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Challenges and prospects in connectivity analysis in agricultural systems: Actions to implement policies on land management and carbon storage at EU level

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ABSTRACT

There is an increasing interest in climate change mitigation agricultural activities and the effects on carbon (C) sinks. It is essential to study, propose and implement agricultural practices to protect the environment and increase crop yields, whilst at the same time aiming to reduce agricultural emissions and increase C sequestration. Further study of these aspects is important in order to identify the best land management practices and policies to protect the environment. So with this objective in mind, the study of connectivity is an opportunity to gain insight into the sustainability of agroecosystems, due to the close relationship among connectivity, biodiversity and C storage. In fact, high connectivity values can be associated with healthy ecosystems and high levels of biodiversity, which can assure better soil protection and can favor sustainability, implying a greater soil C sequestration capacity.

The measure of connectivity's temporal variation using analysis of current connectivity (inter- and intra-compartments) and the development of risk and vulnerability maps are key facts to, on one side, identify areas most prone to habitat degradation and fragmentation, and then, on another side to establish priorities. This proposed analysis must be carried out by sectors and in a stratified way. For it, "Sector agricultural connectivity units" are proposed as a dimensionless measuring concept to implement this assessment.

To establish agricultural land management schemes and programs for policy intervention at European level in order to guide the strategy to address environmental issues in the agricultural sector, we propose a set of lines of action focused mainly on three aspects: the development of National Action Plans, the establishment of Monitoring Programs, and the integration of their outcomes with the information from available databases through Big Data treatments and other analysis tools. Furthermore, to achieve this goal, the role of farmers can not be underestimated and the communication problems between farmers and scientists should be solved.

1. Introduction

With the Kyoto Protocol (UNFCCC, 1997) a drastic change of attitude towards climate change was initiated. The Kyoto Protocol covers not only emissions of greenhouse gases (GHGs) but also considers the role of sinks, i.e. any process or mechanism that takes away greenhouse gas from the atmosphere. It has been known for some time that increasing soil carbon content by rehabilitating degraded soils and the widespread adoption of soil conservation practices reduces atmospheric carbon (Piccoli et al., 2016; Powlson et al., 2016; Dendooven et al., 2012; Lal, 2012).

Agriculture is not only a means to provide food to the population, but it can also be used as a carbon sink, providing ecosystem services (Jones et al., 2016; Srivastava et al., 2016; Lescourret et al., 2015; Tsonkova et al., 2015; Wood et al., 2015; Banwart et al., 2014; Aertsens et al., 2013; Mandlebaum and Nriagu, 2011). In order to compensate the climate change, there is increasing interest in climate mitigation agricultural activities and the effects on carbon sinks (Ragot and Schubert, 2008; Johnson et al., 2007; Schneider, 2007). The Kyoto protocol considers land use, land use change and land management in agriculture and forestry activities as key facts. If greenhouse gas emissions are not reduced, climate changes are expected to affect food production, health and the environment negatively. The Food and Agriculture Organization of the United Nations (FAO) has stated that agriculture "can be part of the solution by contributing to the mitigation of climate change through conservation, carbon sequestration and

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substitution, and by establishing agricultural systems designed with ecological criteria that may soften extreme events". In order to increase crop resilience to changing environmental conditions and stress factors, farmers need access to climate data such as: agrometeorological tools (to monitor crop growth and post-harvest phase); agro climatic zoning models (to highlight crop characteristics in particular climatic settings); and biodiversity management resources (FAO, 2007).

In all EU member states, farmers keep the countryside alive and maintain the rural way of life. Farmers supply public goods – the most important of which is the good care and maintenance of soils, landscapes and biodiversity. The market does not pay for these public goods. To remunerate farmers for this service to society as a whole, the EU provides farmers with income support. Farmers can be adversely affected by climate change. The Common Agriculture Policy (CAP) provides them with financial assistance to adjust their farming methods and systems to cope with the effects of a changing climate (European Commission, 2012). In the new orientation of the reform Horizon 2020, the Commission has addressed the issue of "greening" or practices beneficial to the environment. These practices of "green payment" cover three aspects: crop diversification, maintenance of permanent pasture and maintenance of ecological interest areas. Environmentally sustainable farming, which uses natural resources prudently, is essential for food production and quality of life.

Farmland ownership fragmentation is one of the important drivers of land-use changes. It is a process that in its extreme form can essentially limit land management sustainability. Land ownership fragmentation also leads to loss of the sense of responsibility for the condition of the land and landscape. Extreme farmland ownership fragmentation can be identified as a major cause of unsustainable land use. Among the most frequently affected land degradation types we can point out the reduction of organic matter (Sklenicka, 2016). Degradation affects soils, biomass, water, and socio-economic services derived from ecosystem. Land use change and the resulting physical and functional disconnection of ecological networks are some of the driving forces of biodiversity loss. Landscape planning and environmental assessment are essential instruments for addressing such problems (Pietsch, 2017).

