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Yield and economic performance of agroecological transitions in the Global South

A geospatially-augmented meta-analysis

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2026

Joint Research Centre
https://joint-research-centre.ec.europa.eu

JRC146888
EUR 40759

PDF ISBN 978-92-68-40902-2 ISSN 1831-9424 doi:10.2760/3732827 KJ-01-26-265-EN-N

Luxembourg: Publications Office of the European Union, 2026

How to cite this report: De Marinis, P., Ceriani, R., Rega, C., Schievano, A., Callenius, C.,. et al., *Yield and economic performance of agroecological transitions in the Global South - A geospatially-augmented meta-analysis,* Publications Office of the European Union, Luxembourg, 2026, https://data.europa.eu/doi/10.2760/3732827, JRC146888.

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Abstract

This meta-analysis evaluates the effects of agroecological transitions on farm economic performance across the Global South. By drawing from 350 primary studies, the analysis compares farming systems adopting at least two agroecological farming practices with similar simpler systems, adopting no or fewer agroecological practices. The effects on 3 main socio-economic indicators are quantified: i) crop yield, ii) gross income, and iii) production costs. The final analysis is based on 76 observations on yields, 42 on income and 19 on production costs.

Findings show that, compared to similar but more simplified/conventional systems, the application of two or more agroecological practices leads to an average 14.3% increase in yields, a 44.5% increase in gross income, and a 36.5% reduction in production costs.

The study also examines how local factors affect these outcomes, using a geospatial-augmented approach: when local pedoclimatic variable were not reported they were derived from public geospatial dataset, knowing the studies' location. Yield is significantly moderated by pedoclimatic factors, with the greatest advantages in cooler, stable climates and soils with lower clay content. Conversely, economic benefits appear more consistent across different scales and irrigation regimes, suggesting they are driven more by management choices and input substitution than by biophysical constraints.

This study constitutes one of the first meta-analysis that measures, at field/farm level, the socio-economic outcomes of transitioning towards more agroecological farming in the Global South. While findings are statistically significant, further analysis on a larger database is needed to gain more context-specific results across different pedo-climatic conditions.

Acknowledgements

The Authors would like to thank prof. Stefano Bocchi and prof. Francesco Fava from the Department of Environmental Science and Policy of the University of Milano, for their valuable comments and support

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Executive summary

Agricultural systems in the Global South are under pressure by escalating climate variability, soil degradation, and a heavy reliance on expensive external inputs. Agroecology—a holistic approach applying ecological principles to farming—is proposed as a transformative solution, but policy adoption has been hindered by a lack of consolidated, large-scale evidence. While there is now a solid body of evidence on the environmental benefits of agroecology, evidence on farms' economic performance is more limited and mostly qualitative.

This report contributes to bridging this science-policy gap by providing a rigorous quantitative synthesis of how "agroecological transitions" (moving from simple to complex farming practice bundles) impact the livelihoods of farmers in the Global South. The primary objective is to determine whether these transitions can simultaneously improve productivity, increase profitability, and reduce farm-level production costs.

Key findings

Agronomic performance (yield)

The meta-analysis detected a significant positive overall effect of 14.3% on yields. However, this result is sensitive to specific pedo-climatic conditions, namely:

- *Soil texture*: yield advantages decrease as clay content increases. It may be explained by the fact that heavy, clay-rich soils are more susceptible to compaction and poor aeration under the reduced-tillage regimes common in agroecology.
- *Climate sensitivity*: higher temperatures and high temperature variability, measured as the coefficient of variation (CV), negatively moderate yield responses. The identified benefits of agroecology are thus less marked under conditions of extreme temperature, which likely levels down performances across all farming systems.
- *Water management*: irrigated systems showed more positive effects than rainfed ones, as irrigation buffers the moisture stress that can otherwise limit yields. However, irrigation was not a statistically significant moderator.

The strongest yield effects were found in small-scale experimental plots. However, also farm-level observations confirmed significant economic returns.

