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An overview on long-term agro-ecosystem experiments: Present situation and future potential

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ABSTRACT

Modern Long Term Agricultural experiments (LTAE) have a long history initiated when modern agricultural science was just at its beginning. After about 180 years from the start of the first of the classical Rothamsted experiments in 1843, these experiments still maintains a consistent appeal for researchers and the interest on LTAEs is growing, as shown by the increasing number of papers dealing with long-term effect of agricultural practices, frequently considering topics, such as sustainability, environmental quality, species-adaptation impacts, that were never envisioned by the founders of classical LTAEs. However, these experiments have numerous constraints and weakness that have to be clearly understood and evaluated when using the data, especially for up-scaling or modelling purposes.

Nevertheless, in our vision, the strengths and the opportunities of LTAEs are still overwhelming, particularly if connected in networks allowing a standardisation of procedures and facilitating the access to data and to the experiments of researchers external to the institution hosting the LTAE.

1. Introduction

The definition of Long Term Agroecosystem Experiment (LTAE) encompasses two basic concepts: the inherent experimental nature of the system and the long-term duration. The first concept is relatively easy to be defined. An experiment should consider a planned manipulation of a system, designed to answer to some specific hypothesis. This marks a boundary between experimental (manipulated) and non-experimental (observational) studies, where the aim is to depict the evolution of a natural system, ideally without influences from the observator. The definition of long-term is, on the other hand, more challenging because it depends on the temporal dynamic of the phenomena under study. Empirical criteria have been considered to define an experiment as long-term and, generally, a LTAE should be at least 15–20 years old to be out from its initialisation phase. Knapp et al. (2012), presenting the criteria for LTAE considered within the North-American Long Term Ecological Research (LTER) network, defined a LTAE as 'one that is planned to exceed or already exceeds six years in length'. This latter definition is interesting because moves the focus on planning of experiments: a real LTAE should be designed from the beginning to have a long-term structure, having clear in mind the research hypothesis and planning it in a sustainable way, both from the biological and economical point of view.

Modern LTAEs were first initiated in the mid 1800s. Most of them were started to assess the effects of some production factor (mostly fertilisation) on productivity and were not primarily designed to be long-term structures (Rasmussen et al., 1998; Johnston, 1997). After the classical Rothamsted experiments started in 1843, many other LTAEs were initiated in United States (Morrow plots were established in 1876 and Sanborn Field in 1888), in Denmark (Askov in 1894), in Germany (Eternal Rye in 1878 and Static Fertilizer in 1902), in Australia (Rutherglen in 1913, Longerenong in 1917 and Waite in 1925), in Poland (Skierniewice in 1923) and in Canada (Lethbridge in 1911 and Breton in 1930) (Rasmussen et al., 1998). It is worth noting that most of the older LTAEs are situated in temperate climates and in highly developed countries.

2. Aims of LTAEs

Although the original purposes of LTAEs were to define the immediate effects of crop management on crop yield and other soil characteristics (SOM, P availability, N dynamics, etc.) (Karlen et al.,

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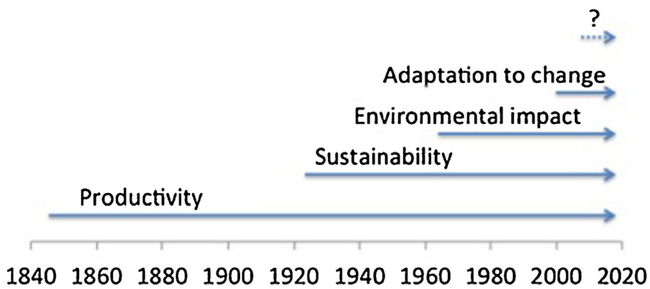

Fig. 1. Evolution of the main topics of agricultural long-term research. Redrawn from Rasmussen et al. (1998).

2013; Bhogal et al., 2015) in the last decades many other potential uses arose (Morari et al., 2006; Stockmann et al., 2013).

As a general rule, LTAEs are essential when considering parameters characterised by a slow temporal dynamics. Indeed, in complex systems the initial response trajectories of monitored factors can be different from the long-term change. Short-term experiments are focused on these initial trajectories, while long-term experiments allow to depict which are the mechanisms involved in temporal dynamics and on the variation of trajectories in time (Knapp et al., 2012).

