Food and Agriculture Organization
of the United Nations

A Literature Review and Key Agri/Environmental Indicators

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the Global Strategy to improve Agricultural and Rural Statistics**

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A Literature Review and Key Agri/Environmental Indicators

Table of Contents

List of Tables

List of Figures

List of Graphs

Acronyms and Abbreviations

ADB	Asian Development Bank
AFOLU	Agriculture Forestry and other Land Use
AQUASTAT	FAO Statistical Database for Water
CA	Conservation Agriculture
CATIE	Tropical Agricultural Research and Higher Education Center
CBD	Convention on Biological Diversity
CSA	Climate-Smart Agriculture
CGIAR	Consultative Group on International Agricultural Research
CO2	Carbon Dioxide
DDT	Dichlorodiphenyltrichloroethane
EAA	Ecosystem Approach to Aquaculture
EAF	Ecosystem Approach to Fisheries
EEA	European Environment Agency
ESS-ENV	Environment Team/Statistics Division of FAO
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	FAO Statistical Database
FDES	Framework for the Development of Environment Statistics
FiBL	Forschungsinstitut fuer Biologischen Landbau
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GEMS	Global Environment Monitoring System
GGE	Greenhouse Gas Emissions
GLADA	Global Land Degradation Assessment
GLADIS	Global Land Degradation Information System
GLASOD	Global Assessment of Soil Degradation
Gt	Gigatonne
HLPE/FSN	High Level Panel of Experts on Food Security and Nutrition
IFAD	International Fund for Agricultural Development
IFOAM	International Federation of Organic Agricultural Movements
INRA	Institut National de la Recherche Agronomique (National Institute of Agricultural Research)
IPCC	Intergovernmental Panel on Climate Change
IPM	Integrated Pest Management
ITPS	Intergovernmental Technical Panel on Soils
IUCN	International Union for Conservation of Nature
LADA	Land Degradation Assessment in Drylands
Km^3/y	Cubic Kilometers per Year

K_2O	Potash
MA	Millennium Ecosystem Assessment
MSF	Master Sample Frame
Mt	Megaton
N	Nitrogen
NH_3	Ammonia
NSO	National Statistical Office
N2O	Nitrous Oxide
OECD	Organization for Economic Co-operation and Development
P	Phosphorus
SAFA	Sustainability Assessment of Food and Agriculture systems
SCPI	Sustainable Crop Production Intensification
SEEA	System of Environmental-Economic Accounting
SEEA-CF	System of Environmental-Economic Accounting-Central Framework
SEEA-AFF Fishing	System of Environmental-Economic Accounting- Agriculture, Forestry and
SEEA-Water	System of Environmental-Economic Accounting - Water
SNA	System of National Accounts
SOC	Soil Organic Carbon
SOLAW	State of the World's Land and Water Resources for Food and Agriculture
SWSR	Status of the World's Soil Resources
UNCCD	United Nations Convention to Combat Desertification
UNCED	United Nations Conference on Environment and Development
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UNSC	United Nations Statistics Commission
UNSD	United Nations Statistics Division
UNSDSN	United Nations Sustainable Development Solutions Network
USDA	United States Department of Agriculture
WFP	World Food Programme
WHO	World Health Organization

Preface

The Global Strategy to Improve Agricultural and Rural Statistics (Global Strategy) is an initiative endorsed by the United Nations Statistical Commission at its forty-first session in February 2010 that provides an essential framework for meeting the current and emerging data requirements from policymakers and other data users. Notably, many countries, especially those in the developing world, lack the capacity to produce and report even the minimum set of agricultural statistics required to monitor national trends.

The Action Plan of the Global Strategy is centred on three pillars: (1) establish a minimum set of core data; (2) integrate agriculture into the national statistical system; and (3) foster sustainability of the statistical system through governance and statistical capacity building. The main elements of the Global Strategy Action Plan are governance, country assessments and technical components (technical assistance, training and research). The technical components are interlinked and well-articulated to form a consistent capacity development programme in which the research component (research plan) plays a crucial role. Under the Global Strategy Output 3 "research for new cost effective methods for data collection, analysis and dissemination developed and disseminated", sixteen research thematic domains, covering different aspects of agricultural world, were established.

Sustainability has become one of the main references for international and national development goals in which the development of an international collection of indicators, methods and procedures to measure and monitor agricultural sustainability is essential. For this reason, the research thematic domain entitled "SUST – Data collection methods on sustainable agriculture" was inserted into the Global Strategy Action Plan. The objective of this research thematic domain is to provide a framework for agricultural sustainability indicators and related statistical definitions, and measurements tools covering the economic, social and environmental dimensions. In addition, to develop guidelines on best practices, efficient and cost effective methodologies are needed for countries to use to generate, in particular, agri-environmental statistics and indicators.

The five specific SUST research topics are: SUST-1: indicators and collection methods for gender-related data; SUST-2: measuring youth employment and decent work in agriculture; SUST-3: data collection methods for agri-environmental indicators; SUST-4: measuring agricultural productivity and efficiency; SUST-5: framework and methods for measuring and monitoring agricultural sustainability. These research topics cover the three sustainable development dimensions that are related to agriculture.

Regarding the research topic for SUST-5, the Global Strategy decided to refocus the output of the research and to start to work with the group in FAO responsible for accomplishing the strategic objective No.2 of the organization related to increasing and improving the provision of goods and services from agriculture, forestry and fisheries in a sustainable manner (henceforth SP2 programme). The purposed of this joint effort is to develop methodological guidelines for countries to report on progress with regard to Sustainable Development Goal indicator 2.4.1. defined as the "proportion of agricultural area under productive and sustainable agriculture."

The scope of the SUST-3 research topic extends beyond the concept of sustainable agriculture; however, this research will be harmonized with the findings reached by the Global Strategy/SP2 project, and the final guidelines will include a set of indicators for the assessment of sustainable agriculture related to the environment dimension.

Acknowledgments

This publication has been drafted by Antonio Lumicisi, leading adviser on agricultural and environmental statistics on the basis of the thematic area reports provided by three expert advisors involved in the framework of the SUST-3, data collection methods for agri-environmental indicators research work.

Ademar Romeiro, author of the thematic area report on general thematic aspects most relevant for measuring the interactions between agriculture and the environment; Julie Hass, author of the thematic area report on evaluation and prioritization of agri-environmental statistics and indicators; Aldo Femia, author of the thematic area report on gap analysis on data and methodological needs for the production of agri-environmental indicators.

This work has been conducted in close collaboration with Monica Madrid, Global Strategy focal person of the SUST-3, data collection methods for agri-environmental indicators research work, and under the coordination of Flavio Bolliger, the Global Strategy Research Coordinator.

The Global Strategy extends thanks to the experts involved in the peer review's work of this document: Cristina Klimsza Sabalain (Argentina), Alasdair Cohen (United States of America – University of California) and Francesco Tubiello (Italy – FAO). It also extends thanks to the members of the Scientific Advisory Committee of the Global Strategy (Vijai Bhatia, Seghir Bouzzafour, Jacques Delincé, Cristiano Ferraz, Eva Laczka, Dalisay Maligalig Bakary Sacko, Edwin St. Catherine, Michael Steiner and Zhengyuan Zhu) for their valuable suggestions.

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 The present document will be presented to the experts of the ad hoc expert group meeting planned for the fall of 2017, as a basis for further work of SUST-3, data collection methods for agri-environmental indicators research.

Executive Summary

State of the environment: major agriculture impacts

It is generally accepted that the Anthropocene era started with the Industrial Revolution. This human dominated epoch is characterized by changes in the global environment caused by human actions that can be associated with the rapidly growing reliance on fossil fuels and consequent emergence of industrialized forms of agriculture. Agriculture, in particular, a primary sector that is directly and indirectly, pushing the planet beyond sustainable thresholds.

Changes in land and freshwater use, interference in nutrient cycles, biodiversity loss and ocean acidification are some of the key areas that need to be prioritized in efforts aimed at reducing human pressures. Agriculture directly and indirectly related to those threats is therefore one of the most important human activities that need to be dealt with through the development and implementation of interventions aimed at improve its impact.

Significant gains in agricultural production and productivity in the recent years has caused negative impacts and the persistent confluence of pressures on the Earth ecosystems. These combined negative impacts will eventually compromise the ability to use natural resources to sustain food production, as well as other economic and social benefits. Replacing natural ecosystems to expand crop and pasture areas and the intensification of agriculture by increased irrigation, fertilization, pesticides utilization and mechanization are the main causes of the environmental impacts.

As the global impact of humanity on natural resources has increased, the connections between soil health and broader environmental concerns have begun to emerge. The links of soil degradation to soil erosion and loss of soil productive properties and nutrient imbalances has become more prevalent over the past two decades, with the majority of the world's soil resources now considered to be in only fair, poor or very poor condition.

Other agriculture impacts that need to be considered are the use of water resources and pressures on biodiversity because of habitat loss and fragmentation, the increasing use of biofuels, pollution caused by pesticides use and, last but not least, climate change.

Agriculture and environment: interactions and challenges

The process of agriculture intensification was increased to meet the demand for food, feed and fiber from a growing human population. Through more efficient agricultural practices, farmers have found ways to increase crops yields. In the twentieth century, there was a shift in the paradigm of agricultural production towards a model aligned with the industrialized world in which mechanization, processes standardization, use of labour-saving technologies and chemical use to increase crop efficiency became the new paradigm.

Only a few years ago, it was recognized that accelerated gains in agricultural productivity based on the increment of external inputs have had negative effects on natural resources and the environment where agriculture is developed. The impacts of those gains are now seen as being so destructive that the productive potential and the future availability of those resources is now being questioned.

The first agricultural revolution, which accompanied the great industrial revolution during the seventeenth and eighteenth centuries, was based on the spread of innovations on the ecological management of the agri-ecosystem used to augment its ecological efficiency. A new crop rotation system (Norfolk) integrated with animal husbandry enhanced the organic matter content in soils, resulting in spectacular growth in land productivity entirely based on the management of ecosystem services.

However, some limitations have proven to be fatal for the survival of this type of agri-ecosystem. One example, in particular, is farmers' limited capacity to maximize their income by cultivating only the best priced crops. This constraint can be reduced or even eliminated through a system of incentives and disincentives.

For agriculture to be sustainable and productive, a single, system vision that maximizes synergies, mitigates negative externalities and minimizes harmful competition between sectors must be adopted.

Towards a definition of sustainable agriculture

In the body of literature on agriculture, a large number of definitions of sustainable agriculture have been proposed, pointing out the different aspects of sustainability (environmental, social and economic). However, to build agri-environmental indicators, the environmental pillar must be primarily considered when taking into account the broadly acceptable definition of sustainable agriculture, as, for example, the one proposed by the Technical Advisory

Committee of the Consultative Group on International Agricultural Research (CGIAR, 1988):

"Sustainable agriculture involves the successful management of resources for agriculture to satisfy changing human needs, while maintaining or enhancing the quality of the environment and conserving natural resources."

In general, sustainable agriculture is not independent on sustainable development and therefore can also be defined as: being able to endure for millennia by maintaining the environment and its capability of producing economically accessible, high quality food for consumers while allowing for high living standards for producers (farmers).

Additionally, when comparing sustainable and conventional agricultural practices, organic farming methods have shown to perform much better in cases in which a series of indicators have been considered. Conventional agriculture cannot meet the needs of the current population without continuing to compromise environmental integrity. In contrast, benefits associated with sustainable agriculture, such as organic farming, within the social, economic, and environmental realms are compelling reasons to view sustainable agriculture as the most viable way to accommodate the needs of the growing world population.

The ecosystem-based approach suggests that at the scale of cropping systems, management should be based on biological processes and integration of a wide range of plant species and varieties (hence a more diverse and resilient system) and on the judicious use of external inputs, such as fertilizers and pesticides.

The adopted basic template for sustainable farming practices is: the careful management of the organic matter to keep its content in the soil according to biological parameters of sustainability; the physical protection of the soil against erosive factors (rainfalls and wind) by a protective vegetal cover; and the copying of natural biodiversity through crop associations and crop rotations (which are in time crop associations and more compatible with mechanization). In addition, it includes the management of what can be referred to as agri-ecosystem boundaries, namely that the farmlands should be intermingled with live-fences, woods and other non-cultivated spaces, such as meadows and natural prairies, which would support biodiversity and ecosystem service provisions, such as pollination, pest control, micro climate regulation and scenic beauty.

Agri-environmental indicators

Monitoring and measuring agriculture, and, in particular, agri-environmental indicators, is not an easy task. The main focus of the Global Strategy to improve agricultural and rural statistics is to develop and implement approaches for the collection and adequate use of statistics relevant to agriculture.

Demand for robust statistics on environment is constantly increasing in parallel with increasing environmental degradation. Policy and economic decisions that take into account environmental issues are being made more frequently. In fact, there is no shortage of environmental indicators. However, the challenge is to identify a set of consistent, concise, easy and robust agri-environmental indicators that would be available for most developing countries.

A large number of agri-environmental data and indicators have already been developed to monitor the interactions of agriculture and the natural environment. Those indicators have multiple purposes, including, for example, monitoring policies, evaluating pressures, describing landscapes and building of indices. With regard to the United Nations methodological approaches, the Framework for the Development of Environment Statistics (FDES) and the System of Environmental-Economic Accounting (SEEA) are the main statistical frameworks used to support countries worldwide in the production of basic environmental statistics and their connections to the economy. With regard to global data, FAOSTAT provides the most comprehensive database on agriculture statistics, including agri-environmental indicators.

The Framework for the Development of Environment Statistics is a flexible, multipurpose conceptual and statistical framework that assists in structuring, synthesizing and aggregating relevant data into statistical series and indicators. It provides a structure to guide the collection and compilation of environmental data and to synthesize data from various subject areas and sources and targets a broad user community, including environmental statisticians in National Statistical Offices (NSOs), environmental ministries and agencies, as well as other producers of environment statistics.

The System of Environmental-Economic Accounting (SEEA) is an accounting system that describes and quantifies the interactions between the economy and the environment. Central to the SEEA is a system approach to organizing environmental and economic information that covers, as completely as possible, the stocks and flows that are relevant to the analysis of environmental and economic issues.

FAOSTAT agri-environmental indicators represents the main global reference for agri-environmental statistics, related to the information of agriculture and its interaction with the environment. This information system had led to the construction of a more efficient data-sharing mechanism using an open data strategy with broader collaboration between systems and data integration at the global level. In addition to its core statistical data, FAOSTAT includes an analytical database on agri-environmental indicators and an emissions database for the monitoring of the environmental performance of agriculture to track trends in environment impact, and to provide information to assess the effects of the integration of agri-environmental concerns into policy measures. The FAO agri-environmental dataset currently includes more than 30 indicators distributed across ten different domains.

FAO has the most comprehensive information about agriculture, forestry and fisheries for countries worldwide. However, the data that are publicly available through FAOSTAT are typically more aggregated than what are available in the reporting databases or from country-level information systems. Although currently the data are used to produce a certain set of indicators, it may be possible to develop other groupings to produce additional indicators that may be more relevant to monitoring aspects of agriculture that would show if favorable agricultural practices were implemented.

A proposal of a concise set of agri-environmental indicators

The purpose of the present work is to develop a concise set of indicators that can be used to monitor whether agricultural practices are affecting the environment. In particular, it focuses on indicators that describe the condition of components, such as soil, water, land and biodiversity that are critical elements affecting food production systems. Assessing the biophysical condition or "health" of those components is crucial when attempting to measure or determine if implemented agricultural practices are moving towards a sustainable food production.

To evaluate crucial elements affecting agricultural production, six domains have been identified: soil management; water management; nutrient and pesticide management; land use management; biodiversity; and energy use. Based on these domains, the proposed primary indicators are: soil health; proportion of renewable fresh water resources abstracted for use by agriculture; agrochemical use; change in agricultural land use; changes in land cover; and energy use per agricultural output.

Currently, existing indicators correspond either to flow indicators or stock (capital) indicators. The first ones measure something over time, and are typically expressed in physical or monetary units per time period. The second ones describe the status of something at a certain point in time. Furthermore, indicators are distinguished based on the approach used to collect them. Single purpose data collection, the approach used by organizations for years, often involves collecting data to answer only one policy question or one reporting need. This approach has proven to be very costly. The statistical system is moving away from this approach to using multipurpose data systems that serve multiple user needs.

Indicators that focus on capital may not change very much from one year to the next. They are not very sensitive to incremental changes or there are long time-lags before a change can be measured so that short-term changes are not easily visible. Only over longer periods of time can the trends in the data be noted. For this reason, it is relevant to also have a number of related indicators that can show that the system is not static. Short-term monitoring lends itself to flow type indicators that are relevant to the changes in capital/stock. These are typically indicators that show the pressures on the capital or stocks.

Another problem may be that certain types of soil, surface water and groundwater analyses are not feasible – perhaps because of analysis costs or lack of hydrological monitoring systems or data. In such cases, collecting information about farming practices that influence those indicators, such as use of fertilizers and pesticides can be used as alternatives. Given the challenges related to the proposed capital-based indicators, a number of supplemental/alternatives indicators are suggested (Chapter 6, Table 8). Indicators that are based on "flows" are typically easier to measure.

The type of data and how they are collected is of course important. Some data are needed at the field level, such as information on tillage practices. Some data are needed along a watershed – for the water pollution measurements and for water basins and aquifers for withdrawals of water use resources. Changes in land use can be at an aggregated level when analysing satellite pictures, but it can also be at the farm level, depending on how the indicator is devised. The data for the indicators may be a combination of on-site measurements, area monitoring, remote sensing, statistical estimations and modelling that are to be used to develop the figures for the indicators.

A gap analysis on data and methodological needs for the production of agri-environmental indicators

There is no single homogeneous, complete and updated source of information for all countries, covering all domains of the agriculture-environment interaction, and, given the wide variety of situations, generalizations are quite difficult to make, on both the geographical and the topics dimensions. Nevertheless, whenever it has been deemed sensible, synthetic judgments have been included in the report on the basis of information covering developing countries from most regions of the world. Details have been included only for the cases in which summary documents produced by other experts can be quoted or referred to, as, for example, in the case of African and Latin American Countries, for which country and/or regional reports on agricultural and/or environmental statistics are available. For other world regions or countries, information has been drawn directly from country surveys that were carried out among data producers and users made available for the present research.

The only international database containing agri-environmental indicators with worldwide coverage is the one maintained by FAO (FAOSTAT). Other highly authoritative international organizations in the field are the Organization for Economic Co-operation and Development (OECD) and Eurostat, both of which report agri-environmental indicators in their databases for their member States, which are countries with above-average levels of statistical systems' development. All statistics reported in FAOSTAT, OECD and Eurostat, as well as databases in other international organizations, are subject to the specific quality assurance frameworks. In all cases, problems concerning the quality of basic data by countries may occur, and herein lies the objective of this present work, namely to strengthen national data collection, analysis and reporting processes.

A basic set of agricultural statistics is produced almost everywhere. Most countries, in addition to carrying out censuses, regularly produce basic data on area and crop production and on their livestock and fisheries. The production of this core information appears to be generally well established in national and regional data production systems. One of the principal data gaps on drivers of global environmental change concerns precisely "agricultural systems". In particular, basic information is needed on inflows and outflows of nutrients and water and on other important resource flows. In almost all thematic areas, data availability is geographically unbalanced with data tending to be scarcer in developing countries. Land, water, biodiversity and chemicals feature among the themes for which important and urgent data are needed as the greatest information gaps are associated with those themes.

Countries collect basic data which can be (though not necessarily are) used for calculating agri-environmental indicators (agri-environmental indicators-relevant data) on different occasions and with different methods, ranging from expert opinions to administrative data and from surveys with personal interviews to remote sensing. Of course, not all methods are suited for all items, so there is a certain coupling between topics and sources. In general, the data do not come from the use of robust statistical methods, such as surveys with probabilistic sampling, but instead are more often from information supplied by diverse informants without the use of objective methodologies and estimates based on forecasts or informants continue to be the method adopted by the majority of countries.

The quality of the reported data does not always depend on the level of development of the statistical system, as there appears to be a high degree of variability across countries and domains.

Besides the usual actors relevant for agricultural statistics – NSOs, ministries of agriculture, forestry and fisheries, and other producers and users of statistics – all institutions concerned with the environment are stakeholders of growing importance for the agri-environmental domain. In most countries, however, agricultural statistics continue to be developed mainly by the ministries of agriculture, forestry and fisheries rather than by NSOs. Information needs in the agri-environmental domain are often expressed by the ministry of the environment based on what emerges from the Global Strategy regional and country reports and in-depth country assessment questionnaires.

Countries are facing varying constraints in the production of agri-environmental statistics and indicators. These limitations are related to institutional, technical or financial factors. Substantial coordination efforts are needed to ensure convergence of international initiatives in order to avoid dispersion of resources and confusion in the potential beneficiaries of the cooperation projects that are sometimes faced with multiple offers of training and support on certain topics, while other areas are left aside. Furthermore, capacity-building, as far as human resources enhancement is concerned, should be targeted and focused on combining statistical skills and technical knowledge in a balanced way.

Data would greatly benefit from having, on the one hand, technical staff involved in the recording of administrative data, given that they tend to know more about the statistical aspects and the importance of the data for the decision-making process. Tools should be provided to understand what needs to be done and how and to better familiarize the institutions involved in the collection process with technological solutions on data-collection and organization. On the other hand, statisticians should be provided with some basic knowledge of the technical aspects, such on phytosanitary products and on the functioning of the agri-environmental system, so that they can better understand the credibility of the data that are provided by respondents to surveys or contained in administrative records.

Conclusions and next steps

Describing agriculture - environment interactions and identifying key aspects that distinguish favorable agricultural practices was the first step in determining what it is needed to measure with a new set of indicators. It is important to establish the boundaries of what it is necessary to describe – otherwise it is difficult to justify what to include or exclude from the indicator list – and, as a result, the number of indicators typically expands to unwieldy lengths.

As the condition of certain natural components – soil, water, land, and biodiversity – is at the core of the implementation of a sustainable food production system, a set of indicators was developed to particularly monitor those natural resources. The set was kept to an absolute minimum, in order to facilitate its application in countries with less developed information and statistical systems.

The next step of the SUST-3 research topic involves addressing the lack of methodologies for the production and establishment of agri-environmental indicators. This final objective of the SUST-3 research topic is comprised of a methodological proposal to cover the gaps identified in the present literature review, a field-test protocol construction to perform a pilot test of the potential methodologies and a field-test report that presents and consolidates findings from field-tests. These activities are used to set the guidelines on the measurement of environmental variables, the compilation of statistics and the establishment of related indicators.

1
Introduction

The present work was developed within the framework of the Global Strategy research topic SUST-3, data collection methods for agri-environmental indicators. It aims to guide developing countries in the production of agri-environmental statistics and indicators. Research topic SUST-3 consists of the following specific objectives:

i. Identify and describe the measurable aspects of the interactions between the agriculture and the environment. Propose a set of statistical indicators and variables for the measurement of the linkages between agriculture and environment, along with their data needs, assumptions and desired properties;

ii. Assess the needs of improving existing methodologies and addressing the lack of methodologies for the production and establishment of agri-environmental indicators; and

iii. Develop and/or improve comprehensive and relevant methodologies for the production and establishment of agri-environmental indicators and include a set of key indicators for the measurement of "sustainable agriculture", related to the environmental dimension of sustainability.

The above i-iv objectives are addressed in the present literature review, breaking down main topics in three thematic areas: (a) most relevant general thematic aspects for the measurement of the interactions between agriculture and the environment; (b) assessment of the production of environmental statistics and indicators in developed and developing countries; and (c) evaluation and prioritization of agri-environmental statistics and indicators. Each thematic area was assigned to an expert adviser, who worked as an author or main contributor of related parts (see acknowledgments section).

This literature review was compiled on the basis of the thematic area reports provided by expert advisors. By revising, complementing and harmonizing specific reports a comprehensive document was achieved that will serve as basis for the final objective of the SUST-3 research topic, namely the development of guidelines for the measurement of agri-environmental variables and the establishment of related indicators. This final objective of the SUST-3 research topic is comprised of a methodological proposal to cover the gaps identified in the literature review, a field-test protocol construction to perform pilot tests of the potential new methodologies and a field-test report that presented and consolidated findings from the implementation of the field tests.

This literature review includes an assessment of existing data collection activities and data availability for the establishment of agri-environmental indicators (focused mainly on developing countries), and a proposal of statistical indicators for the measurement of agriculture/environment linkages. It also includes a gap analysis related to data and methodological needs for the production of agri-environmental indicators.

The work was submitted to experts for a peer review in order to ensure that it is comprehensive, scientifically sound and a practicable document. Their findings and suggestions, as well as those of the Global Strategy Scientific Advisory Committee and CATIE experts, were incorporated into the present document, which will serve as basis for a subsequent ad hoc expert group meeting planned for the fall 2017. The aim of the expert group meeting, where participants are experts from private and public institutions, from developed and developing countries, is to support and guide the setting guidelines on measurement of agri-environmental variables and the establishment of related indicators.

The literature review is comprised of eight chapters:

Chapter 1 contains the introduction.

Chapter 2 introduces a general discussion of the state of the environment in the light of the major agriculture impacts.

Chapter 3 reports on some specific interlinkages between agriculture and environment, with an analysis of those interactions and challenges.

Chapter 4 introduces the concept of sustainable development as applied to agriculture, with an analysis of the path taken to come up with a definition for sustainable agriculture.

Chapter 5 provides information on agri-environmental indicators, analysing the diverse international frameworks for the reporting and production of agri-environmental indicators.

Chapter 6 presents the proposal of a set of key indicators for the measurement of the environmental dimension of sustainability.

Chapter 7 provides information on a gap analysis related to data and methodological needs for the production of agri-environmental indicators.

Chapter 8 contains a summary of conclusions and indicates future steps to be undertaken.

2

State of the Environment: Major Agriculture Impacts

In the present chapter, a general discussion of the state of the environment – at the global level – through the major agriculture impacts is presented. The discussion concentrates on the concept of planetary boundaries to its relation to the agriculture sector, with a focus on broader agricultural activities, including the forestry, livestock and fishery sectors, relevant to the environment.

2.1. The planetary boundaries framework and its relation to agriculture

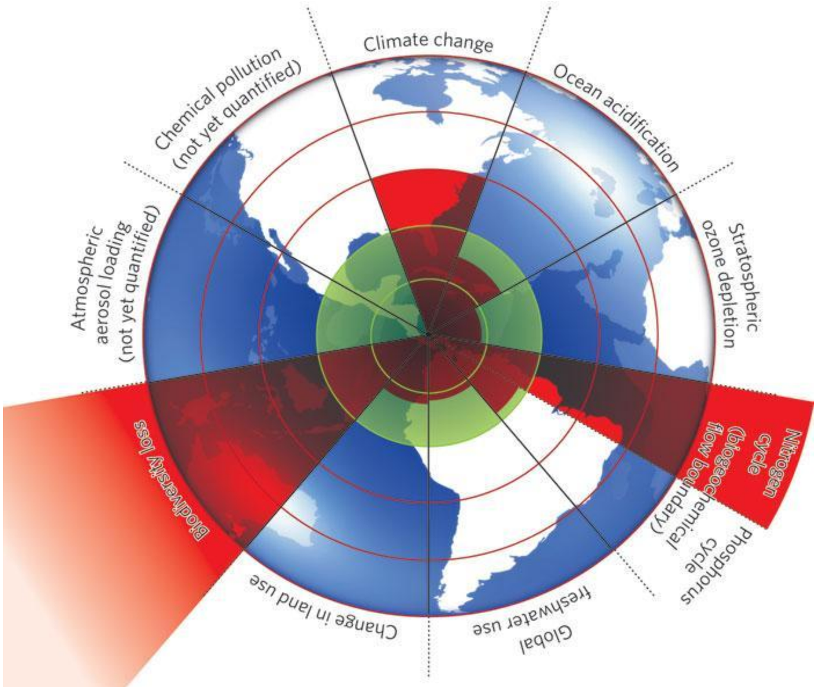
According to Rockström *et al.* (2009), the Anthropocene era has emerged as a result of the Industrial Revolution.[1] This era is characterized by a global environmental change caused by human actions, which has pushed the Earth system outside of its stable environmental state and has resulted in negative, catastrophic and irreversible consequences. These human actions can be associated with the rapidly growing reliance on fossil fuels and the development of industrialized forms of agriculture.

Within the framework proposed by Rockström *et al.* (2009),[2] planetary boundaries define the safe operating space for humanity with respect to the Earth system and are associated with the planet's biophysical subsystems or processes. The authors explain that if thresholds are crossed, the Earth's systems could change into a new state, causing significant harmful consequences for humans. Thresholds can be assessed by using control variables, such as carbon dioxide (CO2) concentration, land cover changes and extinction rates. Defining thresholds is not a simple task. Depending on the system, if some thresholds are crossed, it is likely that increases in the risk of affecting the functioning of other systems, such as land and water degradation, will influence the climatic system.

[1] In the previous era, the Holocene, changes occurred naturally and the planet retained regulatory capacity to enable human existence and development mainly because the natural processes (temperatures, fresh water availability and biochemical flows) remained stable.
[2] In 2009, a group of 28 internationally renowned scientists, led by Johan Rockström, proposed the frame of planetary boundaries, which are in the upper limits on nine environmental parameters. The parameters can be used to define a safe planetary operating space that will allow humanity to continue to develop and thrive for generations to come.

Rockström *et al*. (2009) has identified nine Earth-system processes and associated thresholds which, if crossed, could generate problematic environmental changes. The nine processes are climate change, rate of biodiversity loss (terrestrial and marine species), interference with the nitrogen and phosphorous cycles, stratospheric ozone depletion, ocean acidification, global freshwater use, land use changes, chemical pollution and atmospheric aerosol loading.

Figure 1. Beyond the boundary



"The inner green shading represents the proposed safe operating space for nine planetary systems. The red wedges represent an estimate of the current position for each variable. The boundaries in three systems (rate of biodiversity loss, climate change and human interference with the nitrogen cycle), have already been exceeded"

Source: Rockström *et al* (2009), p. 473.

Table 1. Planetary boundaries

Earth-system process	Control variable	Boundary value	Current value	Preindustrial value
Climate change	Atmospheric CO2-concentration (ppm by volume)	350	400	280
	Change in radiative forcing (W/m^2)	1.0	1.5	0
Rate of biodiversity loss	Extinction rate (number of species per million per year)	10	> 100	0.1–1
Nitrogen cycle (part of a boundary with the phosphorus cycle)	Anthropogenic nitrogen removed from the atmosphere (millions of tonnes per year)	35	121	0
Phosphorus cycle (part of a boundary with the nitrogen cycle)	Anthropogenic phosphorus flowing into the oceans (millions of tonnes per year)	11	8.5-9.5	-1
Stratospheric ozone depletion	Stratospheric ozone concentration (Dobson units)	276	283	290
Ocean acidification	Global mean saturation state of aragonite in surface seawater (omega units)	2.75	2.90	3.44
Global freshwater use	Global human consumption of water (^{km3}/y)	4,000	2,600	415
Change in Land use	Land surface converted to cropland (percent)	15	11.7	low
Atmospheric aerosols loading	Overall particulate concentration in the atmosphere, on a regional basis	To be determined		
Chemical pollution	Concentration of toxic substances, plastics, endocrine disruptors, heavy metals, and radioactive contamination into the environment	To be determined		

Boundary crossed

Boundary not crossed

Source: Rockström *et al.* (2009), p.473.

Notes: ppm, W/m^2, watts per square meter; km^3/y, cubic kilometers per year.

The planetary boundaries framework suggests that three of the Earth-system processes – climate change, rate of biodiversity loss and interference with the nitrogen cycle – have already transgressed their boundaries. A brief description of these three system processes is given below:

- **Climate change.** "Climate boundary has two parameters: atmospheric concentration of CO2 and radiative forcing (the rate of energy change per unit area of the globe as measured at the top of the atmosphere)" (Rockström *et al*., 2009, p.473). The boundary value for these parameters is indicated in Table 1. The transgression of these boundaries will lead to irreversible changes, such as the loss of major ice sheets, sea-level rise and abrupt shifts in forest and agricultural systems.[3]

- **Rate of biodiversity loss.** Species extinction in this era has overcome the natural rate. Human activities related to "conversion of natural ecosystems into agriculture or into urban areas; changes in frequency, duration or magnitude of wildfires and similar disturbances; and the introduction of new species into land and freshwater environments" (Rockström *et al*., 2009, p. 473). The presence of a wider range of species and varieties in ecosystems will maintain their resilience[4]. In agriculture, for example, there is evidence that ecosystems that depend on a few or single seed varieties are more vulnerable to diseases, pest and other risks, reaching undesired states. According to the planetary boundaries framework, the contribution of biodiversity to ecosystems resilience should be measured. However, science has not come up with the answer to solve this question in an aggregate level, and the best approach is to come up with a preliminary estimation of the biodiversity role from information derived from species extinction processes.

- **Nitrogen and phosphorus cycles.** Global cycles of nitrogen and phosphorus are disturbing the Earth systems in a very important manner. Increasing amounts of nitrogen and phosphorus resulting from human activity through modern agriculture are the main cause of environmental

[3]The authors mentioned three additional reasons behind the proposed climate change as a planetary boundary, namely models' underestimation of the severity of climate change, the stability of the large polar ice sheets and evidence that some of the Earths subsystems are already moving outside their stable Holocene state.

[4] Resilience can be defined as the ecosystem's ability to recover or to adjust from impacts. In 1973, C. S. Holling introduced the word resilience into the ecological literature to help understand the non-linear dynamics observed in ecosystems. Ecological resilience was defined as the amount of disturbance that an ecosystem could withstand without changing self-organized processes and structures (defined as alternative stable states). According to Holling, it is the "measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables" (Holling 1973, p. 14, referenced also in www.ecologyandsociety.org/vol12/iss1/art23/table1.html. Other authors consider resilience as a return time to a stable state following a perturbation. A new term, "adaptive capacity", has also been introduced to describe the processes that modify ecological resilience (Gunderson 2000).

pollution. The production and use of fertilizers has led to the spreading of millions of tonnes of nitrogen, which have become reactive in the atmosphere, pollute waterways and coastal zones, accumulate in land systems and add a number of gases to the atmosphere. Evidence of changes and impacts in the state of lake systems and marine ecosystems caused by the nitrogen cycle and phosphorus flows support the view that they are important planetary boundaries.

To close, based on this short explanation of the planetary boundaries framework and its relation to agriculture, it is clear that changes in land use, freshwater use, interference in nutrient cycles, biodiversity loss and ocean acidification are areas that must be prioritized in efforts to reduce human pressures on ecosystems, and that agriculture is one of the major activities in which improvements must be incorporated.

2.2. Global agricultural activities and their relationship with the environment

Agriculture performance in the past years has led to significant gains in agricultural production and productivity, but it has also produced a series of negative impacts and the persistent confluence of pressures on Earth ecosystems is seriously compromising the capacity to produce food and other economic and social benefits.

Agriculture is the dominant activity driving important environmental threats, such as climate change, biodiversity loss and land and freshwater degradation. As a consequence, it is a major force pushing the environment beyond the Earth planetary boundaries. However, one of the greatest challenges that agriculture is facing today and will continue to face in the coming years is the need to increase food production from the 8.4 billion tonnes currently to almost 13.5 billion tonnes a year (FAO 2014). Achieving that level of production from the already seriously depleted natural resource base will require profound changes in the food production system.

