a respective soil layer. This is a key factor for improved soil fertility and carbon sequestration.

Spatial scale: plot/field
Temporal scale: decades

Formula:

$$\textbf{SOCi stock (Mg C ha}^{-1}\textbf{) = OCi x BDfinei x (1 - vGi) x ti x 0.1}$$

SOCi = soil organic carbon stock (in Mg C ha^{-1}) of the depth increment i
OCi = organic carbon content (mg C g $soil^{-1}$) of the fine soil fraction (< 2 mm) in the depth increment i
BDfinei = the mass of the fine earth per volume of fine earth of the depth increment i (g fine earth cm^{-3} fine earth = dry soil mass [g] – coarse mineral fragment mass [g]) / (soil sample volume [cm3 – coarse mineral fragment volume [cm3])
vGi = the volumetric coarse fragment content of the depth increment i
ti = thickness (depth, in cm), of the depth increment i
0.1 = conversion factor for converting mg C cm^{-2} to Mg C ha^{-1}

or RothC model (Coleman & Jenkinson, 1995)

Δ between t0 and t1, where t= time

References

- ✓ *FAO. 2019. Measuring and modelling soil carbon stocks and stock changes in livestock production systems – Guidelines for assessment. Version 1 – Advanced copy. Rome. 152 pp.*
- ✓ *Klaus & Rattan, 2016. Soil Organic Carbon- An Appropriate Indicator to Monitor Trends of Land and Soil Degradation within the SDG Framework?. Umweltbundesamt, Texte | 77/2016*
- ✓ *Coleman, K. & Jenkinson, D.S (1995) ROTHC-26.3:* A model for the turnover of carbon in soil. *IACR Rothamsted, Harpenden, Herts.*

Nitrous oxide emissions (CC2)

Dimension: environment
SAFA Theme and Sub-Theme: Greenhouse Gases / Climate Change
Project internal reference: WP5

Short description
Change in nitrous oxide emissions by the diversified cropping system

Object:
Impact on soil N_2O emissions from diversification. Besides the contribution to the GHG balance, N_2O also indicates how much gaseous nitrogen losses appear and how the nitrogen cycle reacts on certain management.

Spatial scale: plot/field
Temporal scale: year/crop rotation

Formula:

Yearly cumulative N_2O emissions = sum of linear interpolated emissions [g N_2O per year]

Reference

- ✓ *EUROSTAT- Agro-environmental indicators https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_greenhouse_gas_emissions#Nitrous_oxide_emissions_from_the_agricultural_sector*

Methane emissions (CC3)

Dimension: environment
SAFA Theme and Sub-Theme: Greenhouse Gases / Climate Change
Project internal reference: WP5

Short description
Change in soil methane emissions by the diversified cropping system

Object:
Change in soil CH_4 emissions. Besides the contribution to the GHG balance, CH_4 gives some hints on soil aeration and the carbon cycle.

Spatial scale: plot/field
Temporal scale: year/crop rotation

Formula:

Yearly cumulative CH_4 emissions = sum of linear interpolated emissions [g CH_4 per year]

Reference

- ✓ *EUROSTAT- Agro-environmental indicators https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_greenhouse_gas_emissions#Nitrous_oxide_emissions_from_the_agricultural_sector*

Greenhouse Gas Balance (CC4)

Dimension: environment
SAFA Theme and Sub-Theme: Greenhouse Gases / Climate Change
Project internal reference: WP5

Short description
Impact on the balance of all greenhouse gases (GHG)

Object:
This indicator includes soil GHG emissions and CO_2 emissions from management (machinery), pesticide use and fertilisation. This indicator measures the balance between direct GHG emissions and on-site carbon sequestration (both expressed as ton CO_2 equivalent during the analyzed time-frame. (source SAFA)

Spatial scale: plot/field
Temporal scale: year/crop rotation

Formula:

$$Bn=E-R$$

Δ between t0 and t1, where t= time

Bn = net balance,
E= emission CO_2,
R= removal CO_2

Reference

✓ *SAFA, 2013.*

Nutrient availability (S1)

Dimension: environment
SAFA Theme and Sub-Theme: Land/Soil quality
Project internal reference: WP5

Short description
With this indicator we aim to impact on nutrient availability by the diversified cropping system by using fuzzy logic metrics.

