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Literature Review, Meta-Analysis, and Mega-Analysis in Ecological and Agricultural Sciences

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Abstract

Literature review is an important component in any scientific research. In ecological and agricultural sciences, many studies have been conducted over years. With accumulation of scientific studies and published papers, it is critical to summarize and evaluate these previous research findings. Different literature review methods have been applied, including traditional qualitative literature review, quantitative meta-analysis, and more recently, mega-analysis, or meta-meta-analysis. Here we briefly describe these different approaches and draw attention to the recent development of data synthesis. Several case studies were used to illustrate the application of these methods in the ecological and agricultural sciences.

Keywords

Systematic Review, Quantitative Synthesis, Meta-Meta-Analysis, Second Order Meta-Analysis

1. Introduction

Traditional literature review, currently widely used meta-analysis, and more recently mega-analyses have been applied in ecological and agricultural sciences to summarize and synthesize the findings from multiple studies [1] [2] [3] [4]. One common purpose of these reviews is to summarize the current research status on a specific research topic, identify knowledge gaps, and provide future research direction [2] [3]. Of three methods, traditional literature review is the oldest approach. It is a critical analysis and summary of the existing research literature on a specific topic. Traditional literature review provides a systematic and comprehensive evaluation of the existing literature, but the conclusions are mostly qualitative [1] [2]. Meta-analysis is a statistical method that combines the results of multiple individual studies and provides a more robust and quantitative conclusion. It increases statistical power and provides a more precise estimate of effect size. Mega-analysis is a new approach similar to meta-analysis but synthesizes the results of multiple meta-analyses. As a result, a more comprehensive and robust estimation of the overall effect can be generated. These methods are very useful but each has its own strengths and shortcomings. To better use these tools in ecological and agricultural sciences, we briefly describe the purposes of these methods, steps to use them, and advantages and limitations of these methods. Case studies are provided to demonstrate the uses of these methods in ecological and agricultural sciences.

2. Literature Review

The main purpose of a literature review is to summarize and synthesize published information in a particular subject area such as ecological and agricultural sciences [3] [5] [6] [7]. A literature review is a comprehensive evaluation of published studies on a specific topic. The review often demonstrates knowledge and understanding of the academic publications by summarizing, analyzing, and synthesizing the existing knowledge and results [8]. Usually, a literature review includes a summary of published research and a critical evaluation of them, thus, can provide a solid background of the subject area. It helps researchers familiarize themselves with a specific research topic. A good literature review also provides the latest information with the status in the research field and helps in being up to date in the trends and findings [3] [9]. Overall, literature review can provide background information, highlight the significance of the research being conducted, find the areas of controversy, identify gaps in existing knowledge, formulate new research questions or problems, and inform the direction of future research [8] [10].

A literature review involves the following steps: 1) develop the research question and scope of the review; 2) search for relevant studies using databases with keywords; 3) select studies based on inclusion and exclusion criteria; 4) evaluate the quality of the selected studies; and 5) synthesize the findings and draw conclusions [5] [10].

Literature review has long been used in scientific studies including ecological and agricultural sciences to assess the research topics mostly qualitatively [3] [5]. For example, Walther *et al.* [9] reviewed the ecological impacts of climate change on both flora and fauna from the species to the community levels. They found coherent pattern of ecological change across systems and ecological responses to recent climate change were already clearly visible. Warmer temperatures had affected the phenology of organisms, the range and distribution of species, and the composition and dynamics of communities [9]. Juroszek and Tiedemann [11] summarized the state of knowledge of potential climate change effect on insects, pathogens and weeds, and provided suggestions for researchers on how to conceptualize and prioritize future research strategies. The review also identified gaps in research areas, for example, the need of increased number of studies in subtropical and tropical areas and more multi-factorial field experiments. Drewry *et al.* [3] reviewed the effect of irrigation on soil physical properties including water movement and storage in pastoral systems. They found that few studies have been conducted in temperate climates, and changes in physical properties under irrigation in temperate and sub-humid climates were more variable compared to arid and semi-arid climates [3]. Bulk density was increased in some studies, reduced in some, and remained constant in other studies (**Table 1**). There appeared to be a knowledge gap on the effects of irrigation on the physical properties of soils from certain soil orders. Recommendations such as considering a wide range of soil orders, quantifying soil infiltration parameters, and developing components for models or tools were provided for future research [3].

However, there are some shortcomings of traditional literature review. The major one is the biased interpretation. The researchers may selectively choose the publications that support their view and hypothesis, thus, leading to a skewed analysis of the research [7]. Quality and quantity of selected publications will dramatically impact the quality of the review. If the selected references are not exhaustive and of poor quality, the review may not provide a reliable conclusion. Conducting a comprehensive literature review could also be very time-consuming, as it requires a great effort to search, select, and analyze the relevant studies. Overall, traditional literature review can provide a comprehensive understanding of the current state of knowledge on a topic but is often being thought of as subjective and inconclusive [12] [13] [14].