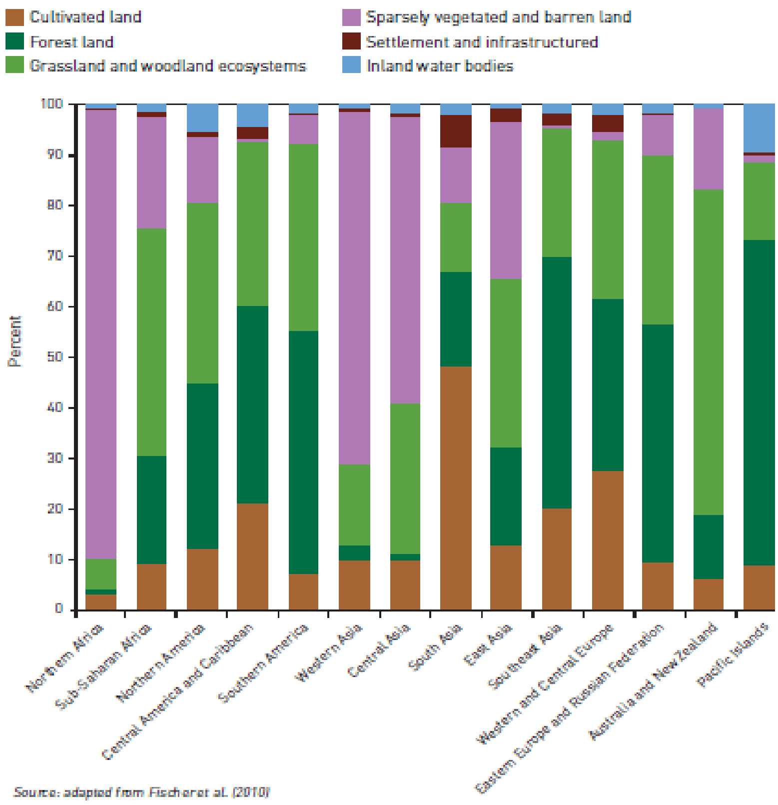
The following description of pressures on ecosystems from agricultural activities is important for gaining an understanding of the main areas related to agriculture for which significant changes must be made in order to remain within Earth's planetary boundaries.

2.2.1. Agricultural land and agriculture intensification

The global land area is 13.2 billion hectares. About 12 percent of it is used for cultivation of agricultural crops, 28 percent is under forest, and 35 percent comprises grasslands and woodland ecosystems (FAO 2011a, Figure 1).

With regard to cultivated land, FAO reported in its statistics system (FAO 2016f) that in 2013, croplands[5] covered about 1.5 billion hectares – about 12 percent of Earth's land area – while pastures covered 3.3 billion hectares – about 26 percent of Earth's area.

Graph 1. Worldwide regional distribution of land use and land cover



Source: FAO (2011a).

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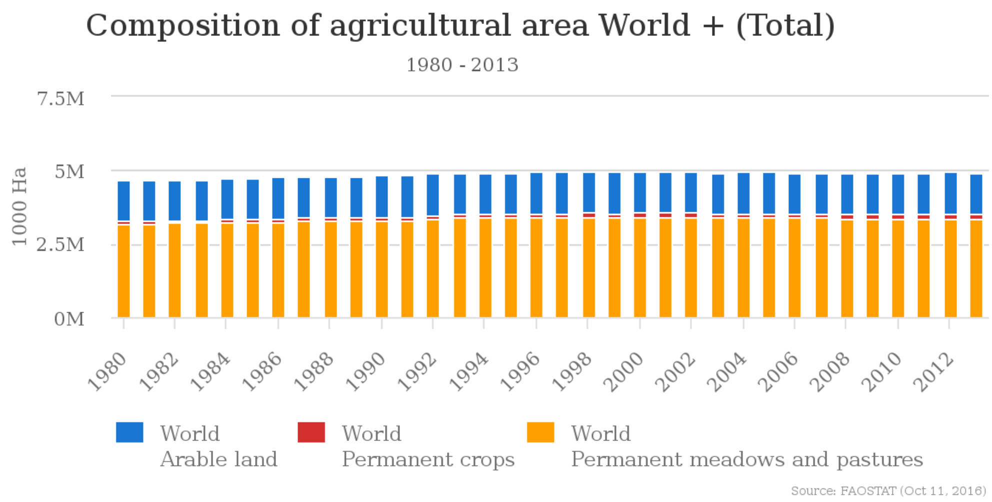
[5] Equal to the sum of world's arable land + world permanent crops.

Graph 2. World composition of agricultural area



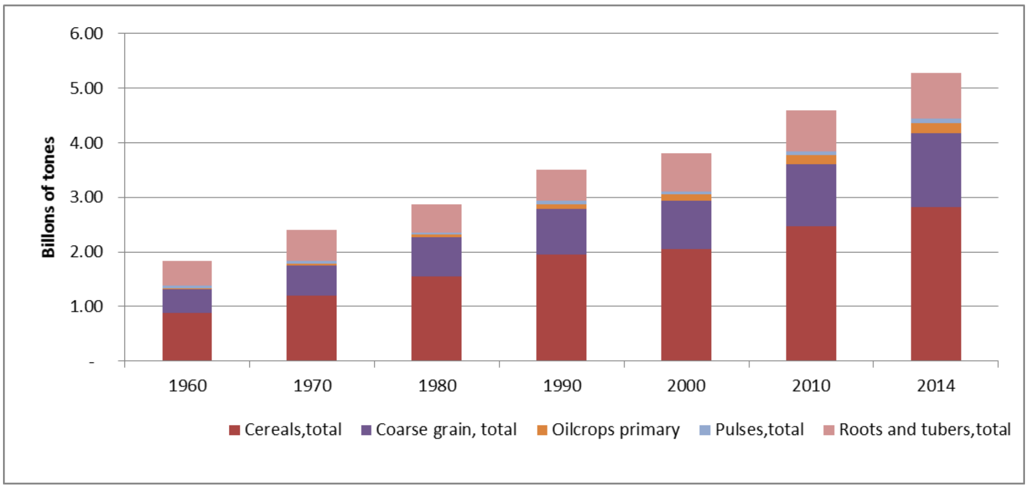
Source: FAO (2016f) (accessed 18 October, 2016).

Note: M, million.

Between 1980 and 2013, the world's croplands and pastures expanded by 275 million hectares (about 6 percent) (Figure 2). While globally the increase in croplands and pastures seems to be declining, a significant expansion is obvious in the tropics and little change or a decrease is observed in other zones, as is the case of the temperate regions (Foley et al., 2011). This redistribution of agricultural land towards the tropics has had implications on food production, food security and the environment.

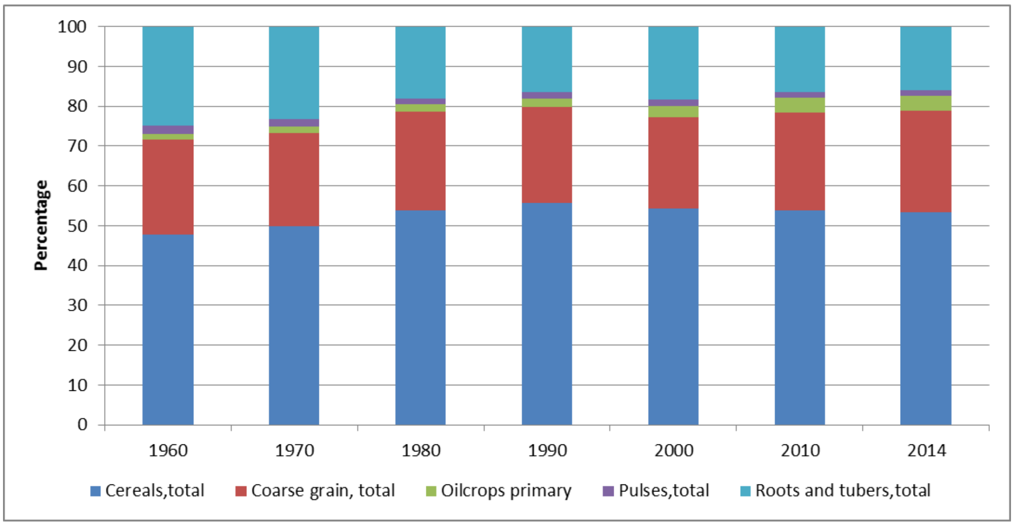
Global crop production also increased in line with the expansion of agricultural land. FAO (2016f) reports that crop production (in common groups, such as cereals, coarse grains, oil crops, pulses, roots and tubers and vegetables) increased by 60 percent in the period 1980-2010 (Graphs 3 and 4). It must be highlighted that the observed high proportional increase in crop production occurred at a lower proportional increase in cropland area, indicating that, at the global level, the increased crop production is related to enhanced crop yields.

Graph 3. Crop production (billions of tonnes), by main crop groups (1960-2014)



Source: Author's elaboration based on information available from FAO (2016f).

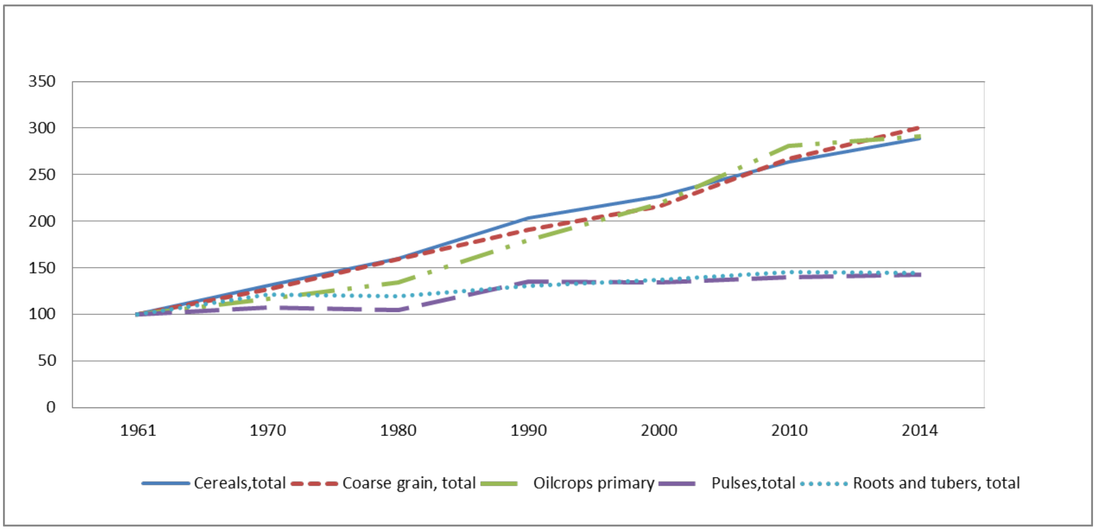
Graph 4.Composition (%) of crop production, by main crop groups (1960 -2014)



Source: Author's elaboration based on information available on FAOT (2016f).

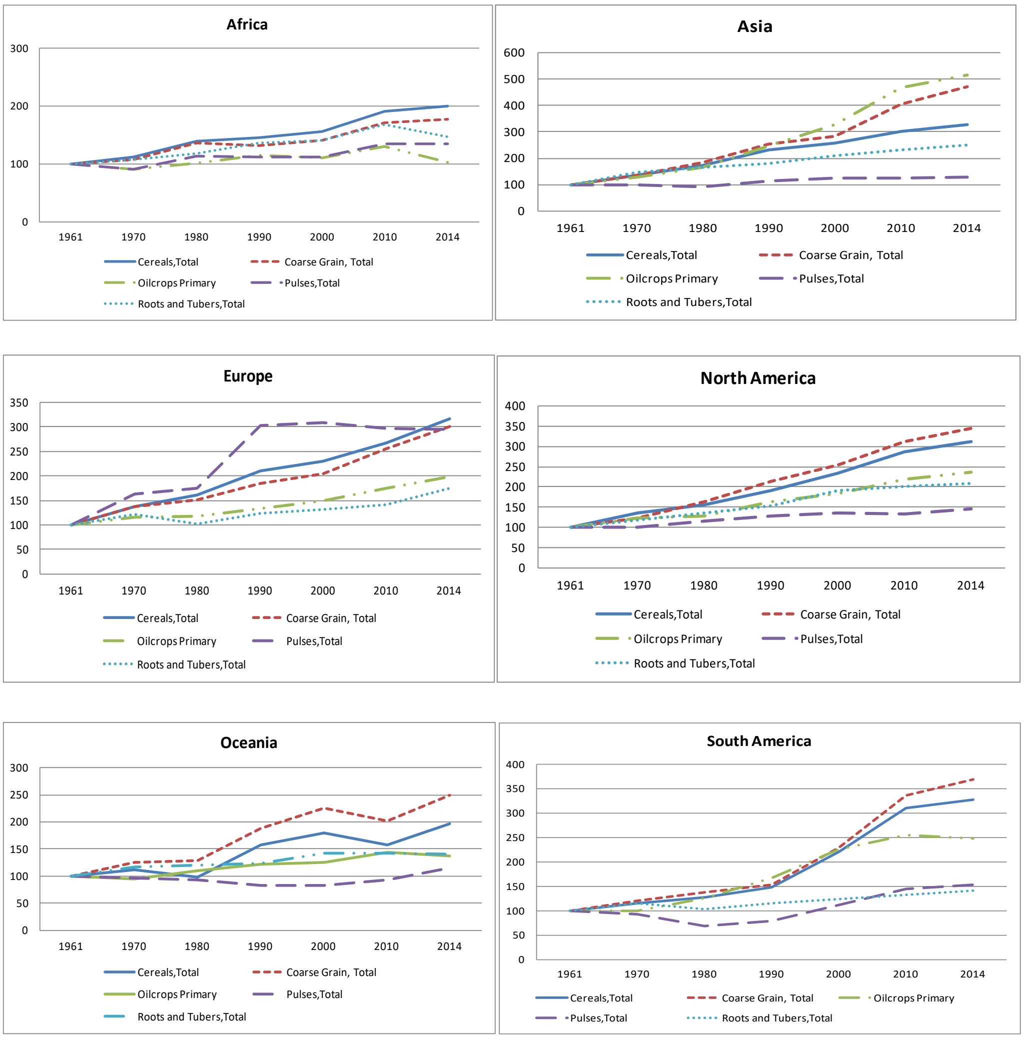
The greatest variations in yield crops in the period 1980-2010 were registered in oil crops (116 percent), coarse grains (89 percent) and cereals (81 percent), as shown in Graph 5. This is a very general analysis. Development in yields of major crop groups deserves individual analysis, by region, country, crop and agricultural practices. In Box 1, for example, a graphical analysis of the evolution of yield by main crop groups and regions for the period 1961-2014 is presented.

Graph 5. Change in yields by main crops (1961=100)



Source: Author's elaborations based on information available from FAO (2016f).

Box 1. Change in yields by region and main crop groups (1961=100)



Source: Author's elaborations based on information available from FAO (2016f).

This increase in yields is explained by the dramatic rise in the use of agricultural inputs and advances in crop breeding; FAO (2015) noted that the used of nitrogen fertilizer increased by a factor of seven, phosphorus fertilizer by a factor of three and irrigation water by a factor of two.

Replacing natural ecosystems to expand crop areas and pastures, the intensification of agriculture by irrigation, use of synthetic fertilizers and pesticides and mechanization are the main causes of the negative environmental impacts derived from food production. This agricultural intensification is also problematic because of the implications relating to the global emissions of greenhouse gases, the increased scarcity of other inputs and contamination of water sources.

2.2.2. Changes in forest land

Forests and trees are essential for agriculture development. They stabilize soils and climate,[6] regulate water flows and provide shade, shelter and habitat for pollinators and natural predators of important agricultural pests. "When integrated judiciously into agricultural landscapes, forests and trees can therefore increase agricultural productivity, help ensure food security for hundreds of millions of people, for whom they are also important sources of food, energy and income, including in hard times" (FAO 2016c, p.4). Nevertheless, agriculture is still the major driver of deforestation globally.

Trends in land-use change that focus on the loss of forests through conversion to agriculture and gains in forest area on land previously used for agriculture are presented in SOLAW report (FAO 2016c). A historical relationship between forest loss and increased demand for agricultural land exists because of population growth, however forests have also naturally have been re-established as deforestation pressures have eased.

Considering climatic domains[7] until the late nineteenth century, deforestation was most prevalent in the temperate areas of the world, being now greatest in the tropics. During the period 2000-2010, FAO (2016c) reported a net forest loss of seven million hectares per year in tropical countries and a net gain in agricultural land of six million hectares per year. This net loss of forest is occurring in the low-income group of countries.[8] It also stated that, "large-scale commercial

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[6] Forests are considered an important sink for atmospheric CO2 because of their ability to store carbon in their biomass and soil. Forest systems constituted a total carbon sink of 2.4 billion tonnes of carbon per year from 1990 to 2007. (UNEP 2012, p.73).
7 Boreal, temperate, subtropics and tropics.
8 There were significant regional variations: Central and South America, sub-Saharan Africa and South and Southeast Asia all had net losses of forest and net gains in agricultural land.

agriculture accounts for about 40 percent of deforestation in the tropics and subtropics, while local subsistence agriculture, infrastructure, urban expansion and mining respectively account for 33 percent, 10 percent, 10 percent and 7 percent" (p.8)[9]. The significance of particular drivers of deforestation depends, to a large extent, on the circumstances of each country; factors affecting global trends in land use are considered in more detail in the SOLAW 2016 publication.

Forest losses over the period 2010–2015 (most of which was natural forest) were offset partially by a combination of natural expansion, often on abandoned agricultural land (2.2 million hectares per year), and the establishment of planted forests (3.1 million hectares per year).[10] FAO (2016c) reports that net gains in forest and net losses in agricultural areas in Europe, North America and North-East Asia. Among the factors contributing to net increases in forest area are reduced pressure on forests as a result of economic growth, declining rural populations, improved agricultural productivity and effective policies aimed at expanding forest area.[11] Moreover, the global forest area designated for protection of soil and water increased from about 272 million hectares in 2000 to about 299 million hectares in 2010, an annual increase of some 2.77 million hectares, or 0.97 percent. Similarly, the global forest area designated for biodiversity conservation has increased from about 303 million hectares to about 366 million hectares, an annual increase of about 6.33 million hectares or 1.92 per cent.

2.2.3. Soil conditions

As the global impact of humanity on natural resources has increased, the connections between soil and broader environmental concerns have evolved. According to the Status of the World's Soil Resources (SWSR)[12] report (FAO & ITPS 2015), a large number and breadth of concepts related to soil condition have been expanding rapidly over the past two decades. One of them is the

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[9] The report highlights significant regional variations, for example, "commercial agriculture accounts for almost 70 percent of the deforestation in Latin America, but for only one third in Africa, where small-scale agriculture is a more significant driver of deforestation" (FAO 2016c, p.8).
[10] Forest plantations, generally cultivated for industrial purposes, increased by 50 million hectares globally between 2000 and 2010, reaching 264 million hectares or 7 percent of the total forest area. Asia accounted for 28 million hectares, or 58 percent of this increase. Generally, monoculture plantations tend not to enrich local biodiversity, but they do provide ecosystem services including timber, carbon and water storage and soil stabilization (UNEP, 2012, p. 72).
[11] These changes can be seen graphically represented in the full report available from wwww.fao.org/3/a-i5588e.pdf , pages 13-16.
[12] The report synthesizes the work of about 200 soil scientists from 60 countries and provides a global perspective on the current state of the soil, its role in providing ecosystem services, and the threats to those services.

concept of soil degradation,[13] developed under the Global Assessment of Soil Degradation (GLASOD)[14] project in 1974 (see Box 2) in which an inventory of soil degradation was developed and types of soil degradation were evaluated.

The specific threats considered in the SWSR report are soil erosion, compaction, acidification, contamination, sealing, salinization, water logging, nutrient imbalance, such as nutrient deficiency and nutrient excess, and loss of soil organic carbon (SOC) and biodiversity. Most of those threats are directly related to agricultural activities. However, agriculture is not the only cause of soil degradation; other causes that are equally attributable to soil degradation are urban development, industrialization, use of heavy machinery and deforestation.

In brief, in the SWSR report, it is noted that "while there is cause for optimism in some regions, the overwhelming conclusion from the regional assessments is that the majority of the world's soil resources are in only fair, poor or very poor condition. In sum, the most significant threats to soil function at the global scale are: soil erosion, loss of SOC and nutrient imbalance" (p.66). Additionally, the document includes a table with the global summary of threats to soil functions in which conditions and trends are assessed by main regions.

2.2.4. Status in the use of water resources

Agriculture is by far the largest global water user. According to SOLAW report, (FAO, 2011a), over the last 50 years, more than 40 percent of the increase in food production came from irrigated areas, which have doubled, while land under rainfed systems has declined slightly. Agriculture accounts for 70 percent of all water withdrawn from aquifers, streams and lakes.

[13] This concept and its assessment have been developed as part of a more holistic assessment of human-induced degradation carried out by FAO, UNEP and other United Nations agencies (FAO & ITPS 2015).
[14] GLASOD was the first comprehensive assessment of global soil degradation. It was based on expert opinion only. From GLASOD, subsequent assessments were completed: the Land Degradation Assessment in Drylands (LADA), the Global Land Degradation Assessment (GLADA) and the Global Land Degradation Information System (GLADIS). From them, other important environmental assessments have taken place, the Millennium Ecosystem Assessment (2003) and the periodical review of the State of the Environment by UNEP with the GEO-reports (UNEP 2012). FAO published the SOLAW report in 2011. The Economics of Land Degradation initiative provided, in 2015, the first estimate of the cost of land degradation at the global scale. More specific information on GLASOD is in section 4.2.3.1.

Box 1. The Global Assessment of Human-Induced Soil Degradation

The Global Assessment of Human-Induced Soil Degradation (GLASOD) has identified five degrees of soil degradation:

0. No degradation.

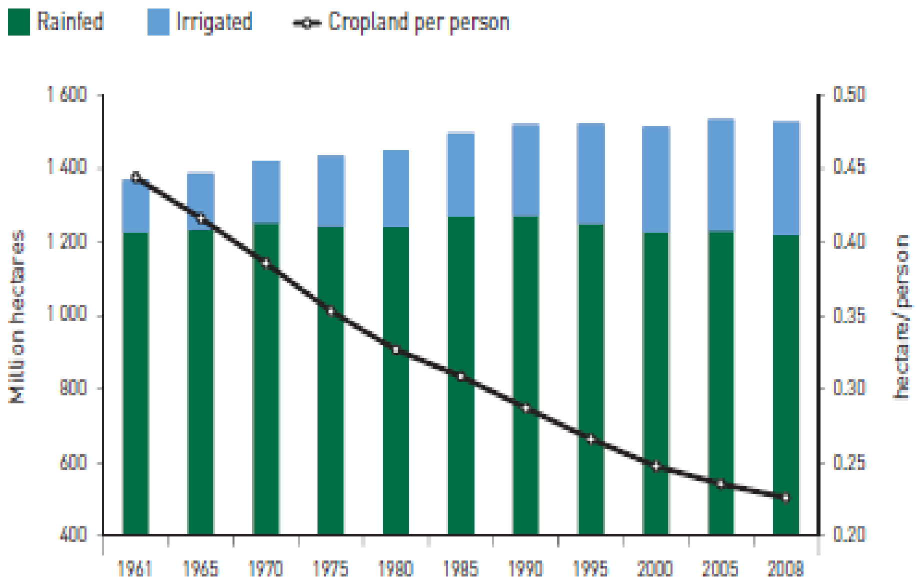
1. Light: The terrain has somewhat reduced agricultural suitability, but is suitable for use in local farming systems. Restoration to full productivity is possible by modifications of the management system. Original biotic functions are still largely intact.

2. Moderate: The terrain has greatly reduced agricultural productivity, but is still suitable for use in local farming systems. Major improvements are required to restore productivity. Original biotic functions are partially destroyed.

3. Strong: The terrain is not productive at the farm level. Major engineering works are required for terrain restoration. Original biotic functions are largely destroyed.

4. Extreme: The terrain is completely and irredeemably not productive anymore. Original biotic functions are fully destroyed.

Graph 6. Evolution of land under irrigated and rainfed cropping (1961-2008)



The black line (cropland per person) refers to the right y-axis

Source: FAO (2011a).

Although rainfed agriculture is the world's predominant agricultural production system, the global area equipped for irrigation continues to expand at a rate of 0.6 percent per year. Nevertheless, the increase in environmental damages in key land and water systems has reached a point in which the damages are affecting production and the welfare of human beings and nature. The following is written in the SOLAW report:

"... irrigation has had direct benefits in terms of production and incomes, and indirect benefits in terms of reduced incidence of downstream flood damage, there have also been associated impacts whose costs may at times outweigh the benefits of production. These impacts may include reduction in environmental flows, changes in downstream access, or reduction of the extent of wetlands, which have important ecological functions and are critical ecosystems for biodiversity, nutrient retention and flood control" (FAO 2011a, p. 17).

It is recognized that constrained irrigated production caused by water scarcity and competition for water with other sectors result in environmental stress and socio-economic tension, particularly in countries with low and medium incomes and rapid population growth. In regions where water scarcity occurs, agriculture is expected to be more affected by this than by the availability of land.

With regard to groundwater, its abstraction is vital for irrigation systems, but regulations pertaining to the use of it are not usually enforced. This is leading to the overexploitation of underground water, which cannot be offset by the natural replenishment rates and is resulting in a decline in aquifer levels and creating an obvious risk for the sustainability of food production. These withdrawals are projected to continue to increase, putting further pressure on aquatic ecosystems, which also require water of adequate quantity, quality and timing for sustained health.

Referring to freshwater water, UNEP (2012) has noted, for example, that groundwater is threatened by pollution, particularly high nitrate concentrations, that has originated in agricultural areas, mainly because of the continual use of fertilizers. Another continuing and pervasive water quality problem is the nutrient pollution and eutrophication resulting from excessive nutrient pollution from human sewage, livestock wastes, fertilizers, atmospheric deposition and erosion.

In addition, the toxic chemicals found in water bodies include traces of metals, such as cadmium, lead and mercury, pesticides and their by-products, such as dichlorodiphenyltrichloroethane (DDT) and chlordecone, industrial chemicals and combustion by-products. Even though the use of some substances is forbidden in many countries, they are still used in many places and thus continue to accumulate in aquatic systems, leaving a legacy of sediment contamination; in fact, they are found in 90 per cent of water bodies.

2.2.5. Problems associated to the livestock sector

Based on the High Level Panel of Experts on Food Security and Nutrition (HLPE/FSN) report published in 2016, the livestock sector has played a central role in the development of food systems. In addition to representing one third of global agricultural gross domestic product (GDP), and having other economic implications, such as market concentration in agricultural supply chains and farm income, livestock characteristics, such as animal-feed demand, intensification of production at the farm level and land use have environmental consequences. In other words, “livestock has often set the speed of change in agriculture in recent decades” (HLPE/FSN 2016, p.14).

Livestock is the largest user of land resources (HLPE/FSN 2016). In fact, in 2013, permanent meadows and pastures represented 26 percent (3.1 billion hectares) of the global land area and feed crops account for one third of the global arable land. Moreover, the HLPE/FSN (2016) report states that between 33 and 40 percent of global arable land is used to grow feed crops; and together, permanent meadows, pastures and land dedicated to the production of feed represent 80 percent of total agricultural land.

At the global level, "as a driver of deforestation, demand for feed, and transportation and processing infrastructure, the livestock sector is directly and indirectly responsible for 14.5 percent of GHG [greenhouse gas] emissions" (p.16). In addition, livestock is a major user of water resources, including irrigation water for animal feed production (this varies considerably across countries and production systems).

"However, the wide diversity of livestock systems worldwide means that livestock has varying impacts on the socio-economic viability of communities, and on natural resources and the environment, including climate change" (p. 39).

"Over the last 20 years, increasing demand for livestock products has been met primarily through a shift from extensive, small-scale, subsistence, mixed crop and livestock production systems towards more intensive, large-scale, geographically-concentrated, commercially oriented and specialized production units" (HLPE/FSN 2016).

In small-scale farms, the improvement of animal production can be associated with increasing labour productivity, the use of improved management practices, such as feeding with crop residues or using manure as fertilizers, the procurement of services off-farm, and the adoption of improved animal breeds. This degree of farm operations' mechanization can be considered as industrial and has enabled farmers to invest in technologies and greater market integration, offering the possibility of improved economies of scale. "This intensification has led to a decrease in mixed farming systems: most cereals are produced on specialist arable farms, and large-scale industrial units dominate the monogastric, such as pigs and chicken, livestock sector. As production systems become more efficient, less feed is needed to produce a given unit of a livestock product, with positive effects on the environment. Consequential changes in stover production are expected to occur, but they will vary widely from region to region" (HLPE/FSN 2016, p. 52).

In the above description of livestock systems, many of themes are identified as a key area for action towards making agriculture more sustainable, in particular aspects related to resource efficiency in production, maintenance of production systems within critical planetary limits, ecosystem services preservation and reduction of land degradation, biodiversity loss and pressures on water use and quality reduction. High-income countries, in particular, and increasingly in middle-income countries, are areas where the growth and impact of industrialized livestock production (transport and processing) and associated environmental impacts are more relevant.

In addition, livestock production growth and its productivity are frequently achieved through the use of antibiotics, hormones, genetic material and intensive feeding practices on pasture, rangeland and feedlots. Bacteria in poultry litter, veterinary antibiotics, anti-parasitic medicines and hormones are examples of the contaminants that are introduced into the environment and affecting human health through livestock production. The cumulative effect of releases from livestock production and agriculture creates a pressing need to monitor the environmental consequences. However, many rangeland systems still make positive contributions to biodiversity and landscapes.

High Level Panel of Experts on Food Security and Nutrition report (2016) noted that biodiversity in agroecosystems, including the animal component, performs important ecological services beyond food production and that animals are often an essential part of ecological cycles. For example, some livestock systems are among the most vulnerable to climate change, particularly those in dry areas, and to new environment-related emerging diseases.

2.2.6. Problems faced by the fisheries sector

Oceans and inland waters provide significant benefits to humanity. According to the FAO report, the State of World Fisheries and Aquaculture (FAO, 2016b), the fisheries sector "supplies 17 percent of global animal protein in people's diets and support the livelihoods of some 12 percent of the world's population" (p.87). In addition, HLPE/FSN (2014) has reported that at the global level, 158 million tonnes of fish were produced in 2012, of which 136 million tonnes were used for human consumption. This figure can be broken down to 11.6 million tonnes from inland fisheries, 79.7 from marine capture fisheries, 41.9 from inland aquaculture and 24.7 from marine aquaculture.[15]

Despite its relevance, FAO (2016b) states that today it is widely acknowledged that stress caused by human activity on the oceans and rivers' life have reached unsustainable levels and there is evidence of overexploitation of resources, pollution, degrading habitats, declining biodiversity, expansion of invasive species, climate change and acidification. For instance, "wetlands, mangroves, salt marshes and sea grass beds are being cleared at an alarming rate, exacerbating climate change and global warming" (p.81). Other factors, such as poor governance, management and practices, including illegal, unreported and

[15] These figures are expressed in live weight equivalent, including, non-edible parts, such as shells of mollusks and head parts of fish, and without accounting for post-harvest losses.

unregulated fishing and inefficient aquaculture operations, are considered to be drivers of unsustainable fisheries and aquaculture production.

Regarding marine fisheries, overfishing is the most significant pressure on this sector from an environmental and resource perspective. FAO (2016b) reveals that "the percentage of stocks fished at biologically unsustainable levels increased, especially in the late 1970s and 1980s, from 10 percent in 1974 to 26 percent in 1989. After 1990, the number of stocks fished at unsustainable levels continued to increase, albeit more slowly, to 31.4 percent in 2013" (p. 38).[16] As for the state of inland fisheries resources, the scarcity of information related to this activity has not allowed to make similar analyses as those conducted for marine fisheries.

However, it can be noted that the marine and inland fisheries are confronted with competition from other activities (economic and recreational) and with various environmental risks. HLPE/FSN (2014) has pointed out that for marine and inland fisheries, the most impactful activities are "oil drilling, energy installations, coastal development and construction of ports and other coastal infrastructures, dams and water flow management" (p.48). Fisheries are also suffering from competition in the use of water and because of modifications made to river beds. Indeed, dams disrupt riparian ecosystems as a result of stream flow changes, which also causes hydrological changes to have further impacts on fisheries-related activities. One of the most evident effects of dams is the obstruction of movements of migratory fish along river courses, disrupting breeding cycles and thus jeopardizing the population's viability.

With regard to climate change aspects, an estimated 40 percent of the carbon in the atmosphere that becomes bound in natural systems is cycled into the oceans and wetlands. The performance of marine fisheries depends on changes in global and regional climate when interacting with many factors, such as the distribution and ecology of the natural resources present in these ecosystems.

About marine ecosystems, HLPE/FSN (2014) has indicated that climate impacts are already visible. For example, it has been reported that "changes in the species composition of marine capture fisheries, linked to changes in ocean

[16] In 2013, FAO found in an assessment on world marine fishery resources that the share of fish stocks within biologically sustainable levels has exhibited a downward trend, declining from 90 percent in 1974 to 68.6 percent in 2013. Thus, 31.4 percent of fish stocks were estimated as fished at a biologically unsustainable level and therefore overfished. Of all the stocks assessed in 2013, 58.1 percent were fully fished and 10.5 percent were underfished. The share of underfished stocks decreased almost continuously from 1974 to 2013, but that of fully fished stocks decreased from 1974 to 1989 before rising to 58.1 percent in 2013. The full report is available at www.fao.org/docrep/015/i2389e/i2389e.pdf

temperatures; changes in the geographic distribution of fish species: an increase of warmer water species at higher latitudes and a decrease of subtropical species in the tropics" (p. 50).

Regarding coastal areas and coral reefs, the effects of climate change combined with other pressures, such as pollution, ecosystems degradation and overfishing, are devastating. "60 percent of coral reefs are considered to be under immediate threat from local anthropic pressures, rising to 75 percent with climate change. Aquaculture production of calcifying organisms, such as mollusks, will experience loss of habitats because of ocean acidification" (HLPE/FSN 2014).

To end, information on climate change impacts on inland fisheries and aquaculture is scarce. Some studies refer to decreases in production, changes in species composition, water stress and competition for water resources and fish biodiversity loss.

2.2.7. Pressures on biodiversity

Biodiversity is defined as "the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems" (IUCN 2014, p.5). The Convention on Biological Diversity (CBD 2008) gathers most of the progress on this concept, pointing out that biodiversity means "the diversity of life in all its forms - the diversity of species, of genetic variations within one species, and of ecosystems" (p. 284).

In the context of farms and ranches, agricultural biodiversity (or agrobiodiversity) "refers to the diversity of life within the farming system, ranging from soil microorganisms to the diversity of genetic resources, crops, insects and other species that are needed for production. The term also includes diversity in surrounding landscapes and ecosystems that influence agriculture" (FAO 2016d, p. 4).

The pressure on biodiversity continues to increase. Habitat[17] loss and degradation from agriculture, overexploitation and pollution remain the predominant threats.

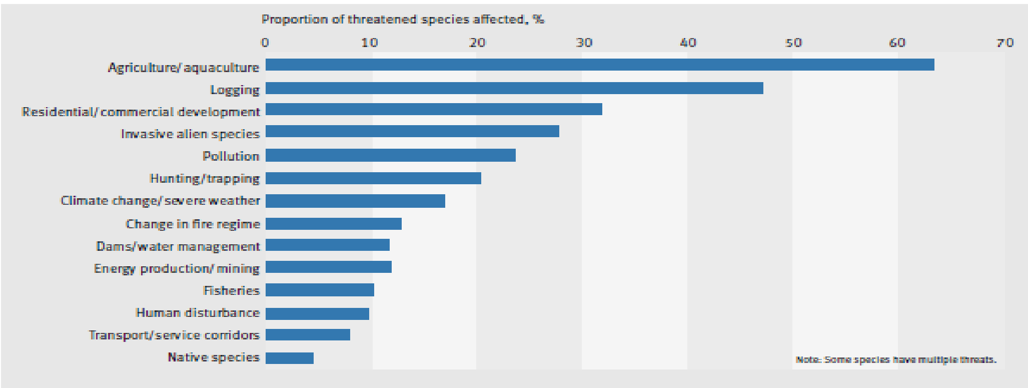
Habitat and biodiversity loss in the terrestrial domain has been caused largely because of the expansion of agriculture. Moreover, large-scale commercial agriculture has adversely affected agrobiodiversity. While freshwater

[17] Habitat is the place or type of site where an organism or population naturally evolves.

ecosystems are severely affected by fragmentation because of aquaculture, wetlands have also declined by 50 percent in the twentieth century as a consequence of floodplain systems (UNEP 2012).

Overexploitation of species to meet consumer's demand is a threat to biodiversity; unregulated overconsumption is a driver behind the decline of terrestrial, marine and freshwater species. Considering overexploitation in terrestrial systems, it is possible to state that "major exploited groups include plants for timber, food and medicine; mammals for wild meat and recreational hunting; birds for food and the pet trade; and amphibians for traditional medicine and food".[18] In the case of marine fish stocks, the rate of overexploitation and depletion has increased from 10 percent in 1974 to 32 percent in 2008.