This result is the most robust one as it is based on the largest number of observations.

B. Economic performance (income and costs)

Gross income: application of agroecological practices was associated with a 44.5% increase in gross income. Unlike yield, income gains remained consistent across different spatial scales (from small plots to full farms) and irrigation regimes. This result is relatively robust as regards the overall direction of the effect size, but less so as for the absolute magnitude, as the sample size is smaller compared to the one on yield.

Production costs: farmers applying agroecological practices saw an average cost reduction of 36.5%. These savings mainly stem from reduced reliance on purchased synthetic fertilizers and pesticides, replaced by on-farm resources like green manure, compost, and biological pest control. This result is statistically significant but should be taken with caution as it is based on a relatively low number of observations (n =19)

Lower reliance on external inputs: the economic data suggests that agroecology tends to decouple farm profitability from the volatility of external input markets, offering a pathway to greater financial stability.

Methodology: the practice-based approach

The research employed a systematic evidence synthesis, building upon the previous JRC work on categorising farming practices and their socio-economic and environmental effects. To be included in the final analysis, studies were required to have a clear counterfactual comparison and implement at least two distinct agroecological practices in the intervention (e.g., organic fertilization combined with crop rotation).

The full database from which individual results were considered included 215 yield observations, 130 gross income observations, and 92 cost observations. The final meta-analysis focused on high-quality data with reported variance, covering 76 observations for yield, 42 for income, and 19 for costs. For each observation, the farming systems where at least two agroecological practices were adopted are referred hereinafter as "interventions. The cropping systems to which they are compared (referred to as "comparators" in the statistical analysis) can be considered as simpler systems relying on one to four practices, often including the use of mineral fertilizers and agrochemicals to manage soil fertility and crop protection, which substitute more complex functional interaction in the agroecosystem.

Here, simplification arises not only from the lower number of practices adopted, but also from a simplified understanding of plant nutrition, i.e. the assumption that nourishing plants with external input (in comparators) is equal to nourishing the soil, which will in turn feed the crops (often found in interventions).Conversely, the systems defined as agroecological systems operate through different logic bundling six or more practices on average, such as organic management (in turn a set of different practices), nitrogen-fixing crops, and intercropping. Successful transitions are not about replacing one input with another, but about a fundamental redesign of the complex farming system.

A random-effects model was used to account for geographic and management variability. Mixed-effects meta-regressions analysed how factors such as soil properties (clay content, soil pH, soil organic carbon), climate (temperature, precipitation), and spatial scale (plot, field, farm) influenced the results.

Discussion and policy implications

The sensitivity of yields to clay and temperature confirms that when it comes to promoting agroecology, too general recommendations are ineffective. Policy should instead support site-specific extension services that help farmers adapt practices to their local pedoclimatic reality—for example, focusing on specific tillage techniques in clay-heavy regions.

The report identifies a critical gap in economic research. While yield data is abundant, high-quality data on production costs and labour is scarce. To build more robust evidence-based policies, future research must prioritize the standardized reporting of economic indicators.

Conclusions

This analysis demonstrates that agroecological transitions can offer a viable and robust pathway for agricultural development in the Global South. Findings show that on average the adoption of two or more agroecological practices increase yields and gross income while reducing production costs. While these findings remain context dependent and the estimated effect sizes cannot be directly generalised across settings, they nevertheless indicate a consistent positive pattern. Overall, this study contributes to filling the gap of robust, quantitative evidence on economic performance of agroecology in the Global South.

1. Introduction

1.1. Context and problem statement

Globally, food systems are responsible for the transgression of five planetary boundaries and constitute a major pressure on the remaining four (Rockström et al., 2025). Within food system, primary production (i.e. agriculture, fishery and livestock raising) is the main driver of ecological depletion. Agricultural activity is at the same time a major contributor to climate change, and one of the sectors that is most affected by it. This is especially true in the Global South, where agriculture supports the backbone of national economies and local livelihoods and vulnerability to climate change and climate extremes is very high (FAO and WMO, 2026). Such instability threats food security, especially within marginalized communities reliant on rain-fed agriculture (Rojas et al. 2019; Yuan et al. 2024). There is a pressing need to supporting farming systems able to better adapt to climate change and counter soil degradation while contributing to food and nutrition security.