Table 1. Summary of the general effects of irrigation on soil physical properties for studies in the literature (Drewry *et al.* [3]).

Climate, region	Management	Bulk density	Macroporosity	Available water capacity	Reference
Semi-arid, sub humid, humid. Otago, NZ	Unirrigated vs flood irrigated soil	Increase	Decrease	Increase more in soils with lower rainfall	Richard and Cossens (1966)
Semi-arid, sub humid, humid. Otago, NZ	Unirrigated vs flood irrigated soil	Increase	Decrease	Increase more in soils with lower rainfall	Richard and Cossens (1968)
Canterbury, NZ	Flood irrigation, sheep grazing	No change	No change	No change	Srinivasan and McDowell (2009)
Arid, Thar Desert, India	Physiochemical properties, no, low, high flood irrigation	Decreases		Increase	Singh *et al.* (2013)

3. Meta-Analysis

Meta-analysis is a statistical technique that combines the results of multiple individual studies to generate an overall effect size and identify sources of variability and heterogeneity across studies [1] [2] [15] [16] [17]. It is widely used in the field of medicine, psychology, and ecological and agricultural sciences. As meta-analysis combines results from many individual studies on a particular research topic, it increases sample size and the statistical power to detect an effect, leading to a more robust, precise, and accurate estimate of the true effect size. Meta-analysis can also identify and resolve the conflicting results and provide new insights into the relationship between the causes and outcomes [14] [18]. The findings of meta-analyses can guide clinical practice, policy-making, and future research by providing a more general and comprehensive summary of the available evidence in the research areas [14].

The general steps in meta-analysis typically include a systematic review of the literature using certain keywords, selection of relevant studies based on certain criteria, extraction of data mostly including sample size, mean and standard deviation of response variables in the control and treatments, and a statistical analysis of standardized effect sizes such as response ratio to combine the results of individual studies [1] [19] [20]. The detailed step-by-step guide on how to conduct a meta-analysis has been published in several papers [2] [18] [21]. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) needs to be followed when conducting meta-analysis [14]. In brief, the followings are the steps typically involved in a meta-analysis: 1) Formulate the research question and search for relevant studies. A comprehensive search for relevant studies should be conducted with keywords using multiple databases such as Web of Science and Google Scholar [18]. 2) Select the studies. Based on the inclusion and exclusion criteria (e.g., sample size, mean and standard deviation in the control and treatment should be reported), all studies to be included should be included. 3) Extract data. Data from the eligible studies, including effect size estimates and measures of variability (such as standard deviations or standard errors), and other site and covariate variables should be extracted [2]. 4) Calculate the effect size and mean or pooled effect size. An effect size measure should be selected (e.g., response ratio) and calculated for each study, and pooled effect size could be estimated from the individual studies [1] [19]. 5) Evaluate heterogeneity and present and interpret the results. The effect size, confidence interval, and measures of heterogeneity should be presented in a clear and concise manner and correctly interpreted considering the strength of the evidence, the precision of the estimate, and the implications for practice or future research. 6) Assess study quality. Most often, the quality of the studies including publication bias needs to be evaluated using certain tools such as the funnel plot [14] [21].

In ecological and agricultural sciences, meta-analysis has been widely applied since 1990s [1] [2] [19] [22] [23] [24]. For example, Rustad *et al.* [25] conducted a meta-analysis and synthesized data on the responses of soil respiration and plant productivity to warming at 32 research sites. They found that warming (0.3˚C - 6.0˚C) increased soil respiration by 20% (95% confidence interval CI of 18% - 22%), and plant productivity by 19% (15% - 23%). Luo *et al.* [2] compiled data from 104 published papers and investigated the impact of elevated CO_2 on carbon and nitrogen accumulations in land ecosystems and found that elevated CO_2 significantly increased carbon and nitrogen pool sizes in plant and soil, ranging from a 5% increase in shoot nitrogen content to a 32% increase in root carbon content. Deng *et al.* [26] synthesized the results from 112 published studies and evaluated the effects of elevated CO_2 on the nitrogen (N) and phosphorus (P) ratio (N:P ratio) of terrestrial plants. Results show that terrestrial plants grown under elevated CO_2 enhanced plant growth, had lower plant N and P concentrations, but higher N and P pool sizes, and a lower N:P ratio due to more enhancement in P (**Figure 1**). Huang *et al.* [27] reported no-tillage increased crop yield (49% for barley) and decreased greenhouse gas emissions by synthesizing 740 paired measurements from 90 articles. Song *et al.* [17] synthesized 2230 individual studies with 1119 experiments and quantified the responses of key carbon-cycle variables such as ecosystem productivity and soil respiration to warming, precipitation change, elevated CO_2, and N deposition. Increases in global change drivers consistently accelerated carbon-cycle processes, but decreased precipitation slowed down these processes [17]. More recently, Guo *et al.* [28] analyzed 174 studies of N application impact on crop production and found that N fertilization had a positive effect size in crop yield (response ratio = 0.56 ± 0.03) and in global warming potential (0.37 ± 0.05).