Graph 7. Major threats to vertebrates listed as critically endangered, endangered or vulnerable on the International Union for Conservation of Nature Red List



Source: UNEP (2012).

With regard to pollution, pesticide and fertilizer effluents from agriculture and forestry (and other sectors) harm biodiversity directly through increased mortality and reduced reproductive success, and indirectly through habitat degradation.

With regard to the use of genetic modified organisms in agriculture, this practice remains controversial because it can be seen as a potential threat to or as an opportunity for biodiversity conservation. Considering biodiversity concerns, several risks from genetic modified organisms have been identified, including, among them, the loss of genetic diversity of agricultural species and their wild relatives through gene flow; the capability of the genetic modified organism to escape and potentially introduce the engineered genes into wild populations; the prevalence of the gene after the genetic modified organism has been harvested;

[18] Vie *et al.* (2009, referenced in UNEP (2012, p. 150).

the susceptibility of non-target organisms, such as insects that are not pests, including loss of biodiversity; and increased use of chemicals in agriculture. However, the environmental safety aspects of genetic modified crops vary considerably according to local conditions and deserve specific studies.

2.2.8. Biofuels as an alternative source of energy

The implications of the rapid growth in the production of biofuels based on agricultural commodities have been discussed widely. The introduction of policies that promote the production of liquid biofuels in developed countries has been based on their anticipated positive contributions to climate change mitigation, energy security and agricultural development. However, the increasing demand for agricultural commodities for the production of biofuels is having significant repercussions on agricultural markets. Their negative impact on the food security of millions of people around the world and the environmental impacts of biofuels are also important themes that need to be discussed further. UNEP (2012) states that "while ethanol has been widely used in Brazil for two decades, its use accelerated globally at the end of the 1990s, increasing by 20 percent each year to reach 30 million tonnes of oil equivalent in 2009. In the early years of the twenty-first century, biodiesel became available, with production growing at around 60 percent per year, reaching nearly 13 million tonnes of oil equivalent in 2009" (p.15).

Environmental concerns about biofuel production are associated with the effects resulting from land clearance and conversion, the introduction of potentially invasive species and overuse of water. An additional cause for concern is the purchase or leasing of land by wealthier countries to produce them. This occurs typically in developing and sometimes semi-arid countries. It is a trend that may have serious impacts on fossil and renewable water resources, as well as on local food security (UNEP 2012).

"The impact of biofuels on greenhouse gas emissions (GHG) differs according to feedstock, location, agricultural practices and conversion technology. In some cases, the net effect is unfavorable. The largest impact is determined by land-use change – for example through deforestation – as agricultural area is expanded. Other possible negative environmental effects – on land and water resources, as well as on biodiversity – also depend to a large extent on land-use changes" (FAO 2008, p. 55).

Although biofuel production remains small in the context of total energy demand, it is significant in relation to current levels of agricultural production. The potential environmental and social implications of its continued growth must be recognized. For example, reduced GHG emissions are among the explicit goals of some policy measures to support biofuels production. Unintended negative impacts on land, water and biodiversity are examples of some to the side effects of agricultural production in general, but they are of particular concern with respect to biofuels. The extent of such impacts depends on how biofuels feedstock are produced and processed, the scale of production and, in particular, how they influence land-use change, intensification and international trade.[19]

2.2.9. Pollution caused by pesticides use

Pesticide is "any substance or mixture of substances that is used to prevent, destroy or control pests — including vectors of human or animal disease, and unwanted species of plants or animals" (United Nations 1997, p.405). Some examples of pesticides are insecticides, herbicides, fungicides and rodenticides.

There are many environmental concerns associated with pesticides, starting with the fact that these compounds are designed to kill specific pests but often reach non-target organisms, as well. Pollution caused by pesticides use is another major concern. According to the United Nations Environment Programme (UNEP), more than "90 percent of sampled water and fish were found to be contaminated by several pesticides and estimates indicated that about 3 percent of exposed agricultural workers suffer from an episode of acute pesticide poisoning every year" (UNEP 2012, p.1).

There are still concerns about the level of organochlorine insecticides in riverbed sediments and soils even though the use of them ended 10 to 25 years ago. Currently used pesticides still include insecticides that were heavily used in the 1960s and are now banned in most developed countries, such as DDT and chlordane. Moreover, endosulfan sulphate, the metabolite of endosulfan, which are still used in many countries, is a very common contaminant of surface and groundwater.

The extent of human exposure and the health effects are widely recognized. More than 70 percent of the populations of low-income countries live in rural areas, and 97 percent of rural populations are somehow engaged in agricultural production. Developing countries account for one third of global pesticide use. In fact, the vast majority of pesticide poisonings occur in low-income countries.

[19] For a better understanding of environmental impacts of biofuels, see (FAO 2008).

2.2.10. Climate change: complex interactions and inextricable links

The agricultural sector is currently at the centre of the global debate as one of the sectors in which greater efforts must be dedicated to adapting to climate change. This is because this sector directly depends on the natural resources that are directly affected by climate and variability in climatic conditions. Similarly, the agricultural sector contributes significantly to GHG that cause global warming and associated climate change, so its contribution towards stabilizing the global climate through better management of crops, land and livestock should be a priority. Implementation of good agricultural practices would result in reduced GHG and increased carbon sequestration through good quality of plant biomass and soils (FAO 2016e).

How climate change affects agriculture?

"In many regions, agricultural production is already being adversely affected by rising temperatures, increased temperature variability, changes in levels and frequency of precipitation, greater frequency of dry spells and droughts, increasing intensity of extreme weather events, rising sea levels, and salinization of arable land and freshwater" (FAO 2016e, p.5). The intensification of these phenomena will make it more difficult to carry out agricultural activities.

While in some cases warmer temperatures may be beneficial for growing some crops in certain regions, usually non-optimal increases in temperature and deficiency of water and nutrients are directly affecting crop yields. Similarly, the occurrence of floods or droughts not only reduces crop yields, but it also generates crop losses. In many regions, increases in temperature are already expected with decreases in precipitation, posing a challenge for the development of agriculture. Most pests, diseases, and weeds thrive in warmer and wetter environments and with higher atmospheric CO_2 content.

Extreme temperatures environments with low water availability are unsuitable for crops cultivation. As for livestock, the stress generated in animals by an increase in temperature produces a greater propensity for diseases and attacks by parasites, which in many cases, reduces the fertility of the females leading to lower production of milk and meat. Heat stresses, on the other hand, also results in less food consumption, which translates into a lower feed conversion rate. Climate change also threatens the carrying capacity of grasslands and rangelands and feed production for non-grazing systems.

There is no precise prediction of the impacts of climate change on agriculture. The most recent reports from the Intergovernmental Panel on Climate Change (IPCC) mentioned that effects can occur at different scales depending on the regions (referenced in FAO 2016e); for example, "projections of impacts on crop yields counterbalance each other at global level until about 2030, but the balance after that becomes increasingly negative" (p.6). Similarly, in high latitudes, growth periods for some crops may be prolonged without major repercussions on the crop-yields; they could even increase compared to the expected ones without the effects of climate change. On the contrary, at low latitudes, crop-yields would be affected by climate change and higher losses are expected in regions where climate variations will be extreme.

Box 3. Summary of climate change impacts on agriculture

- Increased frequency and intensity of extreme climate events, such as heat waves, droughts and floods, leading to loss of agricultural infrastructure and livelihoods.
- Decrease in fresh water resources, leading to water scarcity in arable areas.
- Sea-level rise and coastal flooding, leading to salinization of land and water, and risks to fisheries and aquaculture.
- Water and food hygiene and sanitation problems.
- Changes in water flows affecting inland fisheries and aquaculture.
- Temperature increase and water scarcity affecting plant and animal physiology and productivity.
- Beneficial effects on crop production through carbon dioxide "fertilization".
- Detrimental effects of elevated tropospheric ozone on crop yields.
- Changes in plant, livestock and fish diseases and in pest species.
- Damage to forestry, livestock, fisheries and aquaculture.
- Acidification of the oceans, with extinction of fish species.

Source: FAO (2016e, p. 21).

As mentioned before, fisheries and aquaculture are already affected by climate change. For example, warmer waters are leading to the extinction of many fish species and changing the habitat ranges of others. Similarly, changes in water temperatures increase the risk of diseases occurrence along the productive chain. "The world's oceans are becoming more, owing to increases in the levels of atmospheric CO2, with particularly severe consequences for the fisheries that depend on shellfish and squid, mangroves and coral reef systems. The increased frequency and intensity of storms, hurricanes and cyclones will harm aquaculture, mangroves and coastal fisheries" (FAO 2016e, p. 5).

Regarding forests, although the benefits of climate change are under discussion, given that forests can benefit from CO_2 increases in the atmosphere, higher temperatures and precipitation, losses of native and endemic species, lower yields in forest products and serious damages as a result of storms, floods and natural disasters may occur as a result of climatic variation.

How agriculture contributes to climate change?

Agriculture contributes directly and indirectly to the emissions of the three major greenhouse gases: CO2, methane (CH3) and nitrous oxide (N2O). GHG that are classified in the IPCC reports as originating in "agriculture, forestry and other land use - AFOLU" are caused mainly by deforestation, livestock production and soil and nutrient management and have been estimated to constitute 21 percent of total global emissions — 10.6 gigatonnes (Gt) of CO2 de equivalent in 2014 (FAO 2016e).

It is widely known that a significant amount of methane and nitrous oxide are released by the livestock sector. Methane is produced by ruminant livestock during digestion and also escapes from stored manure and organic wastes. Nitrous oxide emissions are an indirect product of organic and mineral nitrogen fertilizers after they have been applied to cropland (FAO 2016e). Enteric fermentation is responsible for 40 percent of CO2 emissions, followed by manure left in pastures (16 percent) and rice cultivation (10 percent).

AFOLU does not include greenhouse gas emitted in the production processes of agricultural inputs such as fertilizers, nor does it cover the stages of transport and distribution along the food-chain. If they were to be included, agricultural sector emissions would increase by more than one third of the current share. Similarly, GHG emissions along the food-chain vary, depending on the country. For example, in developing countries the greatest production of gases is concentrated in agricultural production, while in developed countries, the emissions are the same in the stages of production and distribution.

Table 2. Three main sources of agricultural greenhouse gas emissions in 2014, by region

Ranking	Countries in developed regions	Eastern and Southeast Asia	Latin America and the Caribbean	Northern Africa and Western Asia	Oceania, excluding Australia and New Zealand	Southern Asia	Sub-Saharan Africa
1	Enteric fermentation (37%)	Rice cultivation (26%)	Enteric fermentation (58%)	Enteric fermentation (39%)	Cultivation of organic soils (59%)	Enteric fermentation (46%)	Enteric fermentation (40%)
2	Synthetic fertilizers (17%)	Enteric fermentation (24%)	Manure left on pasture (23%)	Manure left on pasture (32%)	Enteric fermentation (14%)	Rice cultivation (15%)	Manure left on pasture (28%)
3	Manure management (12%)	Synthetic fertilizers (17%)	Synthetic fertilizers (6%)	Synthetic fertilizers (18%)	Manure management (14%)	Synthetic fertilizers (15%)	Burning savannah (21%)

Source: FAO (2016e, p. 41).

3

Agriculture and Environment: Interactions and Challenges

The process of agriculture intensification was increased to meet the demand for food, feed and fiber from the growing human population. Through more efficient agricultural practices, farmers have found ways to increase crops yields. In the twentieth century, there was a shift in the paradigm of agricultural production towards a model aligned with the industrialized world in which mechanization, processes standardization, use of labour-saving technologies and chemical use to increase crop efficiency became the new paradigm.

In this chapter, some relevant specific interlinkages between agriculture and environment are presented, along with an analysis of those interactions and challenges. At the end of the chapter, the sustainable agriculture concept is introduced as an appropriate framework for the analysis to be presented in the document.

3.1. A global historical assessment

According to FAO (2011b), intensification of agriculture is a historical and evident fact, given the need to meet increasing demand for food, feed and fiber from a growing human population. Through more efficient agricultural practices, such as the use of disease resistant plants, the construction of terraces to conserve soil and irrigation canals, the preparation of land for growing crops with tillage practices and the application of manure as fertilizer and sulfur as a pesticide, farmers have been able to increase the yield of their crops.

In the twentieth century, a shift in the paradigm of agricultural production occurred. Under the new paradigm, the management of natural resources was abandoned and the care of ecosystems was based on a model aligned with the new industrialized world, which included mechanization, process standardization and the use of labour-saving technologies and chemicals application to increase crop efficiency. As a result of the use of agricultural machinery driven by fossil fuels, intensive tillage, high-yielding crops, irrigation systems, and manufactured inputs, a significant increase in crop productivity has been achieved.

The green revolution is considered to be the beginning of the intensification of agriculture in the developed world. In the 1950s and 1960s, higher yields were observed in cereal crops stemming from genetically modified varieties cultivated under irrigation systems and accompanied by the use of fertilizers and pesticides. Practices for maintaining soil fertility were based on the use of fertilizers, while the herbicides provided alternatives for weed control and allowed for crops to be rotated without having rest periods.

Only a few years ago, it was recognized that the rapid gains in agricultural productivity have had negative effects on natural resources and the environment from which agriculture is developed. The impacts of this have been so destructive that the productive potential and the future availability of these resources is now in doubt. "Negative externalities of intensification include land degradation, salinization of irrigated areas, over-extraction of groundwater, the buildup of pest resistance and the erosion of biodiversity. Agriculture has also damaged the wider environment through, for example, deforestation, and the emission of greenhouse gases and nitrate pollution of water bodies" (FAO 2011b p.5).

3.2. The rise of monoculture

For centuries, the Ukrainian black soils (chernozem) were praised for not only being fertile, but also for being able to support wheat crop after wheat crop up to 10 years. During that time period, the introduction of a leguminous crop was required to restore the sanitary conditions of the soil mainly regarding nematode infestations. All over Europe, very few soils exhibited the desired characteristics that permitted a farmer to cultivate only the most prized crops and to be free from the "slavery of animal husbandry". In the United States of America, the abundance of land enabled millions of poor peasant immigrants to become "profit maximizers", putting "all the eggs in the same monoculture basket". However, without the introduction of the "artificial" fertilizer, the inevitable degradation of the soil caused would have limited farm production. The first artificial fertilizers were guano from Ecuador and saltpeter from Chile, followed later by the chemical fertilizers after Liebig's discover in the middle of nineteenth century.

As it is known, the discovery of Liebig about plants nutrition cleared the way for the rise of the chemical fertilizers industry which, in turn, made it possible for a greater number of farmers to adopt the practice of monoculture and to abandon the integrated animal husbandry practice. In Europe, animal husbandry was practiced mainly by the smaller farms located in less favourable places. In the more productive regions, such as "la Beauce" in France, the technology applied to monocultures would eventually allow the farmers to replace the old crop rotations systems by a "dreamed" rotation scheme: blé d'hiver, vacances de ski, mais d'été, vacances dans la Côte d'Azur (winter wheat, ski holidays, summer corn, holydays in Côte d'Azur) (Gervais, Jollivet & Taverny 1976).

By the end of the nineteenth century, soil came to be mainly viewed just as a nutrient deposit that could be restored by putting in chemical fertilizers. In the United States of America, the main mission of the numerous regional experimental research stations that accompanied the western expansion of agriculture was to test chemical fertilizers, especially because of the widespread fraud in the mineral composition of the different brands offered in the market. Moreover, mainstream environmental economists have only recently accepted this "ecological" model of the soil as a deposit of nutrients as suitable "proof" of their premise that capital can substitute natural capital. The value of soil losses to erosion, and its reposition, could be calculated by just summing up the market prices of the different nutrients lost.

Meanwhile, in the main agronomical research institutions in different countries, this "ecological" model of soil was debunked by the advancements of scientific research. The development of soil science, because of its much greater complexity, initially lagged behind other scientific fields, such as agricultural chemistry. However, advancements in soil sciences had led to the realization of a more complex soil ecological model. Soils is now viewed as a complex ecosystem, capable of producing different ecosystem services. The two visions, however, coexisted for a long period.

In some institutions, such as the National Institute of Agronomical Research of France (Institut national de la recherche agronomique (INRA) and the United States Department of Agriculture (USDA), warnings from scientists about the negative impacts caused by monocultures and their associated farming practices were given for decades starting in the beginning of the twentieth century. However opposite views about this problem were maintained. For example, in the United States of America, there were differing views between researches of regional experimental stations and those from the Department of Agriculture, and between soil scientists and researchers more directly engaged in finding solutions to farmers' problems in France.

In France, a clear-cut diagnosis about the degradation dynamics of the so-called modern farming practices was reached in the 1970s by scientists working in agricultural research institutions. A dynamic characterized by the substitution of lost agri-ecosystem services by agricultural equipment and chemical inputs, a substitution itself environmentally damaging. Remy & Marin-Lafleche (1976) have observed that in France because of the lowering of the organic matter content in the soil, its physical structure had become more and more susceptible to climate factors and passage of heavy machinery. As a result, new procedures and types of equipment and chemicals were developed to compensate for the degradation of soil structure, but they were not designed to stop the degradation; some of them have even aggravated the situation in the long run.

In the wake of the so-called "green revolution", "modern" agricultural practices started to be introduced in the 1960s in poor countries by international research institutions, such as the International Rice Research Institute, in the Philippines and the International Maize and Wheat Improvement Center, in Mexico. The research essentially focused on the improvement of monocultures of the three large humanity staple foods. The green revolution was a great success in terms of the increase in land productivity, but it was accompanied by socio-economic problems denounced by Pearse (1980) from the United Nations Research Institute for Social Development. The socio-economic problems arose precisely from the fact that the green revolution "technological package" implied a complete substitution of the traditional labour-based management of ecosystem services by capital (equipment and chemicals), which excluded millions of impoverished farmers, in addition to causing serious environmental problems.

In response to the criticisms, those international research institutions changed their research agenda to include an ecological approach deemed to be more appropriate for the socio-economic conditions of the impoverished farmers. The institutions, which increased to 15 and established themselves as CGIAR, redefined their goal to not only increase food security, but also to improve human health and nutrition, reduce rural poverty and to ensure sustainable management of natural resources. Under this new approach, the lack of capital is substituted by the (abundant) labour to be employed in a scientifically improved management of the agri-ecosystem. Initially, for many, this would be the appropriate approach given the context of poverty, but it should be progressively abandoned as the farmers obtain more capital and become in a position to buy the "modern" inputs. Eventually, however, it came to be viewed as a real alternative to agricultural improvement.

3.3. Back to sustainable farming?

Sustainable farming practices presuppose a more complex agri-ecosystem. In the past, when farmers lacked access to heavy equipment and exogenous inputs, such as agri-chemicals, the only way to keep the productive capacity of their agri-ecosystems was by ecologically managing them. The so-called first agricultural revolution, which accompanied the great industrial revolution in eighteenth and nineteenth centuries, was based on the spread of innovations (known since the Middle Ages) in the ecological management of the agri-ecosystem that greatly augmented its ecological efficiency. A new crop rotation system, known as the Norfolk system from the name of the English county where it was developed, when integrated with animal husbandry resulted in spectacular growth of land productivity that was entirely based on the management of ecosystem services.

It is worth noting the reason why the system was first developed in Norfolk county. The county had poor soil, but it was a light mineral drained sand soil that was easier to work. This soil was conducive for the new system, which required intensive work of seedbed preparation. Eventually, it became one of the best soils of the country. As shown below, the new crop rotation system associated with animal husbandry enhanced a lot of the organic matter content in the soil, compensating the lack of mineral colloids. As a result, in a relatively short period of time the fragile sand soils became very stable and resistant to erosion, and gained the other properties of a rich and well-structured soil.

The rationale behind this crop rotation system included the following economic component: the rotation order of the selected crops should be adapted to biological constraints in terms of the suitability of the structure and the biochemical conditions of the soil left by a crop to the following one, but it could also accommodate an economic constraint, such as the cost of spreading the manure in the field.

Having those constraints in mind, the pioneering farmers came up with the now classic four crops rotation scheme: 1. roots/tubercula; 2. wheat; 3. leguminous plants; and 4. other types of cereals (less prized in the market and less demanding in terms of fertilizers). Roots and/or tubercula were put in the opening of the rotation scheme for technical and economic reasons. One reason behind this is that as crops were already growing inside the soil, a costly preparation of the seedbed was required so that the soil would still be in excellent condition for the next very demanding crop, wheat. Another supporting factor was that as roots and tubercula are resistant to high levels of nitrogen, it was possible to concentrate on spreading the manure in only one parcel (25 percent) of the field at each time. After wheat, a leguminous crop was introduced with the objective to restore part of the nitrogen consumed by wheat through the fixation of atmospheric nitrogen and control of weeds that begin to sprout after two crops. Finally, the fourth crop, a less demanding cereal, such as oat and barley closed the rotation scheme.

For the associated cattle raising, the first and third crops represented a very balanced source of carbohydrates (beets, mangolds, turnips) and proteins (leguminous plants) to feed more numerous and heavier animals which, in turn, produced a greater amount of manure to be composted with the harvest wastes. In a compost, pile hungry microorganisms eat the waste to produce CO2, water and humus. The resulting compost, an ecosystem service produced from bacteria, is an excellent natural fertilizer with a high content of nitrogen fixed in an organic structure that prevents it from volatilizing or leaching into the groundwater, but is easily available for the crops.

However, this type of agri-ecosystem presented three limitations (constraints) that proved to be fatal for its survival:

1. It implied more complex work management.

2. It was labour intensive and required more complex labour-saving mechanization.

3. It limited the capacity of the farmers to maximize their income by cultivating only the best priced crops.

For small but intensively cultivated areas, some technical solutions for the constraints 1 and 2, i.e. a robotic application in precision farming, such as horticulture, have already been formulated and are ready to be applied in the market (Olewitz 2016). For large-scale open field agriculture, however, these constraints are still in play. In general, as for constraint 2, it is now easier to produce more flexible multipurpose equipment without significant cost increases. The robotic applied to agriculture mechanization appears destined to foster a revolution in the field. However, constraints 1 and 3 remain important barriers to the adoption of ecologically more balanced farming practices. As for constraints 1, it must be kept in mind that the specialization and the mechanization it allowed for represented a revolution in terms of the alleviation of the hardships of the farming work. Presently, it is even possible for a farmer specialized in cereal production to watch his Global Positioning System-guided tractor ploughing his fields from the porch of his house.

More complex work management, even without the hardships of heavy manual work, goes against this trend. It would be necessary for a more ecologically conscious farmer to abandon this “comfort zone” and adopt a more demanding, albeit more fulfilling, management work. Actually, an ecologically managed agri-ecosystem would transform the farmer into a “natural resources manager”.

Constraint 3 could be reduced or even eliminated through a system of incentives and disincentives. Monocultures should be discriminated against and polycultures favoured through agricultural policies. It is an empirical question to know how much more costly these policies would be as compared to the present ones. Society should be willing to pay for it. As indicated, there is also a link between constraints 1 and 3. The policies of price guarantees should be based on ecologically sound agri-ecosystems and not on products.

3.4. A vision for sustainable food and agriculture: the role of the Food and Agriculture Organization of the United Nations

The latest call for enhancing food security and nutrition and a more sustainable agriculture was made at the United Nations Conference on Sustainable Development, held in Rio de Janiero, Brazil, in 2012. From this conference, the United Nations initiated the formulation of a set of Sustainable Development Goals and launched the Zero Hunger Challenge. Meanwhile, United Nations organizations and agencies have adopted a framework for advancing environmental and social sustainability, which calls for a common vision (FAO 2014). The vision of sustainable food and agriculture is therefore a world in which food is nutritious and accessible for everyone and natural resources are managed in a way that maintained ecosystem functions to support current as well as future human needs.

For several decades, FAO has been at the forefront of work aimed at achieving sustainable agriculture, taking the lead in defining concepts and promoting international treaties, policies, strategies and programmes for sustainable development in food and agriculture and developing approaches and frameworks at the subsector level, such as the Ecosystem Approach to Fisheries and Aquaculture (2009), Save and Grow, the framework programme for sustainable crop production intensification (2011), the Global Agenda for Sustainable Livestock (2010), Sustainable Forest Management, the Global Soil Partnership, Climate-Smart Agriculture, Coping with Water Scarcity, adopted to varying degrees by countries.

To sum up and better introduce the next chapters on sustainable agriculture, FAO has proposed five interconnected principles for the transition towards sustainable food and agriculture. They are: (1) improving efficiency in the use of resources; (2) direct action to conserve, protect and enhance natural resources; (3) protect and improve rural livelihoods, equity and social well-being; (4) enhance resilience of people, communities and ecosystems; and (5) promote responsible and effective governance mechanisms. These principles balance the social, economic and environmental dimensions of sustainability in agriculture, and provide a basis for developing policies, strategies, regulations and incentives to guide the transition to a truly sustainable food production, while promoting resilience through an adaptive response to shocks and opportunities (FAO 2014). Under each of the five principles, a substantial number of examples of key policies and practices is presented by FAO for each of the source sectors identified (crops; livestock; forestry; aquaculture; and fisheries). Some of them are identified as the building blocks of this proposal for a minimum set of key indicators for sustainable agriculture.

To achieve sustainable and productive agriculture, a single, system vision that maximizes synergies, mitigates negative externalities and minimizes harmful competition between its sectors needs to be adopted (FAO 2014).

4

Towards a Definition of Sustainable Agriculture

In the body of literature on agriculture, many definitions of sustainable agriculture have been proposed, which point out the different aspects of sustainability (environmental, social and economic). However, to build agri-environmental indicators, the environmental pillar must be the primary consideration. The topic of this chapter is the concept of sustainable development applied to agriculture and its ecological approach. Included in the chapter are an analysis of the path taken to come up with a definition for sustainable agriculture and a basic template for sustainable farming practices.

4.1. From a sustainable development definition

To successfully define the sustainable agriculture concept, it is important to reflect on the meaning of sustainability as derived from the concept of sustainable development. The well-known Brundtland Report entitled "Our Common Future" (UNCED, 1987), which includes concerns contained in the Stockholm Declaration (United Nations 1972) and the World Charter for Nature (United Nations 1982) represents the environmental milestone with regard to the term "sustainable". According to the Brundtland Report, sustainable development is the one that "... meets the needs of the present without compromising the ability of future generations to meet their own needs". It is contained within it two key concepts:

- The concept of needs, in particular the essential needs of the world's poor, to which overriding priority should be given; and
- The idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs.

Meeting the needs of the future depends on how well societies balance social, economic, and environmental (three pillars) objectives or needs hen making decisions. For each pillar, there are different objectives (World Bank 2001):

Table 3. Sustainable development pillars by objectives and needs

Pillar	Objectives and needs
Economic	Services; household needs; industrial growth; agricultural growth; efficient use of labour.
Social	Equity; participation; empowerment; social mobility; cultural preservation.
Environmental	Biodiversity; natural resources; carrying capacity; ecosystem integrity; clean air and water.

Source: World Bank (2001).

Different objectives and needs often conflict with each other, particularly when considering short-time scales. For example, agricultural growth might conflict with conserving natural resources. Yet, in the long term, responsible use of natural resources in the present timeframe will help to ensure the availability of resources for sustaining agricultural growth far into the future.

4.2. To a sustainable agriculture definition and the recommended sustainable farming practices

The concept of sustainable agriculture can be defined from different perspectives based on the main focus, which usually fluctuates between the environment, humans, or a combination of both of them.

The three-pillar integrated approach of sustainable agriculture as formulated by FAO is the following: "the management and conservation of the natural resource base and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such development (in agriculture, forestry and fishery) conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable" (FAO 1989).[20] Recently, this approach has been confirmed and strengthened by the High Level Panel of Experts on Food Security and Nutrition (HLPE/FSN 2016) of the Committee on World Food Security, which defines sustainable agriculture development as "the agricultural development that contributes to improving resource efficiency, strengthening resilience and securing social equity/responsibility of agriculture and food

[20] Available at http://www.fao.org/docrep/w7541e/w7541e04.htm

systems in order to ensure food security and nutrition for all, now and in the future".

The body of literature available on this topic includes many definitions of sustainable agriculture, which usually point out the numerous and varying aspects concerning sustainability. In 2017, the Global Strategy produced a literary review that includes in one publication most of the definitions, technical and academic concepts and developments about sustainable agriculture.[21]

"Sustainable agriculture is one that balances equitably interests related to environmental quality, economic viability, and social justice among all sectors of the society." (Allen *et al.* 1991).

"Sustainability in agriculture essentially means the harmonious balance between agricultural development and components of the agro-ecosystem. This equilibrium is based on a proper use of locally available resources (such as climate, soil, water, vegetation, local crops and animals, skills and knowledge own the resort) to put forward an agriculture that is economically feasible, environmentally protected, culturally adapted and socially just, without excluding external inputs They can be used as a complement to the use of local resources." (García-G, 2009)

Broadly speaking, the latter authors distinguished two main approaches:

1. One mainly referring to ecological and technological aspects, that emphasize sustainability and conservation of natural resources, environmental quality, and in some cases, the profitability of the agricultural establishment.

2. A second wider perspective that incorporates social, economic, and political elements affecting sustainability of agricultural systems at the national and international levels (Allen *et al.* 1991).

Based on a summation provided by Feher & Listanyi 2013, sustainability definitions can be classified into four main groups22 in relation to the maintenance of human wellbeing, the survival of the human race, the flexibility of productive systems and also some non-economic concepts, the latter major goal being the preservation of cultural heritage and maintenance of traditional diverse ecological systems.

[21] For more information consult Hayati (2017).
[22] In particular, this specific grouping was provided by Szakàl (1998).

Another possible classification can be conducted considering the different degrees in which the three main elements of sustainability are usually emphasized (Feher & Listanyi 2013). The role of the technology-centred approach includes strategies that aim to reduce environmentally harmful activities. These are, for instance, organic farming, biofarming and extensive or low-input farming.

A broader perspective goes beyond the scope of the farming systems and contemplates sustainability as a system that is able to neutralize or tolerate harmful effects or negative externalities from crop production. This broader perspective – aligned with the broader concept of sustainable development (originally ecodevelopment) – integrates the three pillars (economic, environmental and social). Among them, the environmental dimension has been focused on the most. As sustainability itself might be interpreted as an environmental problem, it deals with the impacts of negative and positive externalities from agricultural activity, and conservation of biodiversity (Feher & Listanyi 2013). The economic pillar deals with typical economic issues that affect agricultural systems, such as subsidies, competition, profitability and competitiveness; while the social pillar deals with aspects linked to preservation of cultural values, continuing existence of rural communities, the role of local institutions (Feher & Listanyi 2013) and issues related to gender equality, food security (FAO & ADB 2013) and income, employment generation, labour, and health (UNSDSN, 2013).

All of these are acceptable approaches and represent valuable efforts to provide comprehensive definitions. However, if the objective is to build agri-environmental indicators, the environment or ecological system (hence the third pillar), must be primarily considered while keeping in mind the need to come up with a comprehensive yet broadly acceptable definition of sustainable agriculture. These criteria are incorporated in the definition proposed by the Technical Advisory Committee of CGIAR: "Sustainable agriculture involves the successful management of resources for agriculture to satisfy changing human needs, while maintaining or enhancing the quality of the environment and conserving natural resources" (Dumanski *et al.* 1998).

Basically, the implementation of sustainable agricultural practices must be able to conserve in the very long term (millennia), the productive capability of the agri-ecosystem. Therefore, the concept of sustainable agriculture is closely related to the one of permaculture (permanent agriculture).[23]

Similar concepts dealing with the ideal of sustainability have been historically questioned on the grounds of their social and economic feasibility. Critics have assumed that the technological patterns followed by the modernization of agriculture – towards simplified productive systems (hence monocultures) based on genetically selected plants with a high capacity of response to fertilizers – were the most efficient and the only capable way to produce enough food to fulfil the growing needs generated by accelerated human population growth. Although many had recognized that this agricultural model was not sustainable in the long term, they had hoped for an alternative solution for food production to be found in the years to come (Dumond 1949).

According to Hayati (2017), despite wide consensus as to its relevance, there has been considerable variation in terms of how sustainability in agriculture is defined and how it is actually pursued in the policy-making process. This is partly because it is a derivative of a range of "alternative" types of agricultures, such as organic, regenerative, low-input and ecological agriculture.

From the many available sustainable agriculture definitions, the one from the Technical Advisory Committee of CGIAR can be accepted as the most suitable for the SUST-3 research topic, as it is more concise and objective in addition to being the least controversial. It reaffirms that the ecological sustainability of agriculture depends on the conservation and/or improvement of the natural resources it relies on. However, if one were to be critical, it can be argued that this definition falls short when considering the social and economic dimensions, reduced "to satisfy changing human needs". Human needs can be identified from several perspectives. From a farmer's point of view, it must take into account the alleviation from – or even more the elimination of – the hardships of the traditional farming work and the equalization of their family income to the average urban family income. From the consumers' point of view, access to affordable high-quality food should be considered. In particular, the modernization of agricultural has brought down food prices to the point that average household spending on food in the developed countries has fallen to just

[23] "Permaculture is a philosophy of working with, rather than against nature; of protracted and thoughtful observation rather than protracted and thoughtless labour; of looking at plants at animals in all their functions, rather than treating any area as a single-product system" (Mollison1995).

10-15 percent (7 percent in the United States of America) of the total spending.[24] Of course, it can be argued that with the reduction in prices, the quality of the products was also affected (less nutritious and more contaminated with pesticides residues). The agricultural modernization path followed by the developed countries can be seen as an efficient market response to these needs: it was a very sustainable social and economic trajectory from the point of view of both producers and consumers.

The challenge to deal with the now perceived constraints of the ecological dimension of this modernization path is precisely the following: how to move towards a more sustainable agricultural production without undermining the sustainability of its social and economic dimensions measured as farmers' higher living standards and more affordable but still high-quality food for consumers.

In developing countries, this modernization pattern was not socially and economically sustainable from most producers' perspective, as they could not secure the necessary investments to participate in this modernization trend. The reason for that was quite simple: in developed countries, agricultural modernization was part of a development process in which the urban-industrial expansion attracted rural workers, which, in turn, raised the opportunity cost of the rural labour.

In most developing countries, however, because of their peculiarities, the modernization of agriculture should have followed a different trajectory. They should have considered one that was more compatible with the prevailing low opportunity cost of the rural labour in which the advantages of the accumulated scientific knowledge, i.e. a more labour-intensive agri-ecosystem based on integrated management of natural resources, were considered. This pattern could have helped to improve the farmers' living standards and led to a marginal reduction in consumer food prices, but in the long run, increasing labour productivity in farming was the only way to conciliate higher living standards for farmers and lower food prices for consumers.[25]

From a social point of view, sustainable development depends on a balanced rural exodus. A balanced rural exodus should be understood as a process in which the expansion of good employment opportunities in urban areas is a greater factor than poverty or lack of opportunities in rural areas. Historically, the case for most poor countries has fallen between two extreme situations: in

[24] Some of the variation of households spending on food can also be explained by differences in food habits in different countries in addition to food prices and per capita incomes. However, what is important is the downfall trend in food prices. See (Economist 2013).
[25] For a recent discussion on the topic see Dorward (2013).

one extreme, countries had overpopulated rural areas and low urban-industrial expansion; in the other extreme, countries had rapacious rural oligarchies that prevented rural workers from getting access to abundant land, causing them to migrate to urban areas independently of employment opportunities. In both cases, the opportunity cost of the rural labour was low, what would have required adequate agricultural and agrarian policies as part of an overall development policy aimed at creating a virtuous process of urban-industrial expansion coupled with increasing real wages.[26]

Based on the discussion above, the process of defining the sustainable agriculture concept is therefore not independent from the sustainable development notion. As a result, the definition must incorporate social and economic components. To sum up, the concise concept of sustainable agriculture of CGIAR can be substituted by an equally concise concept in which the meaning of "changing human needs" is expanded to the producer's need of good working conditions and living standards and the consumer's need for affordable yet high-quality food. On the other hand, the idea of an agriculture sector capable of "maintaining or enhancing the quality of the environment and conserving natural resources" can be expressed without losing its meaning as agriculture that can endure for millennia.

Thus, sustainable agriculture, which includes economic, social, and environmental components, can be redefined as one that can endure for millennia while being capable of producing affordable high-quality food and enabling producers (farmers) to have high living standards.