Fuzzy logic is a mathematical tool with which heterogeneous information can be analysed. The use of fuzzy logic is based on the idea that the line between acceptance and rejection of a value for an agro-environmental indicator is not based on a two-folded logic (good/bad) but rather blurred. This means that in some case it is not appropriate to refer to an exact values or a threshold for an indicator, but is advisable to consider a range of acceptability. Fuzzy logic deals with these kinds of uncertainties providing a framework analysis where all the rules and assumptions are completely explicit and can be changed or updated as our knowledge about the system improves (Bockstaller et al., 2008).

Object:

Nutrition availability index (NI) is a complex indicator, encopassing many soil variables, based on fuzzy-logic multiple-metrics.

Spatial scale: plot/field or group

Temporal scale: year/crop rotation

Formula:

NI= complex indicator based on fuzzy-logic multiple-metrics

Calculation:

The nutrition index can be calculated either using all input data or using a minimum, mandatory, set of data as indicated in the Table 1. Firstly, the set of *variables Vs* = {*a*1, *a*2, …, *ai*, …, *an*} is defined. *Vs* should include all the properties which affect the environmental aspect to be assessed, i.e. the capacity to sustain plant nutrition. Next, for each variable the range of values is set, according to experts' knowledge, scientific references or panels. The single indicators are normalised.

Through a fuzzy logic procedure (fully described in Peche and Rodrigues (2012)) the final NI indicator is calculated. The contribution of each variable to the final index is defined from a panel and must be explicit.

The range of NI is between 0 and 1, where 0 is positive and 1 is negative.

Table 1 - Input data for complex nutrition index (all variables are analysed in laboratory according to Alvaro-Fuentes et al., (2019)).

Variable/Attribute	Variable_code	Unit	Unfavorable limit	Favourable limit	Input Basic set
pH	pH	[non-dimensional]	5.5	8.5	x
Electrical conductivity	EC	[dS/m]	4	0.5	
N content	Nt	[g/kg]	0.8	2	x
P available	Pav	[mg/kg]	5	150	x
Exchangeable Ca	Caex	[cmol/kg]	1	60	
Exchangeable Mg	Mgex	[cmol/kg]	0.5	8.3	
Cu bioavailable	Cuba	[mg/kg]	2	500	
Zn bioavailable	Znba	[mg/kg]	0.5	500	
Fe bioavailable	Feba	[mg/kg]	2	250	
Mn bioavailable	Mnba	[mg/kg]	0.5	500	

References

- ✓ *Álvaro-Fuentes J., Lóczy D., Thiele-Bruhn S., Zornoza R. 2019. HANDBOOK OF PLANT AND SOIL ANALYSIS FOR AGRICULTURAL SYSTEMS. Crai UPCT ediciones.*
- ✓ *Bockstaller, C. et al., 2008. Agri-environmental indicators to assess cropping and farming systems. A review." Agronomy for sustainable development 28.1 (2008): 139-149*
- ✓ *Denis at al., 2017. Assessment of soil fertility status using nutrient index approach. Academia Journal of Agricultural research 5(2):28-38, doi:10.15413/ajar.2017.0303*
- ✓ *Peche, R. and Rodríguez, E., 2012. Development of environmental quality indexes based on fuzzy logic. A case study. Ecological Indicators 23 (2012): 555-565.*

DIVERFARMING

Nitrogen balance (S2)

Dimension: environment
SAFA Theme and Sub-Theme: Land/Soil quality
Project internal reference: WP5

Short description
A nitrogen balance calculates the balance between nitrogen added to an agricultural system and nitrogen removed from the system per hectare of agricultural land.

Object:
Indication of the potential surplus of nitrogen (N) on agricultural land (kg N per ha per year). It also provides trends on nitrogen inputs and outputs on agricultural land over time.