In this context, agroecology is being promoted as an approach that can improve food security and climate resilience by diversifying production and reducing socio-economic vulnerability in the Global South (Dagunga et al. 2023). The European Union (EU) supports agroecological transitions in third country partners through a coordinated set of policies and programmes anchored in the EU Green Deal. The New European Consensus on Development and the Regulation on the Global Europe Neighbourhood, Development and International Cooperation Instrument (NDICI) give legal basis to promote environmentally sustainable agriculture, including agroecology, within external cooperation (EC 2017, 2021). The NDICI thematic programme "global challenges" finances climate , biodiversity and food system related interventions (EC 2022a)The Commission communication on safeguarding food security commits to analytical and policy support for resilient agri food systems, is emphasising agroecological research and innovation (EC 2022b). The Global Gateway Strategy (EC 2021) frames EU investment abroad around sustainability and climate resilience, supporting specific packages such as the EU Africa Agro Food Investment Package and the Global Gateway Africa Europe Investment Package.

The EC Directorate General for International Partnerships (DG INPTA) co-funds and coordinates the DeSIRA+ initiative to foster the adoption of agroecological innovations by small-scale farmers and small medium enterprises of the African agri-food sector. The project also supports farmers' organisations, civil society and private sector actors to scale innovations and promotes enabling policy environment for agroecology at national, regional and continental levels. Recently, DG INTPA has released an Operational Guide on Agroecology (EC 2024) to standardise implementation.

Under Horizon Europe, the European Union funds agroecology research with a budget of € 670 million for 2021 2027. In this frame, the Agroecology Partnership was established, bringing together the European Commission and 111 partners across 31 Member States, Associated Countries, and Third Countries. It supports research, living lab networks and capacity building across partner countries to generate actionable knowledge and technologies. The partnership is open to associated and third countries, enabling international collaboration beyond the EU.

Policy support to agroecology shall be based on robust, reliable and up-to-date knowledge. A growing body of scientific evidence examines the potential advantages of agroecological practices compared to conventional farming, including on yield and food security (Akinola et al. 2024), climate risk and long-term productivity (Bezner Kerr et al. 2023), profitability (Didarali and Gambiza 2019) and carbon sequestration (Lunn-Rockliffe et al. 2020).

Despite these promising results, significant challenges persist in validating the broader efficacy of agroecology. A primary limitation is the lack of comprehensive, large-scale and quantitative evidence, particularly regarding the synergistic effects of multiple practices implemented as integrated, whole-farm systems (Snapp et al. 2021). Research is often constrained by data scarcity across diverse agroecological zones (Akinola et al. 2024) and consolidated evidence on combined effects at the landscape level is scarce (Mouratiadou et al., 2024). This is a critical barrier that limits evidence-based policy in the Global South, where transitions often require a total redesign of farming systems rather than the adoption of isolated techniques (Piraux et al. 2024). Addressing these knowledge gaps through rigorous meta-analysis is therefore essential to provide a balanced foundation for sustainable agricultural development (FAO 2019).

1.2. Objective and scope

This research establishes a quantitative evidence library to evaluate the multi-dimensional impacts of agroecological transitions, focusing on the Global South. Adopting a meta-analytical methodology, this study systematically screened over 350 primary studies to identify counterfactual comparisons between conventional farming and farming systems applying at least two distinct agroecological practices. Following a standardized analytical workflow, the research quantifies effect sizes on three socio-economic indicators: crop yield, gross income, and production costs. To address the documented need for evidence regarding integrated systems, the study utilized the IMAP-FP dataset (Schievano et al. 2023) to categorize more complex, agroecology-oriented intervention systems versus simpler or less complex comparator systems, as extracted from primary literature. Furthermore, the inclusion of covariate analysis—such as soil type, temperature, and irrigation systems—allows for an assessment of trade-offs along a pedoclimatic gradient. By accounting for these variables, this study intends to inform more context-specific agroecological transition strategies in the selected the Global South regions covered by the evidence base.