Ultimately, regarding the right agricultural model to carry on, certainly, the science of agriculture has allowed human populations to grow exponentially and dominate the world's landscapes. Advancements in agricultural-related sciences have enabled humans to manipulate entire ecosystems to help ensure their survival, guaranteeing continued food supply and quality. However, as populations continue to grow, natural resources are becoming more limited. Water and energy use, as well as food production are essential elements that are determining the world's population survival. Therefore, it is crucial that strong emphasis be placed on improving the efficiency of the natural resources to enable the sustainability of these elements. When comparing sustainable and conventional agricultural practices, for instance, organic farming methods have

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[26] The labour issue is indeed a key factor, especially in high-income countries where labour demand comes with the relatively recent focus on organic production and agro-ecological farming approaches. However, this issue goes beyond the purposes of the present research line.

shown to perform much better considering a series of indicators. Conventional agriculture cannot meet the needs of the current population without continuing to compromise the environment.

In contrast, benefits associated with sustainable agriculture, (e.g. farming systems implementing good agricultural practices), within the social, economic and environmental realms are compelling reasons to consider sustainable agriculture as the most viable way to accommodate growing population needs (Stony Brook University 2016). Nevertheless, it is important to highlight that implementation of sustainable agricultural practices have become challenging in agri-ecosystems that have been overly simplified and where the implementation of conventional practices, such as particular tillage practices or, heavy use of fertilizers, might be the only alternative to keeping these areas under production, such as soy production in Argentina. As a result of particular conditions related to the history of land use, much effort should be put into implementing good agricultural practices, whenever possible, as part of the drive to find a balance between food production and natural resources conservation.

Box 2. Ecological agriculture and sustainable agriculture

The two terms, "ecological agriculture" and "sustainable agriculture" are sometimes used improperly.

Ecological agriculture is understood to be the application of ecological principles to agricultural ecosystems (agri-ecosystems). Agronomy as a science has evolved in that direction, both through applying ecological principles to solve agronomic research questions within official agronomic research institution related, for example, to soil sciences, or through the development of other agricultural practices and techniques, such as organic, biological or biodynamic agriculture and permaculture, all considering ecological principles in the management of the natural resources inside the agri-ecosystem in order to be productive but lowering the negative externalities of conventional agriculture. The Norfolk rotation system is a classic example of ecological farming that is related to characteristics of efficiency, diversity, self-sufficiency, self-regulation and resilience.

In short, ecological agriculture is a technical/scientific concept. It has nothing to do with the normative concept of sustainable agriculture. It has to do only with the ecological dimension.

4.3. Foundations of sustainable agricultural practices and recent sustainable agriculture paradigms

The task of developing and promoting good agricultural practices must also be accompanied by the promotion of international treaties, policies, strategies and programmes for sustainable development in food and agriculture, and the formulation of approaches and frameworks at all relevant levels.

One of the more recent approaches that focuses on sustainable agriculture is included in the FAO publication *Save and Grow* (FAO 2011b). Under this approach, the new paradigm "sustainable crop production intensification- SCPI" – consisting of a highly productive and environmentally sustainable agriculture – was introduced. The *Save and Grow* publication deals with the crop production dimension of sustainable food management through an ecosystem approach that draws on nature's contributions to crop growth, such as soil organic matter, water flow regulation, pollination and biocontrol of insect pests and diseases" (FAO, 2011b, p. iv). The sustainable crop production approach specifically combines traditional knowledge with modern technologies and also encourages the use of conservation agriculture (CA)[27] based on the notion of boosting yields while restoring soil health, controlling insect pests by protecting their natural enemies and avoiding collateral damages to water quality by reducing the excessive use of mineral fertilizers by using precision irrigation systems.

Although SCPI constitutes an integral concept dealing with sustainable production, it is important to highlight previous efforts. During the last five decades, there have been various efforts oriented towards defining the type of agricultural development necessary to determine the much-needed balance between food production and sustainable use of natural resources. For instance, three major concepts have paved the way to the definition of SCPI.

The development of terms, such as agroecology, which can be traced back to the 1930s, eco-agriculture and to the 1970s and much more recently the emergence of the climate-smart agriculture concept, introduced by FAO in 2010, during The Hague Conference on Agriculture, Food Security and Climate Change. These approaches have been pivotal in gaining an understanding of sustainable agriculture and have, over the years, become a major priority for policy makers in their efforts to achieve ecosystem-based food production. Particularly, the ecosystem-based approach has been endorsed over the past two decades at global levels in agricultural management, but more importantly as farmers´ began to

[27] Conservation agriculture is an approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment. For more information see www.fao.org/ag/ca/1a.html.

adopt sustainable agricultural practices, such as integrated pest management (IPM) and climate-smart agriculture, often building on traditional techniques. SCPI is a more systemic approach to managing natural resources; it is founded on a set of science-based environmental, institutional and social principles while the climate-smart agriculture (SCA) approach, for instance, is much more directed towards dealing with issues related to the future impacts of climate change future impacts, focusing on agricultural practices that help to mitigate greenhouse gases while adding resilience (adaptation) to the food production systems.

The ecosystem approach suggests that at the scale of cropping systems, management should be based on biological processes, the integration of a range of plant species and the judicious use of external inputs, such as fertilizers and pesticides (FAO 2011b). SCPI is based on agricultural production systems and management practices that include: maintaining healthy soils to enhance crop nutrition; cultivating a wider range of species and varieties in associations, rotations and sequences; using well adapted, high-yielding varieties and good quality seeds; and integrating management of insect pests, diseases and weeds and efficient water management.

To attain an optimal impact on productivity and sustainability, SCPI must be applicable to a wide variety of farming systems and adaptable to specific agro-ecological and socio-economic contexts. It is recognized that appropriate management practices are critical to realizing the benefits of ecosystems (FAO 2011b, p.11).

Regarding the management practices of SCPI, the ones that are appropriate for sustainable agriculture production are described in next paragraphs.

a. Maintaining healthy soils to enhance crop nutrition

By the beginning of the twentieth century, it was already clear that the prevailing modern farming practices in the United States of America implied a very short-time horizon for the soil productive capacity.28 In the Great Plains, the erosion (mainly eolic) was so severe that in a few decades, the productive topsoil was destined to be entirely lost. Erosion is still one of the main factors undermining the practice of sustainable agriculture worldwide, especially in tropical (and poor) regions that are usually subjected to heavy rainfalls. Specifically, soils are typically exposed during the preparation of seedbeds and thus vulnerable to the erosive effect of heavy rainfalls, a much stronger erosion factor when compared

[28] See the report of King (1911), a chief of the USDA Division of Soil Management, which he wrote after his retirement.

to temperate regions where rainfalls are more evenly distributed throughout the year.

Soil erosion caused by water induces annual fluxes of 23-42 Mt29 nitrogen and 14.6-26.4 Mt phosphorus off agricultural land. These losses in nutrients are usually replaced through chemical fertilization, which represents a significant economic cost for farmers. In poor regions, such as sub-Saharan Africa, farmers lack the economic resources necessary to compensate for the nutrient loss. As a consequence, the loss of nutrients caused by erosive drivers is much higher than the amount of fertilizer applied (FAO & ITPS 2015). The inability to compensate for the nutrient loss, either through organic or chemical fertilization practices, compromises the capacity of these soils to sustain food production in the short and long term.

In comparison to agri-ecosystems, in natural ecosystems, protection of soils against erosive factors is granted through a more diverse protective vegetal cover and through the presence of more erosion-resistant soils resulting from an adequate organic matter content. The content of organic matter present in soils is a key variable supporting food production sustainability. Organic matter present in soils provide resources to a wide variety of organisms, from bacteria to insects, which, in turn, produce organic colloidal components that contribute to the cohesion of the soil, among other benefits.

Most soils covered with monocultures have low content of organic matter and are vulnerable to erosion. Furthermore, monoculture plantations in soils depleted of organic matter are far more susceptible to diseases and pests, as they do not benefit from the plant protection service provided by biodiversity associated with the presence of vegetal cover and the wide variety of organisms associated with healthy soils. For instance, beneficial nematodes – ones that only attack soil dwelling insects and leave plants and earthworms alone – cannot survive in soils that lack adequate organic matter content, while their nasty relatives – the nematodes that attack the roots of the plants – can. Thus, chemical control of nematodes is paramount in these simplified systems of soil-related sciences. This was particularly the case in the twentieth century, during which the complex relationship between soil condition and plant growth was studied extensively. The complex relationships are shaped and influenced by a variety of factors as confirmed by the findings of an extensive list of soil specialists, working across different countries and ecosystems.[30]

[29] Mt = Megaton = one million tonnes.
[30] A pioneering work worth note is Russel (1912).

The main findings of soil-related sciences highlight the intricate interactions among a myriad of organisms that feed primarily on organic matter. The individual role as well as the interactions between those organisms result in services that are beneficial for plant growth. In agricultural fields, those services can be maintained and improved through specific soil management practices. In addition to being reservoirs of nutrients, soils provide ecosystem services, such as: (a) resistance to erosion; (b) water absorption and storage (c) assistance to plant root development; (d) nutrient supply; and (e) contribution to plant resistance to diseases and pest attacks and outbreaks. The provision of those services is dependent on the presence of an adequate organic matter content.

Resistance to erosion, water absorption and storage, and assistance to plant root development are the result of a soil sponge-like complex structure in which mineral and organic colloids are aggregated in very stable compounds thanks to the biological activity of the myriad of soil organisms. This structure is well oxygenated and has a high water retention capacity, facilitating plant root growth and development to sustain plant growth. Nutrient supply and contribution to plant resistance to diseases and pest attacks and outbreaks are also the result of biological activity of soil organisms; more precisely, they are the result of their enzymatic activity, which produces chemical substances capable of transforming unassimilable mineral compounds into nutrients readily available for plant absorption. Similarly, the production of metabolites enhances plant disease resistance. Finally, the bacteria of soils have an extraordinary potential for atmospheric nitrogen fixation, a crucial activity when considering the negative effects associated to the release of those elements into the atmosphere.

Conservation of soil characteristics, and thus the capacity to provide ecosystem services can be achieved through the implementation of good agricultural practices that foster healthy soils and vegetal cover. In natural ecosystems, a protective and usually diverse vegetal cover supports soil ecosystem functions. In agricultural areas, these natural conditions can (and should) be mimicked whenever possible by implementing such activities as crop associations and crop rotations. The use of minimum or zero tillage techniques that incorporate harvest wastes into the soil create a protective vegetal layer that enrich and insulate soils from erosive drivers is important in the post-harvest season, particularly in regions with heavy precipitation patterns such as the tropics.

While soil erosion rates are still very high on extensive cropland and rangeland areas, in recent decades, they have been greatly reduced in several regions of the world. Some of the best examples documenting erosion rates reduction in croplands are the result of initiatives undertaken in the United States of America and Brazil. Average water erosion rates in the United States cropland areas were reduced from 10.8 to 7.4 tonnes ha^{-1} yr^{-1} between 1982 and 2007. Similarly, wind erosion rates were reduced from 8.9 to 6.2 tonnes ha^{-1} yr^{-1} over the same time period. In Brazil, soil erosion reduction has been the result of a no-tillage policy that has been in place since 1980. This policy has led to an estimated erosion reduction that fluctuates between 70 to 90 percent over large areas of Brazilian cropland. Several studies have demonstrated that erosion rates can be greatly reduced in nearly every situation through the application of appropriate management techniques, namely good agricultural practices, and the addition of engineering interventions, such as terraces and waterway constructions. However, despite these encouraging examples, in many agricultural regions around the world, adoption of soil conservation practices continue to be challenging and one of the most important aspects that need to be strengthened in order to foster sustainable food production (FAO & ITPS 2015; Pansak *et al*. 2008).

Sustainable food production must include measures aimed at reducing negative impacts to soil health. Soil erosion, sealing, contamination, acidification, salinization, compaction and nutrient imbalance, among others, are some of the most important factors threatening food production sustainability by compromising soil quality. Implementation of good agricultural practices leading to the enhancement and/or restoration of soil desirable characteristics, such as soil carbon content and diversity of soil organisms are crucial to secure food production for years to come.

b. Main management practices in farming systems

According to FAO (2011b), farming practices required to implement differ according to local conditions and needs. However, in all cases, farming systems need carry out the following:

- "Minimize soil disturbance by minimizing mechanical tillage in order to maintain soil organic matter, soil structure and overall soil health;

- Enhance and maintain a protective organic cover on the soil surface, using crops, cover crops or crop residues, in order to protect the soil surface, conserve water and nutrients, promote soil biological activity and contribute to integrated weed and pest management; and

- Cultivate a wider range of plant species – both annuals and perennials – in associations, sequences and rotations that can include trees, shrubs, pastures and crops, in order to enhance crop nutrition and improve system resilience" (FAO 2011b, p.17).

As mentioned previously, most of those key agricultural practices are generally associated with the concept of CA. However, the implementation of those agricultural practices must be accompanied by additional management practices such as:

- "Use of well adapted, high-yielding varieties with resistance to biotic and abiotic stresses and improved nutritional quality;
- Enhanced crop nutrition based on healthy soils, through crop rotations and judicious use of organic and inorganic fertilizers;
- Integrated pests, diseases and weeds management through the application of environmentally friendly practices whenever possible, judicious pesticide application as well as its avoidance whenever possible; and
- Efficient water management, by obtaining "more crops from fewer drops" while maintaining soil health and minimizing off-farm externalities" (FAO, 2011b, p. 19).

These additional management practices need to be carefully considered as they contain elements of great importance in the development of an unquestionable sustainable agriculture. For example, with regard to the use of high-yielding varieties, the collection and conservation of seeds that can help improve existing germplasm banks is envisioned.

Furthermore, when referring to crop productivity being dependent on biodiversity and organic matter content, the source of these elements may come from natural sources whenever possible, ideally from properly made mixtures of mineral and organic fertilizers. Similarly, productivity can also be enhanced through the use of precision irrigation systems and other complementary practices designed to conserve water quantity and quality must be taken into account (FAO 2011b).

Other practices, such as the following: use of plant varieties resistant to insect attack; clean and certified planting material; crop rotations to suppress pathogen; elimination of infected plant; IPM, which may include considering the appropriate and timely use of synthetic pesticides, if necessary; weed management, considering manual weeding techniques, whenever appropriate and possible; keeping aggressive tillage practices to a minimum, whenever possible; and the use of biological agents to control pests and diseases, must be incorporated into cropping systems so they are applied regularly across the wide variety of food production systems (FAO 2014b).

To sum up, the basic template for ecologically sustainable farming practices consists of the following: the careful management of the organic matter in order to keep its content in soil based on the biological parameters of sustainability; the physical protection of the soil against erosive factors (rainfall and wind) by a protective vegetal cover; and copying the natural systems biodiversity through crop associations and crop rotations. Furthermore, this template must carefully take into account the management of what can be referred to as "agri-ecosystem boundaries": farmlands should be intermingled with living-fences, woods and other non-cultivated spaces, such as meadows and permanent pastures, which would offer habitat for biodiversity, providing important ecosystems services, such as pollination and pest control; maintenance and/or restoration of those non-cultivated spaces is crucial to support biodiversity as well as the desired for microclimate regulation, and because their presence adds important elements to the overall scenic beauty of those human-dominated landscapes.

Following this template would make it possible to work towards the reduction of agrichemical use and to explore alternatives to minimize the negative effects derived from the increasing use of mechanized systems. The latter is extremely important, as the increasing use of mechanized cropping systems has led to the creation of extensive monocultures and thus less resilient systems. Those resulting oversimplified systems contrast with the notion of long-term sustainability, as they have become dependent on external inputs, such as fertilizers and pesticides, to maintain productivity, which, in turn, has had devastating effects on biodiversity conservation and thus ecosystem service provisioning. This oversimplification pattern along with the knowledge of its impacts on natural resources, has led, over the past three decades, to the rediscovery of the ecological principle of sustainable farming practices. Some of the practices recommended in this report have been adopted in various degrees and depending on cropping systems, but the socio-economic factors that led to the spread of monocultures and the "modern agriculture paradigm" (based on the use of external inputs) are still in play.

c. Other broader issues that need to be taken into consideration when referring to sustainable farming systems and practices

To develop sustainable management of cropping systems, additional elements must be considered, such as energy use and waste disposal.

In general, policy that targets the development of rural energy with an agricultural focus remains limited. Agriculture has a dual role, as an energy user and producer. Energy production in agricultural systems is usually in the form of bioenergy, although it has a specific role as a user and promoter of other renewable energy sources, such as photovoltaic. The role of farmers as consumers and producers of energy resources offers important rural development opportunities and has a potentially important impact on climate change mitigation through lowering the system fossil fuel dependency by focusing on using renewable energies whenever possible. Nevertheless, it is important to recognize the many challenges related to the advancement of bioenergy technology, particularly those related to technical capacities and affordability, as most farmers cannot access many of the new technologies. Finally, opportunities are highlighted by the positive impacts of bioenergy on the environment and the associated economic benefits in the long term (FAO 2000).

Price and availability of energy sources add constraints to efforts aimed at achieving sustainable agriculture. As fossil fuel supplies decline, availability decreases and prices rise, having a direct impact on agricultural input prices, and consequently on agricultural production costs. Fossil fuels should no longer be the only source of energy that supports increased in food productivity. Diversification of energy sources must be considered whenever possible in order to reduce overall production costs, particularly in the context of agricultural intensification scenarios. Alongside energy sources diversification, measures to reduce overall system energy demands are essential to promote sustainable cropping systems. Appropriate mechanization can lead to improved energy efficiency in crop production. The implementation of good agricultural practices has shown that those requirements can be reduced by up to 60 percent when compared to conventional farming, for instance (FAO 2011b).

Correct disposal of wastes is crucial for the development of sustainable agriculture. Poor waste management is an immediate threat to the natural resources agricultural production depends on. When not properly handled, they can pollute surface and groundwater and contribute to air pollution. Manure is the first thing that comes to mind with regard to farm waste. While manure is an important component, farm waste in livestock systems usually also includes waste forage, dead stock, and silage effluent and milk house waste. In other productive systems, such as horticulture, culls, diseased product, wash line sediment and processing plant wastes are common by-products. In addition to those “natural” by-products, all farm operations generate plastic waste material ranging from silage wrap to pesticide or drug containers. Waste management that incorporates the 4Rs principle of reduce, reuse, recycle and recover should be the first option considered in efforts aimed at achieving sustainable agriculture.

The application of the 4Rs in agriculture should adhere to the following:

- Reduce the amount of waste product generated;
- Reuse the waste product on the farm or provide it for others to use;
- After reducing and reusing as much of the waste product as possible, recycle the product either on-farm, through the use of organic fertilizers, or off-farm, through plastic recycling programmes, for example; and
- Recover methane gas from manure waste.

Farm by-products should only be treated as waste and continue to be disposed of only after considering the 4Rs principle. Many of the farm by-products have the potential to become a very important resource for boosting on-farm productivity, which also makes them a valuable economic asset, if managed correctly. In this sense, manure is considered a valuable resource because of its fertilizing and soil conditioning properties, while horticultural wash water can be economically recycled (Jacobs 2002). Greater effort must be made to promote the development of farms that apply the 4Rs principles.

4.4. The other agriculture sectors: livestock, fishery and forestry

Sustainable agriculture practices must be implemented in all agriculture sectors including livestock, fishery and forestry.

4.4.1. Sustainable practices for livestock

The overarching goal of sustainable agricultural development is to ensure food security and nutrition for all now and in the future, while taking into account observed trends of climate change and increasing scarcity of natural resources.

The growing and rapidly evolving demand for food, and the even greater competition for land and other resources, raises concerns about the sustainability of expanding livestock production systems and their impacts on the environment (Scherf & Pilling 2015; HLPE/FSN 2016). Livestock production has been identified as a key area for action in efforts to reduce stresses on natural resources (in particular land and freshwater), and to reduce GGE and contribute to climate change adaptation (The Government Office for Science 2011; Steinfeld *et al.* 2006).

Recently, the High Level Panel of Experts on Food Security and Nutrition (HLPE/FSN) conducted an analysis on the livestock sustainability challenges in agricultural development that takes into account four broad categories of livestock systems: smallholder mixed farming; pastoral; commercial grazing; and intensive systems. While some environmental challenges, such as climate change, concern all types of livestock systems, others are specific to one or more of the four identified categories. For example, land degradation and biodiversity loss need to be addressed with regard to smallholder mixed farming; extreme events and water scarcity represent greater challenges in pastoral systems; deforestation and land conversion in commercial grazing; and air, land, water pollution and high water use in intensive systems (HLPE/FSN 2016). While some of the identified sustainability challenges are related to the three sustainable development pillars (see Section 4.1), others are more related to specific topics, including the role of women in those agricultural systems or management of animal welfare.

A common approach towards achieving sustainable livestock development would therefore entail combining technical interventions, investments and enabling policies and instruments, and the involvement of a variety of stakeholders operating at different scales. In summary, three particular interlinked principles should help shape those pathways towards sustainability of livestock production: (1) improve resource efficiency; (2) strengthen resilience; (3) improve social equity/responsibility outcome (HLPE/FSN, 2016).

The work of HLPE/FSN concludes with some recommendations that aim to strengthen the contributions of the livestock sector to sustainable agricultural development. For each of the four livestock systems, specific recommendations have been proposed. In particular:

- Recognize the importance of smallholder mixed farming systems and support them by, for example, leveraging the potential of livestock as a means for sustainable livelihoods;

- Recognize and support the unique role of pastoral systems by, for example, considering the use of innovative financing mechanisms to invest in the provision of basic services adapted to the needs and ways of life of pastoralists;

- Promote the sustainability of commercial grazing systems by, for example, supporting sustainable management of livestock, pastures and feed in order to minimize harmful environmental externalities, including by promoting models of production that conserve biodiversity and ecosystem services while reducing GHG; and

- Address the inherent challenges of intensive livestock systems by, for example, developing innovative approaches, working with farmers' organizations across diverse scales in order to facilitate the use of manure as organic fertilizer – and to promote the use of crop co-products or residues and by-products as feed including through technical innovations (HLPE/FSN 2016)

Box 3. The role of agroforestry systems

Agroforestry systems offer a way to increase the diversity of species within otherwise commonly simplified crop systems. Agroforestry promotes the integration and interaction of crop, trees and livestock. It can be entirely mechanized, as in the case of alternating strips of permanent and non-permanent crops, or be more complex in terms of vegetation structure. The implementation of agroforestry systems is compatible with small scale family farms, as the inclusion of a tree component within these systems represent an additional source of income and a step towards farm diversification.

Two models can be considered for the integration of crop-livestock production: one fully integrated and one partially integrated. In the fully integrated model, animal waste is composted and utilized to fertilize crops (as in the classic Norfolk system). In a partially integrated model, the livestock production is integrated through a crop-pasture rotation system. The animals are not confined and their waste is not composted. These models have been developed and proposed in Brazil by the Brazilian Enterprise of Agricultural Research as the only integration scheme acceptable by most farmers.

4.4.2. Sustainable practices for fisheries

Fisheries and aquaculture are important sources of food, nutrition, income and livelihoods for hundreds of millions of people around the world. World per capita fish supply reached a record high of 20 kg in 2014, thanks to vigorous growth in aquaculture, which currently provides half of the fish for human consumption and has led to a slight improvement in the state of some fish stocks as a consequence of improved fisheries management (FAO 2016b). However, despite notable progress in some areas,[31] the state of the world's marine fish stocks has not improved overall.

[31] See footnote 18 for more information on world's marine fish stocks figures.

In the framework of the 2030 Agenda for Sustainable Development and the Sustainable Development Goals, a set of 17 aspirational objectives with 169 targets and 230 indicators, are expected to guide actions of Governments, international agencies, civil society and other institutions over the next 15 years (2016–2030). Several of the Goals and related indicators are directly related to fisheries and aquaculture and to the sustainable development of the sector. One goal, in particular, focuses on the oceans (Sustainable Development Goal 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development). FAO is playing a leading role in this area.[32]

The sustainability of fisheries production is crucial for the livelihoods, food security and nutrition of billions of people. National governments and international organizations devote considerable resources towards ensuring the sustainability of fish resources. One action that is continually promoted is to inform consumers, through labelling, as to whether products come from a sustainable fishery. This consumer advice can function as a reward for well-managed fisheries and as a lever to improve fisheries management (FAO 2016b).

When considering that sustainability is related to the concept of continued provision of ecosystem services to society, the current pressures on fishing are threatening the long-term productivity of the resource, and thus benefits generated from it cannot be sustained. Another common measure of the environmental dimension of sustainability in the fisheries sector is related to management practices, including monitoring changes in the state of the resource and the ability to take effective action to respond to those changes (FAO 2016b).

As for aquaculture, with increasing activities in the coastal and offshore areas, the need for coordination across sectors using marine ecosystems has become a requirement for sustainable use of those ecosystems, with a consequent emphasis on the need for integrated management of human activities (FAO 2016b).

Broadly speaking, various approaches have emerged to improve sector-based management, such as EAF and EAA,[33] while others focus on integration across

[32] FAO is proposed to serve at the "custodian" agency for 20 indicators, for Sustainable Development Goal 2, 5, 6, 12, 14 and 15. Regarding Goal 14, FAO is active with its Blue Growth Initiative, which assists countries in developing and implementing the new global agenda in relation to sustainable capture fisheries and aquaculture, livelihoods and food systems, and economic growth from aquatic ecosystem services. It promotes the implementation of the Code of Conduct for Responsible Fisheries (The Code) and the ecosystem approach to fisheries and aquaculture. Reflecting the objectives of several the Goals, it especially targets the many vulnerable coastal and fisheries-dependent communities where ecosystems are already under stress from pollution, habitat degradation, overfishing and harmful practices (FAO 2016b).

[33] The ecosystem approach to fisheries is based on a risk management framework, which is also being developed for aquaculture (EAA). It covers the principles of the CODE and provides a

sectors, such as ecosystem-based management and marine spatial planning.34 Ecosystem-based management and the marine spatial planning are being advocated to deal with sustainability issues of aquatic ecosystems. At the same time, approaches, such as EAF and EAA, are being promoted to enhance fisheries and aquaculture management practices. Although seemingly similar, these approaches address different levels of governance, the ecosystem-based management deals with multisectoral issues and EAF and/or EAA deal with sectoral issue. These approaches are required to strengthen aquatic ecosystem governance (FAO 2016b).

4.4.3. Sustainable practices for forestry

A strong mutual relationship exists between forestry and agricultural activities. Sustainable management of both forestry and agriculture, and integrating them in land-use plans are essential for achieving the related Sustainable Development Goals and ensuring food security and tackling climate change. Unfortunately, agriculture is still the major driver of deforestation globally, and agricultural, forestry and land policies are often contradictory (FAO 2016c).

Forest area has declined globally by 129 million ha (3.1 percent) between 1990 and 2015; Earth forest cover is now just less than 4 billion ha. Although the rate of global net forest loss slowed from an annual average of 7.3 million ha in the 1990s to 3.3 million ha between the years 2010 and 2015 (FAO 2015), deforestation remains one of the main concerns in the process of achieving a sustainable agricultural production (Economic and Social Council 2015). Halting deforestation would benefit hundreds of millions of people, including many of the world's poorest, whose livelihoods depend directly on forest goods and services. It would also contribute to mitigating the effects of climate change, protecting habitats for 75 percent of the world's terrestrial species, while contributing to the overall Earth's resilience – thereby supporting sustainable agriculture (FAO 2016c).

Sustainable agriculture and sustainable forest management are recognized as global priorities, but decisions concerning land use and natural-resource priorities are not always made in an integrated fashion. There is a pressing need to better coordinate policies related to forests and agriculture at national and regional scales in order to more clearly highlight their role with regards to food

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methodology for implementing them. It also covers the ecological, social and economic dimensions of sustainability and identifies the most appropriate governance arrangement in the given context. It also provides an approach to identify the major threats in a given context. Based on the outcomes of EAF and EAA planning process, identification of most appropriate technologies, practices and management measures follows (FAO 2014).

[34] See UNESCO (2015).

security, rural and thus national and regional development. Some case-studies clearly highlight the opportunity and necessity to mainstream integrated land-use planning as a tool for achieving sustainable land management, improving ecosystem resilience, enhancing synergies and complementarities among land uses at various scales, and addressing potential conflicts (FAO 2016c).

a) FAO (2016c) proposes some recommendations that can be adopted as basis for further analysis on sustainable practices on forestry, which are aimed at improving governance and management of land-use change through the following:

b) The improvement of cross-sectoral coordination of policies on agriculture, food and forests. In particular, in areas in which there is concern about the implications of population growth (for example) for agriculture, food and forests, analyses could examine the extent to which agricultural intensification and improved agroforestry can meet food-security needs as a basis for developing explicit targets on land-use conversion.

c) Promoting greater public investment in agriculture and forests. In particular, such investment should focus on catalysing private investment; improving processing, distributing and marketing infrastructure; promoting innovation and best practices through research, development and extension; and developing the capacity of producer and community organizations. Direct public investment in, for example, afforestation programmes should aim to achieve wider social and environmental benefits, such as climate-change mitigation, combating land degradation, enhancing agricultural resilience and improving livelihoods, particularly in communities directly dependent on these resources.

d) Designing policy instruments to promote sustainable agriculture and sustainable forest management. Selecting the appropriate tools to support policy implementation is vital. For example, if large scale commercial agriculture is a main driver of land-use change, policy tools must include effective actions for regulating these commercial activities. On the other hand, in cases in which local subsistence agriculture is the principal driver, policy tools must include a variety of measures that address poverty, along with actions to improve local agricultural and other land-use practices, for instance through the implementation of environmentally friendly productive systems, such as agroforests.

e) Improvements in tenure rights and legal frameworks. In particular, the legal framework should provide certainty on land tenure and the rights over land and forest resources.

f) Strengthening institutions and stakeholder engagement. In particular, the institutional framework should promote using a participatory approach of all stakeholders as much as possible.

g) Integrated land use. In particular, integrated management approaches, such as agroforestry, agroecology, climate-smart agriculture and the adaptation of livestock grazing regimes, should be promoted.

5

Agri - Environmental Indicators

Demand for robust statistics on environment is constantly increasing in parallel with increasing environmental degradation. Policy and economic decisions that take into account environmental issues are being made more frequently. In fact, there is no shortage of environmental indicators. However, the challenge is to identify a set of consistent, concise, easy and robust agri-environmental indicators that would be accessible to most developing countries.

A large number of agri-environmental indicators have already been developed to monitor the interactions of agriculture and the natural environment. In this chapter, information on agri-environmental indicators, particularly those already considered within diverse international frameworks, is presented.

5.1. The global context

As stated in previous chapters, over the past 50 years, intensive agriculture heavily dependent on external inputs has propelled increases in global food production and averaged the per capita food consumption, however, the global malnutrition rates remain high.[35] At the same time, it has adversely affected or even depleted natural resources of agro-ecosystems, jeopardizing future productivity, while contributing to GHG and thus accelerating and exacerbating the negative effects associated with climate change.

By 2050, the global population is projected to rise from more than seven billion today to approximately nine billion, requiring a 60-percent increase in global food production, and up to a 100-percent increase in developing countries, relative to 2009 levels (FAO 2011a; FAO 2011b). Based on population growth projections, by 2050, an additional one billion tonnes of cereals and 200 million

[35] While food security concerns have historically focused on total calorie intake, they now encompass the so-called “triple-burden” of malnutrition: hunger (deficiencies in dietary energy intake), which is referred to in this report, and affects mainly the less developing countries; micronutrient deficiencies (such as iron, vitamin A, iodine and zinc), which affect some two billion people; and increasing over nutrition, which currently affects more people than hunger does. In 2014, the World Health Organization (WHO) estimated that more than 1.9 billion (39 percent) adults, aged 18 years and over, were overweight, with more than 600 million (13 percent) of them obese (WHO 2015).

tonnes of livestock products will need to be produced every year (Bruinsma 2009). Given the diminishing area of unused land suitable for agriculture, meeting that demand will require an increase in crop productivity in the face of heightened competition for land and water resources, increasing fuel and fertilizers prices and the impacts of climate change.36 One of the major current challenges is therefore to place food production and consumption on a truly sustainable footing (FAO 2011b).

The development and implementation of approaches for the collection and use of statistics relevant to the agricultural sector that integrate environmental issues is the main objective of this research.

Recent international agreements have set targets for environmental, or environment-related conditions, such as biodiversity, GHG emissions and land degradation. Among them, the development of Sustainable Development Goals is one of the most important set of targets agreed to by the global community. The repeated measuring and long-term monitoring of environmental and agriculture indicators are fundamental to track real progress towards achieving the Goals at the global scale. In this sense, agri-environmental indicators constitute an important measuring tool and provides key information about the policies and measures that countries can undertake in order to restore and/or maintain the capacity of the environment to provide services that are essential to support food production and thus sustainable development.

The demand for statistics on agri-environmental indicators is continuously increasing in conjunction with the need for better evidence-based policy to more effectively tackle environmental degradation. Policy and economic decisions that take into account environmental issues are being made more frequently, and no shortage of environmental indicators exist so far. However, constructing a consistent and concise set of agri-environmental indicators that can provide the necessary information to track food production practices that can be related to sustainable development remains a challenge. Additionally, these agri-environmental indicators should be robust but also easy to produce as they must be available for developing countries.

5.2. Existing international frameworks

A large number of agri-environmental datasets, indicators and sets of indicators have been developed to monitor interactions between agriculture and the

[36] Agriculture is a major contributor to greenhouse gases, accounting for 13.5 percent of global GGE (IPCC 2007).

environment. These indicators have multiple purposes, including, among them, monitoring policies, building of aggregated indices, evaluating pressures and describing landscapes. Before proposing yet another set of agri-environmental indicators, it is worth examining some of the existing ones in order to incorporate new ideas and avoid making known mistakes.

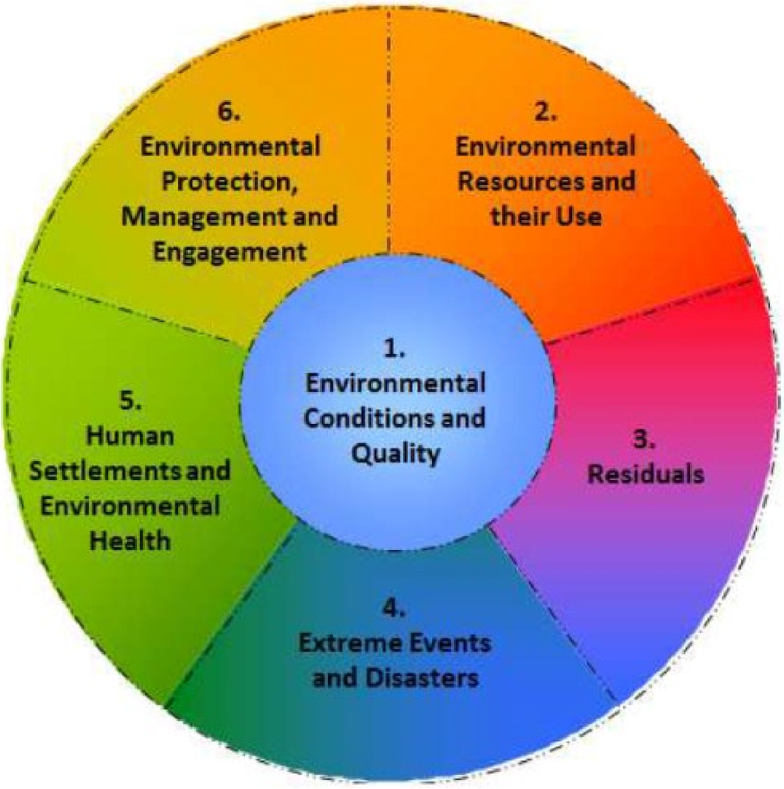
The following sections provide a short overview of the main known frameworks for assessing environmental data and indicators.

5.2.1. The Framework for the Development of Environment Statistics

The Framework for the Development of Environment Statistics (FDES) is a flexible, multipurpose conceptual and statistical framework that assists in structuring, synthesizing and aggregating relevant data into statistical series and indicators. It provides an organizing structure to guide the collection and compilation of environmental data and to synthesize data from various subject areas and sources. It targets a broad user community, including environmental statisticians in NSOs, environmental and/or agriculture ministries and agencies, as well as other producers of environment statistics.

