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Research article

Measuring the environmental effects of organic farming: A meta-analysis of structural variables in empirical research

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ABSTRACT

This study examined the structural variables affecting the environmental effects of organic farming compared to those of conventional farming. A meta-analysis based on 107 studies and 360 observations published from 1977 to 2012 compared energy efficiency (EE) and greenhouse gas emissions (GHGE) for organic and conventional farming. The meta-analysis systematically analyzed the results of earlier comparative studies and used logistic regression to identify the structural variables that contributed to differences in the effects of organic and conventional farming on the environment. The statistical evidence identified characteristics that differentiated the environmental effects of organic and conventional farming, which is controversial. The results indicated that data sources, sample size and product type significantly affected EE, whereas product type, cropping pattern and measurement unit significantly affected the GHGE of organic farming compared to conventional farming. Superior effects of organic farming on the environment were more likely to appear for larger samples, primary data rather than secondary data, monocropping rather than multicropping, and crops other than fruits and vegetables. The environmental effects of organic farming were not affected by the study period, geographic location, farm size, cropping pattern, or measurement method.

1. Introduction

Organic farming has been recognized as one of the most reasonable alternatives to conventional agriculture for overcoming the crisis of climate change. Organic farming is currently practiced in 162 countries around the world on 37.2 million hectares of farmland, accounting for .86% of agricultural land in 2011 (FiBL and IFOAM, 2013). Markets for organic foods have been increasing since the European Union (EU) Regulation EEC 2092/91 was enacted in 1991. Worldwide sales of organic food and drinks reached $63 billion from 2008 to 2011 (Soil Association, 2013). The growing importance of organic farming has created an urgent need to compare the environmental effects of organic and conventional farming methods (Venkat, 2011). Because organic farming focuses on sustainability, it is often perceived to have less detrimental effects on the environment than conventional farming, which relies on external inputs to a greater extent (Gomiero et al., 2008).

In recent decades, studies investigating the environmental impacts of organic farming compared to conventional farming have produced conflicting findings. Although some studies have found organic farming to be superior, others have not. The results of environmental assessments of organic farming are difficult to compare because the extant studies have employed different methodologies and measurement procedures (e.g., Hansen et al., 2001; Haas et al., 2001; Stölze et al., 2000). In addition, farming outcomes are extremely sensitive to meteorological and natural conditions. Consequently, a systematic and critical analysis is required to identify and evaluate the structural characteristics of studies that have investigated the environmental effects of organic farming, and to provide guidelines for future research. The present paper reports the results of a meta-analysis of environmental assessment studies of organic farming to identify the variables that contributed to their assessments and to provide recommendations for future studies. This meta-analysis seeks to identify the structural variables that accounted for differences between studies that found better performance in organic farming systems and studies that did not.

The next section reviews literature that compares the environmental effects of organic and conventional farming systems, and

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presents the research framework, which includes the structural variables derived from the literature. The third section describes the meta-analysis and the methods employed in this analysis. The fourth section presents the results of the analysis, and the final section summarizes the findings and presents recommendations for future research.

2. Literature review and research framework

2.1. Environmental effects of organic farming

In recent decades, many studies have compared the environmental effects of organic and conventional farming systems, primarily in Europe and North America. Some scholars have comprehensively reviewed previous studies to assess the environmental effects of organic and conventional farming on energy use and greenhouse gas emissions (GHGE) (Azeez and Hewlett, 2008; Gomiero et al., 2008; Hill, 2009; Lynch et al., 2011, 2012; Niggli et al., 2009; Ziesemer, 2007). Others have conducted simulation studies to predict the effects of converting from conventional farming to organic farming on energy use and GHGE (Acosta-Alba et al., 2012; Halberg, 2008; Hansen et al., 2001; Pelletier et al., 2008; Point et al., 2012; Tzilivakis et al., 2005).

The extant studies have produced different conclusions regarding environmental performance due to differences in the methods employed, which include differences in data sources, sample size, statistical analyses and measurement. In a comprehensive review of the literature comparing the environmental effects of organic and conventional farming, Bertilsson et al. (2008), Gomiero et al. (2008), MacRae et al. (2011), and Mondelaers et al. (2009) found that organic farming was more likely to result in less energy use and lower GHGE per unit of land but higher energy use and emissions per unit of output. However, the results varied due to differences in farm characteristics, data sources, measurement methods and types of analyses. The variability of study results requires the identification of the structural variables that were associated with the conflicting outcomes found in these studies.

Three papers have reported the results of meta-analyses of studies investigating differences in the environmental effects of organic and conventional farming systems. A number of performance measures were assessed, including biodiversity and abundance (Bengtsson et al., 2005), GHGE and environmental pressure (Mondelaers et al., 2009), and nutrient losses, effects on biodiversity, GHGE, eutrophication potential, acidification potential, energy use and land use (Tuomisto et al., 2012). The results of these meta-analyses revealed that organic farming was associated with better outcomes for per unit of land but that there were no differences per unit of output. However, none of the meta-analyses identified the structural variables that accounted for the conflicting results of previous studies.