2. Materials and methods

The methodological framework for this study employs a systematic evidence synthesis, designed to provide a statistically sound analysis of agroecological transitions. The approach integrates newly collected primary data with existing JRC datasets, i.e. the iMAP-FP dataset (Schievano et al. 2023). The latter is an evidence library that compiled results from systematic screenings of peer-reviewed meta-analyses (published since 2000) on 34 categories of sustainable farming practices and their impacts on climate, environment and productivity. This integration facilitates a standardized classification of agricultural interventions based on codified practices.

2.1. Evidence base and dataset construction

Quantitative data were extracted from a pool of 385 primary studies, of which 364 were included in two recent qualitative systematic reviews (Bezner Kerr et al. 2023; Mouratiadou et al. 2024). To ensure analytical consistency, these studies were screened against three mandatory inclusion criteria:

— The presence of a clear and counterfactual comparison: more complex, agroecology-oriented systems (“interventions”) versus simpler systems (“comparators”)

— The implementation of at least two distinct agroecological practices in interventions.

— The availability of quantitative mean and variance data.

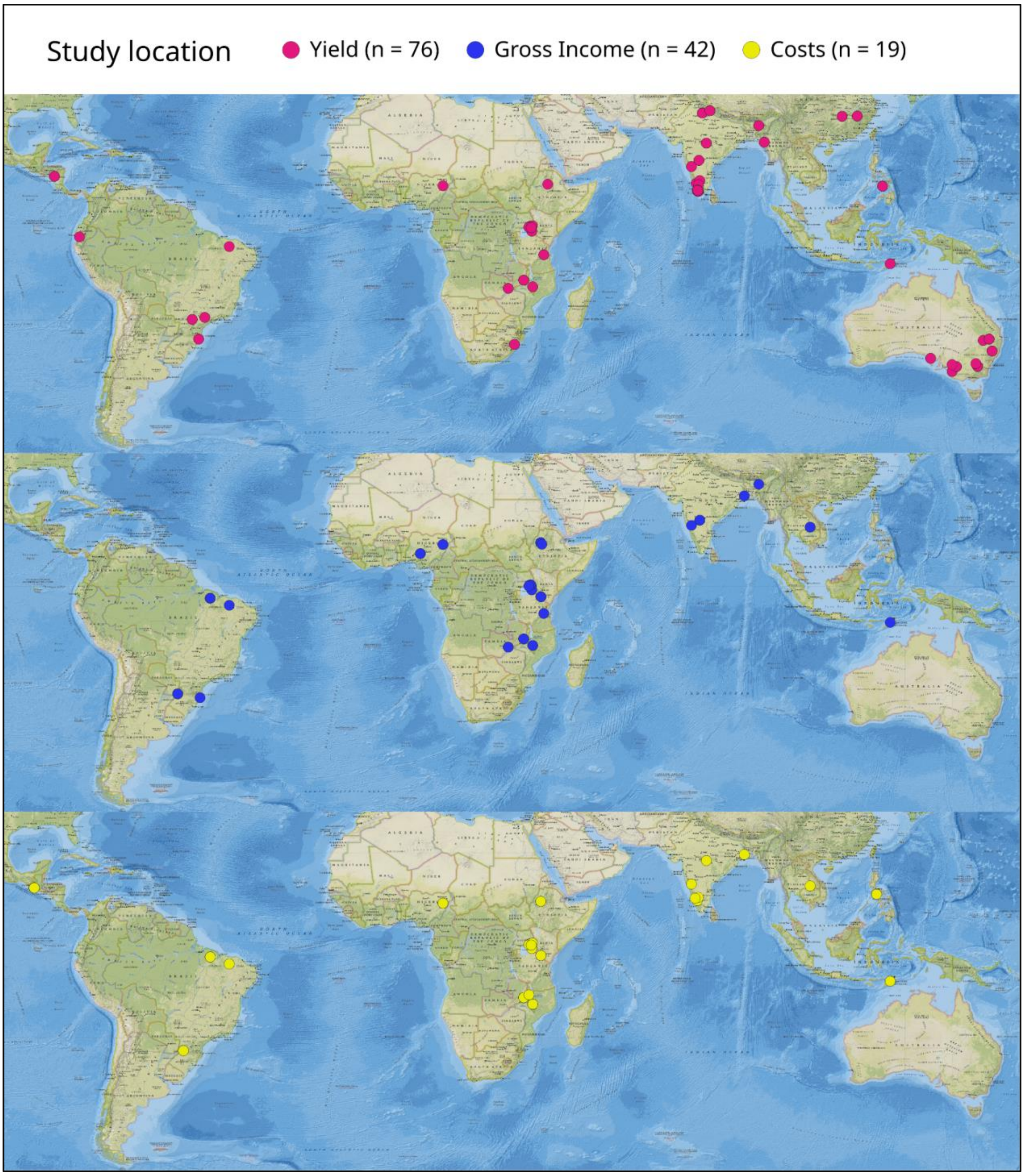
— The final evidence base was operationalized into a structured database (“full evidence library”) containing paired observations for yield, gross income and production costs.