The FDES 2013 (UNSD 2016) organizes environment statistics into six fundamental components: environmental conditions and quality; environmental resources and their use; residuals; extreme events and disasters; human settlements and environmental health; environment protection, management and engagement (Table 4). Environmental conditions and quality (component 1) is at the centre of FDES. The other five components were established based on their relationship with the central component 1. Each of the six components is broken down into subcomponents that, in turn, contain relevant statistical topics and individual statistics. The statistical topics represent the quantifiable aspects of the components. While at the component level FDES has been designed to be conceptually distinct, the content of each component may overlap in some cases. Hence, often the same statistics can be used to describe more than one component.

Figure 2. The components of the Framework for the Development of Environment Statistics



Source: UNSD (2016).

Table 4. Components and subcomponents of the Framework for the Development of Environment Statistics

Component 1: Environmental Conditions and Quality	Sub-component 1.1: Physical Conditions Sub-component 1.2: Land Cover, Ecosystems and Biodiversity Sub-component 1.3: Environmental Quality
Component 2: Environmental Resources and their Use	Sub-component 2.1: Mineral Resources Sub-component 2.2: Energy Resources Sub-component 2.3: Land Sub-component 2.4: Soil Resources Sub-component 2.5: Biological Resources Sub-component 2.6: Water Resources
Component 3: **Residuals**	Sub-component 3.1: Emissions to Air Sub-component 3.2: Generation and Management of Wastewater Sub-component 3.3: Generation and Management of Waste Sub-component 3.4: Release of Chemical Substances
Component 4: **Extreme Events and Disasters**	Sub-component 4.1: Natural Extreme Events and Disasters Sub-component 4.2: Technological Disasters
Component 5: **Human Settlements and Environmental Health**	Sub-component 5.1: Human Settlements Sub-component 5.2: Environmental Health
Component 6: **Environmental Protection, Management and Engagement**	Sub-component 6.1: Environmental Protection and Resource Management Expenditure Sub-component 6.2: Environmental Governance and Regulation Sub-component 6.3: Extreme Event Preparedness and Disaster Management Sub-component 6.4: Environmental Information and Awareness

Source: UNSD (2016)

FDES (UNSD 2016) includes a comprehensive, though not exhaustive, list of environmental statistics (named as the Basic Set of Environmental Statistics within the FDES document) that can be used to measure topics within components. The basic set is organized into three tiers, which include six different components (table 5), based on the level of relevance, availability and methodological development of the statistics. This basic set is relevant to, and recommended for use by, countries at all stages of development.

FDES seeks to guide the formulation of environmental statistic programmes in countries lacking or at early stages of developing environmental statistics. It helps: (a) identify the scope and constituent components, subcomponents and statistical topics relevant to interested countries; (b) contribute to the assessment of data requirements, sources, availability and gaps; (c) guide the development of multipurpose data collection processes and databases; and (d) assist in the coordination and organization of environmental statistics, given the interinstitutional nature of this particular domain.

Table 5. Distribution of statistics of the FDES, by tier and component

Number of Statistics	Component 1	Component 2	Component 3	Component 4	Component 5	Component 6	Total
Tier 1	32	30	19	4	12	3	**100**
Tier 2	58	51	34	11	22	24	**200**
Tier 3	51	43	5	16	20	23	**158**
Total	141	124	58	31	54	50	**458**

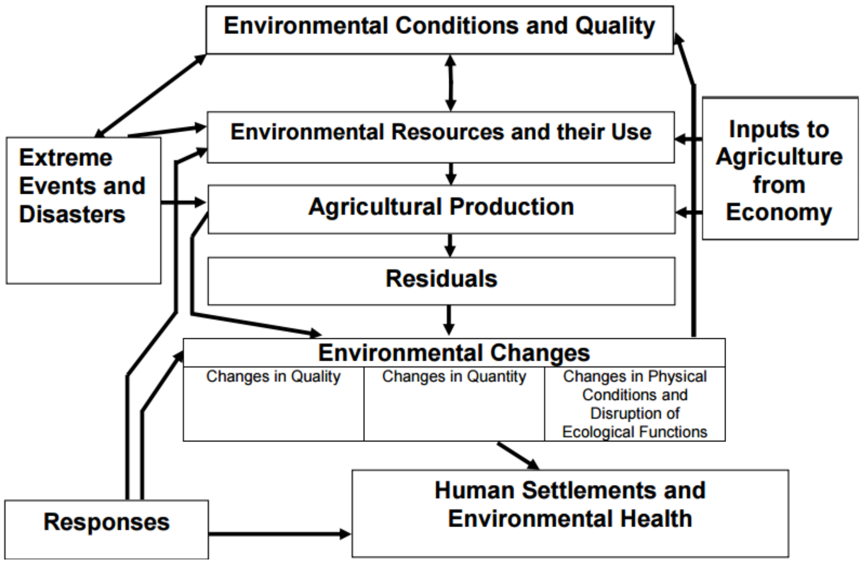
Source: UNSD (2016)

FDES includes two statistical themes related to crops and livestock as part of subcomponent 2.5: biological resources[37] within component 2: environmental resources and their use.

FDES organizes the relevant environmental statistics needed to inform about issues related to agriculture and the environment and presents the relationship between its components as the environmental conditions and quality, the basic ecological support for agriculture, the demand of inputs, residuals, agricultural wastes, extreme events and natural disasters, and responses of society aimed at protecting, managing, and restoring environmental resources, among others. Basically, it focuses on summarizing the different interactions between environment and agriculture (Figure 3) through a structure that allows the inclusion of components, subcomponents and topics containing statistics needed to inform about these interactions (Figure 4).

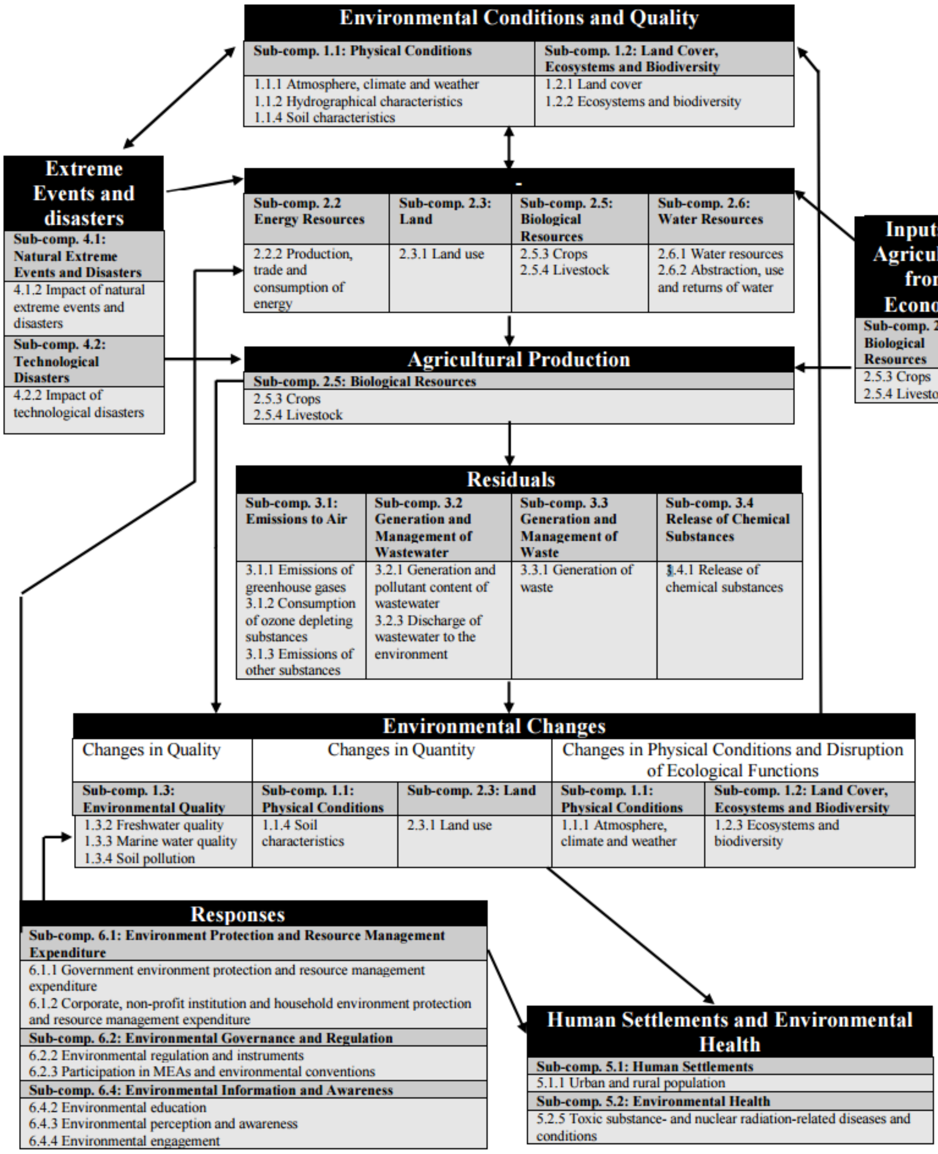
[37] The many linkages between agriculture and the environment for statistical purposes can be consulted in FDES Chapter 5, section 5.4 agriculture and the environment.

Figure 3. The relationship between agriculture and environment in the FDES



Source: FDES (UNSD, 2016, p. 257).

Figure 4. FDES topics containing statistics needed to inform about agriculture and environment



Source: FDES (UNSD, 2016, p. 262).

Note: the coding corresponds to the FDES structure.

5.2.2. The System of Environmental-Economic Accounting

The System of Environmental-Economic Accounting Central Framework 2012 (SEEA-CF) is the first international statistical standard for environmental-economic accounting. It is a multipurpose conceptual framework for understanding the interactions between the economy and the environment and describing stocks and changes in stocks of environmental assets. Under this system, environmental statistics and their relationship to the economy is placed at the core of national official statistics (UNSC 2012). Several specialized guidelines for developing different SEEA-CF accounts have been developed, including ones for water, energy, agriculture, forestry and fishing.

Central to SEEA is a systemic approach for organizing environmental and economic information that covers, as completely as possible, stocks and flows, both material and monetary, which are relevant to the analysis of environmental and economic issues. The system applies the accounting concepts, structures, rules and principles of the System of National Accounts (SNA-2008) (United Nations 2009), in which economic data from different sources – companies and government, international trade data from customs and taxes collected by various levels of government, among others – are assembled by accountants in NSOs and central banks designated to comprehensive, coherent accounts that can provide different types of information and indicators about national economies. Because SEEA-CF organizes how the link between economy and environment – in terms of stocks and flows – is quantified, it offers a coherent economic-environmental framework for the development of meaningful agri-environmental indicators. In practice, environmental-economic accounting includes the physical and monetary statistics for the compilation of supply and demand tables, functional accounts, such as the environmental protection expenditure accounts, and asset accounts for natural resources.

Ultimately, SEEA is a single tool for harmonizing and aligning data from various agencies within a national statistical system, and to make them systematically comparable with value and employment data from national accounts. The data used in the accounts, as for the national accounts already in use, may include information drawn from surveys and censuses, administrative sources and, increasingly, geographic information systems.

In general, FDES and SEEA are relevant and can be seen as aspects of the same process towards improving statistics. FDES helps to develop core statistics and SEEA helps to point out and select the variables that are relevant for conducting a meaningful analysis of joint environmental economic problems.

5.2.2.1. The System of Environmental-Economic Accounting for Agriculture, Forestry and Fisheries

A specific SEEA application that is relevant to the present work on agri-environmental indicators is dedicated to the System of Environmental-Economic Accounting-Agriculture, Forestry and Fisheries (SEEA-AFF) (Global Strategy, 2015b), which is a statistical system for organizing data to enable the description and analysis of the relationships between the environment and the economic activities related to agriculture, forestry and fisheries. SEEA-AFF was approved by the United Nations Statistical Commission (UNSC) in 2016 as an internationally approved document to support SEEA-CF. SEEA-AFF covers the following statistics domains, each divided into an asset account and a production supply and utilization account:

- Agricultural products and related environmental assets;
- Forestry products and related environmental assets;
- Fisheries products and related environmental assets;
- Water resources;
- Energy;
- GHG;
- Fertilizers, nutrient flows and pesticides;
- Land;
- Soil resources; and
- Other economic data.

SEEA-AFF relies on the whole body of concepts and methodologies of national core and satellite accounts, making it a powerful tool for harmonizing information relevant to the sustainability of agricultural activities. Notably, SEEA-AFF has coherent asset accounts, allowing for the description of these activities' resource base, and flow accounts, allowing for the description of pressures on the environment.

5.2.3. The FAOSTAT agri-environmental indicators

In the light of the discussed rationale of ecologically sustainable agri-ecosystems and the main frameworks for assessing environmental indicators, this paper now provides an analysis of the FAO agri-environmental indicators that are available at its global statistical database known as FAOSTAT. The information system can serve as a building block based developing a consistent and concise set of agri-environmental indicators.

FAOSTAT agri-environmental indicators related to the information on agriculture and its interaction with the environment offer the main global reference for agri-environmental statistics. This information system includes an efficient data sharing mechanism that uses an open data strategy with a broad collaboration between systems and data integration at the global level. In addition to its core statistical domains, land use, fertilizers and pesticides, FAOSTAT includes an analytical database on agri-environmental indicators and an emissions database to support analyses of the environmental performance of agriculture to track trends in environmental impacts and to provide information to assess the effects of the integration of agri-environmental concerns into policy measures. The FAO agri-environmental dataset, co-developed by FAO in coordination with OECD and the Directorate-General of the European Commission (Eurostat), extends data to more than 200 countries and territories, and currently includes more than 30 indicators under ten different domains:

1. Air and climate change;
2. Energy (use in agriculture and bio-energy production);
3. Fertilizers;
4. Land (area, use-change, irrigation, conservation, cropping patterns and organic, protection);
5. Livestock;
6. Pesticides;
7. Soil (erosion, degradation and carbon);
8. Water;
9. Emissions by sector; and
10. Emissions intensities.

A variety of types of data is currently used in developing those indicators. In its present revision, FAO plans to only maintain those indicators that are directly computable from their basic statistic domains, namely those that are either directly communicated by countries (land use, fertilizers and pesticides) or analytically estimated by FAO (emissions).

FAO currently has the most comprehensive statistics databases on agriculture, forestry and fisheries based on data officially collected from its Members through its questionnaires. The two corporate data repositories are FAOSTAT and FishSTat, which focus on crop, livestock and fisheries production data. They are complemented by AQUASTAT and FRA,[38] which focus on water and forest resources, respectively. These FAO core statistics, mainly taken from FAOSTAT, are used to produce the FAOSTAT set of agri-environmental indicators. This work focuses in part on their description, as well as on the analysis from which additional indicators relevant to monitoring sustainable agriculture practices can be developed to enrich this core set of agri-environmental indicators. It is hoped that the enrichment of these core set of indicators will result in advanced in monitoring progress in achieving sustainable food production and in providing concise and robust information that can be used as guidance to countries in the path towards achieving the Sustainable Development Goals.

5.2.4. Other indicators sets and a general assessment

Beyond the work of FAO, FDES and SEEA, other sets of indicators or descriptions of indicators for agriculture, sustainable agriculture and ecological agriculture,39 can be found in a number of literature reviews and organizations. For example, Hayati, Ranjbar & Karami (2011), focused on the concept of sustainable agriculture (considering the environmental, social and economic as interdependent aspects) and identified the following parameters as being important aspects of the ecological component of sustainable agriculture:

- Improved water resource management
- Usage of pesticides, herbicides and fungicides
- Usage of animal andorganic manures
- Usage of green manures
- Physical inputs and efficient use of input
- Trend of change in climatic conditions
- Usage of chemical fertilizer
- Conservational tillage (no/minimum tillage)
- Control erosion
- Microbial biomass within the soil
- Energy

[38] FAO has been monitoring the worlds forests at 5 to 10-year intervals since 1946. The global forest resources assessments are now produced every five years in an attempt to provide a consistent approach for describing the worlds forests and how they are changing. The assessment is based on two primary sources of data: country reports prepared by national correspondents and remote sensing which is conducted by FAO together with national focal points and regional partners.

[39] Basically, in terms of disseminated statistics, FAO, OECD and EUROSTAT have developed their indicators together. EUROSTAT collects from and disseminates to European Union and accession countries); OECD collects from estimates for and disseminates to OECD countries. FAO estimates and disseminates at the global level. This is the main difference among them. There is no particular difference among them at the methodological and scientific level.

- Physical yield
- Crop diversification
- Use of alternative crop
- Usage of fallow system
- Crop rotation
- Cropping pattern
- Cover crop/mulch
- Depth of groundwater table
- Protein level of crops
- IPM

The environmental theme included air, soil, water, energy and biodiversity. "Air" included air quality and buffering wind speed. "Soil" included concepts of minimizing losses, chemical and physical quality and buffering against soil mass flux (mudslides and landslides). "Water" included surface and groundwater and also soil moisture. Water flow buffering – flooding and runoff regulation – was also included. "Energy" included adequate energy flows and availability. "Biodiversity" included planned and heritage biodiversity and the diversity and functional quality of habitats. These descriptions appeared to have has a strong focus at the farm level.

Hayati, Ranjbar & Karami (2011) proposed an index to measure agricultural sustainability at the farm level, which consisted of seven components: cultivation of sustainable crops; conservational cultivation; crop rotation; diminishing of pesticides and herbicides usage; soil mulching; and the use of organic fertilizers.

The ongoing open debate on what is and how to measure sustainability within the context of agriculture makes it difficult to establish and measure related indicators. Sustainability typically requires cause and effect to be established. This is difficult to do in complex systems in which many processes and strategies occur over an extended period of time, such as full crop rotation, which must be carried out at least five years before results can be detected.

As part of work of the World Resources Institute on creating a sustainable food future, Reytar, Hanson & Henninger (2014) conducted a scoping analysis of indicators of sustainable agriculture. For this work, environmental sustainability of agriculture was defined as "minimizing the environmental impacts of agriculture", but the work also included measuring the environmental sustainability of increased food production.

Reytar, Hanson & Henninger (2014), first selected the most relevant "thematic areas" regarding environmental sustainability in agriculture. The objective of this work was to inform the design of a proposed agricultural transformation index.

The most relevant "thematic areas" identified were water, climate change, land conversion, soil health and pollution (nutrients and pesticides).

In addition to those five thematic areas, three generic stages of a "causal chain" of action – or a sequence of behaviors and results – were identified. The sequence was public policy, farmer practice and biophysical performance. This is similar to the OECD driving forces – pressure – state – impacts – response (DPSIR) framing for analyses related to the environment. The DPSIR model is not linear or sequential, whereas the three-step approach used here, similar to the pressure-state-response model, which was a precursor of DPSIR, was described as a sequence from which "government policies can influence farmer practices, which in turn can determine on-the-ground biophysical performance or conditions" (Reytar Hanson & Henninger, 2014, p. 8).

Reytar Hanson & Henninger (2014), evaluated indicators in a thorough manner, presenting selected indicators using a traffic light (red/yellow/green) evaluation across a number of availability and quality dimensions. Work by Reytar Hanson & Henninger (2014) can be helpful in identifying indicators for sustainable agriculture, however, the bias towards increased food production and the purpose behind developing an index needs to be acknowledged. Because data availability was part of the evaluation, it can also be helpful in developing an indicator set for countries with less developed statistical systems.

In a study carried out for Pulse Canada (2011), the following four elements of sustainability have emerged as the highest priority for measurement related to the production and processing chain, and end users:

a) GHG/product carbon footprint;

b) Impacts on water/water use;

c) Impacts on biodiversity; and

d) Soil health.

The measurement areas were connected to the impacts in the following way:

Focus area	Impacts
1. No-tillage/conservation tillage	Soil quality, greenhouse gases, water quality
2. Crop rotation diversity	Biodiversity, greenhouse gases
3. Nutrient management	Soil quality, greenhouse gases, water quality
4. Water use efficiency	Water use, biodiversity
5. IPM	Water quality, biodiversity

Although this study stated that there is a "shifting focus from practice-based to outcome-based measurements – moving evaluations away from how something was grown, and moving towards measurement of actual impacts on the environment", the types of indicators were still mostly flow related, which would show pressures on the environment.

Another example is the Eurostat indicator set, which was established to monitor parts of the common agriculture policy of the 2030. Eurostat uses four agri-environmental categories for the dissemination of 28 indicators: 1. farm management; 2. agricultural production systems; 3. pressures and risks to the environment; and 4. state of natural resources.

For analytical purposes, the DPSIR approach is used to organize these indicators. The agri-environmental category for each indicator was added to Table 6 to show this other dimension.

Table 6. Eurostat agri-environmental indicators

Domain	Subdomain	Number	Title of indicator	Indicator category
Responses	Public policy	1	Agri-environmental commitments	Agricultural production systems
		2	Agricultural areas under natura 2000	State of natural resources
	Technology and skills	3	Farmers' training level and use of environmental farm advisory services	Farm management
	Market signals and attitudes	4	Area under organic farming	Agricultural production systems
Driving Forces	Input use	5	Mineral fertilizer consumption	Farm management
		6	Consumption of pesticides	Farm management
		7	Irrigation	Agricultural production systems
		8	Energy use	Farm management
	Land use	9	Land use change	Pressures and risks to environment
		10.1	Cropping patterns	Agricultural production systems
		10.2	Livestock patterns	Agricultural production systems
	Farm management	11.1	Soil cover	Farm management
		11.2	Tillage practices	Farm management
		11.3	Manure storage	Farm management
	Trends	12	Intensification/extensification	Agricultural production systems
		13	Specialization	Agricultural production systems
		14	Risk of land abandonment	Pressures and risks to environment

Table 7. Eurostat agri-environmental indicators (continued)

Pressures and benefits	Pollution	15	Gross nitrogen balance	Pressures and risks to environment
		16	Risk of pollution by phosphorus	Pressures and risks to environment
		17	Pesticide risk	Pressures and risks to environment
		18	Ammonia emissions	Pressures and risks to environment
		19	GHG	Pressures and risks to environment
	Resource depletion	20	Water abstraction	Pressures and risks to environment
		21	Soil erosion	Pressures and risks to environment
		22	Genetic diversity	State of natural resources
	Benefits	23	High nature value farmland	State of natural resources
		24	Renewable energy production	Agricultural production systems
State / impact	Biodiversity and habitats	25	Population trends of farmland birds	State of natural resources
	Natural resources	26	Soil quality	State of natural resources
		27.1	Water quality – nitrate pollution	State of natural resources
		27.2	Water quality – pesticide pollution	State of natural resources
	Landscape	28	Landscape – state and diversity	State of natural resources

Although the Eurostat indicator set is policy based, by also putting it into the DPSIR framework, the indicators can be used more easily for analysis from an environmental perspective. This set comprises a combination of indicators for describing and monitoring the condition of natural resources, such as soil, water and land, and the depletion of soil and water resources. As European Union agriculture policy not only focuses on sustainable agriculture, some specific aspects included in the Eurostat indicator set are only suitable for European countries. Accordingly, this set of indicators would not be a suitable generalized set of indicators, for example, one that would be appropriate for developing countries.

Recently, the FAO Statistics Division elaborated Table 7, which provides the state-of-the-art in terms of the agri-environmental indicators data domains in FAOSTAT, compared to those available in Eurostat and OECD. To this regard, as already stated, FAOSTAT can be considered as a solid base for further work on selected agri-environmental indicators.

Table 8. Agri-environmental indicators in FAOSTAT and their correspondence in the Eurostat and Organisation for Economic Co-ordination and Development domains

DOMAIN	FAOSTAT	Eurostat	OECD
Soil/Soil erosion	-	-	-
Average carbon content in topsoil as a % of weight	(1999, 2008)	-	-
Average land degradation in GLASOD	(1999, 2008)	(1990-2011)	✓(1990-2011)
Soil erosion in GLASOD/% agriculture with moderate to severe water/wind erosion	(1999, 2008)	(t2020_rn300) (2000, 2010)	✓(1990-2011)
Water			
% total water withdrawal from agriculture	(1965-2010)	(env_wat_abs)(2005-2014)	(1990-2010)
Fertilizers	-	-	-
Nutrient use on arable and permanent crops	✓(2002-2010)	-	-
Consumption in nutrients (N)	✓(2002-2014)	(2003-2014) tag00090	(1999-2009)
Consumption in nutrients (P2O5)	✓(2002-2014)	(2003-2014) tag00091	(1999-2009)
Consumption in nutrients (K2O)	✓(2002-2014)	(2003-2014) tag00092	(1999-2009)
Land	-	-	-
% anual change (agriculture)	✓(1961-2011)	-	-
% of total land as agriculture area	✓(1961-2011)	-	(1990-2010)
% of total land as protected terrestrial areas	✓(1961-2011)	-	
% of agriculture area as arable land	✓(1961-2011)	-	(1990-2011)
% of agriculture area as permanent crop	✓(1961-2011)	-	(1990-2011)
% of agriculture area as organic agriculture area	✓(1961-2011)	-	(1990-2010)
% of agriculture area as conservation agriculture area	✓(1974-2011)	-	-
% of agriculture area as total area equipped for irrigation	✓(1961-2011)	-	-
Pesticides	-	-	-
Active ingredient on arable and permanent crops	✓ (1990-2010)	-	-
Fungicides	✓ (1990-2014)	(1997-2008)	(1990-2011)
Herbicides	✓ (1990-2014)	(1997-2008)	(1990-2011)
Insecticides	✓ (1990-2014)	(1997-2008)	(1990-2011)
Other pesticides	-	-	-

Table 7. Agri-environmental indicators in FAOSTAT and their correspondence in the Eurostat and Organisation for Economic Co-ordination and Development domains (continued)

Emissions by sector	-	-	-
% of total NH3 emission from agriculture	(1980-2009)	(1990, 2010)	(1990-2010)
GHG emissions for agriculture	✓(1961-2014)	-	-
% Share of GHG emissions from agriculture/LULUCF to total emissions	✓(1990-2010)	(1990-2010) (tsdcc210)	(1990-2010)
Emission Intensities of agricultural commodities (meat, milk, egg, cereals, rice)	✓(1961-2014)	-	-

Source: Created by the FAO Statistics Division in 2016.

Note: ✓ indicates automatic update from core FAOSTAT data.

From a private stakeholder perspective, it could be useful to refer to the Sustainability Assessment of Food and Agriculture systems (SAFA), a holistic global framework for the assessment of sustainability along food and agriculture value chains (Box 6).[40]

Finally, other existing frameworks and systems, such as the already mentioned 2030 Agenda for Sustainable Development, the Millennium Declaration, the Sustainable Development Index and the indicator approaches within Rio Conventions, including, among others, the United Nations Framework Convention on Climate Change (UNFCCC), the United Nations Convention to Combat Desertification, CBD and SAFA, are somehow compatible to the above main frameworks but not relevant to further analysis in the context of this particular effort. It is important to highlight that the Sustainable Development Goals are considered in this literature review as the general political framework which other specific operative frameworks related to the environmental dimension rely on, with the specific target to calculate and measure each single sustainable development goal, as identified and recognized at the international level.

Based on the revised definitions of sustainable agriculture, a description of a basic template of ecologically sustainable farming practices, and through a

[40] SAFA is an initiative in which its concept was developed through FAO cooperation with the ISEAL Alliance (www.isealalliance.org/) and through several expert meetings held between 2009 and 2013. Many experts extended their knowledge and insights during the different SAFA events, including sustainability concerned partners in academia, associations, food industry, multi-stakeholder organizations and experts working within the United Nations system and FAO. All SAFA resources are freely downloadable from: www.fao.org/nr/sustainability/sustainability-assessments-safa.

review of a variety of different indicator sets in Chapter 6, a concise agri-environmental indicator set is proposed.

Finally, as mentioned in the introduction, the Global Strategy is participating in the development of methodological guidelines for Sustainable Development Goal indicator 2.4.1: proportion of agricultural area under productive and sustainable agriculture, which will be taken into consideration in the development of agri-environmental indicators, which will be proposed in this project.

Box 4. The sustainability of food and agriculture systems

SAFA establishes an international reference for assessing trade-offs and synergies among all dimensions of sustainability. It has been prepared so that enterprises, whether companies or small-scale producers, involved with the production, processing, distribution and marketing of goods, have a clear understanding of the constituent components of sustainability and how strength, weakness and progress could be monitored. By providing a transparent and aggregated framework for assessing sustainability, SAFA is intended to harmonize sustainability approaches within the food value chain and further good practices (FAO- SAFA, 2014, v).

SAFA is mainly targeted to small, medium and large-scale companies and other stakeholders that work in agriculture (crop, livestock, forestry, aquaculture and fishery value chains). However, as a framework and harmonized global assessment approach, SAFA could also be relevant for government strategies, policy and planning.

The guiding vision of SAFA is that food and agriculture systems worldwide are characterized by four dimensions of sustainability: good governance; environmental integrity; economic resilience; and social well-being. For each of these four dimensions of sustainability, SAFA outlines essential elements of sustainability based on international reference documents and conventions. The 21 themes and 58 subthemes of SAFA were defined through expert consultations. Default performance indicators (subject to periodic reviews) for each subtheme facilitate the measuring of progress towards achieving sustainability. SAFA assessment involves adaptation to geographic, sector-specific and individual conditions of the assessed entity and the comprehensive use of existing documentation, standards and tools (FAO-SAFA, 2014, v-vi).

5.3. A new set of indicators: establishing the starting point

When working on indicator sets – or developing a composite indicator – the identification and precise definition of the phenomenon or concept to be measured or understood is the first step, because something that is poorly defined is likely to be badly measured (OECD & Joint Research Centre-European Union 2008). In other words, it is important to understand what is required to know before deciding how it is going to be measured. In addition, identifying the theoretical framework to be used for making evaluations is equally important. Understanding the criteria for making judgements regarding trends (i.e. is the indicator showing an improvement or not?) – is also fundamental. If the framework or perspective or paradigm changes then the evaluation of the indicators may change.

For example, in the early 1900s, a shift in industrialized countries towards intensive farming practices occurred, which advocated increased soil tillage and greater use of chemical fertilizers and pesticides. Indicators related to tillage rates, use of fertilizers and pesticides were evaluated as being "good" if they were increasing. However, as knowledge about soil and pollution increased, the evaluation criteria for intensive farming practices changed. While indicators did not change – tillage rates, use of fertilizers, and use of pesticides were still evaluated –, the way the trends of those indicators were interpreted changed when the theoretical framework changed from intensive, industrial farming to the use of good agricultural practices and sustainable agriculture.

Given that currently there is no universally accepted definition of sustainable agriculture, and following the discussions in Section 3.3, farming systems involved in the implementation of good agricultural practices are used as a starting point for understanding the concepts being described within an agri-environmental indicator set, that countries independently of the progress made in developing their statistical programmes, could use to evaluate the status of their food production systems while considering sustainability across temporal scales.

5.3.1. Definition of the indicator set content: relevance, measurement and limitations

Determining the scope of an indicator set – in other words, what is "in" or "out"/included or excluded in the indicator set – is an important step in developing the set. If this is not done, then hundreds of indicators based on different preferences will most likely be included.

When working on a proposal for a concise set of agri-environmental indicators, decisions related to, for example, indicator selection, relevance, measurement and scale, the approach proposed by Becker (1997, p.42) may be useful. In this example, existing sustainability indicators are evaluated by applying a matrix approach in which aspects related to scientific quality, ecosystem relevance, data management and sustainability paradigm are considered. Furthermore, during the process of selecting the best possible indicator, one can cover a broad range of aspects or considerations, not all of which can be equally met. Accordingly, a balance must be found between scientific accuracy and pragmatic decision-making in order to select an indicator that is realistic and robust.

Considering the specific, measurable, attainable, relevant and timely (S.M.A.R.T.) goal-setting technique,[41] the general criteria that it would apply for this research work is as follows:

a) Relevance, in order to achieve sustainable agri-environmental objectives;

b) Methodological soundness, in order to have robust indicators;

c) Feasibility and measurability, in order to have indicators that can be easily and clearly quantified;

d) Efficiency and efficacy, in order to have a concise set of indicators that capture or can relate to a broader range of aspects; and

e) Acceptance, in order to have indicators that are widely accepted, easy to interpret and cost effective.

This approach guides the ultimate goal of this research work that is to set a concise set of agri-environmental indicators.

5.3.2. Lessons learned from the work to set the Sustainable Development Indicators

The Joint United Nations Economic Commission for Europe (UNECE)/OECD/Eurostat Working Group on Statistics for Sustainable Development has identified two main approaches, which were used as frameworks for setting the Sustainable Development Indicators (United Nations

[41] The S.M.A.R.T. goals technique is the most popular method used for goal setting in the world. There are a number of variations of this technique but the most common version states that a well set goal should be: S. = specific, M. = measurable, A. = attainable, R. = realistic and T. = time based.

2008).[42] One approach is based on specific sustainable development strategies and policies and the second one uses the concept of community capitals – and different types of capital: financial, built, natural, human, cultural, political and social. These two approaches have strengths and weaknesses.

The policy-based approach has strong links between the indicators and policies, but this could have biased the Sustainable Development indicators set towards policy priorities at the expense of other aspects of sustainable development. In this case, the definition of sustainable development is considered a social construct, which is defined by the politicians through their strategies and policies. Policy makers can typically communicate more easily about these types of indicators as they are directly related to government policies. However, when governments or policy changes, then the indicators also typically need to change.

The community-capital-based approach is based on a sustainable development definition that includes non-declining per capita wealth over time (United Nations 2008). Under this approach, the definition of sustainable development is more theoretical. Some challenges related to this approach are valuation methodologies, substitutability, including thresholds, and critical capital stocks, measuring national sustainability or global sustainability and whether the concept is future only oriented or also includes present conditions.

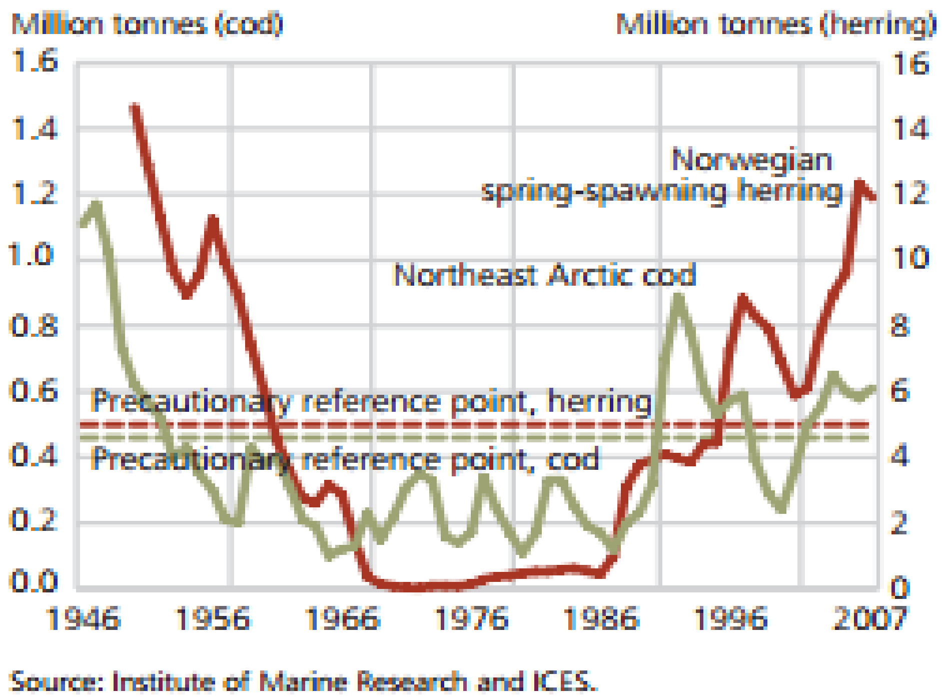
However, in terms of the types of indicators proposed from the work to set the Sustainable Development Indicators (United Nations 2008), when using either approach, there is always a combination of both capital and flow types of indicators. The idea of measuring both capital and stocks and flows is found in various indicator sets and can be an important approach to consider when constructing indicator sets.

The description and measurement of the capital, amount and quality, identifies if the activities based on that capital can continue in perpetuity or if the capital is being consumed bit by bit from non-sustainable activities. One of the challenges associated with environmental systems is that there are often non-linear properties associated with the system, including thresholds and critical points, such as tipping points that need to be considered in the evaluation of the stocks. An example of using precautionary reference approaches to fish stocks – a type of a minimum threshold – is shown for the cod and herring fisheries in Norway (Graph 8). The fishing quotas were set based on whether the spawning stocks were above the minimum threshold or not, and as the graph shows, it was

[42] The information on work to set the Sustainable Development Indicators is available at https://sustainabledevelopment.un.org/.

necessary to ban fishing of those species for a number of years until the spawning stocks recovered enough to allow fishing again.