LTAEs, and the archived material from them, are essential for understanding many of the problems facing farmers, ecologists and policy makers (Richter et al., 2007), from SOM decline to acidification, to nutrient efficiency and leaching from soils to adaptation to climate changes, and so on (Dick, 1992; Giardini and Morari, 2004; Mazzoncini et al., 2011; Amato et al., 2013; Blanco-Moure et al., 2013; Buysse et al., 2013; Lehtinen et al., 2014; Migliorini et al., 2014; Lassaletta et al., 2014; Congreves et al., 2015).

Rasmussen et al. (1998) indicates that most of the main topics now developed within LTAEs, such as sustainability, environmental quality, species-adaptation impacts, were never envisioned by the founders of classical LTAEs (Fig. 1).

Also in the next future new questions will probably arise and the maintaining of proper designed long-term experiments seems to be the best way to cope with these new problems. In particular, Likens and Lindermayer (2011) identified the LTAEs as the best way to:

1. Document and provide baselines against which change or extremes can be evaluated.
2. Detect and evaluate changes in ecosystem pattern and function.
3. Guide and evaluate evidence-based environmental legislation (e.g. laws to control air and water pollutants).
4. Evaluate ecological responses to natural or experimental disturbance.
5. Identify ecological surprises.
6. Generate new and important questions about ecological dynamics.
7. Provide empirical data for testing ecological theory and develop models.
8. Provide information for data mining when exploring new environmental questions.

3. Literature analysis

In order to understand the reasons that have driven many researcher to implant LTAEs and to analyse which kind of observation have been done in the frame of LTAEs, an analysis on the paper published on this topic in the last 50 years using the Scopus database, one of the most common peer-reviewed literature database, has been carried out.

The analysis has been conducted taking into account six "time slot" (1964, 1974, 1984, 1994, 2004 and 2014) to highlight how the interest of the agronomic researchers on LTAEs and the relative observations carried out within them have changed over time. The analysis on Scopus was done searching for "long term experiment" AND "soil" in article title, abstract, keywords, all document type within the subject area "Life Sciences" and limiting the research to "Agriculture and Biological Science". By reading the papers reported in the database; it was possible to quarry the following information each year:

(i) *Total number of papers published on LTAEs.*
(ii) *Number of papers with a relevant agronomical interest*, excluding papers based on data obtained by LTAE <10 years, papers about forestry, botanic and so on, papers without information on LTAE duration.
(iii) *Main treatments tested in LTAE* (i.e. LTAE objectives) divided in five categories:
  (iv) *Fertilization* (including different combinations of mineral and organic fertilization, crop residues soil incorporation, green manuring, soil amendment with different substances).
(v) *Crop rotation.*
(vi) *Cropping systems.*
(vii) *Soil tillage* (including tillage systems, tillage systems coupled with fertilization or crop rotation).
(viii) *Other* (including irrigation, pasture management and grazing).
(ix) *Kinds of observation carried out on LTAE* (i.e. LTAE utilization) divided in five categories:
  (x) *Crop features* (including crop yield, crop root system, weeds, plant species richness).
(xi) *Soil characteristics* (including phosphorus, potassium and nitrogen availability, soil organic carbon, soil physics, soil fungal community, soil microbial community).
(xii) *Greenhouse gas emission.*
(xiii) *Modelling* (including SOC dynamic modelling, crop yields modelling and phosphorus availability modelling).
(xiv) *Other* (including water consumption and water use efficiency).
(xv) *Country where LTAE has been implanted.*

Table 1 summarises the results of the analysis on the aspects (i), (ii) and (v). Data clearly indicate that the interest of the agricultural scientists on LTAEs rose exponentially in the last thirty years considering both the total number of papers on LTAE and the selected papers on this topic.

According with the origin of the LTAEs described in the selected papers, great part of the experiments are located in the developed countries (EU mainly and North America) but in the last ten years the interest for LTAEs raised also in other countries such as Brazil, Argentina, China and India: in 2014 the number of papers on LTAEs coming from these countries have passed those coming from EU plus USA and Canada.

Regarding LTAE objectives (Table 2), our analysis indicates that the main interest of the agricultural scientists over the years was focused on fertilization (both looking at the absolute values and the relative ones). In this context, the specific interest on "organic and mineral fertilization" has grown over the years within the LTAEs going to the detriment of LTAEs that compared mineral or organic fertilization treatments separately (data not shown). The studies on fertilization strongly increased between 1994 and 2004, nearly in the same period in which the first results from LTAEs coming from South America, China, India and developing countries appeared on the international literature. Nowadays (2014), 64% of the peer-reviewed papers based on LTAEs are referred to fertilization.

Another LTAE relevant objective is soil tillage; the interest for this subject strongly increased from 2004 and 2014.