Geographically, primary study sites are widely distributed across the tropics and subtropics, spanning both hemispheres and multiple continents. The locations extend from ~37°S to ~30°N in latitude and from ~91°W to ~151°E in longitude, indicating coverage across the Americas, Sub-Saharan Africa, South/Southeast Asia, and Oceania (**Figure 1**). While not part of the Global South strictly speaking, studies from Australia meeting the above-mentioned criteria were included as the climatic conditions are broadly comparable to those in other areas of Africa and South America at similar latitudes.

Yield observations are concentrated in India and Australia, with additional clusters in Zambia, the Philippines, China, and Kenya. Gross income observations are most represented in Kenya and Argentina, followed by Brazil and Zambia, with smaller contributions from India, Ethiopia, and Nigeria. Costs observations are most frequently located in Guatemala and Kenya, with further representation in Brazil, Malawi, Ethiopia, Nigeria, and a spread of smaller contributions from several other countries. s. Among the three considered outcomes, yield is the most extensively documented outcome, with 215 effect-size observations derived from 39 primary studies. The economic outcomes are represented by smaller bodies of evidence, with gross income including 130 observations from 22 studies and costs including 92 observations from 19 studies.

The reporting of uncertainty measures (such as standard deviations or standard errors) is moderate across all outcomes. Results on yield include uncertainty information in 77 out of 215 observations (36%), while for gross income and costs are both around 41%. For the costs, variability is more frequently reported for the intervention systems than for the comparator systems, indicating some asymmetry in the reporting of uncertainty across study arms.

Figure 1. Location of evidence extracted from literature and included in the full evidence library for analysis (n = the number of observations used in the meta-analysis).



Source: Authors' elaboration

The body of literature spans more than two decades of research. Yield observations range from 1996 to 2022, with a median publication year around 2009. Observations reporting gross income range from 2004 to 2021, with a median around 2014–2015, while cost-related observations range from 2000 to 2021, with a median around 2013. Overall, this suggests that the literature addressing economic outcomes is more recent than the literature focusing on yield.

In terms of experimental design, the evidence is largely derived from small-scale experimental or farm-level observations. Only 3% are landscape scale observations, while 39.9% are farm level observations, 8% are field scale, and 55.1% are plot scale observations. Yield observations are most frequently obtained from plot-level and farm-level experiments (48.8% and 29.3% respectively), with smaller numbers of observations conducted at the field or landscape scale (15.8% and 6% respectively). A similar pattern is observed for gross income, which is highly concentrated in plot- and farm-level analyses (66.9% and 32.3%). Cost-related observations are also primarily derived from plot- and farm-scale observations (53.3% and 46.7%), with no evidence reported at broader spatial scales.