Graph 8. Spawning stock and biomass precautionary approach reference points for North-East Arctic cod and Norwegian spring-spawning herring



Source: Institute of Marine Research and ICES, referenced in Statistics Norway (2009, p. 35).

5.3.3. Conceptual structure of environmental indicators

Flow indicators measure something over time. Typically, these indicators are expressed in physical or monetary units per time period, for example, cubic meters of water per hour or amounts of pesticides used per year. There are also indicators, which are descriptions of the status of something at a certain point in time; these are stock or capital indicators.

Income and expenses are flows in and out of a bank account and often are described per month or year – annual income, monthly electric bill and monthly food expenses, for example. Whereas, the balance in a bank account at the end of the year is a measure of financial capital or financial asset and thus a measurement of the stock condition in a specific moment in time.

In the context of agri-environmental systems, the focus for policy makers is on the "environmental end-states" (Moxey, Whitby & Lowe 1998), or, in other words, on the state of the environment. In this condition, the environment would be considered a natural or environmental resource – or according to SNA/SEEA an "asset". When measuring an asset, typically there is a description of the amount of the asset at the beginning of the time period and then again at the end of the time period. Changes in the asset can then be seen between the start and the end of that particular time period. It is a comparison between conditions at one point in time to another point in time.

As mentioned in Paragraph 5.2.2, SNA-2008 (United Nations 2009) and the SEEA-CF 2012 (UNSC 2014) have established a standard methodology for asset accounts. For natural resources, SEEA-CF provides the most relevant guidelines, which are then expanded through SEEA-AFF to the specific factors relevant to agriculture, forestry and fisheries.

One of the recommendations from the "GDP and beyond" Communication from the European Commission (EU-COM, 2009) and the Stiglitz-Sen-Fitoussi Commission report (Stiglitz *et al.* 2011), was to also focus on wealth and wealth distribution and not just on gross domestic product (GDP) and production (hence measures of flow).

Learning from the work related to the Sustainable Development Indicators and the Stiglitz-Sen-Fitoussi Commission report, as well as from the insights from Moxey, Whitby & Lowe (1998), focusing on the state of the agri-environment systems provides insights into the sustainability of the natural resources and not just on the pressures.

As the focus of this research work is on agri-environmental indicators having indicators that monitor the stocks and flows of natural capital elements that are critical to sustain agricultural productions, such as soil, water, energy and land, is warranted and needed.

This research work is also supported by one of the targets of Sustainable Development Goal 2, which points to maintaining ecosystems and improving land and soil:

"By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaption to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality."[43]

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[43] A/RES/70/1.

And, in particular, ongoing indicator 2.4.1 “proportion of agricultural area under productive and sustainable agriculture”, will help in the reporting on the progress being made towards reaching this target.

5.3.4. Multipurpose data systems

Single purpose data collection has been the approach used by organizations for years. Data are often collected to answer only one policy question or one reporting need. This approach has proven to be very costly. The statistical system is moving away from this approach towards multipurpose data systems that serve multiple user needs. This means that data are collected one time, and used many times. This also means that different data – from surveys and censuses, administrative sources, monitoring stations and remote sensing, among others – need to be brought together in systematic ways to build complete pictures. Things that have been counted twice need to be eliminated, and knowledge gaps need to be filled.

Having a framework that helps the compiler put the pieces together is very helpful. As it is already known how the picture is supposed to look, an attempt is made to put the pieces together. A number of statistical frameworks that assist in organizing fragmented data sets into coordinated information systems have been developed and refined over the years: SNA, SEEA and FDES are those statistical frameworks; they already been introduced in sections 5.2.1 and 5.2.2.

Indicators that are obtained from existing accounting systems may include more complete information and be more internationally comparable when the data are assembled in standard ways. Using consistent definitions and classifications will assist in the integration of different data sources. When developing an indicator set, it can be very useful to identify where the statistics and indicators could come from by referencing the different sections of these United Nations statistical systems – and whether they are primarily from statistics or are also from an accounting system.

5.4. An ecosystem approach for agri - environmental indicators– what is it trying to measure?

It is necessary to describe and define what is going to be measured before a set of appropriate measurement criteria and indicators are developed. As discussed before, this is the first and main challenge when it comes to monitoring and measuring sustainable farming practices simply because there is no consensus on the definition of these practices nor on what constitutes a basic set of agri-environmental indicators.

However, common aspects that are considered part of an ecosystem approach to agriculture and the practices that would be supportive of this approach have been identified (See Chapter 5), and indicators that could help describe these different aspects can be proposed.

In the present work, practices that describe different aspects of the ecological approach of agriculture are identified, considering the SCPI, conservation agriculture, smart agriculture approaches and a variety of existent different descriptions and sets for agri-environmental indicators described earlier.

In particular, as already stated in Paragraph 4.3, FAO (2011b, p.11) describes the SCPI as one approach both highly productive and environmentally sustainable and is based on "agricultural production systems and management practices that include: maintaining healthy soil to enhance crop nutrition; cultivating a wider range of species and varieties in associations, rotations and sequences; using well adapted, high-yielding varieties and good quality seeds; integrated management of insect pests, diseases and weeds; and efficient water management."

This description specifically identifies some of the flows that are important to measure "use of key inputs" – and the types of indicators (efficiency or ratio type) that are needed to monitor if "higher rates of efficiencies" are being obtained.

FAO (2011b) also describes the following three core technical principles for farming systems for SCPI, which that focus is place on natural capital and flows – in the form of input efficiencies:

- "Simultaneous achievement of increased agricultural productivity and enhancement of natural capital and ecosystem services;
- Higher rates of efficiency in the use of key inputs, including water, nutrients, pesticides, energy, land and labour;
- Use of managed and natural biodiversity to build system resilience to abiotic, biotic and economic stresses."

In this description, the focus is strongly on the state of the system – natural capital, ecosystem services and biodiversity and not just on the farming practices. This emphasis can be important when deciding on the types of indicators needed to monitor sustainable food production.

Regarding conservation agriculture, FAO (2015) states that it is characterized by three linked principles:

1. Continuous minimum mechanical soil disturbance
2. Permanent organic soil cover; and
3. Diversification of crop species grown in sequences and/or associations.

This is in line with the basic idea of sustainable farming practices, which has been developed by this research work (see Section 4.3) with a clear focus on soil and soil condition.

Corsi, *et al*. (2012, ix) support this view and state that, "most of the world's agricultural soils have become depleted in organic matter and soil health over the years under tillage agriculture,[44] compared with their state under natural vegetation". However, this degradation apparently can be reversible and soil organic matter content and soil health can be improved if conservation agriculture practices are implemented. So here there is again a focus on soils and their overall condition.

In evaluating these different aspects, what would be considered "good"? In this case, FAO[45] states that at the field level, the following are considered positive, "no or minimum soil disturbance, to enable the soil surface to be protected by organic cover for as long as possible, and to manage crop rotations and associations to enhance soil and agri-ecosystems health and to conserve and utilize crop nutrients from various soil horizons."

An important concept here is that measuring these conservation agriculture aspects may need to be done separately, but they are linked and therefore each aspect by itself is not sufficient – and measuring these different aspects in association with the other aspects is part of the challenge. For example, reduced tillage by itself is not considered to be sufficient to be referred to as conservation agriculture.

These definitions and descriptions have provided some insights in the attempt to describe an indicator set, but, as indicated, as there are a large number of already

[44] According to Corsi *et a*l. (2012, v), traditional tillage agriculture is one of the two most common types of agriculture - the other one is conservation agriculture, with respect to their effects on soil carbon pools.
[45] See http://www.fao.org/agriculture/crops/thematic-sitemap/theme/spi/scpi-home/managing-ecosystems/samandca/en/.

established agri-environmental indicator sets, it is worth taking them into account to find commonalities. In the next chapter, the discussion is centred on set indicators proposal.

6

A proposal of a Concise Set of Indicators for Sustainable Agriculture

The purpose of the present chapter is to present a concise set of indicators that can be used to monitor whether agricultural practices are affecting the environment and/or if those practices are contributing to the implementation of a more sustainable agriculture. In particular, the focus is on indicators that describe the condition of components, such as soil, water, land and biodiversity, that are critical elements affecting food production systems. Assessing the biophysical condition or "health" of those components is crucial when attempting to measure or determine if agricultural practices are contributing to the effort to achieve sustainable food production.

6.1. Maintaining stocks of natural resources critical for agriculture

Identification of suitable indicators for the measurement of sustainable farming practices should rely on information about stocks of natural resources needed for agriculture. Once the different critical stocks are identified, then indicators for the measurement of the extent and condition of those stocks can be proposed in the form of agri-environmental indicators.

These critical natural resources include a series of elements that are essential for agricultural production. They are the following: the spatial or physical dimension, which refers to the actual physical space needed to develop the activity, namely the area/land; the diversity of genetic material in the form of different seed varieties; and the medium or substrate in which agricultural products need to be nurtured –soil is typically the main substrate. Other necessary inputs include nutrients, water and energy, which may also result in negative impacts, such as pollution in the form of runoff, air emissions and waste (plastics). Measurement of the extent and condition of each of those different resources is required in order to identify increasing or decreasing trends that may affect their quantity and quality.

Using the concept of capital assets or stocks helps to identify what is important for sustainability over the long term as depletion and degradation of natural resources is by definition detrimental to food production sustainability.

In the context of natural resources, SEEA-CF 2012 (UNSC 2014, §5.75) defines depletion as:

"…Depletion, in physical terms, is the decrease in the quantity of the stock of a natural resource over an accounting period that is due to the extraction of the natural resource by economic units occurring at a level greater than that of regeneration." (p.187).

When referring to depletion rates, SEEA-CF 2012 (UNSC 2014, §2.95) states that it is important to first identify whether the natural resource is non-renewable or renewable. If it is non-renewable, then the depletion rate is equal to the extraction rate. If it is renewable, then the calculation of the depletion rate needs to also take into account the capacity of the natural resource to regenerate over time.

6.2. Challenges in the measurement of stocks and flows

In general, the measurement of stocks (quantity) of natural resources and the assessment of the condition of those stocks (quality) is not an easy task. However, it is extremely important as both quantity and quality of natural resources influence flows coming from and to those stocks.

Using as an example the dynamics of bank accounts, if cash withdrawals are made at a greater rate than cash deposits, then at some point, the account balance (or stock of funds) will be depleted and become zero. At this point, no further cash withdrawals can be made, compromising the existence of the bank if several accounts show the same patterns. The careful monitoring of the different account balances is evidently just as important as measuring the number of transactions (credits and debits) when evaluating the economic activities of an account holder.

Similarly, in the case of stocks of natural resources needed for sustaining agricultural production, monitoring the stocks also means having to monitor the flows (replenishment and extraction rates), as it is important to understand the system dynamics that be able to foresee potential problems.

An assessment of stock quantity and quality allows access to timely information about whether they are increasing or decreasing and also gives an indication of the depletion rates and of lifetimes of particular natural resources stocks. For renewable resources to be sustainable, the stock needs to be non-decreasing over time. Moreover, the quality of the stock also needs to be maintained (or potentially improved if it is already in a poor state); in other words, there needs to be no degradation in the condition or quality of the natural resource overtime.

Long-term measurement of extent and health of the natural resources is preferred and must be prioritized whenever possible. However, as a result of challenges associated with their measurement, and because changes in the conditions of those stocks can be minimal in the short term and thus are very difficult to detect, it may be more realistic and feasible to measure certain flows that would give a proxy for the condition and extent of the natural resources upon which the flows depend.

6.3. Main agri - environment indicators – focus on natural resources

Considering the diverse nature of the challenges associated with the measurement of natural resources stocks and flows, this analysis is not aiming to propose a comprehensive monitoring system for policy or management of the agricultural sector at the national level. Alternatively, the main goal is the identification of a concise set of variables that can be used to monitor the progress of agricultural practices towards sustainable agriculture. Additionally, the main focus of this particular effort is on crops and does not include (at the moment) practices related to animal husbandry or fisheries.

Choosing indicators that best describe the condition of the stock of critical components of cropping systems is essential for the establishment of an appropriate monitoring scheme. Elements, such as soil, water, land and genetic material (biodiversity), represent four main natural resources capital components[46] that are required to sustain agricultural production. Additionally, energy use, is an important external input in food production. Dependence on fossil fuels continue to be a challenge, as it has negative impacts on the atmosphere. Additionally, mechanization of farming practices affects soil characteristics. The biophysical condition or "health" of soil, water, land and biodiversity as natural capital resources is important when trying to measure or determine if implementation of good agricultural practices are supporting sustainable agriculture. Monitoring fluctuations in the condition of these critical

[46] More information on natural capital components available at www.eea.europa.eu/soer-2015/europe/natural-capital-and-ecosystem-services.

resources is thus imperative and can be done by identifying indicators that are useful and robust over the long-term as well as in the short term.

Evaluation of existing data is required prior to proposing a set of agri-environmental indicators. Data sources from the FAO are used first and then other sources, such as Eurostat and the European Environment Agency (EEA), are also examined. To assist in the development of the proposed indicators, references to FDES and SEEA are also provided. These should enable the development of indicators based on existing international statistical standards.

Based on the latter, the following indicators are proposed:

6.3.1. Indicators of soil management

Soil degradation is a widespread problem (Corsi *et al.* 2012; FAO & ITPS 2015). Most of the world's agricultural soils have become depleted in organic matter and soil health over the years under tillage agriculture compared with their state under natural vegetation (Corsi *et al.* 2012).

This first indicator aims to provide insights into "soil health". Soil health, also referred to as soil quality, is defined by The United States Department of Agriculture (USDA) as the continued capacity of soil to function as a vital living ecosystem that sustains plants animal, and humans.[47] This definition is fundamentally related to soil biodiversity and the need for healthy soil to be alive and in a condition that certain functions for producing food and fiber can be carried out.

Eurostat has a more complex approach to soil quality, described as the ability of soil to provide agri-environmental services through its capacities to perform its functions and respond to external influences. In the agri-environmental context, soil quality is described as the capacity of soil to produce the input-needed to attain optimal productivity, the soil-response to climatic variability, and carbon storage, filtering, buffering capacity.[48]

In summary, a healthy soil is that which, in the absence of contaminants (or below toxic levels) and external inputs, is able to sustain a relevant organic matter content and microbiological diversity so that productivity does not vary over time. That is, it has the same capability to provide ecosystem services, such as biomass production in the agri-environmental context, over time. This

[47] See https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/
[48] See http://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_soil_quality=

definition, as suggested by USDA, relates to the importance of managing soils so they are able to sustain food production for future generations.

Maintaining or restoring soils so that they have “healthy” characteristics is a major component of the ecological approach for sustainability in agriculture; agriculture should manage soil ecosystems to provide nutrients for plant growth, absorb and hold rainwater for use during dryer periods, filter and buffer potential pollutants from leaving cropping fields, serve as a firm foundation for agricultural activities and provide habitat for soil microbes to flourish and diversify in order to keep the ecosystem functioning as it best.

Usually soil organic content (SOC) in topsoil represents one of the main dimensions to be considered with regard to soil health. A high level of, in non-contaminated soils resulting from a well-balanced land cover and land management activities is likely to prevent excessive soil erosion, provide quality habitat for soil organisms, and act as a sink for atmospheric carbon, thus mitigating the negative effects of climate change. In general, soils with higher soil organic content have a richer biodiversity pool, as it is the necessary basis for soil organisms to survive.

FAOSTAT contains data on carbon content in topsoil for some countries, indicating that high SOC relates to good soil conditions from an agro-environmental point of view. Soils with organic carbon content less than 1 percent in weight are generally affected by soil degradation processes and erosion, while soils with 1-10 percent organic carbon content have high agricultural value. FAOSTAT indicates that once a stable state of SOC is reached using the criteria of increasing it is no longer appropriated. Instead, the assessment of soils’ health through levels of SOC may need to be conducted considering a reference state describing the optimal conditions for the specific soil type.

However, the SOC levels change at very low rates over time. Changing management practices will have a measurable impact on the SOC only after several years. In general, as the measurement errors related to the SOC are high, a reliable assessment of changes in the SOC over time require large amounts of samples (Smith 2004). This is costly and therefore often not feasible in practice.

If it is not possible to measure SOC or soil organic matter in an appropriate manner because of, for example, restrictions related to costs, statistical sampling techniques and time, then considering agricultural practices known to typically influence the SOC and minimize soil degradation, such as erosion, acidification, contamination and nutrient imbalance can be used as proxies. Corsi *et al*. (2012)

discuss the implementation of such practices to help reverse soil degradation processes. The practices cited are keeping the disturbance impact and interactions between mechanical implements and soil to an absolute minimum, using effective crop rotations and associations, and leaving crop residues as a carbon source on the soil surface. Moreover, CA-related practices, such as no-tillage or minimal tillage, types of crop rotation and sequences, applications of manure and compost, and use of cover crops, are known to increase SOC. In comparison to practices, such as intensive tillage, burning and removing residues, which are known to have a negative impact on soil quality by decreasing the SOC.

Finally the *Voluntary Guidelines for Sustainable Soil Management* that FAO (2017) developed within the framework of the Global Soil Partnership provide general technical and policy recommendations on sustainable soil management, including a set of practices related to minimizing soil erosion, enhancing soil organic matter content, fostering soil nutrient balance and cycles, preventing, minimizing and mitigating soil salinization and alkalization, preventing and minimizing soil contamination and acidification, preserving and enhancing soil biodiversity and minimizing soil sealing, among others.

Measuring these types of practices and developing related flow-type indicators can be used as proxies or supplemental indicators to track and monitor changes in organic carbon content in soil.

6.3.2. Indicators of water management

For the assessment of water, the indicator "*proportion of renewable freshwater resources abstracted for use by agriculture, forestry and aquaculture*" is proposed. Water abstraction in this context is defined as total freshwater used for agriculture activities, including ground and surface water.

The use of irrigation may help to reduce the adverse effects of extreme climatic conditions occurring under current climate change trends. However, abstraction rates become unsustainable when they exceed replenishment rates. Monitoring the use and replenishment rates for renewable resources is important to ensure that the resource is not being systematically depleted.

Ideally, as other sectors of the economy also rely on water resources in order to carry out their activities, information about the total amount of water used is needed to compare abstraction rates against the total availability of freshwater resources. SEEA-AFF Section 4.10 plus SEEA-CF and SEEA-Water include guidelines that can be used for establishing a comprehensive representation of the supply and use of freshwater resources. If there is not enough information to establish water accounts, approximation of total water used for agriculture along with the rates of replenishment of groundwater and/or total amounts of fresh water, are the minimum information needed. The availability of water varies depending on seasonality; these fluctuations must be taken into consideration when developing water statistics and accounts.

Water is an important and limiting factor in agricultural production. It is a resource on which the survival of crops and animals is highly dependent. Therefore, knowing whether water abstraction rates are sustainable will directly indicate whether agricultural activities are sustainable. However, there are two main challenges associated with measuring this indicator. One of them is difficulty in obtaining reliable information on the total amount of freshwater. The second one is difficulty in obtaining robust and disaggregated information on water used for agriculture and other human activities.

6.3.3. Indicators of nutrient and pesticide management

The third indicator "agrochemical use" considers water and soil quality, specifically the pollutants contributed by agricultural sources. The information provided by this indicator will likely be correlated with indicators 1 and 2, but it will also provide additional information related to sources of contaminants, which is not thoroughly covered by previous indicators. Runoff from contaminated soils containing nutrient excesses, pesticides and other chemicals can negatively impact downstream surface water quality, as well as, groundwater through leaching. In addition to depletion, the degradation or pollution of water can affect not only agriculture but also have an impact on all other activities that depend on this resource. Soil is another key resource that can be negatively affected by excess nutrients, particularly from those coming from fertilizer and pesticide applications. Additionally, management and disposal of agrochemical containers and plastic products use in food production can become significant sources of water and soil pollution. Therefore, it is important to carefully consider and monitor fluctuations in water quality and availability as well as on the use of pollutant elements that can have a dual effect on water and soil.

Assessment of pollutant sources, however, is not an easy task. One of the main challenges associated with measuring pollution is to correctly attribute pollutants to the agricultural activity. This is because nutrient load and pesticides detected may not have originated only from agricultural activities but they can also be the result of runoff from urban sources, wastewater treatment plants and other non-agricultural sources. Given those limitations, some supplementary data may be needed to fully capture the nutrients and pesticides dimension arising only from agriculture activities. These data would focus on the use or application of nutrients, pesticides and other chemicals in agriculture activities. SEEA-AFF[49] provides guidance for the development of supply and use tables to assist in organizing data in a systematic and comprehensive manner so that the proxy or complementary flow indicators are developed in a consistent manner. If the data can distinguish whether the source is from agriculture or from other human activities, then these supplies and use tables can be helpful in systematically organizing the data.

6.3.4. Indicators of land use management

Related to the subject of land use management, the fourth indicator is "change in agricultural land use", with a focus on detailed agriculture land use categories. For this indicator, the total amount of land used for different purposes and with different levels of intensity (then highly correlated to indicator 1) are assessed at various points in time in order to determine changes between two different time periods.

The SEEA-AFF[50] explains the asset account for land that would be needed for developing this indicator. The SEEA-AFF categories of agriculture land use only include arable land, permanent crops, permanent meadows and pastures (cultivated or naturally growing). It may be desirable to include additional, more detailed, levels of arable land by type of crops or other categories.

FAOSTAT considers the percent of annual change in agricultural area as one agri-environmental indicator, and relates land use to GHG; developing asset accounts for land use would help in using the rather fragmented information on land use available from FAOSTAT. When examining the categories for agriculture, land types can also be subdivided based on crop patterns. This additional information may be used to inform about biodiversity conservation value of these agricultural land uses, and then correlated to indicator 5.

6.3.5. Indicators of biodiversity

Related to the assessment of biodiversity levels, the fifth indicator is "change in land cover". Conventional agriculture is one of the main pressures leading to deforestation and the resulting loss of biological diversity/biodiversity. Monitoring changes in land area and the different land cover types,[51] such as mature and secondary forest, live fences, riparian forest and natural regeneration,

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[49] See: SEEA-AFF, United Nations second Global Consultation draft 2015, section 4.13.
[50] See SEEA-AFF, United Nations second Global Consultation draft 2015, Section 4.14.
[51] See SEEA-CF, Table 5.13 for an example.

can provide macro level information and habitat loss and fragmentation, which can give insights into biodiversity persistence and conservation in agricultural lands. Macro level monitoring can be helpful in providing a broader perspective on biodiversity conservation rather than having only a species-level focus. The comprehensive nature Index developed for Norway (Skarpaas, Certain & Nybø. 2012) may be the best approach for robust monitoring of biodiversity at the country scale, but the data requirements for that approach are extensive for countries with undeveloped and/or non-existent monitoring and statistical systems.

SEEA-CF establishes a statistical land cover classification[52] and FAO has worked on the Land Cover Classification System and related analysis and data, which may be helpful in developing methodologies for this indicator.

The identification of exactly which approach would provide the most useful information related to changes in land cover and use and biodiversity in agricultural landscapes needs to be further evaluated in the context of countries that possess undeveloped information systems. Particularly, as some methodologies are based on the analysis of satellite images and others are based on field observations.

6.3.6. Indicators of energy use

Related to sustainable energy use, the sixth indicator is "energy use per agricultural output", in which tracking the total energy use and the proportion of the total that fossil fuels compose is required. If the data sources come from SEEA-CF energy accounts and the national accounts, then agricultural production in terms of production value rather than value added would be preferable as agricultural subsidies can influence the economic landscape. This indicator would provide information on energy efficiency, a sustainable crop production identification technical principle. Also, as countries increase the use of mechanization, this indicator will make marked jumps in helping to identify agricultural practices that are heavily reliant on fossil fuels. Increases in the use of mechanized agricultural practices may have positive impacts on yields, however, shifting from no fossil fuel inputs to a heavy dependence on fossil fuels would most likely depart from the sustainable farming practices template.

[52] See SEEA-CF Table 5.12.

Table 9. Proposed natural capital based agri-environmental indicators and potential alternatives.

Theme domain	Type pf natural resource	FDES/SEEA	Indicator	Alternatives indicators	Variables (type)
Soil management	Soil	FDES Topics 1.1.4 Soil Characteristics and 2.4.1 Soil Resources; SEEA-CF	1. Soil health	1.1 Tillage practices	1.1.1 Type (categorical)
					1.1.2 Frequency (continuous or categorical)
				1.2 Use of protective soil cover	1.2.1 Type (categorical, yes/no)
				1.3 Annual use pattern of burning practices	1.3.1 Frequency (categorical, yes/no)
				1.4 Erosion control practices	1.4.1 Use of erosion control practices (Boolean)
				1.5 Crop rotation practices	1.5.1 Type (categorical, non-exclusive)
Water management	Water	FDES Sub-component 2.6.1 Water Resources SEEA-Water / SEEA-AFF	2. Proportion of renewable freshwater resources abstracted for use by agriculture	2.1 Rain-fed agriculture areas	2.1.1 Area (continuous, ha)
				2.2 Agricultural areas dependent on irrigation systems	2.2.1 Area (continuous, ha)
					2.2.2 Type of irrigation system (categorical)
					2.2.3 Water source type (categorical)
					2.2.4 Quantity (continuous)
					2.2.5 Pattern of use (categorical, all year/seasonal)
				2.3 Rainwater harvesting and storage systems	2.3.1 Type (categorical)
				2.4 Water use for crop processing*	2.4.1 Volume (continuous)
					2.4.2 Treatment after use (Boolean)

Table 10. Proposed natural capital based agri-environmental indicators and potential alternatives. (continued)

Nutrient and pesticide management	Water, soil	FDES Topic 1.3.2 Freshwater quality; SEEA-Water / SEEA-AFF	3. Agrochemical use	3.1 Fertilizer use	3.1.1 Amount of chemical fertilizer
					3.1.2Amount of organic fertilizer
				3.2 Fungicide use	3.2.1 Amount of chemical fungicide
					3.2.2 Amount of biological fungicide
				3.3 Pesticide use	3.3.1 Amount of pesticide
				3.4 Herbicide use	3.4.1 Amount of herbicide
				3.5 IPM practices	3.5.1 Use of IPM management practices (Boolean)
				3.6. Agrochemical containers management	3.6.1 Amount
					3.6.2 After use treatment
				3.7 Use of plastic for soil cover/fruit cover/Other	3.7.1 Amount
					3.7.2 After use treatment
				3.8 Sales of chemical fertilizers and pesticides*	-
Land use management	Land	FDES Topic 2.3.1 Land Use; SEEA-CF / SEEA-AFF	4. Change in agricultural land use	Cropping pattern	Area under each crop type Intensification level of each crop type (ha)
Biodiversity	Land / Soil / Genetic diversity	FDES Subcomponent 1.2 Land Cover, Ecosystems and Biodiversity; SEEA-EEA	5. Changes in land cover	5.1. Proportion of habitat types	5.1.1 Area under each habitat type (ha)
				5.2 Implementation of good management practices	5.2.1 Number of good practices (nominal, non-exclusive)
Energy use	Climate	FDES Topic 2.2.2 Production, trade and consumption of energy; SEEA-CF: physical flow energy accounts	6. Energy use per agricultural output	6.1 Fossil fuel use	6.1.1 Amount (l)
					6.1.2 Type of fuel
					6.1.3 Category of use
				6.2 Clean energy use	6.2.1 Type of clean energy
					6.2.2 Category of use

*National-level statistics.

6.4. Challenges with the proposed natural resource indicators

An inherent problem with indicators that focus on stocks, such as natural resources, is that they do not change very much from one year to the next. In other words, short-term changes are not easily detectable because the stocks are not very sensitive to incremental changes or there are long time lags before any changes can be measured. It is only over longer periods of time that trends start to emerge. Consequently, the collection of large amounts of data are required over long periods of time.

For this reason, it may be relevant to also have a number of related (alternative) indicators that can show the system's dynamics over the shorter term. Short-term monitoring lends itself to flow type indicators that are relevant to the changes in capital or stocks. These are typically indicators that show the pressures on the capital or stocks.

Other challenges are associated with the feasibility of the types of soil, surface water, groundwater, and land use and land cover analyses, given the relatively high costs or lack of hydrological monitoring systems. Here again, collecting information about farming practices that influence those indicators (for example, use of fertilizers and pesticides) could be used as alternatives.

Given those challenges related to the proposed natural resource-based indicators, a number of supplemental or alternative indicators are suggested. Indicators that are based on "flows" are typically easier to measure, but those flows need to be directly related to the stocks they are supposed to be measuring.

6.5. Potential alternative and supplemental indicators (flows)

In the effort to identify relevant alternative indicators, examining the pressures that influence the state of the natural resource is a good starting point. The pressures start at the farm level – and the specific farming practices and farming systems.

Alternatives for soil health

Among the factors that influence soil health are minimum soil disturbance, use of organic fertilizers versus inorganic fertilizers, crop rotations and plant associations, maintaining a permanent soil cover and leaving crop residues on the soil surface.

An indicator that focuses on tillage practices and burning of crop residues is one place to start development. Some examples are the Eurostat agri-environment indicator 11.2 “arable areas by tillage practices”, FAOSTAT data on burning crop residues and the UNFCCC reporting of greenhouse gases based on the IPCC methodology for agriculture.

Alternatives for the proportion of renewable freshwater resources abstracted for use by agriculture

Although the preferred indicator aims to measure the proportion of the total renewable freshwater resources that are being used for agriculture, namely the net depletion, the total amount of water used for agricultural activities, the amount of water used in irrigation or area with irrigation equipment would give an idea about the pressure being placed on the natural resource.

FAOSTAT has an indicator for the percent of agriculture area that is equipped for irrigation.

Other potential indicators are water use per unit of production (crop yield), which would be an efficiency indicator. Comparisons between water abstraction rates to water replenishment rates are also relevant although information related to those rates would be difficult to obtain in some parts of the world.

Alternatives for agrochemical use

Inorganic fertilizer consumption and consumption of pesticides are potential alternatives or if use is not known, then sales of these products would be beneficial. Coefficients of use for different types of chemicals can be found for each crop pattern, which makes it possible to determine how much of the total amount of fertilizers nutrients and/or pesticides active ingredients sold in a year is being used by each cropping pattern. In combination with soil indicators, this would give a very reliable pressure indicator of agricultural land degradation and contamination.

The SEEA-AFF physical flow accounts (supply and use) for fertilizers, nutrient flows and of pesticides, herbicides, fungicides are a useful framework for organizing the various data and for developing the supplemental indicators.[53]

[53] See SEEA-AFF, United Nations Second Global Consultation draft 2015, section 4.13

Alternatives for changes in land use and land cover

Cropping patterns – both Eurostat and FAOSTAT have examples – extend some additional information on the changes in land use in the shorter time periods.

Changes in land use encompass the indicators related to total organic, conservation agricultural areas and total area under conventional farming practices, such as permanent agriculture and arable areas.

Measuring changes in land cover should include changes in forested areas, including, for example, mature and secondary forests, riparian forests and live fences, within conventional and non-conventional agricultural areas. Although they could be exploited, natural land-use types serve as proxies for biodiversity conservation within agricultural landscapes, as these natural areas act as important reservoirs for biodiversity, particularly for species of conservation concern. Some of these natural areas are meadows and permanent pasture areas, which additionally play important roles in protecting sensitive areas, such as the borders of water streams (riparian forests) and steep hill sides (mature and forest areas usually located in areas unsuitable for agriculture). Together with meadows and permanent pastures areas, their spatial distribution inside the agricultural areas and their connectivity are as much important as their percentage in the total of the agricultural area. Both can be referred as sustainability parameters.

Alternatives for energy use per agricultural output

Ideally, the total amount of energy used – differentiating renewable energy and fossil fuel sources –is desirable; either total energy or more likely only amounts of fossil fuel inputs will be available. In that case, the energy efficiency indicator can still be developed as fossil fuel energy inputs, such as vehicle and machinery gasoline and diesel fuels, per agricultural output (in tonnes or in economic terms, such as production value).

7

A Gap Analysis on Data and Methodological Needs for the Production of Agri-Environmental Indicators

This chapter presents a summary of the results of an investigation concerning agri-environmental statistics and indicators, especially by the countries with less developed statistical systems.[54] The field of this research is not delimited by any specific definition of the agri-environmental system. Indicators are the final target of this investigation; however, it considers statistical data more widely, potentially going covering microdata to complex accounting systems, whenever these are relevant as possible supporting bases of agri-environmental indicators.[55] This investigation does not refer to a specific definition of the agri-environmental domain, but it considers as a starting point the areas currently included by international organizations under the agro-environmental indicators heading.

7.1. Introduction: context and purposes

The research begins with a review of the countries' reports to international organizations, mainly FAO through FAOSTAT, based on what is available in the databases of international organization under the heading agro-environmental indicators. This is relevant to the extent that it may be considered representative of what the countries are able to report and of the difficulties in meeting the demand for such indicators. Information is drawn directly from databases, the metadata contained in them, other websites and literature available to the public.

[54] FAO ESS-ENV staff is kindly acknowledged for providing precious hints and useful insights on most of the topics dealt with in this chapter.
[55] The generic expression "AEIs-relevant" is used.

The central part of this analysis goes beyond the international organizations' databases to focus on the actual and potential ability of statistical staff in developing countries to produce information on the environmental aspects of agricultural activities (in terms of pressures, impacts and state of natural resources), beyond what is available in FAOSTAT and other databases of international organizations. It provides a summary of information concerning the aspects relevant to the statistical processes in place in the countries. Availability and quality of statistics relevant for agro-environmental indicators, institutional settings and constraints the countries face while collecting, processing and disseminating the data are considered. The analysis is based on the conceptual framework developed and on information gathered for the in-depth country assessments of Agricultural Statistical Systems, which was carried out as part of the implementation plan of the Global Strategy and its regional partners (Global Strategy, 2014).[56] The aim of these assessments was "to evaluate the agricultural statistics system in the country and determine the national capability to produce agricultural statistics on a sustainable basis. The country assessments provide the basis for determining technical assistance, training and research support required to improve the agricultural statistics system" (African Development Bank Group 2014, p.8).

Countries' ability to produce statistics, according to the assessment's framework, must be considered in a wide sense. First, it is recognized that an enabling general environment is a prerequisite for good results; the focus is then on the supply chain approach to statistical production (input – throughput – output). Therefore, capacity in producing agricultural statistics is reviewed by considering four dimensions: (a) institutional infrastructure (prerequisites); (b) resources (input); (c) statistical methods and practices (throughput); and (c) availability of statistical information (output).

For the country assessments, a comprehensive standard questionnaire, covering information on the main sources of core agricultural data was submitted to the producers and users of agricultural statistics in the countries, under the in-depth country assessment activities, in 2012 and 2013, throughout Latin America and the Caribbean, sub-Saharan Africa, the Middle East, North Africa and the Asia-Pacific regions. Each of the four dimensions is described by a set of elements corresponding to specific sections in the questionnaires. Some of the questions included in the questionnaires are directly informative on agri-environmental indicators relevant statistics.

[56] More information about the In-depth Country Assessment is available at http://gsars.org/wp-content/uploads/2014/07/IdCA-final-3007.pdf.

Not only have the answers to those questions, but also the answers to other questions, which have helped to understand the general framework provided valuable information. In summary, information sources used in this analysis include answers to the Global Strategy questionnaires and Global Strategy regional and the country reports, when available; and other national documents and reports; and information provided by FAO experts in the collection of data from FAO member countries.

As it is investigating a field of intersection between two major fields – agriculture and environment – the work relies, whenever possible, on reports concerning environmental statistics, such as the United Nation Environment Programme (UNEP 2012) and Guevara & Lara (2014) in-depth study of the state of environment statistics in nine Latin American countries. The latter was carried out in the framework of a project for strengthening these statistics, making use of a questionnaire touches upon all the stages of the statistical process and its prerequisites, as in the framework described above.