This study performed a meta-analysis to investigate the structural variables that contributed to the conflicting findings in the literature on the environmental effects of organic farming to determine which structural characteristics were associated with different environmental performance. The structural variables investigated in previous studies were examined, which included data sources (Wood et al., 2006; Pimentel et al., 2005), duration of the data collection years (Bertilsson et al., 2008), measurement methods (Reganold et al., 2001; Deike et al., 2008; Litskas et al., 2011), measurement unit (Gomiero et al., 2008; MacRae et al., 2011; Mondelaers et al., 2009), environmental impact measures (Lynch et al., 2011; Gomiero et al., 2008; Mondelaers et al., 2009), and various farm characteristics. Product (Lynch et al., 2011), location (Petersen et al., 2006; Weiske et al., 2006), size (Mousavi-Avval et al., 2011), and cropping pattern (Bertilsson et al., 2008) of the research farm are included in the farm characteristics. We have added sample size to reflect differences in the statistical sufficiency and study period to check the consistency over time in the studies. These variables are included as they are appeared in all 107 studies used for this meta-analysis. The variables are explained further in the next section.

Other variables are investigated in previous studies, including longitude and latitude, precipitation, temperature, humidity, amount of biomass, soil nutrition and acidification, irrigation, tillage, rainfall, intensity of farming, farm slope, and altitude (Kaltsas et al., 2007; Pimentel et al., 2005; Guzman and Alonso, 2008; Zentner et al., 2011; Moreno et al., 2011; Deike et al., 2008). However, these variables are not considered as they appear insufficient (1–15 times) in the 107 studies used for the meta-analysis.

2.2. Structural variables

In this study, structural variables that have been frequently investigated in comparative studies were classified into the five different categories presented in Table 1: farm characteristics, study characteristics, dependent variables, data sources, and data analyses. Fig. 1 presents the structural categories and their interconnections that served as a framework for analyzing differences in the results of studies on the environmental effects of organic farming.

2.2.1. Farm characteristics

Studies differ with respect to the type of farm employing organic practices and the methods used to measure subsequent environmental effects. Farm characteristics such as geographic location, type of products, farm size, and cropping pattern might affect study results. Farming systems also substantially differ with respect to the type of product and affect on environmental performance. Livestock farming generally uses more energy and emits more greenhouse gasses than crop farming. Previous studies on the environmental effects of organic farming have produced different findings, which depend on the type of product. The types of products examined in this meta-analysis were classified into six categories: field crops, vegetables, fruits, dairy, livestock, and mixed crops.

Because farming is highly dependent on geographic location, which determines natural conditions such as climate, soil, moisture, and environment, the environmental performances of organic farming might also differ. We classified the samples of previous studies into three regions: the EU, North and South America and Oceania, and Asia. Farming systems in these three regions vary markedly with respect to average intensity. Farm size, which differs across countries and continents, also affects the environmental performance of organic farming. Farm sizes in North and South America and Oceania as well as in many European regions are considerably larger for field crops and livestock than in most regions in Asia and certain European regions such as Austria and Switzerland, which exhibit considerably smaller farm sizes. Comparative studies of energy efficiency (EE) have found that farm size has a modest but insignificant effect on EE (Mousavi-Avval et al., 2011).

Cropping patterns also influence the environmental outcomes of farming systems. Monocrop-based industrial agricultural practices have been identified as the key drivers of agricultural GHGE (UNCTAD, 2010). In contrast, crop rotation is one of the most essential and common regulatory norms required for organic farming certification (Codex, 2004; IFOAM, 2005). Thus, cropping pattern, which is classified as either monocropping or multi-cropping, was selected as a variable that might affect the

Table 1
Structural categories and variables.

Categories	Variables
Dependent variables	Environmental effect measures: EE and GHGE
Study characteristics	Sample size: 1–20, 21–100, more than 100
	Duration of data collection: one year, more than one year
Farm Characteristics	Location: Europe, North & South America and Oceania, Asia and Central America
	Products: field crops, vegetables, fruits, dairy, livestock, mixed crops
	Farm size: less than 10 ha, more than 10 ha
	Cropping pattern: monocropping, multicropping
Data source	Study period: before 2005, after 2005
	Data source: field surveys, field experiment farms, secondary data (Database)
Data analysis	Measurement unit: area-based (ratio/ha), output-based (ratio/ton)
	Measurement method: EAM (LCCI), LCA, emergy and others
Environmental effects	Differences in environmental effects of organic and conventional farms

EAM (Energy Analysis Method): The amounts of input and output are converted into input and output energy levels using "energy coefficient" (Moreno et al., 2011) to calculate EE.
LCCI (Life Cycle Climate Impact): Calculates the amount of GHGE using GHG "conversion factors" for each input material and adds the direct emissions generated during the production process.

environmental performance of organic farming. Monocropping refers to single crop farming without rotation and multicropping refers to multiple crop farming with the same rotation during the research periods to compare organic and conventional farming.