Rainfed conditions account for the majority of observations across all outcomes (62.5% globally, 71.7%, 76.9% and 49.8% respectively for Costs, Gross Income and Yield), while irrigated systems appear more frequently in yield observations than in those reporting economic indicators (22.2% globally, 12%, 1.5% and 39.1% respectively for Costs, Gross Income and Yield). Mixed systems, where both rainfed and irrigated conditions are present, represent a smaller share of the evidence (15.3.% globally, 16.3%, 21.5% and 11.2% respectively for Costs, Gross Income and Yield).

Comparator and intervention systems were classified using two complementary descriptors capturing the type of farming system and the specific management configuration implemented in each study. A first variable provided a high-level categorization of farming systems (e.g., conventional farming, organic farming, agroecological farming, diversified cropping systems, sustainable intensification, or silvopastoral systems). Across the dataset, comparator systems predominantly represent conventional or baseline farmer practices, typically characterized by conventional input use, monocropping, or tillage-based management. In contrast, intervention systems correspond to improved systems, adopting agroecological and diversification-oriented practices, including organic management, reduced or no tillage, intercropping or polyculture, legume-based fertility management, sustainable intensification strategies, and agroforestry or silvopastoral systems. A second variable provided more detailed textual descriptions of the specific practices implemented in each comparator and intervention, allowing consistent characterization of management systems across observations.

It is acknowledged in the literature that both agroecological and conventional farming are used to denote ideal types of systems which, in reality, vary across a continuum spectrum of implementation of agroecological principles. Therefore, a comparison between a “pure” agroecological system and a “pure” conventional one is not feasible nor useful, especially in the frame of a meta-analysis, which needs to be based on a large number of observations that will likely be distributed along the above-mentioned spectrum.

Any agricultural farming systems can be classified along this spectrum and qualified as more or less agroecological, depending on the extent to which agroecological principles are locally applied. In practice this comes down to the extent to which: (i) they rely on ecological processes as opposed to purchased inputs; (ii) they are equitable, environmentally friendly, locally adapted and controlled; and (iii) they adopt a systems approach embracing management of interactions among components, rather than focusing only on specific technologies (HLPE-FSN 2019).

Building on this assumption, the present study aims to examine whether transitioning towards more agroecological farming is associated with better socio-economic performance: this means that each individual study included in the analysis a farming systems adopting some agroecological principles through farming practices is compared with a farming system that adopts no or less agroecological practices. For the sake of simplicity, in the remainder if the text we use the wording “agroecological interventions vs conventional comparators” but bearing in mind this means we are comparing more complex, agroecology-oriented intervention systems versus simpler or less complex comparator systems.

2.2. Outcome grouping and operational definitions

Outcomes were analysed in three separate meta-analytical streams corresponding to the structure of the evidence library Overall, 437 observations were identified as potentially usable from the available library.

— Yield: it includes 215 observations from 39 different papers, where outcomes are reported in kg/ha or agronomic equivalents.

— Gross Income: it includes 130 observations from 22 different papers, reporting farm-gate revenue or gross income metrics, allowing for the evaluation of market-based performance of the transition. Units of measure are very mixed across observations (various currencies and time bases like per year, per hectare, etc.), which is typical for economic outcomes compiled from many papers.

— Production Costs: it includes 92 observations from 19 papers reporting production costs or cost components, used to quantify the "economic burden" or potential savings associated with agroecological shifts.

Subsequently, a further filter was applied to select, from the initial pool of observations, only those reporting both the mean effect size and measures of dispersion such as Standard Deviation (SD), Standard Error (SE), or Confidence Intervals (CI). This substantially reduced the usable sample compared to the full evidence library, but on the other hand increases the statistical robustness of the analysis.