Unfortunately, there is no single homogeneous, complete and updated source of information for all countries, covering all domains of the agriculture-environment interaction, and – given the wide variety of situations – generalizations are quite difficult to make, on the geographical and the topics dimension. Information reported in the present analysis, therefore, is at times unavoidably sketchy. Although synthetic judgements about the general status of things are based on information covering developing countries from all regions, and information is reported concerning most regions of the world, details are included for African and Latin American Countries, for which country and/or regional summary reports can be quoted or referred to. For the Middle East and North Africa and Asia-Pacific regions, it relies on the analysis of the in-depth country assessment questionnaire responses, concerning respectively 9 and 38 countries, carried out by the Global Strategy. A further investigation would surely lead to a more detailed and complete picture, but on the whole, it can be considered that the general features of developing countries' statistical systems that are most relevant for agri-environmental indicators have been captured.

The present analysis identifies some options available to countries for improving production of agro-environment statistics and indicators and inputs, which should be taken into consideration for the experimentations foreseen in successive phases of the SUST-3 research topic.

7.2. Agri-environmental statistics and indicators reported to international organizations: country coverage

This section analyses the statistics and indicators that countries with developed or developing statistical systems produce and report to international organizations. This topic was already introduced in Chapter 5 in terms of coverage of data warehouses; some additional information is provided herein, touching upon country coverage, reflecting the countries' ability to provide data.

7.2.1. Main Databases Maintained by International Organizations

Highly authoritative international organizations in the field are the FAO, OECD and Eurostat. These three organization co-developed the agro-environmental indicators they disseminate, and continue to consider collaborating on other activities. OECD and Eurostat report Agro-environmental indicators in their databases for their member States, which are countries with above-average levels of statistical system development, while the only international database containing such indicators with worldwide coverage is the one developed and maintained by FAO through FAOSTAT. In several cases, country data in more than one database are populated by data drawn from the other organizations, mostly OECD and EUROSTAT drawing from FAOSTAT.

For its analytical work at global level, UNEP gathers information on a wide variety of environmental variables (not only for agricultural systems) from a long list of sources, and reports them in its online database. As for agro-environmental indicators and related statistics, however, UNEP also relies almost entirely on FAO (or on the same international sources as FAO). For Eastern Europe, Caucasus and Central Asia, relevant independent work is carried out by UNECE.

FAOSTAT has a dedicated data domain section for ago-environmental indicators. Similar to OECD and EUROSTAT, FAOSTAT reports under the agro-environmental section data time series mostly up to 2011. Specifically, the FAOSTAT dataset reports data for more than 180 member countries and territories on the following domains: agricultural production; agricultural land use; organic farming; transgenic crops; nutrients; pesticides; energy consumption; biofuels; soil erosion; water resources; water quality; ammonia (emissions); greenhouse gas (emissions shares and intensities); and biodiversity.[57] The latest year present in the database is 2011, but this year is not populated for many variables. Some variables, such as transgenic crop, biofuels

[57] In addition to the indicators included in the compendium, OECD also reports under its agro-environmental indicators "food waste". This is a peculiarity, as this indicator is not included in other agro-environmental indicators sets.

production and soil erosion are scantily populated for all years. The emissions intensities domain has been updated to 2014, while those depending strictly on core FAOSTAT variables are currently being updated to the most recently available underlying data, including land, pesticides and fertilizers (1961-2015).

Many of the relevant statistics for calculating the indicators of the agro-environmental indicators section are available in FAOSTAT under other domains, such as “emissions agriculture”, “emissions land use”, “land”, “fertilizers”, “pesticides” and “production”. Importantly, the latter four domains represent the core environment statistical domains of FAOSTAT, disseminating official country statistics collected through questionnaires and updated annually. The analysis of this data warehouse and of the data reported to FAO by countries, relevant for agro-environmental indicators is reported in the next section.

The OECD database contains a section entitled “environmental indicators for agriculture”. It includes two editions (2008 and 2013) of an “environmental performance of agriculture” dataset, reporting data for its 35 member States on the following domains, similarly to FAO: agricultural production; agricultural land use; organic farming; transgenic crops; nutrients; pesticides; energy consumption; biofuels; soil erosion; water resources; water quality; ammonia (emissions); greenhouse gas (emissions); methyl bromide (emissions); and biodiversity.[58] The latest year present in the database is 2011, but this year is not populated for many variables. Some variables, such as transgenic crop, biofuels production and soil erosion, are scantily populated for all the years.

The OECD data warehouse to a great extent contains data drawn from FAO (FAOSTAT for agricultural production, organic farming, erosion risk, water-related indicators; AQUASTAT for several water-relevant variables). It can be observed that:

- Organic farming is very well represented, with data on agricultural land area under certified organic farm management covering all 35 countries (latest year 2010).

- Variables relating to soil erosion are not referred to actual erosion but to *erosion risk* (measured as area of agricultural land having moderate to severe water/wind erosion risk). Even so, this information is only present for a limited and variable number of countries in any given year, never exceeding 14 (reached in 2010).

[58] In addition to the indicators included in the compendium, OECD also reports under its agro-environmental domain “food waste”. This is a peculiarity, as this indicator is not included in other agro-environmental sets.

- Water resources are well represented, with the indicators for water use (total agricultural water withdrawals, total freshwater withdrawals, share of agriculture in total freshwater withdrawals), and for irrigation (irrigated area, share of irrigated area in total agricultural area, irrigation, freshwater withdrawals and two derived ratios) are populated for most countries and with at least one of the indicators covered for any given country.

- The water quality domain, represented by 12 indicators, of which six of them refer to runoff and concentration in water bodies and six to drinking water limits, is very sparsely populated.

- Biodiversity, which refers to the impact on wildlife of agricultural activities, is represented by an aggregated index for the presence of birds of common species and is taken from an external source – about 20 countries have no data after 2008 and 10 have no data series at all. These represent the full variety of OECD countries situations in terms of the stage of development of the statistical system.

In addition to FAO and a dedicated OECD agri-environment indicators questionnaire, OECD data sources comprise: Eurostat for most variables; as for the European Union countries, the International Federation of Organic Agriculture Movement (IFOAM) and Forschungsinstitut fuer Biologischen Landbau (FiBL) for agricultural land area under certified organic farm management; the International Service for the Acquisition of Agri-biotech Applications for transgenic crop; the International Energy Agency for energy consumption; the European Monitoring and Evaluation Programme for ammonia; UNFCCC for GGE; and UNEP for methyl bromide and Institutions within countries.

The agro-environmental section in the Eurostat data warehouse is comprised of nine datasets, concerning only three of the four domains covered by the European agro-environmental indicators selection (farm management practices, agricultural production systems, and pressures and risks to the environment; the one not present is state of natural resources). Most of the other indicators can be found in other sections of the data warehouse. Eurostat data, which are updated regularly, mostly on an annual basis, rely and on data communicated by member States. Member States carry out surveys on agriculture and/or environment and compile economic accounts for agriculture, and many of these are codified in European Union legislation, so that a high degree of harmonization and comparability is granted. The European Environment Agency (EEA) and the European Joint Research Centre provide most of the remaining data, which is mainly related to the state of the environmental resources used or affected by agriculture. There appears to be no data for two indicators (pesticide risk and genetic diversity) at the moment.

In cases in which data reported in the data warehouses presented above are drawn from other agencies, a more thorough investigation of countries' ability to report data would have to consider to what extent those agencies rely on data communicated by countries rather than on other information sources, such as Geographic Information Systems or business associations. This is unfortunately not possible within the timeframe of the present investigation.

It should be noted that under the ongoing revision of the FAOSTAT agro-environmental data domain section, no plan for additional collection from countries is envisioned. Instead, indicators will serve as an international reference set and be computed directly from the core underlying FAOSTAT domains, its core statistical domains, which rely on official country statistics reported to FAO, such as land use, fertilizers and pesticides and crop production, and the analytical domains, which represent FAO estimates of relevant agri-environmental processes, such as emissions from agriculture and land use and organic Fertilizers.

7.2.2. Data reported by countries to the Food and Agriculture Organization of the United Nations – background information

As the present research focuses on the statistical systems of countries not belonging to OECD or the European Union, a deeper analysis only on data contained in FAOSTAT is presented in the following sections. It includes a discussion of the most significant domains (all but livestock, energy and soil).[59] It is not based on the FAOSTAT agro-environmental indicators domain, as the latter is under substantial renovation, but on the underlying core FAOSTAT agri-environmental statistics, which are regularly updated. Importantly, the present analysis integrates information from relevant domains and their metadata with information provided by the relevant FAO experts.

The communication of statistical information to FAO is a duty of its Member and Associate Member Countries, according to the FAO Constitution. Data disseminated in FAOSTAT represent the core corporate level statistics of FAO. With regard to the relevant text in the FAO Constitution, they are in effect official country data, or otherwise referred to as semi-official data, to distinguish them from those directly disseminated by national sources. Indeed, they are

[59] The data source for the latter are GLASOD and the Harmonized World Soil Database. These databases, as well as the perspectives given by GLADIS, are discussed in Chapter 2.

recognized as such by other, relevant international data reporting processes, with the most important one being the UNFCCC/IPCC reporting under the climate convention. National data are collected through official FAO questionnaires through national focal points. Data gaps and data filling is done by FAO statistical staff and are subject to the FAO Quality Assurance Framework. Domain-specific quality assurance activities (the use of best practices, quality reviews, self-assessments and compliance monitoring) are carried out systematically.[60] FAO statisticians communicate with the countries regularly before and after the collection process as part of established validation and QA/QC processes. By doing this, knowledge is acquired on the countries' ability to gather, elaborate and disseminate data.

As in all international reporting processes, it must be considered that the quality of basic data, which affects the quality of the derived indicators, is the responsibility of the reporting countries. Also, similar to most international collection efforts, measurement inaccuracies are likely present because of a lack of harmonization in statistical methods across countries, or whenever national concepts do not comply with the relevant international standards and guidelines.

It should be noted that the FAOSTAT domains are divided into statistical and analytical domains. The latter disseminate data estimated analytically by FAO, such as GHG. The former disseminate data directly collected from countries through annual questionnaires, with imputations performed by FAO statisticians to fill gaps. The coverage of countries in the FAOSTAT statistical domains closely reflects countries' ability to report data.

7.2.3 Data reported by countries to the Food and Agriculture Organization of the United Nations – domains most relevant for agro-environmental indicators

A case representative of the data reported by countries to FAO is that of pesticides statistics. FAO does not make estimates for this domain, so the coverage reflects whatever data are officially reported by countries. Nevertheless, it is not possible to infer much from the absence of data for specific categories, as many of the products listed in the annual questionnaire are not necessarily relevant for all countries. Response rates seem to be high, especially in cases in which FAO supplies technical assistance in monitoring the correct use of pesticides. FAOSTAT country notes indicate that when sales or other figures, such as consumption of a formulated product, distribution or imports for use in the agricultural sector are reported by countries as a proxy for use, which

[60] The FAO Statistics Quality Assurance Framework is available at www.fao.org/docrep/019/i3664e/i3664e.pdf.

is a possibility specified in the questionnaire's instructions, as monitoring actual consumption is usually rather difficult.

The fertilizers statistics dataset contains information on the production, trade, agriculture use and other uses of chemical and mineral fertilizers products in total nutrients and in amounts of product over the time series 2002-present. Earlier information, for the period 1961-2001, is available in a separate, archived dataset. The fertilizer statistics data are validated in terms of summary totals of production, import, export, non-fertilizer use and consumption, separately for the three main plant nutrients: nitrogen (N), phosphate (P205), potash (K2O). Both straight and compound fertilizers are included.

Primary data sources for fertilizers statistics are the FAO questionnaire on fertilizers and UN Comtrade[61] for trade data, and the data collected are routinely checked for internal consistency, such as for outliers and a significant variation in time series, and validated with countries in case of discrepancies. Coverage of countries is quite high (approximately 95 percent). Similar to pesticides and for the same reason, it is not possible to infer much from the absence of data for specific categories, as many of the products listed in the annual questionnaire are not necessarily relevant for all countries. When variables are clearly missing or underreporting is present, gap filling and imputations are performed by FAO in line with international statistical standards, specifically by applying the material flow balance principle.

Primary sources of data on land use and irrigation statistics are the FAOSTAT dedicated questionnaires. Forest area and biomass stock data are taken for dissemination from the FAO forest resources assessment. These official statistics may be complemented with official government data sources, such as yearbooks and ministerial data portals. Data gaps filling and imputations are performed by FAO statisticians in line with international statistical standards, using secondary sources, such as country studies from other international organizations, and including, when available, geospatial information.

Starting in 2010, the FAO Statistics Division land use and irrigation questionnaire includes items on land used for land area under organic production and land area being converted for organic production. The items included are the following: agricultural area certified organic; agricultural area in conversion to organic; arable area organic; arable area in conversion to organic; permanent crops area organic; permanent crops in conversion to organic; permanent meadows and pastures area organic; and permanent meadows and pastures in

[61] UN Comtrade is a free access database to detailed global trade data. It is a repository of official international trade statistics and relevant analytical tables. Available at www.comtrade.un.org.

conversion to organic. Data for imputation and gap filling in this category are supplemented by other sources, such as FiBL, a research institute of organic agriculture, and the Mediterranean Organic Agriculture Network. In 2013, the data collection was extended to area of arable land and permanent crops under protective cover.

Conservation agriculture is monitored and data are disseminated in the context of the FAO AQUASTAT database, which supplies the numerator for the relevant agri-environmental indicators present in FAOSTAT.

In line with recent developments on climate change relevant statistics, FAO produces estimates of GHG emissions from agriculture and land use, and relevant agri-environmental indicator sets, as discussed previously, based on the guidelines and methodology of IPCC, internationally approved for country reporting to UNFCCC. The FAO database provides estimates at the IPCC Tier 1 default method, representing a useful international reference that countries can use for gap filling or advanced QA/QC analysis of their national inventories. The FAO emissions estimates include emissions from deforestation and forest degradation obtained through the stock-change method of IPCC, obtained by combining information on changes in forest carbon stocks from living biomass above and below-ground, and changes in forest area. In addition, they include estimates of emissions from degradation of peatlands, obtained through analysis and aggregation of multiple sources of geospatial information. The emission estimates are disseminated through FAOSTAT along with the underlying activity data.

Data uncertainty depends on the uncertainty of the IPCC coefficients used and the uncertainty of the underlying data. For the greenhouse gas domain, these have been usefully quantified in several accompanying research papers (Tubiello *et al*. 2013; Federici *et al.* 2015).

7.3. Agri-environmental statistics and indicators produced by the countries

The extent to which agriculture and environment have been integrated into the national statistical system[62] is assessed and presented, including an analysis of the underlying statistical sources and resulting data quality.

7.3.1. Data needs and demands: evaluation of the extent to which agriculture and environment have been integrated into the national statistical system

A basic set of agricultural statistics is produced in most countries. In addition to carrying out censuses, countries regularly produce basic data on area and crop production and on livestock and fisheries. This core information is generally well established in national statistical systems. This is an important basis for the development, within agricultural statistics, of specialized information on the environmental aspects, which, however, may not be the primary concern in many developing countries.

As for statistical information on the environment, according to Global Environment Outlook: Environment for the future we want (GEO-5), issued in 2012 and published by UNEP, "Data collected at the national level are some of the most important sources of information to track the state and trends of the global environment. Environment statistics is an emerging field in most countries, and many have only scattered data. Most developing countries currently have no comprehensive environmental observation system. Data may exist but are often discontinuous, making it difficult to establish a baseline to measure change over time or progress against targets." (p.226). This refers to statistics on the environment in general, not to agro-environmental indicators relevant statistics in particular, but the same outlook highlights also that one of the "three principal data gaps on drivers of global environmental change" concerns precisely "agricultural systems". In particular, "basic information is needed on inflows and outflows of nutrients and water, as well as other important resource flows" (p. 217). Moreover, "in almost all thematic areas, data availability is geographically unbalanced and data are generally scarcer in developing countries" (p.219). Land, water, biodiversity and chemicals feature among the themes for which important and urgent gaps are identified in that report.

[62] "The national statistical system is the ensemble of statistical organizations and units within a country that jointly collect, process and disseminate official statistics on behalf of national government" (OECD, Glossary of statistical terms, http://stats.oecd.org/glossary/)

As for statistical information on agriculture, its general state around the last turn of the decade was described in the regional implementation plans of the Global Strategy.[63] Specific information on availability on agro-environmental indicators or agro-environmental-relevant data is available in regional reports for Africa and the Latin American countries, while it must be drawn directly from the in-depth country assessment questionnaires for other regions.

According to the Country Assessment of Agricultural Statistical Systems in Africa (African Development Bank Group 2014), availability of statistical information on agriculture in general in this region is "average", scoring 62 percent of the maximum attainable (African Development Bank Group 2014, p. xiii). This dimension considers the minimum set of core data requirements, as determined by the Global Strategy. Burkina Faso, Ethiopia, Ghana, and Mali score the highest on this dimension (above 80 percent). Whatever data are produced in these countries are made available to users.

On the other hand, some wealthier countries, such as Angola, Equatorial Guinea and Libya, though capable of funding their agricultural statistical activities and infrastructure, do not make the statistical information produced readily available to users. These countries need support in generating the statistical downstream activities of data processing, analysis, and dissemination to users. In general, Ethiopia is the best equipped country in Africa to run an effective and efficient agricultural statistics system and to produce timely, reliable, and sustainable statistics (66.5 percent in the composite indicator considering all dimensions). The next best performers are: South Africa (65.6 percent), Ghana (64.1 percent), Namibia (63.8 percent), and Egypt (62.9 percent). Guinea-Bissau and Libya are the worst performers (below 20.0 percent). This calls for special advocacy and technical support in the worst-performing countries to scale up and streamline the development of agricultural and rural development statistics.

Integration of Agri-environmental Indicators relevant statistics is in some cases done or planned through agriculture statistics strategic plans, such as in the case of the United Republic of Tanzania (United Republic of Tanzania 2014), which explicitly includes the environmental subsector in the definition of the scope of agriculture, defined as "relation between agriculture and the environment, including use of soils and forests, use of forest products and water use" (page 47). In Nigeria, pesticides and fertilizer data are collected for the entire country by the Federal Ministry of Agriculture, and in the individual states by various local authorities, such as in Kwara state "annually, seasonal and daily basis as the case may be and it is collected from administrative records" by the Ministry

[63] These documents are available at http://gsars.org/en/category/publications/action-plans/.

of Agriculture, the State Statistics Office, Producers' Association and others (Adeyemi *et al*. 2014, p. 98). In Uganda, most agro-environmental relevant data are not readily available, such as information on fertilizers and pesticides inputs, but the Ministry of Water and Environment, the Ministry of Agriculture and the Bureau of Statistics are trying to select and gather some data on core indicators and other related data series (Mubiru 2013). Several other institutions of this country are potentially involved, as was indicated by the participation and the dialogue on national production of environmental information relating to agriculture, in a recent joint training held by FAO and World Bank on SEEA Agriculture, Forestry and Fisheries (SEEA AFF) and agriculture's GHG estimates (FAO, 2016).

In Latin American and Caribbean countries, operative national strategies for the development of statistics are, to a great extent, lacking, according to the *Assessment of The Capacities in Latin American and Caribbean countries to Produce and Disseminate Agricultural and Rural Statistics* (Galmés 2016). Information on the state of the national strategies for the development of statistics was available for 27 countries, of which just 12 (44 percent) had an operative national strategy in 2014. In these cases, agricultural statistics are not always included and, when they are, coverage is limited. This "entails a lack of coordination, the absence of a strategic vision, the failure to integrate agricultural and rural statistics into the NSS [national statistical systems] and dialogue with users" (p.14).

Twenty-three out of the 33 countries in the region (including those that did not reply to the questionnaires) held agricultural censuses over the last decade. In general, the available data are published respecting dissemination calendars. Analysis and use of data, however, represents "the weakest element on a regional level", with scores of under 30 percent of the maximum evaluation attainable, agro-environmental balance sheets and indicators. Within this framework, agri-environmental analysis is one of the most limited areas of use: "a significant weakness in the region's environmental auditing is noted (only four countries replied that they undertake such audits)" (p.15). Only 2 countries out of 17 responded to the questions concerning use of data undertake national water audits, and agro-environmental indicators were compiled in just two countries.

On the environmental statistics side, Guevara & Lara (2014) find "a rather high availability (312 of 512 variables) of the basic set of variables" (p. 8), and that "the production of environmental statistics has been institutionalized, but its consolidation is in process" (p.25). Moreover, "the prioritization of variables that are produced in the countries is consistent with FDES" (p. 33). There also is "consistency between national priorities and the production of statistics" (p. 39).

Biological resources are ranked second out of 19 in the list of priorities and availability, and third in the judgments of relevance; land cover, ecosystem and biodiversity are third for priority and relevance, and second for availability; air emissions, water resources and extreme events and disasters, are in the middle of the rankings; and biochemical application and soil resources are at the very bottom.

In seven of the countries analysed "there is at least one existing programme for the production of basic statistics on environment", with published and regularly updated data (35 percent of the variables are updated "frequently", but 23 percent do not have an update period). Subjects of potential interest for agro-environmental Indicators covered by those programmes comprise, agriculture (Surinam), atmosphere and/or air quality (Jamaica, Mexico, Panama, Surinam), biodiversity (Panama, Surinam), climate and natural disasters (Jamaica, Surinam), energy (Mexico), fisheries or fish stocks (Panama, Surinam), forests resources and/or forestry (Panama, Surinam), land use (Surinam), marine resources (Surinam), protected areas (Surinam), soil (Mexico, Panama), water use or resources (Jamaica, Mexico, Panama, Surinam). Only a few countries have adopted a system of environmental accounts. SEEA AFF is currently being tested in Uruguay. Finally, they highlight opportunities for increasing information both in terms of number of variables and of coverage of the existing ones.

According to the analysis of in-depth country assessment questionnaires, available for nine Middle East and North African countries, core data availability is not bad (59 percent), but the integration of agriculture in the statistical system is average, with a score just above 50 percent of the maximum possible, while analysis and use of data are not sufficient (41 percent).

Analysis of the same questionnaires for 38 Asia-Pacific countries indicates that core data availability and the average degree of integration of agriculture in the statistical system are quite low (39 percent and 36 percent of the maximum theoretical score on the questions representing availability and integration, respectively), with even lower engagement in analysis activities (30 percent). Agro-environmental indicators relevant data are evaluated by the following scores, calculated ad hoc by considering availability, responsible institution(s), year of most recent data, frequency, main sources of data, geographical coverage, quality reliability and consistency of data: area planted 92 percent; irrigated areas 65 percent; quantity of water used 54 percent; fertilizer quantity, 74 percent; pesticide quantity, 55 percent; soil degradation, 19 percent; water pollution due to agriculture, 18 percent; emissions due to agriculture, 16 percent;

water pollution, due to aquaculture 8 percent; and emissions due to agriculture, 6 percent.

7.3.2. Statistical sources for data production

No single, comprehensive and specific source or collection method for agro-environmental indicators relevant data exists across the countries (developing and developed) on which information was scrutinized for the present gap analysis. Countries collect agro-environmental indicators relevant data on different occasions and with different methods, ranging from expert opinions to administrative data and from surveys with personal interviews to remote sensing. Of course, not all methods are suited for all items, so there is a certain coupling between topics and sources.

Agro-environmental indicators relevant data, such as on inputs, especially on Land, are usually collected along with other data when the source is a survey. Rarely are these data the main focus of surveys, but information is often taken from other surveys that focus on different aspects of agricultural activities. Also, the main motivations of the surveys quite rarely are environmental concerns; they more frequently focus on economic aspects or food security issues, although environmental impacts are often considered. This is clearly the result of the wide range of topics covered by agro-environmental indicators, which makes it more efficient to collect data in different ways according to what they refer to and to the owners of the information.

According to Guevara & Lara (2014), a high proportion of environmental statistics in Latin American and Caribbean countries are generated starting with administrative records. Geospatial information is not widely used and produced (only six programmes, four of which are in Mexico). Of these, only the programme in Costa Rica entitled "National Land Information System" is of interest for this report.

The methods and practices used for agricultural statistics in Latin American and Caribbean countries have been analysed by Galmés (2016). The data "do not generally come from the use of robust statistical methods like surveys with probabilistic sampling, but rather from information supplied by diverse informants without the use of objective methodologies" and "estimates based on forecasts or informants continue to be the method adopted by the majority of countries in the region" (page 14).

A thorough overview of the data sources used in Africa and in the Asia-Pacific regions based on the results of the country assessments is included in Global

Strategy report (2015b), including summary tables on main data sources by thematic item.

Sources are grouped into censuses, sample surveys, administrative records, estimates and forecasts, special studies, and expert opinions and assessments. For each data item the percentage of usage of these modalities and the total number of countries that responded for the item are given. All sources are used, although to different extents for different items. It should be noted that the number of responding countries also varies widely between items, with the numbers reported in the tables above for environmental characteristics being among the lowest. As for Africa, main sources are sample surveys for crop areas and production (about 40 respondent countries), land use (24 countries) and water-related statistics (about 20 countries). Administrative data are the main source for forests' production of wood (34 countries), fertilizers and pesticides quantities (about 30 countries) and environmental characteristics of agriculture, such as soil degradation, water pollution resulting from agriculture and aquaculture (no more than nine respondent countries for these themes). Asia-Pacific countries follow a very similar pattern, suggesting a strong connection between items and sources. In both cases, census ranks almost always third.

It can be noted that not always territories within a country are covered by a single source for a given domain, especially in federal states. For example, in Nigeria, which seems to have a fairly good coverage of agro-environmental indicators relevant items, statistical information on fertilizers and pesticides inputs is collected by the Federal Ministry of Agriculture. The data are made available by local administrative authorities, such as those in charge of the supply of agricultural inputs, which use the administrative data they collect to fulfil their mandates, clearly covering each individual state. Information on land resources, land use, land degradation and pollution and major soil types are routinely collected by the National Bureau of Statistics of Nigeria.

The Nigerian Ministry of Water Resources, in conjunction with the Federal Ministry of Environment, maintains statistical information on soil degradation, water pollution due to agriculture and emissions due to agriculture (Adeyemi *et al*. 2014). Water availability – in consideration of its importance for food security – is also a key main focus in least equipped countries. For example, in the United Republic of Tanzania, information on water availability, along with other variables, is collected annually by season from sampled villages, through a village questionnaire compiled directly by village agriculture extension officers, who "lack basic statistical skills" (United Republic of Tanzania, 2014, p. viii).

Agricultural surveys are conducted in exist in Middle East and North African countries, but are not scoring high (48 percent).

7.3.3. Data quality

In general, there is high variability across countries and domains, as corroborated by the in-depth analysis presented above on FAO statistical work. According to UNEP, environmental data "are often discontinuous, making it difficult to establish a baseline to measure change over time or progress against targets".

According to the in-depth country-assessment questionnaires for Ghana, Nigeria and Burkina Faso, the reliability of the main agro-environmental indicators (precipitation, fertilizer and pesticides utilization, water and energy consumption, land and agricultural area), rated on a scale of five, ranging from "high reliable" (1) to "unacceptable" (5), these countries score at least 2 (which indicates "reliable") for every indicator.

In the Latin America and Caribbean region, quality of agricultural data, as assessed by the producers themselves, is a relatively weak element of the "availability of information" dimension for agricultural statistics, scoring 51 percent of the maximum attainable, while punctuality and accessibility are strong (Galmés 2016). For environmental statistics, Guevara & Lara (2014) highlight that, considering the high proportion of data that are generated from administrative records, collection and treatment methods of the latter heavily affect the quality of statistics. Therefore, they suggest a diagnosis be made of the system of use of administrative data and possibly action be taken to enhance it, as this is crucial to overall data quality.

In Middle East and North African countries, data scored 66 percent for relevance. International standards are adopted in a not a completely satisfactory way (with an indicator scoring 52 percent), timeliness is high (89 percent), the overall data quality perception by producers is that they are passable (67 percent) and accessibility is considered fair (70 percent).

In the Asia-Pacific region, for agricultural statistics, there is good data accessibility (74 percent), fair use of international classifications (66 percent) and timeliness (65 percent), and an acceptable quality, reliability, and consistency of data (57 percent).

7.4. Institutional settings

"The challenges posed by environment statistics are generally greater than for most other types of statistics [for] several reasons. […] Most significant perhaps is the fact that a NSO must rely heavily on other agencies to collect and supply the bulk of the primary data. Such a high degree of interdependence between different government bodies demands close cooperation and collaboration" (African Development Bank Group 2014).

Different stakeholders and relative arrangements play a role in the production of agricultural statistics. Below, a brief analysis is offered with a view on legal frameworks, statistical infrastructures and capacity.

7.4.1. Stakeholders and internal arrangements

In addition to the usual actors relevant for agricultural statistics – ministries in charge of agricultural activities, NSOs and other producers and users of statistics concerning agriculture, forestry and fisheries – all institutions concerned with the environment – are stakeholders of growing importance for the agri-environmental domain. On the government side, in particular, the ministry of the environment provides resources in this field.

Based on the responses to questions in the institutional settings section of the African in-depth country assessment questionnaire concerning the core data producers, it is clear that the role of NSOs is usually limited to the construction of general indicators, such as GDP per capita, national poverty rate or number of agricultural workers. "Administrative agricultural data systems are often set up in most countries with the major institution being the ministry responsible for agriculture and then other parastatal and private sector organizations" (Global Strategy 2016a, p. i). Also, the production of agri-environmental indicators relevant statistics, such as on fertilizers and pesticides or water and energy consumption, is typically led by the ministries in charge of agriculture, water and environment and other relevant line ministries involved in related projects.

Meteorological departments may provide information about rainfalls, drought conditions, floods, precipitations and weather. Agricultural statistics are produced in Ghana by four ministries (the Ministry of Fisheries, the Ministry of Lands and Natural Resources, the Ministry of Local Government and Rural Development and the Ministry of Finance) and by the National Development Planning Commission (Mubiru 2014; Opare 2014). For certain topics of cross-cutting interest, such as water management, more institutions are involved. In Uganda, the Ministry of Finance Planning and Economic Development, the National Planning Authority, and the Uganda National Farmer's Federation are represented (Mubiru 2013). In Nigeria, the Department of Planning Research and Statistics of the Federal Ministry of Water Resources collaborates with other departments or units in the ministry “for collecting agricultural statistics for the Ministry while the National Bureau of Statistics collates such information for publication and dissemination to users” (Adeyemi *et al*. 2014, p. 98).

In Latin American and Caribbean countries, diverse institutions related to agricultural, rural and environmental activities are involved in the production, analysis and dissemination of sectoral statistics: “80 percent of the countries analysed declare that in addition to the agriculture ministry, other institutions like the finance or planning ministry, the customs department or the environment department have a responsibility for agricultural and rural statistics” and interinstitutional coordination mechanisms exist: “about two fifths of the countries that replied (8 out of 19) affirm that they have an official forum for dialogue among the suppliers and users of agricultural statistics and a similar number declare that they have an informal dialogue forum”. However, only four countries rate the level of dialogue as “adequate” (Galmés 2016, p.14). Guevara & Lara (2014) find that, in the Latin America and Caribbean region, environmental statistics have “taken an institutional nature” with dedicated administrative units and interagency groups, and “countries have begun to use environmental information for the design and evaluation of policies, there is greater use of it when it comes to respond to an international agreement or requirement” (p.42).

In Middle East and North African countries, coordination of national statistical systems seems to be severely lacking, with four countries scoring 0 percent and only one scoring above 70 percent (Morocco), with an average of 34 percent for the nine countries. The situation of the Asia-Pacific countries is slightly better, with only 40 percent being the average score on the variables representing coordination. In particular, the national statistics council, board or committee covers, where existing, forestry and environment (related to agriculture) statistics in 17 out of 38 countries for which information is available, and water statistics in 12 countries.

7.5.2. Legal frameworks

In Africa, “legal frameworks are generally in place, they are operational and adequate to facilitate the collection, compilation, and dissemination of agricultural statistics” (African Development Bank Group 2014, p.18).

As for the Latin America and the Caribbean region, “100 percent of the region's countries […] have laws regulating the national statistical system and its characteristics, offices and institutions in charge of activities, their hierarchical and technical organization, rights and duties of the administration and public, and the statistical secret as fundamental points" (Galmés 2016, p.13). However, laws are sometimes old and their provisions (for example, the need for interinstitutional coordination or the drafting of national statistics plans) are not fulfilled. As pointed out previously, there is a general absence of operative national strategies for the development of statistics (NSDS). On the environment statistics side, Guevara & Lara (2014) find that, in the nine Latin American and Caribbean countries they analysed, the institutional and legal framework is generally favourable for the production of environmental statistics. Indeed, either general statistical laws can be applied to collection of environmental information, or "environmental laws guide to generate environmental information systems" (p.15).

In the "legal framework indicator", seven countries in the Middle East and North Africa score 100 percent (Egypt, Iraq, Islamic Republic of Iran, Jordan, Morocco, Saudi Arabia, and Sudan) and Lebanon scores 80 percent, while only Yemen (0 percent) seems to have no legal basis for agricultural statistics.

Thirty-eight countries in the Asia-Pacific region have a legal or statutory basis for statistical activities in the country in general. In 29 cases, this covers specifically agricultural statistics. However, only in nineteen cases, this is judged to be "adequate" or "workable', in two "somewhat adequate" and in the remaining cases "somewhat inadequate" or "fully inadequate".

7.4.3. Statistical infrastructures and capacity

In Latin America and Caribbean countries, the presence of good infrastructure for agricultural statistics is indicated by the widespread publication of results and regular conducting of censuses. This is partly the merit of international cooperation on sectorial issues. Seventy-nine percent of countries that replied to the regional questionnaire have declared that they have had participated in some sort of significant technical assistance programme with international cooperation for the sector covered over the three years prior to the data of reference. The most important gap highlighted concerns the absence of statistics inventories: "the existence of a national statistics repository is considered to be an important step toward integrating agriculture into a national statistical system. However, less than half of the countries that replied (9 out of 19) declare keeping said inventory" (Galmés 2016, p.15). Guevara & Lara (2014) find that metadata generation is a challenge for environmental statistics, while there is "a good level of international cooperation" also in this field (p. 29). Access to microdata or online databanks remains very low (it is present in only two of the nine countries they analysed).

The record of the prerequisites dimension of statistical capacity (institutional infrastructure) of the African region is evaluated as being “average” (57.2 percent of the maximum attainable score) in the summary of country assessments (African Development Bank Group 2014). Benin, Burkina Faso, Lesotho, Mauritius, Namibia, Nigeria, Rwanda, Tunisia, and Uganda score the highest (above 80 percent) in the region on this dimension. These countries operate with almost all the fundamental institutional requirements in place in their statistical institutions to produce quality, reliable, timely, and sustainable agricultural statistics to meet the demand of users. By contrast, Libya scores the lowest (15.3 percent) on this dimension. Comoros, Chad, Guinea, Madagascar, Swaziland, and Zimbabwe have low GDP per capita, low agriculture value added (percentage of GDP), and weak institutional infrastructure (below 40 percent) for the production of the required agricultural statistics. These countries require both financial and technical support to improve this dimension. Countries, such as Benin, Burkina Faso, Lesotho, Nigeria, Rwanda, and Uganda, have low GDP per capita and low agricultural valued added (percentage of GDP), yet they have a very strong institutional infrastructure (above 80 percent) needed to carry out agricultural statistical activities. This signifies the existence of best practices, which should be emulated by even the rich countries that have poor institutional infrastructure.

Most countries in the African region register a low score (below 50 percent) on the resources dimension. Mauritius is the only country operating above 60 percent of the required standards. The next best performers are Botswana, South Africa, and Zambia, which score between 50–60 percent, followed by Cabo Verde, Ghana, Malawi, Namibia and Rwanda, which score between 40 and 50 percent. Sudan scores the lowest (3.1 percent) on this dimension. Somalia and Liberia are among the poor countries with a high proportion of agriculture value added, but they have a weak resources base for agricultural statistics activities.

In the countries of the Middle East and North Africa, general statistical infrastructure, physical infrastructure and statistical software capability are satisfactory (68 percent, 62 percent and 57 percent), financial resources availability for agricultural statistics average (58 percent) and the quantitative assignation of staff high (84 percent), but data collection technology and information technology (IT) infrastructure are considered insufficient (47 percent and 48 percent) and the human resources training level has a very low score (21 percent).

In Asia-Pacific countries, general statistical activities are on average satisfactory (73 percent), international classifications are widely used (66 percent) and statistical software capability is average (53 percent), while data capture technology is unsatisfactory (41 percent) and IT infrastructure scores quite badly (25 percent).