2.2.2. Study characteristics

The period during which studies capture and analyze data has also varied considerably. Approximately 72% of the previous studies collected data for less than one year. Because organic systems often have lower nutrient inputs and rely on nutrients added to the soil before conversion to organic agriculture, it might take decades for yields to decline to levels reflecting true organic practices. Due to potential overestimation, surveys based on short-term data collection might produce results that are more favorable to organic farming (Bertilsson et al., 2008). Previous studies employing data from field surveys and secondary sources were more likely to limit cross-sectional comparisons to one year or to one crop season, which is not sufficient to capture the spillover effect of nutrient residues in the soil. Only a few studies using secondary sources have employed databases with multi-year data (Meisterling et al., 2009). In contrast, previous studies using data from farms with crop rotation and experimental farms were more likely to perform multi-year comparisons. Studies conducted on the experimental farms of research centers have sample periods ranging from 10 to 30 years (Cavigelli et al., 2009; Gelfand et al., 2010; Hoeppner et al., 2005; Küstermann et al., 2007; Moreno et al., 2011; Nemecek et al., 2011; Nguyen and Haynes, 1995; Pimentel et al., 2005; Reganold et al., 2001; Robertson et al., 2000; Stalenga and Kawalec, 2008; Zentner et al., 2011). In the present study, the duration variable included two categories: one year and multi-year.

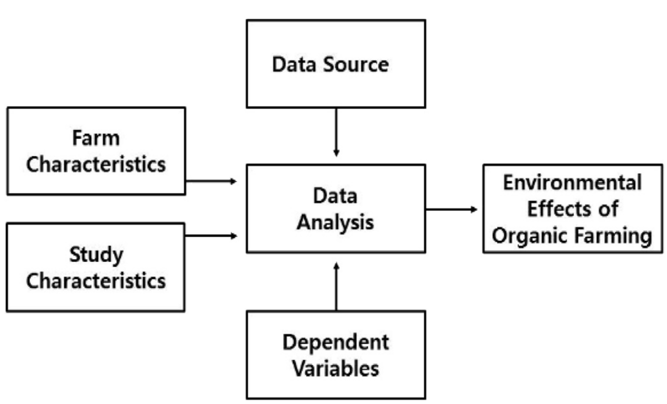

Fig. 1. A framework for the structural factors influencing environmental outcomes for organic farming.

Studies with smaller sample sizes tended to exhibit larger standard errors, making it more difficult to distinguish the effects of organic farming from random noise. Thus, sample size, which is the number of case farms, might affect the comparison results of organic and conventional farming effects. We have classified the sample size variable into three categories: small size (1–20), medium size (21–100), and large size (more than 100). The large sample size represents most national level studies and the medium sample size represents most regional level studies with secondary data. The small size sample usually represents field surveys and experiments. The classification evenly spreads the previous studies into the three designated categories.

2.2.3. Data source

Because study accuracy depends upon the quality of the data analyzed, data should be accurate and contain few and minor errors. Consequently, the type of data source was critical for the analysis. Objective data from secondary sources is easier to obtain. These sources provide more farm samples, which increases the generalizability of the study results. However, data from secondary sources lack detail and flexibility due to the use of predetermined categories. Previous studies were based on three types of data sources: field surveys, field experiments, and secondary databases. These three categories were also used in our meta-analysis. Data collected from uncontrolled selected farm studies are included in farm studies and data from controlled field experiments are included in the field experiments.

Compared to earlier studies, later studies generally exhibited improvements in the models, methods and data employed. The first published comparison of EE for organic and conventional farming systems was reported by Klepper et al. (1977). A few studies were performed after 1977 and before 2000 (Berardi, 1978; Nguyen and Haynes, 1995; Pimentel et al., 1983; Refsgaard et al., 1998), and the number of studies doubled after 2006 compared to the early 2000s. To compare the consistency of the research findings obtained before 2005 and after 2006, the analysis included a study period variable.

2.2.4. Dependent variables

The reported environmental effects of organic farming might be influenced by the effect measures used in the assessment. Although many potential environmental indicators are available, EE and GHGE have been used most frequently in studies that compare organic and conventional farming. A search of over 100 studies on the environmental effects of organic farming based on the Google

Scholar database and the reference lists of previous studies revealed that 45 studies used EE, 40 studies used GHGE, and 22 studies used both EE and GHGE as outcome measures. This body of literature included working papers, research articles and doctoral dissertations published from 1977 through 2012. Consequently, our meta-analysis used EE and GHGE to compare the environmental effects of different farming systems.

2.2.5. Data analysis

The use of EE or GHGE to assess the environmental effects of farming systems required consideration of the unit and the methods of measurement employed because previous studies have used different units and methods to measure EE and GHGE. Several studies measured EE and GHGE based on area (ha). Others measured EE and GHGE based on output (ton). Because the yields of conventional and organic farming might differ, output-based measures often do not favor organic farming, particularly for GHGE (Lynch et al., 2011). Brentrup et al. (2001) used an output-based measure rather than an area-based measure to assess land use efficiency. We employed both output-based and area-based measurement units to compare the results.

Although previous studies have employed different measurement methods to assess the environmental effects of agricultural practices, only a few measurement methods have been used to compare organic and conventional farming systems. In this analysis, the Energy Analysis Method (EAM), Life Cycle Assessment (LCA), Emergy, and other methods, including Life Cycle Climate Impact (LCCI), are compared.

3. Methods

3.1. Meta-analysis

Meta-analysis refers to a set of statistical methods specifically designed to compare and synthesize the results of multiple studies. The method is rooted in the fundamental values of the scientific enterprise: replicability, quantification, and causal and correlative analysis (Bangert-Drowns and Rudner, 1991; Benbasat and Lim, 1993; Kohli and Devaraj, 2003). Meta-analysis enables researchers to test theories based on past research and provides directions for future research (Hunter and Schmidt, 1990). Because earlier studies independently compared the environmental effects of organic and conventional farming systems, this meta-analysis seeks to identify the structural dimensions that were associated with conflicting results in these previous studies. This meta-analysis focused on identifying the structural variables that distinguished studies that found positive environmental effects for organic farming systems and those that did not.