As a result, the quantitative synthesis was performed on 76 observations for yield, 42 for gross income, and 19 for costs. Observations lacking variance information were excluded, explaining the discrepancy with the raw dataset counts. The complete dataset, including observations without variance reporting, is preserved and can be used for subsequent geospatial and complementary analyses.

2.3. Farming practices classification

For this study, experts jointly defined the interventions and comparators, ensuring that the classifications were consistent across the different studies. Initially, descriptive sentences and technical keywords were extracted from the original studies to characterize the specific practices in place for both interventions and comparators. Using these extracted strings as evidence, a panel of experts independently assigned the corresponding iMAP-FP codes to each case, in order to have a standardised classification of farming practices. Subsequently, the experts engaged in a structured review to compare and discuss their individual attributions, resolving discrepancies through consensus-building to finalize the list of codes. This granular, expert-driven approach allowed us to account for the specific technical differences in practices—such as nutrient management, soil conservation, or livestock density—which represent the underlying drivers of the observed impacts on farm productivity and income. The resulting classification codes used to define the dataset are summarized in Table 1 (see Schievano et al. 2023 for details and definitions of each farming practice). It should be remarked that the practice classification assigned codes to practices explicitly reported in primary studies, thus not the full complexity of the studied farming systems under analysis.

2.4. Statistical meta-analysis workflow

2.4.1. Effect size metric

The metric for quantifying the impact of agroecological transitions is the Log Response Ratio (LRR) (Hedges et al. 1999). For each independent study contrast (i) the effect size (Li) is calculated as:

$$L_i = ln \frac{\overline{X}_{AE}}{\overline{X}_{CON}}$$

Where $\overline{X}_{AE}$ is the mean outcome of the agroecological intervention and $\overline{X}_{CON}$ is the mean of the conventional comparator. The LRR is one of the most common metrics used in meta-analyses since it is a scale-free metric, facilitating synthesis across studies reporting outcomes in different units while allowing an intuitive percentage-change interpretation once back-transformed (i.e., e^{Li} - 1).

2.4.2. Meta-analytic model specification

Statistical synthesis was performed in R (v4.8.0) using the Metafor package (Viechtbauer 2010). To calculate the overall effect size of adopting more complex, agroecology-oriented intervention systems versus simpler or less complex comparator systems, a standard random-effects model was employed, estimated via Restricted Maximum Likelihood (REML). This model accounts for the inherent between-study heterogeneity across diverse geographic and management contexts. The overall pooled estimate represents the mean effect of practice adoption. The model is structured as:

$$\boldsymbol{y_i = \mu + \delta_i + \epsilon_i}$$

Where $\boldsymbol{\mu}$ is the overall pooled effect, $\boldsymbol{\delta_i}$ represents between-study heterogeneity, and $\boldsymbol{\epsilon_i}$ is the sampling error. This hierarchical structure ensures that uncertainty is partitioned appropriately between sampling noise and true underlying variability.

2.4.3. Geospatial-augmented analysis, moderators' selection and meta-regression

To deconstruct the observed heterogeneity, we employed mixed-effects meta-regression. We prioritized pedoclimatic moderators to determine how biophysical constraints limit or enhance practice efficacy. To this end, a geospatial augmentation of the evidence library was carried out. This involved extracting site-specific pedo-climatic variables for each study using its geographic coordinates and publicly available geospatial datasets. Soil properties, including clay and silt content, pH, and Soil Organic Carbon (SOC), were derived from the SoilGrids global dataset at a 250 m resolution (Hengl et al. 2017). Temperature and precipitation data were sourced from the ERA5 reanalysis dataset (Hersbach et al. 2020). This allowed us to include these variables in the analysis even when they were not reported in the primary study. This constitutes a significant added value of the employed methodological approach.

To account for both average condition and climate volatility, we calculated the mean and the Coefficient of Variation (CV) for temperature and precipitation over the period 2000-2020. The focus on pedoclimatic variables reflects the hypothesis that biophysical conditions modulate the agronomic and economic outcomes of agroecological transitions.