Spatial scale: plot/field
Temporal scale: year/crop rotation

Formula:
Nitrogen balance (NB) per ha of UAA
Δ between t0 and t1, where t= time

NB = nitrogen balance
UAA=utilised agricultural area

Reference
- ✓ *OECD website at www.oecd.org/tad/env/indicators*

Phosphorus balance (S3)

Dimension: environment
SAFA Theme and Sub-Theme: Land/Soil quality
Project internal reference: WP5

Short description
A phosphorus balance calculates the balance between added and removed phosphorus to an agricultural system per hectare of agricultural land.

Object:
Indication of the potential surplus of phosphorus (P) on agricultural land (kg P per ha per year). It also provides trends on phosphorus inputs and outputs on agricultural land over time.

Spatial scale: plot/field
Temporal scale: year/crop rotation

Formula:
Phosphorus balance (NB) per ha of UAA
∆ between t0 and t1, where t= time

PB = phosphorus balance
UAA=utilised agricultural area

Organic matter (S4)

Dimension: environment
SAFA Theme and Sub-Theme: Land/Soil quality
Project internal reference: WP5

Short description
Soil organic matter quality is one of the most important factors for soil fertility and is dependent on soil management.

Object:
The crop diversification, in particular cover crops increase the soil organic carbon especially in the first soil layers.

Spatial scale: plot/field or group
Temporal scale: year/crop rotation

Formula:

SOC is the carbon component of SOM. Despite the wide range in C concentrations of the different SOM pools, a single multiplication factor may be used to convert SOM to SOC. The most often used factor, known as the Van Bemmelen factor, is 0.58 (Van Bemmelen, 1891). However, a detailed literature survey on the SOM to SOC conversion factor by Pribyl (2010) showed a median value 51% based on 481 observations. For this reason, a SOM to SOC multiplication factor of around 0.50 instead of 0.58 would result, in most cases, in a more accurate estimate of soil C content based on SOM measurements.

SOM = SOC/0.51

∆ between t0 and t1, where t= time

References

- *FAO. 2019. Measuring and modelling soil carbon stocks and stock changes in livestock production systems – Guidelines for assessment. Version 1 – Advanced copy. Rome. 152 pp.*
- *Fließbach, Andreas, et al. "Soil organic matter and biological soil quality indicators after 21 years of organic and conventional farming." Agriculture, Ecosystems & Environment 118.1-4 (2007): 273-284.*
- *Pribyl, D.W., 2010. A critical review of the conventional SOC to SOM conversion factor. Geoderma 156, 75–83*
- *van Bemmelen, J.M. 1891. Ueber die Bestimmungen des Wassers, des Humus, des Schwefels, der in den Colloidalen Silikaten gebunden Kieselsaeuren, des mangans, u.s.w. im Ackerboden. Landwirtschaftliche Versuch Station 37, 279-290.*

DIVERFARMING

Soil compaction (S5)

Dimension: environment
SAFA Theme and Sub-Theme: Land/Soil quality
Project internal reference: WP5

Short description
The crop diversification, in particular the cover crop, preserve the physical fertility

Object: Bulk density measurements indicate soil physical fertility.

Spatial scale: plot/field
Temporal scale: year/crop rotation

Formula:

∆ BD between t0 and t1, where t= time

BD= bulk density

Reference

- ✓ *Álvaro-Fuentes J., Lóczy D., Thiele-Bruhn S., Zornoza R. 2019. HANDBOOK OF PLANT AND SOIL ANALYSIS FOR AGRICULTURAL SYSTEMS. Crai UPCT ediciones.*

DIVERFARMING

Soil erosion by water and wind (L1)

Dimension: environment
SAFA Theme and Sub-Theme: Land/Land degradation
Project internal reference: WP5

Short description
The role of cover crops and crop residues is crucial in mitigating the impact of atmospheric agents (rain and wind) on soil particles; moreover, their presence slow down the water flow that does not infiltrate into the soil, reducing the removal possibility of soil particles.

Object:
Soil loss by water or wind erosion. Data from RUSLE equation or other models.