The debates surrounding meta-analysis started with the emergence of the method [29]. One of the early debates concerned its appropriateness for combining studies with different experimental designs and methodologies (so called mixing apples and oranges). Other debates included publication bias (e.g., negative results are often not published), quality of individual studies, and incomplete data [14] [21]. Inadequate retrieval of all available literature or the inclusion of primary studies that using poorly implemented methods may result in contradictory or inaccurate conclusions [30] [31] [32]. The discrepancy of data collection process and criteria used for data collection could also result in biased estimation of effect size [32].

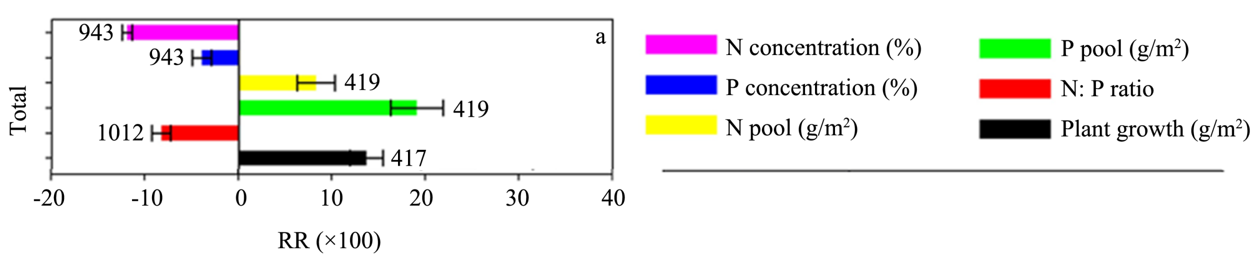

Figure 1. Response ratio (RR) of nitrogen (N) and phosphorus (P) concentrations, N and P pools, N:P ratio, and plant growth biomass to elevated CO_2. Error bars indicated 95% confidence intervals (Deng *et al.* 2016). The sample size for each variable is shown next to the error bar.

4. Mega-Analysis

Meta-analysis is a promising technique for synthesizing individual studies to provide an overall effective size of treatment [1] [2]. However, as the number of meta-analyses in literature increases, results from different meta-analyses on same scientific issues are found to be inconsistent. The overall effective size of treatment generated in meta-analyses is highly dependent on the data selection and methodology used [4] [33]. Recently, mega-analysis, also called meta-meta-analysis or second order meta-analysis, has been applied to provide a systematic review in which the results from multiple meta-analyses are combined and synthesized. The goal of a mega-analysis is to provide a more comprehensive and robust synthesis of the existing evidence from multiple meta-analyses with most updated datasets. This way, a more accurate and precise estimate of the overall effect size can be estimated. Mega-analysis is similar to meta-analysis, as it synthesizes the results from meta-analysis studies; it is also different from meta-analysis, as meta-analysis is based on individual studies. As such, mega-analysis can only be used to address questions that have been investigated in multiple meta-analyses, and to resolve inconsistencies across meta-analyses. Like meta-analysis, mega-analysis can identify sources of variability and heterogeneity in the results and provide a more precise estimate of the overall effect size [4].

Similar to meta-analysis, there are several steps in conducting mega-analysis: 1) Identify the research question and search for meta-analyses publications. 2) Select meta-analyses. Each meta-analysis study needs to be evaluated based on certain criteria to determine if it is eligible for inclusion in the mega-analysis. 3) Extract data. Data from each selected meta-analysis will be extracted, including measures of effect size and variability (e.g., sample size, mean, standard deviation). 4) Statistical analysis. The pooled effect sizes from the included meta-analyses could be calculated based on a statistical model. This will provide an overall estimation of the effect of the treatment from all available data. 5) Interpretation. The results of the mega-analysis, including the pooled effect size and the confidence interval, and any heterogeneity in the results across the meta-analyses could be estimated and presented.