7.5. Agri-environmental statistics and indicators production's constraints

Countries are facing different constraints in the production of agri-environmental statistics and indicators, including institutional, technical, and financial limitations. According to the UNEP GEO5 report, "[t]he recent UNDP/UNEP/GEF synthesis of National Capacity Self-Assessments[64] noted that [… w]hile selecting a list of environmental indicators and collecting information was more straightforward in many countries, the main challenge involved managing this information and coordination of the organizations involved, including research institutions and programmes. National environmental management information systems need to be strengthened, as well as the skill sets of associated staff. Measures to address this include application of standards, use of communication technologies and networks, as well as capacity development, public awareness activities and environmental education" (UNEP 2012, pp. 226-227).

However, as Guevara & Lara (2014) note, "[t]he transversality of the environmental theme necessarily implies the engagement of other agencies in the production of environmental statistics" (p.20). This offers opportunities, besides challenges.

These aspects are discussed in more detail in the sections below.

7.5.1. Institutional: internal organization

Lack of internal coordination in the countries is one of the most commonly reported problems affecting the production of data and – even more - their status, as it is often difficult to identify statistics that are accepted nationally and can be shared as official across agencies. The responsibilities of the various institutions

[64] 2010. Available at https://www.google.it/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwjhyK606PLSAhUFQJoKHRDIC64QFggcMAA&url=http%3A%2F%2Fwww.undp.org%2Fcontent%2Fdam%2Faplaws%2Fpublication%2Fen%2Fpublications%2Fenvironment-energy%2Fwww-ee-library%2Fmainstreaming%2Fnational-capacity-self-assessment-synthesis-report%2FNCSA-101209.pdf%3Fdownload&usg=AFQjCNH6igdfBOvw327QEe4Ix5t9OpoB4Q&sig2=-6chD40UdNAdkR6igwSc1Q

in charge of providing data are often not defined within the countries, so it is not clear which entity is supposed to do the transmission. FAO statistical knowledge and experience confirms that it is not unusual that different institutions report different data on the same items, which can be attributed to using different sources, definitions or methodologies. An additional difficulty is institutional changes and arrangements occur over periods of a few years in many reporting countries.

Although referred to as administrative data, which as seen above are an important source of information for agri-environmental indicators, the following remarks are of general relevance: "The challenge that is pronounced in most countries is lack of coordination of [the] institutions responsible for collection compilation and management of agricultural administrative data as well as lack of coordination with the NSOs. This is exacerbated by the fact that there is no legal framework that guides the required institutional arrangements.

Data collected by the different agencies using different methods, definition of concepts, different formats and by staff with differing skills are therefore usually divergent, inconsistent and unreliable (Global Strategy 2016a, p. i).

The situation is particularly well documented for Latin American and Caribbean countries. As an example, for agricultural statistics in general, the following is a quote on the capacities in Latin American and Caribbean countries to produce and disseminate agricultural and rural statistics can be quoted: "the lack of interinstitutional coordination appears as a factor that is clearly limiting systems' capacity to produce and disseminate statistics" (Galmés 2016, p.13) "Despite the existence of interinstitutional coordination mechanisms, 42 percent of the countries that replied to the questionnaire considered the "lack of interinstitutional coordination" to be a "significant or dominant restriction." Only 35 percent of the countries that replied declared having an active National Statistics Council, Board or Committee. On the other hand, 53 percent declared having an active agricultural statistics council, board or committee" (p.14).

As for the environmental side, Guevara & Lara (2104) conclude that there is a need to "strengthen the institutional connection to share and generate statistic between agencies" (p.7), but they are upbeat about the progress made in this area and note some good practices that can be followed: "the institutional connection is still a challenge [but] it is important to highlight that there has been some progress in this field, the majority of the countries under study have established a committee or institutional body to define policies and technical aspects of environmental statistics production. These committees bring desirable results as the link between institutions, standardized definitions, methodologies, same variables, and information flow" (p.20). The "early incorporation of national statistical offices" is one of the two factors "that affect the effectiveness of these organisms", with the other one being that the issue be addressed "at [the] government level" (p.20). Of the nine countries for which the results of the self-assessment were presented, in six of them "committees or specialized technical groups exist, where in a collegiate manner representatives of different institutions define aspects related to technical standards, methodologies and standards applicable to the projects and processes of generation of environmental statistical information" (p.25).

Cooperation and dialogue between different institutions on agri-environmental indicators relevant statistics clearly improves as awareness grows about the importance of environmental aspects and solid international reporting processes are subscribed. This is responsible for a large portion of progress made in recent decades, with the most important example being the UNFCCC process.

Reporting obligations to FAO and related capacity-building activities are another major driver of coordination within countries, as the data published in FAOSTAT are official data, which countries have to report, as seen above, according to the FAO Constitution. The need to identify which data are official promotes internal dialogue, sharing of data, selection of sources and adoption of sound methodologies.

The situation seems to have improved in recent years in the 57 member countries (mainly African) involved in the CountrySTAT[65] system, based on its staff experience. CountrySTAT, indeed, follows and extends (to the extent countries include data not present in FAOSTAT) the same principle of including only data having an official status and complying with international methodological standards; countries are thus obliged, in order to report data in the platform, to have internal dialogues on the data they want to include in the system. Unfortunately, at present, the impact on agri-environmental indicators relevant data remains limited, as these seldom are the first priority for the countries.

[65] CountrySTAT is a web-based information technology system (www.fao.org/economic/ess/ess-capacity/countrystathome/en) for food and agriculture statistics at the national and subnational levels. It acts as a one-stop center, which centralizes and integrates the data coming from various sources and allows harmonizing it according to international standards, while ensuring data quality and reliability. This supports analysis, informed policy-making and monitoring with the goal of eradicating extreme poverty and hunger. Through national and regional CountrySTAT projects, FAO forms partnerships with statistical offices and the ministries of agriculture, fisheries and forestry, among others, to introduce the system and build the national capacity to use it. In each country, the national government makes a substantial contribution to ensure its deployment and continued training and maintenance.

7.5.2. Technical and methodological: technical assistance, data collection and processing, lack of methodologies and/or improving new methodologies

Methodological guidelines are available and can be easily found in an Internet search on the collection, treatment and dissemination of most agri-environmental indicators relevant variables. The guidelines are developed primarily by FAO, which also instructs and assists countries on how to correctly report data, primarily for FAOSTAT. Nevertheless, interpretation is not always easy and there can be difficulties in complying with the given definitions and requirements for international reporting in the way data are collected. For instance, a specific issue, relevant for the correct measurement of land by use, concerns the estimation of crop area under mixed cropping: double counting may be result as far as total crop area is concerned (see, for example, Global Strategy 2017b). Especially "[t]he subjective methods, often used in developing countries, [which] include the field reporting system, eye estimation, farmer interview and expert assessment […] suffer from certain limitations in terms of the reliability of the data on crop area" (Global Strategy 2016a, p.9; Global Strategy 2017b, p.9). Another example involves fertilizers, for which limiting reporting to either production, trade or consumption by products may lead to difficulties in assessing actual agricultural use. Problems of consistency through time are often revealed by comparing data reported by the same country from one year to the other, such as changes in the unit of measurement or in the reference to products rather than to nutrients or vice versa.

The African country assessments ascertained weakness in applying appropriate agricultural statistics methods and practices in the region (41.4 percent of the maximum attainable score). Some relatively poor countries, such as Ethiopia and Ghana, score highly (60–80 percent) on this dimension. Their respective practices might be considered as possible examples to follow by other countries (both poor and rich) that score low, such as Equatorial Guinea, Gabon, Libya, and the Seychelles. "Areas that require special attention include the adoption of data collection technology; improving infrastructure such as establishing Information and communications technology (ICT) networks and information systems; conducting regular agricultural surveys and censuses; and managing data (including data processing, analysis, interpretation and dissemination to data users)" (African Development Bank Group 2014, p. xiii).

In Latin American and Caribbean countries, "30 percent of the countries considered the lack of solid methodologies for implementing agricultural surveys to be a dominant or significant limiting factor for the development of national statistical capacities. Only 6 out of the 19 countries considered use of surveys based on probabilistic sampling to estimate the main parameters referred to crops or livestock. In the case of those that did not respond to the questionnaire, just 3 out of 14 countries are using probabilistic sampling for their agricultural estimates at least in the last three years (Galmés 2016). This is coherent with the lack of development and failure to update sampling frameworks.

Almost 60 percent (10 of 17) of the countries that replied to the assessment questionnaire's section on critical restrictions consider this item to be a dominant or significant limiting factor for the development of their statistical capacities. According to the same author, there is a general failure to incorporate new data capture technologies. Countries "use combined data capture methods (use of mobile devices and/or pen and paper with manual data entry and/or pen and paper with data scanning). However, 15 of the 19 countries that replied continue to use pen and paper forms with manual data entry to capture data, either exclusively or combined, and just nine use electronic data capture devices at some point in the process" (p. 15).

Guevara & Lara (2014) highlight, among the main challenges associated with the production of environmental statistics in the Latin America and Caribbean countries: the necessity to standardize frameworks used by different countries; an insufficient attitude to "take advantage of technology to facilitate information"; "describe and define criteria for better coverage of the variables for which there is a vague description without a clear representation" (p. 7).

7.5.3. Financial and human resources

Lack of financial and human resources for statistics in general and for agricultural and environmental statistics in particular is certainly an important constraint to the development of agri-environmental indicators. "In a number of countries, there is shortage of qualified staff with poor incentives and motivation to work and poor or no supervision resulting in poor quality data collected and compiled" (Global Strategy 2016a, p. i). According to the UNEP GEO 5 report "many of the constraints on environmental data at the national level are strongly linked with the availability of financial and human resources. The cost of national environmental information systems may vary greatly in different countries, and it is important to ensure that methods for data collection, analysis and dissemination are clear and cost effective" (p.228).

According to the country assessments, Africa is weak in allocating financial resources (24.4 percent of the maximum attainable score) for agricultural statistical activities. “Resources” in this context includes not only finances, but also human resources and physical infrastructure to run the agricultural statistics systems effectively and efficiently. Among the many “dominant constraints” of developing a viable agricultural statistics system are: very low level professional staff; lack of statistical training; no direct budget allocation for data collection for agricultural statistics; and lack of supporting facilities, such as field vehicles, hardware or software for data collection and management.

Guevara & Lara (2014) include the lack of financial resources as being among the main constraints to the production of environmental statistics in the Latin American and Caribbean countries, and as a result is a factor behind the discontinuation of projects, which, in turn, results in 23 percent of the variables not having an update period. Galmés (2016) highlights that budgets remain constant from year to year so the situation does not seem to be improving: “70 percent of countries that replied cite the lack of funds as a significant or critical limiting factor for the development of statistical capacities in the country” (p. 14). Also lack of human resources and knowledge on the relationship between human pressures on ecosystems and the latter’s response is a significant constraint in the region: “the problem of human resources available, either professional or technical staff, in central offices or in the field, is rated in this way [i.e. as “significant or critical limiting factor”] by almost two thirds of the countries (65 percent). Almost half of the countries that replied consider that the availability of transportation for field activities is a dominant or significant limiting factor for the development of their statistical capacities” (p. 14). Finally, Galmés (2016) notes a severe lack of staff training: “the region's weakness in this area is noteworthy. While there is scant data on the budget sums and percentages allocated to training, when asked “is there an official programme or a training policy on agricultural statistics?” either in the country or overseas, only 4 out of the 19 countries that replied to the questionnaire did so affirmatively” (p.14).

7.6. The improvement of global production of agri - environmental statistics and indicators

There are different prospects and options for the improvement of global production of agri-environmental statistics and indicators. The following section offers a brief analysis with recommendations on what next steps may be implemented to improve the necessary statistical process in developing countries.

7.6.1. International statistical standards and reference frameworks development and adoption

As already stated, FDES, SEEA and the other international methodologies will not necessarily lead to improved data production, nor will they have the high impact on data collection necessary to support increased reporting under the process to implement the 2030 Agenda for Sustainable Development Goals and the UNFCCC transparency framework. However, the development and adoption of harmonized methodological references and the activities favouring implementation complying with international standards – from practical guidelines to capacity-building – are likely to enhance countries' ability to produce data relevant for agri-environmental indicators.

SEEA-AFF, in particular, developed by FAO and UNSD, as the application of the SEEA-Central Framework to agricultural, forestry and fishing activities provides, as such, the unifying reference framework for the development of most of the agri-environmental relevant information that is consistent across domains. Widespread adoption of it would greatly enhance the prospects in this field. Specifically, SEEA AFF represents a thematic extension of the SEEA Central Framework, the United Nations statistical standard for the development of information relating to the interaction of the socio-economic system with the natural environment.

Substantial coordination efforts are needed to ensure convergence of international initiatives in order to avoid dispersion of resources and confusion among the potential beneficiaries of cooperation projects, as they sometimes are faced with multiple offers of training and support on certain topics – not always necessarily the most urgent ones for the countries.

7.6.2. Administrative data

Greater focus should be placed on gathering and using data and information that administrations have access to as a consequence of carrying out their missions, specifically with regard to the construction of agri-environmental indicators.

This requires doing methodological work to transform them into statistically acceptable measures of information that is not based on scientific sampling. As Guevara & Lara (2014) explicitly suggest, for Latin American and Caribbean countries, it is necessary "to diagnose, and if necessary to strengthen systems that transform this type of data to environmental statistics, in such a way that it ensures the quality of the information produced" (p. 8).

Research in this sense is important as many countries lack the necessary expertise to do it on their own. As already seen, several recent global survey reports have identified and tackled this problems.[66] Possible solutions suggested involve "establishing channels of communication where they are not [present] or strengthening them where they are; and reviving and maintaining the user-producer committees that provide the avenues for dialogue. The institutions should work towards using harmonized tools, definitions and concepts and they should provide appropriate training to their staff who collect compile and manage administrative agricultural data. A hierarchical training protocol should be designed to be used at all levels" (Global Strategy 2016a, p. i). As for the methodological work required for transforming into statistically acceptable measures information that is not based on scientific sampling, pilot field tests were carried out in Côte d'Ivoire and the United Republic of Tanzania, "reviewing the existing agricultural routine reporting system – examining the administrative records data flow, the coordination and supervision, and comparing the current subjective administrative data collection methodologies with improved methodologies" Global Strategy 2016b, p.10). However, before building capacity on this, it would be important to ensure that a suitable infrastructure is in place. For example, for pesticides, registers should be set up in places in which missing quantities should be integrated within them.

7.6.3. Other international and national sources

As already analysed, some of the indicators published by FAO, OECD and EUROSTAT may be drawn from other international sources, which are considered reliable enough. Exploring further these and other similar potential data sources could be an option for the present project, including as part of the effort to avoid the risk of duplicating efforts done by others.

As an example, the World Database on Protected Areas (Juffe-Bignoli *et al. 2016*), disseminated through the Protected Planet online platform,[67] is the most comprehensive global database of marine and terrestrial protected areas,

[66] The complete collection of FAO-Global Survey report on Administrative is available at http://gsars.org/en/tag/administrativedata/

[67] Available at: www.protectedplanet.net/c/about

comprising both spatial data, (i.e. boundaries and points) with associated attribute data (i.e. tabular information). It is managed by the UNEP World Conservation Monitoring Centre (UNEP-WCMC) with support from the International Union for Conservation of Nature (IUCN) and the World Commission on Protected Areas (WCPA). Protected terrestrial areas data from this source are more updated and complete than those currently included in FAOSTAT, which are sourced from the Millennium Development Goals website. Also, it includes both marine and terrestrial protected area which is not currently covered in the land domain of the agri-environmental indicators of FAO.

Reliability of the data from sources other than official ones must be monitored. Among the possibilities that could in principle be explored is sharing information with international bodies that represent stakeholders other than international organizations, for example with producers of current and fixed assets inputs to agricultural activities, such as fertilizers and pesticides. However, there is some risk that the information they could provide may be biased by the specific interests for which it is collected, so this option should be handled with care.

7.6.4. Remote sensing

Remote sensing offers valuable information on the way land is managed. This information, along with its direct use for the calculation of agri-environmental indicators in the land domain, can give a cross-cutting contribution to the efficient collection of data in other agri-environmental indicators domains that are connected to the use of land, such as optimizing the collection of data on soil and water management. Indeed, the presence or absence of certain elements, such as cultivated fields, orchards, roads, walls, agricultural or other kinds of buildings and machinery and other equipment, may be significant in determining possible land uses of a given area. Information on what is present in the areas provided by remote sensing could therefore be used for designing optimal samples. This approach would be more cost effective: “the processed image data can be used effectively to discriminate broad classes of agro ecological zones and land cover, cropped areas, irrigated areas etc., and can provide a foundation for designing and developing the Master Sample Frame (MSF) database, which combines non-spatial and spatial information across the whole survey area or country. The value of the MSF lies essentially in reducing the costs of survey planning and implementation and sample selection by using the same sampling frame for a number of surveys; this can justify the additional effort required to develop the MSF" (Global Strategy 2016c, p. 11).[68]

Several international organizations, such as the European Space Agency, FAO, the National Aeronautics and Space Administration, and the Joint Research Centre-European Commission provide useful geospatial information, and an increasing number of organizations in the private sector are extending this information, with Google being one example. Recent exponential development in open source tools available over the Internet allows users to analyse high and very high resolution satellite imagery for a wide variety of purposes, including:

- Support multiphase national forest Inventories;
- Land use change assessments;
- Monitoring agricultural land and urban areas;
- Validation of existing maps;
- Collection of spatially explicit socio-economic data; and
- Quantifying deforestation, reforestation and desertification.

One such notable tool, Collect Earth, is produced by FAO in partnership with Google. Remote sensing may further aid users in identifying land management practices, including those of importance to conservation agriculture, such as tillage patterns (for instance, if there are no sheds for machines and equipment, it is likely that no tillage takes place) and on protective soil cover/erosion control (soil cover and its changes can be directly observed). Validation and enrichment of the information it may provide through on-site field observation is useful for direct use and necessary for the validation of modelling exercises if remote sensing data are used to derive other indicators other than those that are related to land. Moreover, it may orientate the collection of data not directly observable remotely. Sampling points from a grid and sending observers to validate remote sensing and gather additional information (as in the European LUCAS survey) could be a valid option for observing land cover, land use, soil and landscape in a consistent matter, delivering comparable figures for all territories included.

In the follow-up to the SUST-3 research topic, these potentialities should be exploited for the calculation of agri-environmental statistics globally and to optimize sample designs. The use of this kind of information has a high

[68] These and other Global Strategy reports on remote sensing and geo-referenced information is available at http://gsars.org/en/tag/geoinfo/

benefit/cost ratio, as pointed out in other recent research carried out under the Global Strategy: "In (the) view of current technical progress, the future of remote sensing in agricultural statistics looks bright – though care is needed in applying it in areas, such as sub-Saharan Africa, where the small size of the fields, crop mixtures and heterogeneity of crop phenology are common limiting factors" (Global Strategy 2015, p.15).

7.7. Need to improve national agri-environmental statistics

According to the UNEP GEO5 report (2012), "The specific needs to strengthen environmental information vary in each country, but normally relate to the following issues.

- Collection of high-quality data that adequately cover a full range of established core indicators that can be used to monitor the state and trends of the environment […], and that are coherent and comparable. […]
- Establishment of long-term monitoring programmes in priority areas – based on consistent support in terms of funding and personnel, amongst others [...].
- Developing the necessary in-country expertise and capacity for data collection, quality assessment, analysis and interpretation on different themes.
- Strengthening institutional arrangements and expertise for coordination of environmental and scientific information that exist in-country but may be fragmented, based on clear roles and responsibilities of different agencies, and the incorporation of economic, social and environmental data into national statistical systems.
- Promoting the easy accessibility of data and information […]
- Supporting institutional and other arrangements that increase the use of national data, indicators and information, for instance for environmental assessments; policy making; convention reporting; and educational, scientific and awareness-raising purposes."(p.227)

The lack of financial and human resources and capacity and insufficient coordination were highlighted several times in the previous chapters as severe constraints to the development of agricultural and environmental statistics. As a brief introduction to this concluding paragraph, it is important to stress the key role of coordination of efforts and targeted capacity-building at the intersection of statistical and agri-environmental knowledge.

Clearly, in developing countries, there are many unmet needs concerning all aspects: from physical infrastructure to acquiring hardware and software, from employing more – and more professional – staff, to training the existing staff, from methodology for general data collection to transport equipment, for example. Even if more funds were made available for activities related to agri-environmental indicators, it is very unlikely that they would be sufficient to fill the wide gaps observed; in any case, there will always be need to make more efficient use of the available resources. It is therefore important that duplications of efforts are avoided, through sharing of information on division of work and collaboration among stakeholders.

This need for efficiency and better coordination is not a specific to agri-environmental indicators relevant statistics, so it will be not dwelled on in this report. However, the relevance of agri-environmental statistic to two thematic fields characterizes their specific needs and potentials. This is relevant in particular when it comes to training of staff. From the review undertaken, it is evident that capacity-building, as far as human resources enhancement is concerned, should focus on combining statistical skills and technical knowledge in a balanced way.

Data would greatly benefit from having, on the one hand, the technical staff involved in the recording of administrative data more knowledgeable about statistical aspects and the importance of the data for decisional process. Tools should be provided to inform the staff what they need to do and how to do it, as well as to familiarize them with technological solutions on data collection and organization. On the other hand, statisticians should be given some basic knowledge of the technical aspects, such as on phytosanitary products and on the functioning of the agri-environmental system, so that they can better understand the credibility of the data provided by respondents to surveys or contained in administrative records.

7.7.1. Soil

According to the UNEP GEO-5 (2012), “baseline data and monitoring of changes in carbon stocks are needed, and evidence is still emerging of the significant carbon sequestration potential of rangelands and grasslands” (p. 221).

As already stated in Chapter 2, a wider perspective on land degradation, including the soil carbon dimension, has been adopted in the GLADIS (2011) project:

"Degradation as a process of decline poses its own problems of measurement. Often baseline conditions are arbitrarily set in time as well as in space. The use of remote sensing data to monitor changes in land cover for instance, is largely limited to a period of the last 30 to 40 years. At present, it is almost impossible to identify and monitor global trends of soil, water, and biodiversity quantity and quality over a short or even long time period. Therefore, indirect modelling approaches have to be used that translate known pressures and ongoing processes on these ecosystem services to simulate their declining trend. Care should be taken not to consider the results obtained blindly at other more detailed levels. These global results provide a first indication of possible pressures and trends at national and local level and allow harmonized comparisons to be made between different land uses or between countries" (p. 10).

The integration, through modelling, of information on different dimensions, aimed at assessing land degradation is a characterizing feature of the GLADIS approach, based on the ecosystems approach and bringing together information from pre-existing and newly developed global databases to inform on all aspects of land degradation. Indicators that are used in Nachtergaele, *et al*. (2011) "are quantitative or semi-quantitative. The former is those for which hard data exist, such as the greenness decline in vegetation, while the latter are secondary information derived through empirical algorithms, such as the Universal Soil Loss Equation for the anticipated soil loss rates, or expert-based relationships, such as the salinization effect in irrigated areas" (p. 13).

To the extent that the inputs of GLADIS are not observed, actual on-field data collection on topsoil conditions, such as what was carried out in the European LUCAS survey, could be usefully coupled with modelling. Laboratory analysis of soil samples may be too expensive, but perhaps simple techniques and classification criteria could be developed in order to start refining knowledge on soil worldwide. In this case, also other integrating soil qualities, in addition to carbon content, could be explored, such as "nutrient availability, which is a particular factor to consider when evaluating soil nutrient mining, and the overall soil constraints (workability, salinity, nutrient availability, toxicity, etc.)" (Nachtergaele, *et al*. 2011, p.20). These soil qualities are currently known in a geo-referenced way.

However, the Global AEZ study (FAO 2008), relies on the Harmonized World Soil Database, in which, according to the same AEZ study: "Reliability of the information contained in the database is inevitably variable: the parts of the database that make use of the Soil Map of the World, such as for North America, Australia, most of West Africa and South Asia, are considered less reliable, while most of the areas covered by SOTER databases[69] are deemed to have the highest reliability (Central and Southern Africa, Latin America and the Caribbean, Central and Eastern Europe)".[70] This gives clear indications for the prioritization of efforts.

7.7.2 Water

According to the UNEP GEO-5 report (2012), compiling comprehensive data on water quality and quantity available remains a priority. Rectifying the limited availability of data on groundwater, including quantity and quality, extraction, uses, management and legislation, should be a priority, as water is being extracted unsustainably in many regions. Agriculture, as a major user, is surely one important target of the action needed. UNEP (2012) also notes that "limited data are available on groundwater contamination from substances, such as nitrates and arsenic" (p.221).[71]

The management of water resources is among the topics that rank high in national priorities but often have a lower level of availability than other variables, deemed less important.

7.7.3 Integrated pest management and nutrient management

Many tools and methodological documents concerning data on pesticides and fertilizers are available. Among them are FAO questionnaires with their notes, census guidelines, and more recently the SEEA-Agriculture Forestry and Fisheries Document, which give further guidance on the use of accounts as a basis for the homogeneous organization of information across domains. This is a field in which often a lot more data are collected – such as through surveys or censuses – than actually analysed and disseminated. Capacity-building activities and the provision of simple tools are crucial for overcoming the current difficulties in countries. Countries should be in a position to make more extensive use of agronomic knowledge for statistical purposes, such as by

[69] SOTER aims to establish a World Soils and Terrain Database, at a scale of 1:5 000 000, containing digitized map units and their attribute data in standardized format. The programme is implemented by FAO, UNEP and the International Soil Reference and Information Centre, under the aegis of IUSS, in collaboration with a wide range of national soil institutes, since 1986.
[70] Available at http://data.euro.who.int/e-atlas/europe/documents/source-data/metadata/metadata-soil-texture.pdf.
[71] Nitrates derive primarily from fertilizers, while the absorption by edible plants of arsenic (whether from natural or anthropic sources) poses threats to human health, thus conflicting with agriculture's socio-economic sustainability.

systematically coupling the dissemination of correct products' usage practices with that of correct data reporting practices.

7.7.4. Pesticides

A significant for data collection is the continuous change in the substances used by countries and their commercial names, coupled with the highly specific technical knowledge required to support the statistics production process. As already pointed out, the creation of registers, when missing, could greatly enhance the situation. Also, developing a tool with the capability to check whether reported and analysed data are realistic, or to estimate consumption if the actual application is not reported, would help to improve the information on pesticides. This tool could consist of a simple list that is constantly updated, which would enable non-experts to easily connect commercial names to active substances, including information on the content in active substances of the main commercial products and possible associations with usage for crops or other conditions. This work would need to build on existing information requirements for notifications, made pursuant to the Rotterdam Convention and from the Harmonized System custom codes. A more sophisticated tool could provide default coefficients or calculation routines for estimating pesticides use based on a range of available information, including, for instance, the number of applications through the agricultural year, kind of pests combated and kind and area of cultivation.

7.7.5 Fertilizers

The main priority with regard to fertilizers is the correct measurement and reporting of production and use data. There seems to be a substantial lack of awareness in the countries on the usefulness of the data and on statistical methods to keep confidentiality, which affects the quality of the responses with regard to the willingness to disclose the data and share them between institutions of the same countries. Confidentiality problems often impair the possibility to publish data, such as on nutrients by-products, more often than necessary. One possible way to improve the methods concerns is to enhance the provision of standards to align the reporting of national production and consumption with the one used for trade (the Harmonized System), in order to be able to compute correctly the material flow balances by product and/or by nutrient.

A common problem affecting the quality of data analysis and dissemination is linked to the need for highly specific technical knowledge required to make informed decisions when performing nutrient balances, such as the common practices of mixing nutrients by country or region. Improvements in supporting nutrient balance assumptions by statisticians may include the creation of a reference table of “reasonable” nutrients usage, depending on crop, kind of soil, climatic zone and other relevant parameters.

7.7.6. Land Use and Land Cover

Remote sensing is the most promising methodology for the collection of land cover and, to some extent, land-use data. Remote-sensing data are regularly used at FAO to validate data concerning land cover and land use. As techniques and knowledge evolve, using satellite or other imagery or geospatial data for producing official data is being considered, at least for the production of synthetic reference data products with global coverage and comparability. Moreover, in addition to directly supplying information on land cover and some land use, it may be easily complemented by other information gathered on the ground, and/or used to direct the search for information on other areas of our interest, especially as for soil properties and water use.

As stated in a recent Global Strategy report: “Georeferenced spatial information and technology assume an important role in the preliminary classification and characterization of the territory; this information enables analysis of land use and landscape, such that a land cover baseline, which can also be linked to other georeferenced data, such as vector, raster and tabular data, can be created to facilitate the identification of the different characters and elements of the territory and data integration” (Global Strategy 2016b).

Limitations to the use of remote sensing information for land use characterization are nonetheless well recognized. In the UNEP GEO-5 report, it is stated that “remote sensing has advanced knowledge of land cover and land use, but reliable information on changes is limited as data from different points in time are often not comparable because of changing sensor technology, insufficient ground truthing” (UNEP 2012, p. 221). Although this field is evolving rapidly, some improvement in these aspects is likely to still be necessary.

As discussed above (Section 7.5.2), multiple uses of land during the year pose methodological challenges and result in some cases of double counts, which may, in turn, imply overestimating land used as cropland. The cost-effective improvement of methods to deal with this issue has been tackled in a dedicated study project, funded by the Global Survey.[72] The follow up to the present study should of course profit from the results of that line of research.

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[72] For the complete list of published technical reports, see http://gsars.org/en/tag/crops/.

7.7.7. Organic farming and Conservation Agriculture

Annually, IFOAM/FiBL publishes a report entitled "The world of organic agriculture, statistics and emerging trends", (latest issue: February 2016), and maintains a global database populated by a survey to which experts from 170 countries contribute. The data collected are also used to populate the OECD data warehouse agri-environmental indicators section and to supplement FAOSTAT.

Derpsch & Friedrich (2009), in their Global overview of a CA adoption report observed that "only a few countries in the world conduct regular surveys on CA [conservation agriculture]/No-till adoption" (p. 5). The situation seems to have improved, but the selection of the latest data on AQUASTAT gives results for 54 countries only, with data ranging from 2005 (Venezuela) to 2014 (Australia).[73]

7.7.8. Biodiversity and protected areas

Agriculture poses threats to biodiversity through use of chemicals, through habitat fragmentation as well as through monoculture and high-yield species selection; it also depends on biodiversity, e.g. as for seeds variety and pollinators. The UNEP GEO-5 report highlighted that there is "a lack of data allowing the linking of trends in the state of biodiversity with the drivers of biodiversity loss" (UNEP 2012, p. 222).

Countries report on the Aichi Biodiversity targets under CBD.[74] As of 21 November 2016, 183 parties submitted their fifth national reports (the process started in 2010; UNEP 2016). In its report for the twentieth CBD meeting (closing 17 December 2016), the Subsidiary Body on Scientific, Technical and Technological Advice, focused heavily on the need for better data. It noted that "the amount of information on the status and trends of pollinators and pollination varies among regions, with significant gaps in data, and also limitations in capacity" and recommended that the Executive Secretary and other organizations among which FAO, "to promote, as a priority, efforts to address data gaps and capacity for monitoring" the above-mentioned status and trends "in developing countries, in particular Africa" (CBD 2016, p. 6).

[73] Also see the analysis on the Land domain data reported in 6.3.1.

[74] Information on Aichi Biodiversity targets under the Convention on Biological Diversity are available at www.cbd.int/sp/targets/.

7.7.9. Threats posed by climate change to agriculture

Based on the recent synthesized scientific research published in the IPCC Fifth Assessment Report (IPCC 2014),[75] the impacts of climate change on agriculture production will be largely negative, especially considering the projected increases in the frequency of extreme events, – some of which are already being observed —, which lead to flooding and damage resulting from drought.

Of course, the evolution of the other indicators already discussed, such as those concerning water availability and soil conditions is very relevant in this respect, but other aspects, such as extreme events and the associated losses in agricultural production may require specific attention. Also adaptation is a relevant theme when it comes to the sustainability of agriculture.

FAO is developing jointly with NASA a new FAOSTAT domain on observed mean temperature change, to be released in the fourth quarter of 2017. Although the information has no direct connection to observations of agricultural areas, it will be valuable to analyse overall crop production risk and correlate national level production statistics. This FAO domain, as well as the ones developed on emissions from agriculture and land use, are aligned with two coordinated UNECE task forces, one is working on defining a set of key climate change-related statistics, while the other one involves measuring extreme events and disasters. The former interestingly includes in the list of indicators being discussed includes not only "occurrence of extreme weather events" in general, but also "agricultural losses from droughts, floods and other severe weather events" (Thunus 2016).

[75] Available at https://www.ipcc.ch/report/ar5/

Conclusions and Next Steps

In the present literature review measurable aspects with respect to the interactions between agriculture and environment are described and identified with the objective to produce statistical indicators, while improving the underlying basic statistics. A concise set of indicators, in particular the ones related to the environmental dimension of sustainability, has been proposed, along with their data needs, assumptions and desired properties. A gap analysis related to data and methodological needs for the production of agri-environmental indicators has also been presented.

Describing sustainable agriculture and identifying key aspects for sustainable agricultural practices was the first step in developing a notion that an indicator set may be needed for measurements, monitoring and reporting. It is important to establish the boundaries of what needs to be described – otherwise, it would be difficult to justify what to include or exclude from the indicator list and the number of indicators typically would expand to unwieldy lengths.

As the condition of certain natural resources– soil, land and water – is at the core of the ecological dimension of sustainability, the indicator set was developed to monitor those natural resources. The set was kept to an absolute minimum to help focus the efforts of countries that have less developed information and statistical systems.

An attempt was made to ensure that the indicators could be unambiguously evaluated and that some data were available, although the data may only be accessible from more advanced monitoring and statistical systems. The indicators are not impossible to develop methodologies for data collection. In addition, this provides at least a starting point for implementing them in countries. However, not all of these indicators can be measured at the farm level and consequently more established monitoring networks may be required than would be the case based on periodic agricultural surveys and censuses. The data collection may also need to be coordinated with other already existing programme, such as the Global Environment Monitoring System (GEMS), which is being implemented by UNEP.

A number of domains that are included in other indicator sets, such as climate change, was excluded because it is often highly correlated with the indicators already included in the set. As with any set of indicators, this proposed set of indicators needs to be put into its context and used appropriately in its interpretation and in making decisions. Moxey, Whitby & Lowe (1998, p. 267) makes the following general warning about agri-environmental indicators, which is worth noting

"…the use of any indicator requires a leap of inferential faith. That is, there is a presumption that the underlying science (environmental or social) is sufficiently well understood to relate currently identifiable and measurable indicators to longer-term end-states."

The next step of the SUST-3 research topic will be to tackle the lack of methodologies for the production and establishment of agri-environmental indicators and their underlying statistics. This final objective of the SUST-3 research topic will comprise a methodological proposal to cover the gaps identified in the present literature review, a field-test protocol construction to perform a pilot test of the potential new methodologies and a field-test report that presents and consolidates the findings of the field tests. These activities will be used to set the guidelines on the measurement of agri-environmental variables and the establishment of related indicators.

In particular, the following actions will be implemented by the end of 2017:

- ACTION 1: based on the present literature review, a preliminary vision of the guidelines on data collection methods for agri-environmental Indicators or for the improvement of existing methodologies will be developed and presented to the expert group meeting planned for the fall 2017.

- ACTION 2: a field test protocol on data collection methods for agri-environmental indicators in selected country(ies) will be developed. These protocols will cover, among others, aspects related to the nature of the test, the conception of the data collection, the analysis phase, the budgets and timeline. This action could be useful also for building and strengthening effective national statistical systems, and for strengthening the linkages between country statistics and international United Nations system, such as FAOSTAT.

- ACTION 3: following the outcomes of the expert group meeting, the first draft of the guidelines will be developed.

- ACTION 4: the field test protocol in selected country(ies) will be fully implemented with the active participation of local authorities.

- ACTION 5: following the outcomes of the expert group meeting and the findings of the field test held in selected country(ies), a draft version of the guidelines on data collection methods for agri-environmental

Indicators or for the improvement of existing methodologies will be developed.

The final version of the guidelines will be finalized in the second quarter of 2018.

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