Spatial scale: plot/field
Temporal scale: year/crop rotation

Formula:
Data from RUSLE equation or other models.

∆ between t0 and t1, where t= time

Reference

- ✓ Terranova, O., et al. "Soil erosion risk scenarios in the Mediterranean environment using RUSLE and GIS: an application model for Calabria (southern Italy)." *Geomorphology*112.3-4 (2009): 228-245.

Heavy metal contents in soil (SC1)

Dimension: environment
SAFA Theme and Sub-Theme: Land/Soil contamination
Project internal reference: WP5

Short description
Amount of heavy metals in soil

Object:
Content of heavy metal in the soil.

Spatial scale: plot/field
Temporal scale: year/crop rotation

Formula: Amount of heavy metals in soil

∆ between t0 and t1, where t= time

Reference

✓ *Álvaro-Fuentes J., Lóczy D., Thiele-Bruhn S., Zornoza R. 2019. HANDBOOK OF PLANT AND SOIL ANALYSIS FOR AGRICULTURAL SYSTEMS. Crai UPCT ediciones.*

DIVERFARMING

Consumption of pesticides (SC2)

Dimension: environment
SAFA Theme and Sub-Theme: Land/Soil contamination
Project internal reference: WP8

Short description
The amounts of different pesticides used for the whole crop rotation

Object:
The consumption of pesticides in agriculture would best be indicated by the rates applied by the farmers. the term "pesticides" refers to the plant protection product and covers the following categories: ‘Fungicides and bactericides’, ‘Herbicides, haulm destructors and moss killers’, 'Insecticides and acaricides', 'Molluscicides', 'Plant growth regulators', 'Other plant protection products.

Spatial scale: plot/field
Temporal scale: year

Formula:

Pesticides(kg)/area(ha)

Kg of pesticides applied in an area (ha); area (ha)

Δ between t0 and t1, where t= time

Reference

- ✓ *Álvaro-Fuentes J., Lóczy D., Thiele-Bruhn S., Zornoza R. 2019. HANDBOOK OF PLANT AND SOIL ANALYSIS FOR AGRICULTURAL SYSTEMS. Crai UPCT ediciones.*

Water quality (W1)

Dimension: environment
SAFA Theme and Sub-Theme: Water/Water quality
Project internal reference: WP5

Short description
Nitrate loss by leaching is used as a proxy for the impact on water quality.

Object:
Nitrate leaching is very relevant to assess the negative effects of agricultural practices on water quality. For this indicator modelled nitrate leaching is used as proxy for potential adverse effects on water quality. ECOSSE will be calibrated with data from the Diverfarming case studies to model nitrogen dynamics and give an estimate for nitrate leaching. The ECOSSE water modifier has its origin in the SUNDIAL model. Water excess is calculated for each 5 cm soil layer to the specified depth in ECOSSE, while leaching between layers is by simple piston flow.

Spatial scale: plot/field
Temporal scale: year

Formula:

nitrate (kg) /area (ha) is considered as leached when leaving the bottom soil layer at 1 m depth modelled in ECOSSE.

Nitrate loss is modelled by ECOSSE: ∆ **between t0 and t1, where t= time**

References

- ✓ *Álvaro-Fuentes J., Lóczy D., Thiele-Bruhn S., Zornoza R. 2019. HANDBOOK OF PLANT AND SOIL ANALYSIS FOR AGRICULTURAL SYSTEMS. Crai UPCT ediciones.*
- ✓ *Flattery, P., Fealy, R., Fealy, R.M., Lanigan, G., Green, S., 2018. Simulation of soil carbon efflux from an arable soil using the ECOSSE model: Need for an improved model evaluation framework? Science of The Total Environment 622–623, 1241–1249.* https://doi.org/10.1016/j.scitotenv.2017.12.077

Available water capacity (W2)

Dimension: environment
SAFA Theme and Sub-Theme: Water/Water quality
Project internal reference: WP5

Short description
Available water capacity is the maximum amount of plant available water a soil can provide.

Object:

It is an indicator of a soil's ability to retain water and make it sufficiently available for plant use.