Mega-analysis provides a better estimation and resolves the inconsistence among different meta-analyses. Inconsistence among different meta-analyses has been recognized in previous studies [4] [34]. Synthesizing the results from meta-analyses could identify potential causes of inconsistence and generate more reliable treatment effects. For example, Hungate *et al.* [34] found different data and methods were used in four data analyses on the effect of elevated carbon dioxide on soil carbon and recommended that meta-analysts should critically assess and report choices about effect size metrics and weighting functions, and criteria for study selection and independence. Krupnik *et al.* [32] reviewed meta-analysis papers on organic farming and conservation farming and found that meta-analysis sometimes appears to fuel rather than diminish controversy. They suggest that the use of meta-analysis to appraise and prioritize agricultural research and development investments should be carefully tempered by consideration of the method's analytical limitations. Critical evaluation of the ways in which researchers interpret data derived from plot-scale experiments and discuss their results in the context of diverse farming systems and at regional or global scales is needed. Young *et al.* [33] have conducted a review and synthesized impacts of agronomic measures on crop, soil, and environmental indicators based on 113 meta-analyses, and reported that nutrient management had the largest impact on crop yields and N uptake. Biochar enhanced crop yield, reduced N_2O and NH_3 emissions, but increased CO_2 emissions. Grados *et al.* [35] conducted a systematic review to assess the N_2O emission mitigation practices in agricultural soils using 27 meta-analyses from 1119 primary studies and found that technology-driven solutions such as enhanced-efficiency fertilizers, drip irrigation, and biochar and optimization of fertilizer rate have considerable mitigation potential. Agroecological mitigation practices such as organic fertilizer and reduced tillage may enhance N_2O emissions. More recently, Kaur *et al.* [4] conducted a mega-analysis and evaluated 18 meta-analyses of the effects of biochar application on soil N_2O emissions (**Figure 2**). The magnitudes of the effects varied among different meta-analyses and biochar application significantly reduced soil N_2O emissions by 38.8% (95% confidence interval from 32.4% to 44.8%). The highest reduction of soil N_2O was found in the laboratory incubation studies (51.6%) compared to the field experiments (27.1%). The results of the mega-analysis are more accurate and representative than single meta-analysis [4].

Similar to meta-analysis, mega-analysis will be impacted by publication bias and quality of meta-analyses included in the study. But the major shortcoming of mega-analysis is data dependence, or the overlap of individual studies used in different meta-analyses [3]. If the overlap is high, mega-analysis would be

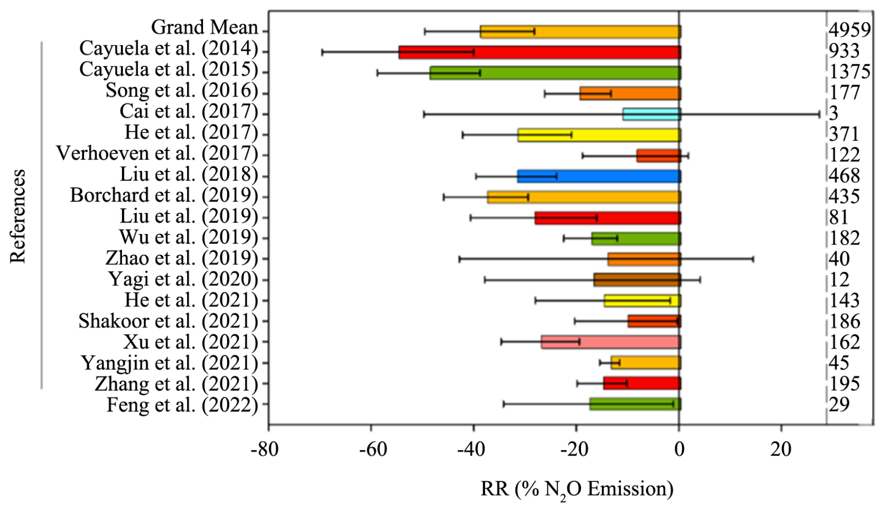

Figure 2. Response ratios (RRs) of biochar application on soil N2O emissions from the meta-analyses and grand mean of RR and its 95% confidence interval (Kaur *et al.*, 2023). The sample size for each variable is shown next to the error bar.

significantly impacted by these individual studies that are repeatedly used in meta-analyses. The results could be more conservative and should be treated with cautions.

5. Conclusion

We provided a brief review of traditional literature review, meta-analysis, and mega-analysis, and their applications in ecological and agricultural sciences. Meta-analysis becomes an increasingly indispensable tool in ecological and agricultural studies and will continue to improve our understanding of ecosystem structure and functioning, crop yield and greenhouse gas emission to environmental changes and agricultural practices [20]. If conducted using sound methods, meta-analysis could provide accurate and quantitative estimations of treatment effects. As more and more meta-analyses are being conducted, a literature review of these meta-analyses becomes necessary. Synthesizing these meta-analyses using mega-analysis could provide even better solution than traditional literature review, as the inconsistency among these meta-analyses could be resolved by estimating a grand mean effect using data from all meta-analyses. Data independence and duplication could be a major issue for mega-analysis [4]. Results of these mega-analyses could be verified using cumulative meta-analysis with non-repetitive datasets from all individual studies used in these meta-analyses. As more data and studies are accumulated in ecological and agricultural sciences, quantitative syntheses would become more and more important in the future.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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