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EXPERIMENTS AS TOOLS IN GEOMORPHOLOGY

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ABSTRACT. *In this introductory article to the special issue "Experiments in geomorphology", the fundamentals of experiments in science, and especially in earth science and geomorphology, are discussed. This is of special interest, as geomorphological sciences crosses scales and thus, different types of experiments are applied for highly variable tasks: (i) Real experiments: to test hypotheses on the process interaction of well defined landscape components; (ii) Quasi experiments: the integrated response of pre-defined morphological units is quantified here; (iii) Hybrid experiments: spatial stratification of the landscape according to statistically evaluable characteristics. A short review on different types of experiments in geomorphology is given, focusing on the processes relevant for soil erosion: splash, inter-rill and linear erosion. Finally, the contributions to the special issue are classified according to the classification of experiments given.*

Los experimentos como herramientas en geomorfología

RESUMEN. *A modo de introducción del número especial dedicado a "experimentos en geomorfología", el presente artículo discute de forma breve la experimentación en Ciencias de la Tierra, y especialmente en el campo de la geomorfología. En este caso, la experimentación se hace especialmente compleja, ya que la geomorfología cruza deferentes escalas y en consecuencia, muy diferentes tipos de experimentos han de ser desarrollados y aplicados: (i) Experimentos reales: en los cuales se analizan hipótesis sobre la interacción de procesos en unidades de paisaje bien definidas; (ii) Cuasi experimentos: se cuantifica la respuesta integral de unidades geomorfológicas pre-definidas; (iii) Experimentos híbridos: con estratificación espacial del paisaje según características analizables de forma estadística. También incluye un breve repaso de diferentes tipos de experimentos, centrándose en aquellos dedicados al análisis de los procesos relacionados con la erosión del suelo. Y finalmente, las contribuciones al número especial son revisadas y catalogadas según la clasificación mencionada anteriormente.*

Key words: experiments, soil erosion, experimental theory, experimental classification, soil erosion measurements.

Palabras clave: experimentos, erosión de suelo, teoría de la experimentación, clasificación de experimentos, medición de la erosión.

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1. Introduction

Experiments are considered to be the most important empirical method in natural sciences. But whilst the observation of natural processes was predominant in ancient times, there has been a development of experimental sciences from mid-17th century (Radder, 2009). Nobel laureate Hannes Alfvén even stated that "We have to learn again that science without contacts with experiments is an enterprise which is likely to go completely astray into imaginary conjecture" (cited by Lundin, 2001). Within Earth science, for more than 100 years experiments have been used to understand the process-response systems of functional geomorphology (Bagnold, 1938; Chepil, 1945; Einstein, 1936; Wollny, 1879). On their basis, fundamentals of process identification and description as well as on experimental design have been defined. But it was only after stating that actual erosion rates exceed soil formation rates by up to 10 times when it became clear that geomorphological research has to shift from a merely descriptive science to a quantitative and experimental scientific approach (Slaymaker, 1991a).

Experiments always contain elements of manipulation and intervention, which make them reproducible (Radder, 2009), and thus allow to reduce the "noise" of the environment (Ahnert, 1980) and to introduce any kind of boundary condition for the phenomena under observation (Bockheim and Gennadiyev, 2009). A very systematic approach is needed therefore not only in defining the problem and proposing the precise questions, or setting up the appropriate hypothesis (Kuhn et al., 2014; Otto and Mönter, 2015), which helps to reduce the complexity of experiments. But also a deep understanding of the interactions of the experiment with its environment: the researcher has to identify and be aware if the interaction is necessary, irrelevant or forbidden for a successful experiment that produces the desired results (Radder, 2009).

2. Experiments in geomorphology

This led to a vivid discussion within the last decades of the 20th century, where Ahnert (1980) defended on one side this very strict view on experiments, criticizing that the *IGU Commission on Field Experiments* was still only talking about measurements – thus putting geomorphology at a level of ancient science of mere observation of nature. On the other side, his position was objected as it was considered that the requested manipulation of the geomorphological system would deliver only artifacts of the experimental setup results, instead of real system observations (Slaymaker, 1991b).