Spatial scale: plot/field
Temporal scale: year

Formula:

AWC= field capacity-wilting point

∆ between t0 and t1, where t= time

AWC= Available water capacity

Reference

- ✓ *Álvaro-Fuentes J., Lóczy D., Thiele-Bruhn S., Zornoza R. 2019. HANDBOOK OF PLANT AND SOIL ANALYSIS FOR AGRICULTURAL SYSTEMS. Crai UPCT ediciones.*

Water use efficiency (W3)

Dimension: environment
SAFA Theme and Sub-Theme: Water/Water management
Project internal reference: WP8

Short description
These indicators provide information on the water efficiency of crops related to crop productivity.

Object:
Water use depends on many factors from soil management to crop type and soil cover. Improving water use efficiency is an important goal of diversifications in farming systems.

Spatial scale: plot/field
Temporal scale: year

Formula:

$$Y/Et$$

WUE is the water use efficiency (kg m^{-3}), Y is the seed yield (g m^{-2}) and Et is the cumulative evapotranspiration (mm).

Δ between t0 and t1, where t= time

Reference

- ✓ *Blum, A. "Effective use of water (EUW) and not water-use efficiency (WUE) is the target of crop yield improvement under drought stress." Field crops research 112.2-3 (2009): 119-123.*

Water scarcity (W4)

Dimension: environment
SAFA Theme and Sub-Theme: Water/Water management
Project internal reference: WP5

Short description
In crop diversification, water management mainly depending on the irrigation system, but the water requirements are lower and it is easier to obtain good yields in non-irrigated conditions or water scarcity.

Object:
Water scarcity is defined as the ratio between water used (WU) and water availability (WA). Hence scarcity is only a problem if water supply is limited.

Spatial scale: plot/field
Temporal scale: year/crop rotation

Formula:

$$WS = WU/WA$$

Water used, water available (rainfall, soil moisture)

Reference

- ✓ *Álvaro-Fuentes J., Lóczy D., Thiele-Bruhn S., Zornoza R. 2019. HANDBOOK OF PLANT AND SOIL ANALYSIS FOR AGRICULTURAL SYSTEMS. Crai UPCT ediciones.*

Earthworms diversity (SD1)

Dimension: environment
SAFA Theme and Sub-Theme: Biodiversity/Species diversity
Project internal reference: WP4

Short description

The measures of earthworm species richness will be taken by WP4 at the end of third crop cycle (2020).

Object:

Earthworms help maintain and enhance the physical condition and function of soils. Their contribution to soil services, such as the flow of water, nutrients and gases, is influenced by earthworm abundance and diversity.

Spatial scale: plot/field
Temporal scale: year

Formula: Shannon-Weaver diversity index equation

Where, SS = number of species $ppii$ = species i individuals proportion within the total (relative abundance, $nnii$ NN) $nnii$ = number of individuals of species i NN = total number of individuals in the sample Shannon-Weaver index value in most natural ecosystems figures between 0.5 and 5, whether its value is rarely lower than 2 or higher than 3. Commonly, agroecosystem Shannon-Weaver index value is lower than 2 in most taxa, which implies biodiversity poverty. Only rich ecosystems or biodiversity hot-spots, as tropical forests or coral reefs present a Shannon-Weaver index value over 3.

Reference

- ✓ *Álvaro-Fuentes J., Lóczy D., Thiele-Bruhn S., Zornoza R. 2019. HANDBOOK OF PLANT AND SOIL ANALYSIS FOR AGRICULTURAL SYSTEMS. Crai UPCT ediciones.*

Crop rotation diversity (SD2)

Dimension: environment
SAFA Theme and Sub-Theme: Biodiversity/Species diversity
Project internal reference: WP3

Short description
Number of elements in the crop rotation

Object:
Diversity in crop rotation can be different crops planted in different years or different crops planted at the same time or within the same year.