Following Glass et al. (1981), the meta-analysis in this study consists of the following steps:

(1) The development of a framework identifying the structural variables explaining differences in the results of previous studies (described above);
(2) A literature search identifying the prior studies to be included in the analysis;
(3) Coding of variables representing the structural variables included in the meta-analysis;
(4) Statistical procedures for meta-analyses based on regression (here, logistic regression); and
(5) Presentation of the meta-analysis findings and recommendations for future research.

Our meta-analysis compared environmental effects by focusing on farm-level studies that employed EE and/or GHGE as environmental effect measures. The analysis was based on research articles, recent working papers, and doctoral dissertations published through December 2012, which were obtained through a literature search based on the Google Scholar database. The analysis also included studies identified by screening the bibliographies of previously published review papers (Azeez and Hewlett, 2008; Gomiero et al., 2008; Hill, 2009; Lynch et al., 2011, 2012; Niggli et al., 2009; Ziesemer, 2007) and other relevant articles. The final analysis was based on 107 studies published from 1977 through 2012 that compared organic and conventional farming systems using EE and/or GHGE as outcome measures, and thus providing 67 EE studies and 62 GHGE studies overall.

3.2. Variable coding and analysis

The independent variables used in the analyses were as follows: (a) sample size, (b) duration of the data collection years, (c) farm location, (d) type of product, (e) farm size, (f) cropping pattern, (g) study period, (h) data source, (i) measurement unit, and (j) measurement method. Table 2 presents these variables, which were identified and coded as described above. The independent variables were fitted into two separate models, one for EE and one for GHGE.

The environmental effect variable, which represented the difference between the environmental performance of organic and conventional farming methods, served as the dependent variable in the meta-analysis. The environmental performance difference might be positive (i.e., organic farming was superior), neutral (i.e., no difference between organic and conventional farming), or negative (i.e., conventional farming was superior). In this study, the outcome variable was binary with a value of 1 (positive) or 0 (neutral or negative).

The logistic regression analysis provided the statistical basis for identifying the structural variables that distinguished between the

Table 2
Variable coding.

Structural variables	Coding	
Sample size	0	1–20
	1	21–100
	2	More than 100
Duration	0	One year
	1	Multi-year
Location	0	Europe
	1	North & South America, and Oceania
	2	Asia and Central America
Products	0	Field crops
	1	Vegetables
	2	Fruits
	3	Dairy
	4	Livestock
	5	Mixed crops
Farm size	0	Less than 10 ha
	1	More than 10 ha
Cropping patterns	0	Monocropping
	1	Multicropping
Study period	0	Prior to 2005
	1	After 2005
Data source	0	Field survey
	1	Field Experiments
	2	Secondary data
Measurement unit	0	Area-based (ratio/ha)
	1	Output-based (ratio/ton)
Measurement method	0	EAM (for EE) or LCCI (for GHGE)
	1	LCA
	2	Emergy & others
Environmental effects	0	Neutral or negative
	1	Positive[a]

[a] Positive outcomes for organic farming represented higher EE and lower GHGE for organic farming in comparison to conventional farming.

EE and GHGE studies that found beneficial effects for organic farming and those that did not.

4. Results

Farm-level research that compares environmental effects for organic and conventional farming systems has been conducted since the late 1970s. The number of studies increased sharply during the late 2000s (Fig. 2). Some of the 67 EE studies and 62 GHGE studies examined multiple farm products and included both area-based (/ha) and output-based (/ton) measures of environmental effects, which increased the number of observations in the meta-analysis to 165 for EE and 195 for GHGE.

Research interest in this issue was stronger in the European countries than in other regions. Of the 165 observations in the EE sample, 124 were located in Europe, 30 were located in North and South America and Oceania, and 11 were located in Asia and Central America. Of the 195 observations in the GHGE sample, 162 were located in Europe, 24 were located in North and South America and Oceania, and 9 were located in Asia and Central America.

4.1. Meta-analysis results for EE

Although several authors used both EE and GHGE, it is more meaningful to examine these environmental effect measures separately. Thus, we performed a logistic regression analysis to determine the effect of the structural variables on the EE benefits of organic farming.

Table 3 presents the frequency distributions of the structural and outcome variables in the studies that use EE as an effect measure. In these studies, 67.3% of the 165 observations exhibited positive outcomes, and 32.3% exhibited neutral or negative outcomes. That is, in terms of EE, organic farming was favored over conventional farming. For the EE comparisons, 45% involved field crops and 66% of the comparisons involved farm sizes over 10 ha.

To identify the structural variables that contributed to the EE superiority of organic farming, a logistic regression analysis was performed. Table 4 presents the results, which identify the structural variables that significantly influence findings of superior EE in organic farming. The logistic regression model provided a good fit. The Chi-square test statistic was significant ($p = .000$) and the Hosmer–Lemeshow test statistic was not significant ($p = .835$).

