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Assessment of the quality of meta-analysis in agronomy

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ABSTRACT

A meta-analysis is a statistical treatment of a dataset derived from a literature review. Meta-analysis appears to be a promising approach in agricultural and environmental sciences, but its implementation requires special care. We assessed the quality of the meta-analyses carried out in agronomy, with the intent to formulate recommendations, and we illustrate these recommendations with a case study relative to the estimation of nitrous oxide emission in legume crops. Eight criteria were defined for evaluating the quality of 73 meta-analyses from major scientific journals in the domain of agronomy. Most of these meta-analyses focused on production aspects and the impact of agriculture activities on the environment or biodiversity. None of the 73 meta-analyses reviewed satisfied all eight quality criteria and only three satisfied six criteria. Based on this quality assessment, we formulated the following recommendations: (i) the procedure used to select papers from scientific databases should be explained, (ii) individual data should be weighted according to their level of precision when possible, (iii) the heterogeneity of data should be analyzed with random-effect models, (iv) sensitivity analysis should be carried out and (v) the possibility of publication bias should be investigated. Our case study showed that meta-analysis techniques would be beneficial to the assessment of environmental impacts because they make it possible to study between site-year variability, to assess uncertainty and to identify the factors with a potential environmental impact. The quality criteria and recommendations presented in this paper could serve as a guide to improve future meta-analyses made in this area.

1. Introduction

Systematic reviews are frequently carried out to compile research studies on a specific subject (Evans and Foster, 2011). They involve a rigorous scientific approach comprising the collection, evaluation and synthesis of all studies on a given topic, sometimes contradictory ones, while limiting the introduction of bias (Bland et al., 1995). Systematic reviews may be qualitative if they provide a synthesis of research studies (*e.g.*, Robson et al., 2002), or quantitative, if they involve the processing of a set of data gathered from previous publications. These two kinds of approaches are useful for summarizing large numbers of papers and for the objective establishment (Gurevitch and Hedges, 1993) of what is known and unknown in a specific field (Yuan and Hunt, 2009).

Quantitative systematic reviews are generally referred to as "meta-analyses" when a statistical treatment is applied to a dataset derived from a literature review. The term "meta-analysis" was first coined by Glass in 1976, in the field of educational science, and is defined as a "statistical analysis of a large collection of results from individual studies" (Glass, 1976). A meta-analysis includes typically the following steps (Borenstein et al., 2009; Doré et al., 2011): (i) definition of the objective of the meta-analysis and of the response variable to be estimated from the data. For example, in Miguez and Bollero (2005), the response variable is the ratio of maize yield after a winter cover crop to maize yield in the absence of a cover crop, (ii) systematic review of the literature and/or of the dataset reporting values of the response variable, (iii) analysis of data quality (*i.e.*, quality of experimental design and measurement techniques, precision of the response variable), (iv) assessment of between-study variability and heterogeneity, (v) assessment of publication bias, and (vi) presentation of the results and of the level of uncertainty.

To date, most of the meta-analyses carried out concerned medical science (Normand, 1999; Sutton et al., 2000). In this field, meta-analysis aims (i) to detect an overall treatment effect, (ii) to evaluate the variability between studies, or (iii) to identify study characteristics associated with really effective treatments (Normand, 1999).

Meta-analysis has become an essential technique in human health, and an international organization, the Cochrane Organization, was created in 1993 to prepare, update and promote meta-analyses in this domain (http://www.cochrane.org/). In human health, meta-analyses have long been considered as a field of research in their own right (Cucherat et al., 1997). Meta-analysis

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Table 1
Definition of the eight criteria used to assess the quality of meta-analyses.

Criterion	Definition
Repeatable procedure	A repeatable procedure for the selection of papers for the meta-analysis is presented
References	A list of the references used for the meta-analysis is provided
Heterogeneity	The origins of the variability of the results are analyzed
Sensitivity analysis	The sensitivity of the conclusion to observations or methods is analyzed
Investigation of publication bias	The publication bias is studied
Weighting	Observations are weighted according to their level of accuracy in the statistical model
Availability of the dataset	The dataset is available in an electronic format or published directly in the paper
Availability of the program	The program used for statistical analysis is made available

has been also applied to other areas of science (although less systematically than in human health), such as ecology (*e.g.*, Arnqvist and Wooster, 1995; Cardinale et al., 2006; Stewart, 2010), plant pathology (Rosenberg et al., 2004; Madden and Paul, 2011) and animal science (Sauvant et al., 2008).