Spatial scale: plot/field or group
Temporal scale: crop rotation

Formula: Number of crops in the rotation

Δ between t0 and t1, where t= time

Plant species richness (SD3)

Dimension: environment
SAFA Theme and Sub-Theme: Biodiversity/Species diversity
Project internal reference: WP4

Short description
Counting of different plant species (Margalef index)

Object:
As only the number of different species, will be considered, not densities of species or individuals, Margalef index is the best option to consider within this biodiversity indicator. Unless this index is actually useful only if species are uniformly distributed, it is the only index found to be calculated with the available information about plan richness.

Spatial scale: plot/field
Temporal scale: year/crop rotation

Formula:

$$d=(S-1)/\ln N$$

Where, S= number of species

N= total number of individuals in the sample.

If counting N was not a feasible option, number of species (S) would be used

Reference

- ✓ *Grubb, Peter J. "The maintenance of species-richness in plant communities: the importance of the regeneration niche." Biological reviews 52.1 (1977): 107-145.*

DIVERFARMING

Soil microbial diversity (GD)

Dimension: environment
SAFA Theme and Sub-Theme: Biodiversity/genetic diversity
Project internal reference: WP4

Short description
Soil microbial diversity measured by metagenomics and Next Generation Sequencing

Object:
The diversity of microbial communities in soil can be measured by molecular techniques. The relationship between diversified cropping systems and microbial communities is not yet understood.

Spatial scale: plot/field or group
Temporal scale: year/crop rotation

Formula: Fungal and bacterial biodiversity; Δ between t0 and t1, where t= time

Reference

- ✓ *Hartmann, Martin, and Franco Widmer. "Community structure analyses are more sensitive to differences in soil bacterial communities than anonymous diversity indices." Appl. Environ. Microbiol. 72.12 (2006): 7804-7812.*

DIVERFARMING

Annual/vegetative cover (ED1)

Dimension: environment
SAFA Theme and Sub-Theme: Biodiversity/Ecosystem diversity
Project internal reference: WP3/WP4

Short description
Average covered soil surface in percent per year

Object:
The more soil surface is covered by plants, the less losses of nutrients, water and organic matter is expected. Diversifications should increase the vegetative cover both during the cropping season and in between.

Spatial scale: plot/field
Temporal scale: year

Formula: Average vegetative cover per month * M
M = number of months when the crop cover the soil

Δ between t0 and t1, where t= time

Reference

✓ *Stocking, M. A. "Assessing vegetative cover and management effects." Soil erosion research methods. Routledge, 2017. 211-234.*

Main crop surface (ED2)

Dimension: environment
SAFA Theme and Sub-Theme: Biodiversity/Ecosystem diversity
Project internal reference: WP3/WP4

Short description
What fraction of the field the main crop occupies

Object:
Multiple- and Intercropping reduce the surface for the main crop but increase the diversity and resilience of the field.

Spatial scale: plot/field or group
Temporal scale: year/crop rotation

Formula:

MainCropSurface/UAA

Δ between t0 and t1, where t= time

UAA = agricultural area utilised(ha)
MAin crop Surface= total area of main crop (ha)

Reference value
Nearly to value 1 indicate that the area is less diversified

DIVERFARMING

Land equivalent ratio (ED3)

Dimension: environment
SAFA Theme and Sub-Theme: Biodiversity/Ecosystem diversity
Project internal reference: WP3

Short description
ED3 compares the yields from growing more crops together (intercropping) with yields from growing the same crops in pure stands or in monocultures.
Object:
This indicator measures the effect of the interactions between crops quantifying and evaluating yield advantage of intercrops compared to the pure crops. The resulting number is a ratio that expresses the land area needed in pure cropping to obtain the same yields as in intercrops.