The goodness of fit of the model was confirmed by the accuracy of classifications, which was 78.18% (Table 5). The model was highly predictive with 90.99% accuracy for cases in which EE for organic farming was superior in predicting the effect variable. However, the accuracy of the model was poor for cases in which EE for organic farming was neutral or negative. The structural variables in the logistic regression predicted the effect variable with only 51.85% accuracy. Thus, further research is needed to identify the determinants of neutral or negative EE for organic farming compared to conventional farming.

The structural variables of product, data source, and sample size were statistically significant. The vegetables and fruits categories exhibited negative statistically significant values, indicating that EE benefits of organic farming were less likely for the categories of vegetables and fruits compared to the category of field crops. Although the values for the dairy, livestock, and mixed crop categories were positive, they were not statistically significant. Overall, organic farming was more likely found to be superior for field crops and livestock than vegetables and fruits.

The logistic regression results also revealed that the EE benefits of organic farming were strongly associated with characteristics of the data. Sample sizes of more than 100 were significantly associated with the EE superiority of organic farming ($p = .006$) compared to sample sizes of 1–20. Data source also significantly affected the EE benefits of organic farming. The significant value for secondary data was negative, indicating that the EE benefits of organic farming were less likely to be supported by secondary data than by field surveys or experiments.

Although other structural variables in the analysis exhibited the expected values, they were not statistically significant. Study period ($p = .944$), location ($p = .799$ and .650), measurement method ($p = .561$ and .540), and farm size ($p = .818$) did not contribute to the EE benefits of organic farming. The EE benefits of organic farming were modest but not statistically significant for duration ($p = .164$), measurement unit ($p = .160$), and cropping pattern ($p = .272$). These findings suggest that study period and location, measurement unit and method used to estimate EE were not associated with EE benefits for organic farming. However, the EE benefits of organic farming were slightly greater for multi-year data compared to one-year data, monocropping compared to multi-cropping, and output-based outcome measures (/ton) compared to area-based measures (/ha).

The results of the analysis indicate that the EE benefits of organic farming were more marked for larger samples and primary data from field studies for the categories of field crops, livestock and multiple crops. However, none of the EE studies from field surveys or experiments had sample sizes over 100. As Table 6 indicates, 27 of 33 studies with sample sizes over 100 (81.8%) exhibited EE benefits for organic farming. Of the studies with sample sizes over 100, 28 studies examined field crops, dairy, livestock, and mixed crops, and 25 of these studies (89.3%) found better EE effects for organic farming. Field studies with more samples in these crop

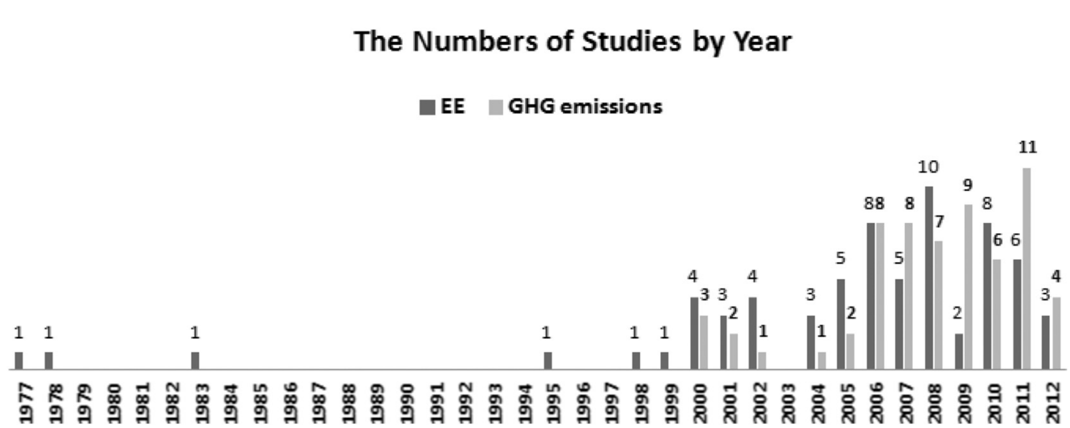

Fig. 2. The number of relevant studies published each year from 1977 through 2012.

Table 3
Frequency distribution of structural variables for studies of EE.

Structural variables	Dimension	Number of observations (%)
Sample size	1–20	60 (35.4)
	21–100	72 (43.6)
	More than 100	33 (20.0)
Duration	One year	112 (67.9)
	Multi-year	53 (32.1)
Location	Europe	124(75.2)
	America and Oceania	30 (18.1)
	Asia and Central America	11(6.7)
Products	Field crops	75 (45.5)
	Vegetables	21 (12.7)
	Fruits	22 (13.3)
	Dairy	19 (11.5)
	Livestock	19 (11.5)
	Mixed crops	9 (5.5)
Farm size	Less than 10 ha	56 (33.9)
	More than 10 ha	109 (66.1)
Cropping pattern	Monocropping	82 (49.7)
	Multicropping	83 (50.3)
Study period	Prior to 2005	59 (35.8)
	After 2005	106 (64.2)
Data source	Field survey	91 (55.2)
	Field Experiments	36 (21.8)
	Secondary data (DB)	38 (23.0)
Measurement unit	Area-based (EE/ha)	92 (55.8)
	Output-based (EE/ton)	73 (44.2)
Measurement method	EAM	102 (61.8)
	LCA	51 (30.9)
	Emergy & others	12 (7.3)
Environmental effects (EE superiority of organic farming	Positive	111 (67.3)
	Neutral or negative	54 (32.7)

Table 4
Results of the logistic regression analysis of the EE benefits of organic compared to conventional farming.