Doré et al. (2011) recommended the more systematic use of meta-analysis in agronomy. A considerable amount of experimental data is available from papers published in agronomic journals, and such data could be reviewed, combined and analyzed with statistical techniques to rank cropping systems (within a given environment) according to their impact on crop production and on key environmental variables, such as water nitrate content, the emission of greenhouse gases (*e.g.*, N_2O) or the presence/absence of species of ecological interest (*e.g.*, earthworms, birds). According to Doré et al. (2011), the meta-analysis framework provides an interesting alternative to dynamic crop models (*e.g.*, Brisson et al., 2003; Jones et al., 2003; Keating et al., 2003; Stöckle et al., 2003; van Ittersum et al., 2003) because these models include several sources of uncertainty (Monod et al., 2006) and their predictions are not always reliable (*e.g.*, Barbottin et al., 2008; Makowski et al., 2009).

Meta-analysis appears to be a promising approach for assessing the agronomic and environmental performances of cropping systems, but its implementation requires special care and the value of a meta-analysis may be greatly decreased by the use of inappropriate techniques. Indeed, there is a risk of biased estimation, misinterpretation and incorrect conclusions in meta-analyses performed without sufficient quality control (Sutton et al., 2000). Several authors have proposed quality criteria that could be used to assess the quality of a meta-analysis (Borenstein et al., 2009; Gates, 2002; Roberts et al., 2006; Sutton et al., 2000), but these criteria have not yet been used to assess the quality of the meta-analyses carried out in agronomy.

We therefore assessed the quality of the meta-analyses carried out in agronomy, with the intent to formulate recommendations. We illustrate these recommendations with a case study on the estimation of the emission by legume crops of nitrous oxide, a very potent greenhouse gas with a global warming potential 296 times greater than that of CO_2 (IPCC, 2007).

2. Materials and methods

2.1. Criteria for quality assessment

We defined eight criteria (Table 1), based on the findings of previous studies (Borenstein et al., 2009; Roberts et al., 2006; Gates, 2002), for assessment of the various steps in meta-analyses carried out in agronomy:

(1) Correct description of the bibliographic search procedures used by the authors to select the individual studies (*i.e.*, papers) and the repeatability of these procedures.
(2) Listing of the references of the selected individual studies used in the meta-analysis.
(3) Analysis of the variability of the results of individual studies, including checking to see whether the results vary between the selected individual studies and, when relevant, investigation of the sources of between-study variability (*e.g.*, using random-effects model). Evaluation of the between-study variability of the response variable and of differences in the accuracy of individual estimates is an important step in a meta-analysis and several statistical methods have been proposed for the estimation of between- and within-study variances (Borenstein et al., 2009).
(4) Analysis of the sensitivity of the conclusions to any change in the dataset and/or in the statistical method used to analyze the data. Sensitivity analyses should be carried out to identify influential data and to assess the robustness of the main conclusions of a meta-analysis to the assumptions made in the statistical analysis.
(5) Assessment of the publication bias, which occurs when only studies with highly significant results are published. In this case, a meta-analysis can lead to a biased conclusion and an overestimation of the effect of a given factor. Publication bias is a predominant issue in meta-analysis and several methods such as funnel plots (*e.g.*, Borenstein et al., 2009; Light and Pillemer, 1984) have been developed to detect the presence of such bias in datasets including published results.
(6) *Data weighting*. When the results reported in the individual studies differ in their levels of accuracy, weighting of the data according to their levels of precision is recommended, based, for example, on the inverse of the variance of the measurements, as suggested by Hedges and Olkin (1985).
(7) Availability of the dataset.
(8) Availability of the program used for statistical analysis.

These last two criteria are used to determine whether the meta-analysis could easily be re-run.

2.2. Assessment of the quality of the meta-analyses carried out in agronomy

The quality of the meta-analyses carried out in agronomy was assessed with the eight criteria listed above. One hundred and thirty-six scientific journals publishing papers in agronomy were selected for this purpose. These journals were referred to in the *Journal of Citation Report* (JCR) as journals publishing papers in *Agronomy*, *Agriculture Multidisciplinary*, *Agricultural Engineering*, or *Environmental Sciences*. Journals belonging to the first three categories are further referred to as *Agronomy* and *Agricultural* journals. The scopes of these journals were analyzed and found to be consistent with either the American or European definition of agronomy. The American Society of Agronomy (ASA) definition is "the application of soil and plant sciences to crop production that incorporates the wise use of natural resources and conservation practices to produce food, feed, fuel, fiber, and pharmaceutical crops while maintaining and improving the environment". The definition of the European Society of Agronomy (ESA) is" the relationships between crops, soils, climates and agricultural practices, and between agriculture and the environment".

The papers published in these journals were screened with a systematic literature search (until August 16, 2011) using the