Spatial scale: plot/field or group
Temporal scale: year/crop rotation

Formula:

YiedlMix1/YieldMono1 + YiedlMix2/YieldMono2 + … + YiedlMixn/YieldMonon

Δ between t0 and t1, where t= time

Mix= yield mixture crop
Mono= yield mono-crop

References

- ✓ *Mead, R. Willey, R.W, 1980. The concept of a Land Equivalent Ratio and advantages in yield from Inter-cropping. Experimental Agric., 16, 217- 218.*
- ✓ *Álvaro-Fuentes J., Lóczy D., Thiele-Bruhn S., Zornoza R. 2019. HANDBOOK OF PLANT AND SOIL ANALYSIS FOR AGRICULTURAL SYSTEMS. Crai UPCT ediciones.*

Total costs (P1)

Dimension: economic
SAFA Theme and Sub-Theme: Investment/Profitability
Project internal reference: WP8

Short description
Full costs associated with the production process, i.e. production factors

Object:
Based on different cost classification systems, the total cost of production can be calculated in various ways, and the most used is derived as the sum of direct and indirect costs of production

Spatial scale: farm level
Temporal scale: year

Formula:

$$Cav= C/UAA \quad (€/ha)$$
$$C = L+F+Fi+W+S+I+E$$

Cavv= costs by ha
C = costs
L = labour costs
F= Fuel costs
Fi= Fertilizer+weed control + crop protection
W= Water costs
S= Seeds or plants costs
I= insurance
E= energy (i.e. electricity)
UAA= agricultural area utilised(ha)

Reference

- ✓ *SAFA, 2013*

Crop Gross Margin (P2)

Dimension: economic
SAFA Theme and Sub-Theme: Investment/Profitability
Project internal reference: WP8

Short description
Assessment of profitability of crops at rotation level by calculating a gross margin, i.e. the difference between revenues and costs.
Object:
This indicator reflects the economic value of production. This number can be differentiated into different sub indicators:

Gross Margin A: Revenues minus truly variable costs per ha

Gross Margin B: GM A minus calculated value of family labour per ha

Gross Margin C: GM B minus capital and overhead costs per ha

Spatial scale: plot/field or group
Temporal scale: year/crop rotation over several years

Formula:

$$CGM=TGP-TDC$$

CGM= Crop Gross Margin; calculated per crop, or summed up over several crops in rotation
TGP= total gross value production at market prices, and gross value of farm subsidies (€) per ha
TDC= total direct costs with (GM B,C) or without (GM A,B) considering the family labour, capital, e.g. machinery, and overhead costs per ha

References

- ✓ *Craheix D., Angevin F., Bergez J.-E., Bockstaller C., Colomb B., Guichard L., Reau R., Sadok W., Doré T., 2011. MASC 2.0, Un outil pour l'analyse de la contribution des systèmes de culture au développement durable. Jeu complet de fiches critères de MASC 2.0. INRA –AgroParisTech – GIS GC HP2E, 133 p.*
- ✓ *Lehtonen, H., 2019. Draft report on optimised farm level management. Working paper in Diverarming WP8, aiming for Deliverable 8.3 "Report on farm level economic benefits, costs and improved sustainability of diversified cropping systems" (due April 2020). 19 p. Available on request: heikki.lehtonen@luke.fi*

Workload (P3)

Dimension: economic
SAFA Theme and Sub-Theme: Investment/Profitability
Project internal reference: WP8

Short description
Change in workload for the farmer due to diversification.

Object:
Diversification can significantly increase the workload due to less intense automatisation or more complex management practices. Workload is a key factor affecting farmers' quality of life. A higher work overload due to diversification will hamper diversification

Spatial scale: plot/field or group
Temporal scale: year/crop rotation

Formula:

(Human work hours in the monocropping) / (Human work hours in diversified system)

> 1: Diversified system is more work intensive then the monoculture
< 1: Beneficial effects on work load from diversification

Product diversification (SP1)

Dimension: economic
SAFA Theme and Sub-Theme: Vulnerability/Stability of production
Project internal reference: WP8

Short description
Number of different crops products sold yearly

Object:
This indicator measures whether the enterprise produces more than one product, or variety of plant or animal for income generation, or offers more than one service.

Spatial scale: plot/field or group
Temporal scale: year/crop rotation

Formula:

Counting the number of products sold

Δ between t0 and t1, where t= time

Review the business records from the strategy and management, production, and check if the enterprise is working towards producing new products, species or variety of plant for income generation.