Structural variables	B	S.E.	p-value
Study publication date	−.036	.511	.944
Location (Compared to Europe)			
N. & S. America & Oceania	−.170	.671	.799
Asia & Central America	.392	.864	.650
Duration	.779	.559	.164
Data source (compared to field surveys)			
Field experiments	1.024	.801	.201
Secondary data (DB)	**−2.815**	**1.366**	**.040****
Measurement method (compared to EAM)			
LCA	−.307	.528	.561
Emergy & others	.576	.940	.540
Sample size (compared to 1–20)			
21–100	.236	.444	.595
More than 100	**4.059**	**1.467**	**.006*****
Products (compared to field crops)			
Vegetables	**−1.994**	**.707**	**.005*****
Fruits	**−1.261**	**.686**	**.066***
Dairy	.715	.801	.372
Livestock	.044	.715	.951
Mixed crops	.001	.825	.999
Farm Size	−.139	.605	.818
Cropping pattern (multicropping compared to monocropping)	−.563	.512	.272
Measurement unit (output compared to area)	.635	.452	.160
(Constant)	.671	.863	.437

−2 Log likelihood = 164.533, Cox & Snell's R^2 = .235, Nagelkerke R^2 = .327.
Model Chi-square = 44.103, p-value = .000(Hosmer–Lemeshow test Chi-square = 3.505, p-value = .835).
Dependent variable: EE superiority of organic farming (positive vs. neutral/negative).
*p < .10, **p < .05, ***p < .01.
The bold represents the statistically significant variables at p=.10

categories may have a better chance to find superior EE effects for organic farming.

4.2. Meta-analysis results for GHGE studies

Table 7 presents the frequency distributions for the structural and outcome variables of the GHGE studies. Of the 195 observations, 67.7% exhibited positive outcomes and 32.3% exhibited neutral or negative outcomes. That is, in terms of GHGE, organic farming was favored over conventional farming. In all, 43.1% of the GHGE comparisons involved field crops and 72.8% of the comparisons involved farm sizes of more than 10 ha. The frequency

Table 5
Results of classifications based on the logistic regression model for EE effects.

		Predicted EE superiority		Classification Accuracy
		Neutral/negative	Positive	
Actual EE Superiority	Neutral/negative	16.97%	15.76%	51.85%
	Positive	6.06%	61.21%	90.99%
Overall Correct Classification		***78.18%***		

Table 6
Studies with better EE effects for organic farming by structural characteristic.

Structural characteristics	No. of samples	No. with better EE outcomes for organic farming	% With better EE outcomes for organic farming
1.Field Surveys and Experiments	127	73	57.5
2.Sample Sizes greater than 100	33	27	81.8
3.Field Crops, Dairy, Livestock, & Mixed Crops	122	93	76.2
Satisfying both 2 and 3 above	28	25	89.3

Table 7
Frequency distribution of structural variables for studies on GHGE.

Structural variables	Categories	Number of samples (%)
Sample size	1–20	94 (48.2)
	21–100	49 (25.1)
	More than 100	50 (25.6)
Duration	One year	147 (75.4)
	Multi-year	48 (24.6)
Location	Europe	162 (83.1)
	America and Oceania	24 (12.3)
	Asia and Central America	9 (4.6)
Products	Field crops	84 (43.1)
	Vegetables	23 (11.8)
	Fruits	11 (5.6)
	Dairy	34 (17.4)
	Livestock	19 (11.2)
	Mixed crops	11 (5.6)
Farm size	Less than 10 ha	53 (27.9)
	More than 10 ha	142 (72.8)
Cropping pattern	Monocropping	106 (54.4)
	Multicropping	89 (45.6)
Study publication date	Before 2005	35 (17.9)
	After 2005	160 (82.1)
Data source	Field surveys	73 (37.4)
	Field experiments	53 (27.2)
	Secondary data (DB)	69 (35.4)
Measurement unit	Area basis (ha)	74 (37.9)
	Output basis (kg, ton, litter)	121 (62.1)
Measurement method	LCCI	60 (30.8)
	LCA	119 (61.0)
	Other	16 (8.2)
Environmental effects (GHGE superiority of organic farming)	Positive	132 (67.7)
	Neutral or negative	63 (32.3)

distribution of the structural variables in the GHGE studies was similar to that of EE studies except for the variables of measurement unit and measurement method. EE studies more often employed area-based outcome measures with EAM as the measurement method, whereas GHGE studies more often used output-based outcome measures with LCA as the measurement method.

A logistic regression analysis was employed to identify the structural variables that were associated with GHGE benefits for organic farming. The analysis results (Tables 8 and 9) identified the structural variables that were significantly associated with better GHGE effects for organic farming. The logistic regression model provided a good fit. The Chi-square value was statistically significant ($p = .000$) and the result of the Hosmer–Lemeshow test was not significant ($p = .341$).

The goodness of fit for the logistic regression model was confirmed by the accuracy of classifications based on the model, which was 72.72% (Table 9). The model did very well in predicting cases in which GHGE organic farming outcomes were superior, predicting the outcome variable with 86.90% accuracy. However, the structural variables in the logistic regression were poor predictors of neutral and negative GHGE outcomes, exhibiting an accuracy of only 42.20%. Thus, further research is needed to identify the determinants of neutral or negative GHGE outcomes for organic farming versus conventional farming. The classification accuracy of the GHGE model was similar to that of the EE model.