According to this, and the certainty that within geomorphological systems it is difficult to isolate, manipulate and alter system components, three different types of experiments have to be defined, according to their goals, experimental setup and level of abstraction and definition (Kuhn *et al.*, 2014; Slaymaker, 1991b; Slaymaker *et al.*, 1982):

(i) Real experiments: to test hypotheses on the process interaction of well-defined landscape components. They need:

a) strictly controlled field conditions,

b) strict boundaries for defining mass and energy balances,

c) the spatio-temporal conditions and characteristics of the natural system are well known.

They allow a clear and high level of falsification of the hypothesis

(ii) Quasi experiments: the integrated response of pre-defined morphological units is quantified here and:

d) pre-defined knowledge is required about the targeted morphological units,

e) the experimental framework is embedded within the magnitude-frequency limits of the morphologically active events,

f) morphological knowledge replaces a strict and formal experimental design.

(iii) Hybrid experiments: based on the spatial stratification of the landscape according to statistically evaluable characteristics. They are based on:

g) spatial stratification of landscape units to be tested,

h) reduced extent of parameter control,

i) system-based conditions of framework.

Classical plot type experiments, such as implemented by the USDA in the 40's of the 20th century (Wishmeier and Smith, 1978) have been assigned to the first type of experiments mentioned above (Bryan, 1991), but later findings have shown a wide range of uncertainty of the boundary conditions, resulting in a high variability of supposed identical plots (Nearing *et al.*, 1999). In addition, several studies have proven the dependency of the results on the size of the plots (Boix-Fayos *et al.*, 2006; Cerdan *et al.*, 2004; Smets *et al.*, 2008). An exhaustive and very critical review on the sources of errors has been published by Boix-Fayos *et al.* (2007) based on 20 years of own measurements. Consequently, plot measurements are for sure quasi-experiments where a wide range of parameters responsible for runoff generation and erosion are outside the experimenter control. Nevertheless, they contributed for a quantitative analysis of soil erosion, regarding different management types (see, among many others, Edwards *et al.*, 2000; Mutchler *et al.*, 1994; Navas *et al.*, 1997; Ries, 1994; Seuffert, 1993). More recently, the results of plot measurements and other methods for measuring soil erosion have been compiled in different studies (Auerswald *et al.*, 2009; Cerdan *et al.*, 2010; García-Ruiz *et al.*, 2015) for quantification of regional or continental erosion rates. Despite of the real and long term value of these measurements, many of them have been dismantled during the last decades, leading to a lack of measured values of soil erosion (Stroosnijder, 2005). This trend has been inverted during the last decade, where different types of plot systems have been installed (e. g. Bagarello *et al*., 2013, 2011, García-Orenes *et al*., 2010, 2009; León *et al*., 2015; Rodrigo-Comino *et al*., 2015, 2016; Todisco *et al*., 2012). The investigation by Kirchhoff *et al*. (2017) included in this special issue takes over the need to gain real-world data on soil erosion, combining plot measurements with rainfall simulations.

Anyhow, there have been clear experimental approaches in geomorphology for developing process concepts (Bagnold, 1941; Chepil, 1945; Einstein, 1936; Ekern, 1950), but also for understanding and quantifying the forces that lay behind geomorphological processes (Ali *et al*., 2013; Becker *et al.*, 2015, Gimenez and Govers, 2002; Govers, 1989; Kinnell, 1993; Luk and Cai, 1990; Marzen *et al*., 2015; Sidorchuk *et al.*, 2008). But for understanding landscape development, there is a need to recognize and quantify basic principles in geomorphology. To represent this level of abstraction, scaled experiments have been developed, mainly in fluvial morphology (Kleinhans *et al*., 2010; Postma *et al*., 2008; Vermeulen *et al*., 2014; Wallerstein *et al.*, 2001) or mass wasting (Major, 1997; Okuda, 1991). Their benefit for understanding geomorphological systems is widely recognised (Kleinhans *et al*., 2010; Paola *et al*., 2009) and has even led to experiments to explain extra-terrestrial geomorphic features (Shinbrot *et al*., 2004; Védie *et al*., 2008). Despite their valuable contribution to geomorphological research, examples of scaled experiments are not present in this special issue, as the authors of all articles have concentrated their work on field experiments for quantifying and understanding geomorphological processes on landscapes under a strong human impact.