Reference
- ✓ *SAFA, 2013*

DIVERFARMING

Variability of yield (SP2)

Dimension: economic
SAFA Theme and Sub-Theme: Vulnerability/Stability of production
Project internal reference: WP3

Short description
Variability of yields measured by coefficient of variation (CV) over the years.

Object:
Assessment of the crop yield stability that is generally assessed in terms of fluctuation of the yields on a long term average. Lower the CV, more stable is the system. This indicator could be used to compare the CVs of the single main crops in different systems or the CVs of different rotations.

Spatial scale: plot/field or group
Temporal scale: year/crop rotation

Formula:

$$SP2 = (\sum_{1}^{i} S_i * CV_i)/(i*S)$$

CV= coefficient of variation (standard deviation/ mean) of the yield (t/ha) of crop i. The yield data (at
least three values) for each crop must be referred to different harvested years.
S_i = area (ha) where crop i is cropped
S = total considered area (field, fields group or farm surface)
i = number of the crops considered in the rotation or during the years taking into accounts
N.B. If two successive crops or mixtures are in the same year, the indicator calculates first their mean
values

Reference

- ✓ *Marten, G. G., 1988. Productivity, stability, sustainability, equitability and autonomy as properties for agroecosystem assessment. Agricultural systems, 1988, 26.4: 291-316.*

DIVERFARMING

Food chain stability (SP3)

Dimension: economic
SAFA Theme and Sub-Theme: Vulnerability/Stability of production
Project internal reference: WP6

Short description
Number of elements in the food chain and geographical distance in the distribution network

Object:
At some point one gets tired but this is an important issue that needs to be reflected

Spatial scale: plot/field or group
Temporal scale: year/crop rotation

Formula:
Number of elements in food chain / geographical distance

Δ between t0 and t1, where t= time

Reference
- ✓ *SAFA, 2013*

Public health (PH1)

Dimension: social
SAFA Theme and Sub-Theme: Human safety and health/Public health
Project internal reference: WP8

Short description
Exposure of farm workers and local community to pollution by pesticides, soot (machinery), ammonia (fine dust) etc.

Object:
This indicator asks whether the enterprise: takes measures to avoid polluting or contaminating the local community; and contributes to the health of the local community.

Spatial scale: plot/field or group
Temporal scale: year/crop rotation

Formula:

Assess if the enterprise has taken measures to avoid polluting or contaminating the local community.

Reference

- ✓ *SAFA, 2013. (S 5.2.1)*

DIVERFARMING

Micronutrient productivity (PH2)

Dimension: social
SAFA Theme and Sub-Theme: Human safety and health/Public health
Project internal reference: WP3

Short description
Amount of micronutrients available in the products

Object:
Micronutrients play a very important role for the product quality. Yet most of the attention is put on macronutrients but the intensively managed fields are getting depleted in the more rare micronutrients. However, the supply of micronutrients plays a very imporant role for a healthy human diet.

Spatial scale: plot/field or group
Temporal scale: year/crop rotation

Formula:

Counting MN ;

MN= Micronutrients measured in the project (as Cd, Pb, Cu..)
compared to mono-cropping

Reference

- ✓ *Álvaro-Fuentes J., Lóczy D., Thiele-Bruhn S., Zornoza R. 2019. HANDBOOK OF PLANT AND SOIL ANALYSIS FOR AGRICULTURAL SYSTEMS. Crai UPCT ediciones.*

DIVERFARMING

Effective participation (PH3)

Dimension: social
SAFA Theme and Sub-Theme: Participation/Stakeholder dialogue
Project internal reference: WP10

Short description
Number of active stakeholder and total number of stakeholders

Object:
The impact assessment of stakeholder participation is necessarily qualitative. While we can measure the number of stakeholder views incorporated, the true measure of performance is really how great the impact has been.

Spatial scale: food system
Temporal scale: year

Formula:

- Number of active stakeholder and total number of stakeholders (Counting ; Δ between t0 and t1, where t= time)
- List the decisions which have been affected by stakeholder feedback.
- Describe how feedback was provided to stakeholder groups on their input or feedback.

Reference

✓ *SAFA, 2013. (G 3.1.4)*