The structural variables of product, cropping pattern and measurement unit were statistically significant. Livestock exhibited a negative statistically significant value ($p = .004$), which indicated that better GHGE effects for organic farming were less likely for livestock than for field crops. Although the values for the vegetable and fruit categories were negative, they were not statistically significant. GHGE effects for organic farming might be less likely for

Table 8
Results of the logistic regression analysis of the GHGE benefits of organic compared to conventional farming.

Structural variables	B	S.E.	p-value
Study publication date	.122	.534	.820
Location (compared to Europe)			
N. & S. America & Oceania	−.115	.650	.860
Asia & Central America	−.615	.989	.534
Duration	.082	.593	.890
Data source (compared to field surveys)			
Field experiments	−.246	.592	.679
Secondary data (DB)	.298	.781	.703
Measuring method (compared to LCCI)			
LCA	−.411	.495	.407
Other	−.121	.842	.886
Sample size (compared to 1−20)			
21−100	.569	.564	.313
More than 100	1.288	.852	.131
Products (compared to field crops)			
Vegetables	−.991	.647	.126
Fruits	−.268	1.026	.794
Dairy	.376	.605	.534
Livestock	**−1.691**	**.584**	**.004*****
Mixed crops	.801	1.006	.426
Farm size (compared to 10 ha)	.140	.600	.816
Cropping pattern (multicropping compared to monocropping)	**−1.108**	**.506**	**.028****
Measurement unit (output compared to area)	**−1.931**	**.453**	**.000*****
(Constant)	**2.491**	**1.000**	**.013****

−2 Log likelihood = 199.427, Cox & Snell's R^2 = .216, Nagelkerke R^2 = .301.
Model Chi-square = 47.404, p-value = .000(Hosmer−Lemeshow test: Chi-square = 9.013, p-value = .341).
Dependent variable: GHGE superiority of organic farming (positive vs. neutral/negative).
*p < .10, **p < .05, ***p < .01.
The bold represents the statistically significant variables at p=.10

Table 9
Results of classifications based on the logistic regression model for GHGE effects.

		Predicted GHGE superiority		Classification accuracy
		Neutral/negative	Positive	
Actual GHGE Superiority	Neutral/negative	13.85%	18.97%	42.20%
	Positive	8.72%	57.87%	86.90%
Overall correct classification		***72.72%***		

Table 10
Studies with better GHGE effects for organic farming by structural characteristic.

Structural characteristic	No. of samples	No. with better GHGE outcomes for organic farming	% With better GHGE outcomes for organic farming
1.Monoculture cropping pattern	104	77	72.6
2.Area-based measurement	74	60	81.1
3.Field crops, dairy, mixed crops	129	94	72.9
Satisfying 1, 2, and 3 above	**12**	**11**	**91.7%**

vegetables (p = .126) than for field crops. The values for other product categories, which included dairy (p = .534) and mixed crops (p = .426), were positive but not statistically significant, which suggests that the GHGE effects for organic farming for these categories were similar to the outcomes for field crops.

The logistic regression results indicated that superior GHGE effects for organic farming were highly dependent on the measurement unit. Output-based (ratio/ton) outcome measures significantly reduced the superiority of GHGE effects for organic farming (p = .000) in comparison to area-based (ratio/ha) measures. These results are consistent with Lynch et al. (2011), which found output-based measures do not favor organic farming, particularly with respect to GHGE, due to the yield differences between conventional and organic farming. The significant value for cropping pattern was negative (p = .028), indicating that the GHGE superiority of organic farming was higher for monocropping than for multicropping.

Other structural variables in the analysis exhibited the expected values but were not statistically significant. Study period (p = .820), location (p = .860 and .534), duration (p = .890), data source (p = .679 and .703), measurement method (p = .407 and .886) and farm size (p = .816) were not associated with better GHGE effects for organic farming. Superior GHGE effects for organic farming were modestly related to sample size but were not statistically significant (p = .313 and .131). These findings suggest that study period, location, duration, data source, farm size, and measurement method were not strongly associated with superior GHGE effects for organic farming. However, superior GHGE effects for organic farming might be associated with larger sample sizes.

The results of the analysis indicated that superior GHGE effects for organic farming were more marked for studies that involved monocropping rather than multicropping and for studies that used area-based rather than output-based effect measures. The meta-analysis results confirmed the results of earlier meta-analyses

Table 11
Comparison of meta-analysis findings regarding the superiority of organic farming.

Structural variables	Outcome measures	
	EE	GHGE
Study period	n.s.	n.s.
Location	n.s.	n.s.
Duration	n.s.	n.s.
Data source	**	n.s.
Measurement method	n.s.	n.s.
Sample size	***	n.s.
Products	***	***
Farm size	n.s.	n.s.
Cropping pattern	n.s.	**
Measurement unit	n.s.	***

*p < .10, **p < .05, ***p < .01; n.s. = not significant.

that found superior environmental effects for organic farming per unit of land (Bengtsson et al., 2005; Mondelaers et al., 2009; Tuomisto et al., 2012) rather than per unit of output. Superior GHGE effects for organic farming were less marked for livestock in comparison to other product categories. As Table 10 indicates, better GHGE effects for organic farming were found for 91.7% of the farm-level studies that involved monoculture cropping patterns, area-based measures, and the product categories of field crops, dairy, and mixed crops.