A healthy ecosystem is linked to high levels of biodiversity. Ecological sustainability refers to the ability to meet the needs of the human population without degrading the ecosystem on which we rely (Callicott and Mumford, 1997) and is considered as a conservation concept (providing ecological services as C sequestration and biodiversity) (Gast et al., 2017; Mononen et al., 2016). Habitat fragmentation is one of the main processes leading to the loss of biological diversity. Connectivity can be favored by managing the set of mosaics identified so as to maintain ecological flows and facilitate movement and continuity of populations.

Natural resources and agronomic practices are key components of agricultural systems; the level of connectivity between these factors affects biodiversity of the agroecosystem, as well as land degradation and habitat fragmentation. This delicate agroecosystem balance is critical for maintaining the three pillars of sustainability; environmentally and economically viable, and socially acceptable. Biodiversity is usually presented as an integrative concept, incorporating both living creatures and the abiotic elements. Abiotic factors are especially important because they directly affect how organisms survive, and most of them as altitude, soil, pollution and nutrients, can vary among ecosystems. Climate and natural disasters, such as forest fires, and soil erosion by water and sediment export across landscapes, are also considered as abiotic factors. All these types of abiotic factors certainly have drastic effects on the ecosystems they encounter.

Respect for certain principles of land use management can lead to increasing long-term resilience and to favor the adaptation of agricultural systems to the effects of climate change. Biodiversity loss is the essential criterion for measuring environmental degradation. Biodiversity conservation is the key of sustainable management and the key factor in maintaining the functions of the agrarian ecosystem. Resilience is an ecosystemic property that derives from biodiversity at multiple scales, ranging from genetic diversity to landscape diversity. Ecosystems can be very resilient but little resistant to a particular disturbance. Changes in ecosystem status translate into a reduction in the production of goods and services, so it can serve as an indicator of degradation. The point at which the ecosystem loses its capacity of restoration or resilience and integrity is called the ecological threshold. If the disturbance is too intense, it gives rise to a cascade of effects that generate marked changes in the ecosystem. The sustainable land management consists of an ecosystemic management, which in an important part has as its underlying objective the continuity of natural resilience.

Further study of these aspects is important in order to address real-world problems related to connectivity. In this context, the synergy between agriculture and biodiversity is often posed in terms of compromise or coexistence. As with all types of human activity, agriculture affects biodiversity, modifying, either positively or negatively, or sometimes contributing to its maintenance. This synergy is said to affect the structural and functional connectivity of the landscape of a region in general and particularly in agroecosystems, which has led to increasing public awareness and policy making.

Interest in connectivity has arisen from the awareness of its multifunctionality (ecological services with market value, self-regulatory capacity of agro-ecosystems…) and reflections on the design of new forms of production to meet the future demands (adaption of systems to climate change, reduction in the use of agro-chemicals…). The association plays an important role in biodiversity, the most resilient element of agro-ecosystems. The term 'agricultural biodiversity' describes, in general, all the elements of biodiversity which are essential for food and agriculture, as well as the components of biological diversity that constitute an agricultural ecosystem. We distinguish between controlled biodiversity (which is the biodiversity of crops and livestock systems chosen by the farmer) and the associated biodiversity that colonizes the agricultural ecosystem (soil fauna, weeds, etc.).

The aims of this work are: i) to integrate connectivity evaluation into action schemes and strategies in agricultural systems in order to identify the best land management practices and best policies to protect the environment as an integrative concept; ii) to propose the development of National Action Plans (NAPs) regarding land management, C sequestration and biodiversity conservation at Member State level; iii) to identify, from information gathered from NAPs, monitoring programs, available databases and big data treatment outputs, the main key factors that should be taken into account in regulatory decisions; iv) to introduce a new measuring concept to develop integrated and coordinated policies in agro-ecosystem at EU level.

2. Materials and methods

Different databases can be considered to obtain information regarding soils at EU level. One of these databases is the published by FAO with more precise information about world soils, which allows the evaluation of land productivity and soil carbon levels (www.fao.org; FAO/IIASA/ISRIC/ISS-CAS/JRC, 2009). The FAO database, called the Harmonized World Soil Database (HWSD, www.iiasa.ac.at/Research/LUC/External-World-soil-database/ accessed in June 2016), provides insight into land productivity, carbon storage and potential for soil carbon sequestration. To build it, four source databases were used to compile version 1.0 of the HWSD: the European Soil Database (ESDB), the 1:1 million soil map of China, various regional SOTER databases (SOTWIS Database) and the Soil Map of the World. Over 16,000 different soil mapping units are included in the HWSD which are linked to harmonised data. Data can be linked to GIS information thanks to the standardized database structure. It is possible to display composition of soil units and selected soil parameters (OC, pH, water storage capacity, soil depth, cation exchange capacity of the soil, total exchangeable nutrients, lime, gypsum contents, sodium exchange percentage,