3. The topics of this issue

Regarding soil erosion processes, experiments have been designed to gain information, process knowledge and quantitative insights into the forces affecting the soil surface during soil erosion. Therefore, a wide range of rainfall simulators have been developed (Seyhan, 1977; Shriner *et al*., 1977) and applied in laboratory research (Geddes and Dunkerley, 1999; Goebes *et al*., 2014; Kinnell, 2005a, 2005b, 2001, 1985; Lassu *et al*., 2015; León *et al*., 2014; McGregor *et al*., 1988; Poesen and Lavee, 1991; Slattery and Bryan, 1994). The development and application of rainfall simulators in the field has opened new insights into soil erosion research (see among many others Arnáez *et al*., 2007; Butzen *et al*., 2015, 2011, Cerdà *et al*., 1998, 1995; Cerdà, 1998; Cerdà and Jurgensen, 2011; Imeson *et al*., 1998; Seeger, 2007). But here, one major problem is still unsolved, which was already mentioned by Bryan and De Ploey (1983): the missing standardisation of rainfall simulators, experimental procedures and principles of measurement of the experiments results. Despite the efforts done within the last years (Iserloh *et al*., 2013a, 2013b; Ries *et al*., 2009), there is still a lack in the methodological development of rainfall simulations (Ries *et al*., 2013). The article provided by Zemke (2017) in this issue will add some valuable information on the issues of rainfall simulation methodology still in debate.

In addition to the article of Kirchhoff *et al.* (2017) mentioned above, Iserloh *et al.* (2017) provide a very holistic view of erosion processes at different scales, which includes a clear landscape stratification, and thus corresponds to hybrid experiments as described in advance. This approach, which consists of handling the different scales in which erosion and geomorphological processes are effective and visible, is also followed within the contribution of Ferrer *et al.* (2017). The contributions by Arnáez *et al*. (2017) and Regüés *et al*. (2017) to this issue are clearly in the focus of the debate described previously, discussing if we are confronted with mere measurements and observations. In my opinion, the measurement of soil infiltration under different land uses is a clear experimental approach to the process of water supply into soils, as the results are as variable as the methods that have been developed until now (Hills, 1971; Mertens *et al*., 2002; Sidiras and Roth, 1987; Šimůnek *et al*., 1999). Thus, they are subject to uncertainty of the results and their interpretation in the same manner as the rainfall simulations. In addition, global change can be addressed as a large-scale experiment, in which the boundary conditions of the landscape as a laboratory are changed deliberately. This provides the unique possibility to observe and quantify emerging geomorphological processes, such as terrace collapses.

The paper submitted by Masselink *et al.* (2017) can be seen in a similar way, as it observes natural processes in an unaltered agricultural system. Anyhow, this paper deserves a special mention as it tackles the concept of connectivity in erosion research. This has been discussed for some time (Borselli *et al*., 2008; Cammeraat, 2002; Cerdan *et al.,* 2004; Darboux *et al*., 2002; de Vente and Poesen, 2005; Lehmann *et al*., 2007; Mueller *et al*., 2007; Okin *et al*., 2009), but never applied, and quantified in an experimental way under the natural conditions of an agricultural landscape.

Contrasting with the contributions presented above, the approach of Pavelka *et al.* (2017) provides an experiment *sensu stricto*, as the influencing factors for soil translocation during soil tillage are clearly identified and controlled. In addition, this experimental approach bridges across disciplines, as it connects the investigation on the usability of different Neolithic ploughs and its effects on the soils.

4. Conclusions

This issue of *Cuadernos de Investigación Geográfica* is not able to come across the different types of all possible experiments in geomorphology, and even less to solve methodological and conceptual discussions on the applicability of experiments in soil erosion research and geomorphology. But the contributions clearly show that experiments are still needed to understand the processes that shape our world. Also these new technological and methodological developments have to be taken into account and applied by geomorphologists because a wide range of understanding of the processes we observe is still missing.

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