4.3. Comparison of meta-analyses for EE and GHGE

Table 11 presents comparison results of the meta-analyses for EE and GHGE. The structural variables of data source, sample size and product type significantly affected the EE of organic farming in comparison to conventional farming, whereas product type, cropping pattern, and measurement unit significantly affected the GHGE of organic farming in comparison to conventional farming. The better EE effects for organic farming were primarily associated with the field study's data source and sample size of more than 100, whereas better GHGE effects for organic farming were primarily associated with monoculture in cropping patterns and area based measurement unit. The results support previous studies that investigated EE with superior performances for organic farming when the data were obtained from field surveys and experiments rather than from secondary data. However, there were no differences based on data sources for studies that investigated GHGE.

Increases in sample size were significantly associated with superior EE effects for organic farming, whereas increases in sample size were only modestly associated with superior GHGE effects for organic farming. The superiority of organic farming was significantly reduced for output-based measurement of GHGE and weakly reduced for area-based measurement of EE. These findings support the Lynch et al. (2011) claim that output-based measures typically do not find benefits of organic farming, particularly for GHGE, due to yield differences between conventional farming and organic farming. Earlier studies found superior performances for organic farming with monocropping compared to multicropping patterns. However, this finding was only significant for GHGE.

For EE, the analysis indicated that superior performances for organic farming were associated with field crops, livestock, and mixed crop farms compared to vegetable and fruit farms. For GHGE, better performances for organic farming were associated with field crops, dairy, and mixed crop farms, whereas poorer performances were associated with livestock, vegetable and fruit farms. None of the other structural variables influenced differences in EE or GHGE between organic and conventional farming. Study publication date, location, measurement method, farm size, and duration did not significantly influence environmental effects for organic farming, which indicates that the influence of these variables on the differences between organic and conventional farming were negligible.

5. Conclusions

In this paper, logistic regressions were estimated to identify the structural variables that were associated with superior environmental effects for organic farming compared to conventional farming. Data source, sample size, and farm products were significant for EE performance and farm products, cropping patterns, and measurement unit were significant for GHGE outcomes of organic farming.

In the EE studies, the superiority of organic farming was more likely to be found in studies with larger samples, field studies, and experiments rather than secondary data. In the GHGE studies, the superiority of organic farming was more likely to be found for studies with monocropping compared to multicropping and with outcome measures based on area rather than output.

The results suggest that future studies should employ enough samples to improve confidence on the performance of organic farming compared to conventional farming. Future studies, especially on GHGE, should be cautious in identifying the appropriate measurement unit because output-based measures often do not favor organic farming (particularly for GHGE) due to yield differences between conventional and organic farming. When land use efficiency and energy productivity are considered, output-based (per weight) measures are more appropriate for assessing EE and GHGE than area-based (per ha) measures. The cropping pattern has a significant impact on GHGE. Therefore, we recommend that future studies investigate monocropping for direct and unbiased comparisons of the environmental effects of organic and conventional farming.

EE studies were more likely to find that organic farming was superior for field crops and dairy farms and less likely for vegetable and fruit farms. GHGE studies were more likely to find that organic farming was superior for field crops, dairy, and mixed crop farms and less likely for livestock, vegetable, and fruit farms. These findings indicate that the comparisons of the environmental effects of organic and conventional farming should take the type of farm product (e.g., field crops, livestock, fruits, or vegetables) into account and that comparisons should be based on the same types of farm products.

The variable of duration is not statistically significant but positive, indicating that longer periods of data collection were associated with positive organic farming performance. However, because these findings did not achieve statistical significance, we recommend that future studies employ long-term data collection and larger sample sizes to obtain reliable data in order to compare organic and conventional farming. Because most organic farms have been converted from conventional farms, time series data are more appropriate to accurately evaluate the effects of organic farms in comparative studies that use EE and GHGE as performance measures.

In summary, future studies should employ larger samples from primary sources, and compare the environmental effects of organic farming for different types of products, cropping patterns, and performance measures.

This paper exhibits several limitations. First, as most samples are from Europe, the logistic regression could not classify the location variable by country, and could not reflect the meteorological and natural conditions. As studies are increasing recently in regions other than Europe, future research should consider country level comparisons.

Second, most studies (67.9% of the EE studies and 75.4% of the GHGE studies) used cross-sectional data and thus did not consider nutrient spillover effects. To compare the environmental effects of organic and conventional farming and to determine the influence of the length of the data collection period accurately, future studies should obtain longitudinal data that examine the effects of multi-seasonal practices.

Third, other structural variables might also affect the environmental performance of farming systems. That is, performance measures other than EE and GHGE should be investigated. Future research should identify additional structural variables and a broader range of environmental indicators to obtain more detailed and comprehensive information on this issue.

Despite these limitations, this meta-analysis identified structural variables that were associated with better environmental effects for organic farming compared to conventional farming. Our empirical findings should improve the reliability of future studies that compare the environmental effects of conventional and organic farming.

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Appendix: Studies Used in the Meta-Analysis

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