To address potential multicollinearity among the soil and environmental covariates, we performed diagnostic correlation and Variance Inflation Factor (VIF) analyses. First, sand and silt contents were excluded a priori from all models to resolve the structural compositional collinearity inherent in soil texture data (where clay + sand + silt = 100%). To assess the remaining covariates, we computed Pearson correlation matrices and calculated VIF values for each variable within each of the three response datasets (Gross Income, Costs, and Yield). VIFs were calculated by regressing each covariate against all other covariates in the model, explicitly including an intercept constant to ensure mathematical accuracy.

A conservative threshold of VIF > 10 was established to identify variables causing severe multicollinearity. If a variable exceeded this threshold, it was systematically removed, and the VIFs for the remaining covariates were recalculated to ensure model stability and the reliability of the regression coefficients.

2.4.4. Publication bias and sensitivity

To ensure the integrity of the resource, we addressed potential small-study effects and reporting bias:

1. Funnel plot asymmetry, assessed via Egger's regression test, for detecting potential publication bias (Egger et al. 1997).
2. Sensitivity analysis, we applied the Trim-and-Fill method to estimate the number and magnitude of potentially missing studies (i.e., "file-drawer" studies) and adjust the pooled effect accordingly (Duval and Tweedie 2000).

These diagnostics ensure that conclusions are not inflated by systematic non-reporting of null or negative outcomes.

3. Results

3.1. Farming practices

Table 1 reports the frequency with which different agricultural practices are mentioned among the interventions and comparators examined in the studies included in the full evidence library. The code is the ID used in Schievano et al., (2023), to classify farming practices uniquely.

With regard to the comparators included in the set of primary studies, we observe on average two coded practices per comparator (SD = 0.8; min = 1; max = 4). For example, a comparator could include a combination of practices no-tillage soil management, the use of improved crop varieties, the application of specific mineral fertilizer types, and soil amendment with lime. It is important to remark that even when a comparator (simple/conventional system) exhibits a moderate level of complexity, the paired agro-ecological intervention is always more complex, thereby preserving the study's definition of "more-complex, agroecology-oriented" systems versus "simpler" conventional comparator systems.

In fact, the interventions are substantially more complex, including on average 6.1 practices per intervention (SD = 6.5 min =2; max =33). It should be remarked that the practice count reflects and coded practices explicitly reported in primary studies, thus not the full complexity of the farming system.

3.1.1. Comparator systems

Focusing on the frequency with which different agricultural practices appear among the comparator systems in the full evidence library, the distribution indicates that comparator systems are characterized by a limited set of practices, with a strong concentration around a few conventional management strategies.

The most frequently represented practice is the use of specific mineral fertilizer types (F41X), which appears 21 times, accounting for 33% of all coded mentions. This suggests that mineral fertilizer management remains a central component of the comparator systems, reflecting the prevalence of input-based conventional farming practices in the baseline systems used for comparison.

The second most common practice is the ban on herbicides and related products (P211), reported seven times (11%). Although less frequent than fertilizer-related practices, this indicates that some comparator systems already incorporate partial restrictions on chemical inputs. Crop rotation (R11) is the next most represented practice, with five mentions (8%), highlighting that certain comparator systems include basic crop management strategies commonly associated with sustainable or conservation agriculture.

A small group of practices appears with moderate frequency, each mentioned three times (5%). These include the cultivation of nitrogen-fixing or protein crops (R121), short-term fallow (R131), and the cultivation of improved crop varieties (R191). These practices suggest that some comparator systems integrate elements aimed at improving soil fertility or crop productivity, even though they remain relatively limited in the overall dataset.

A further set of practices appears only twice (3%), including limits on mineral fertilizer inputs (F121) and the use of compost (F46). The low frequency of these practices indicates that organic amendments and stricter input limitations are not commonly included in the comparator systems.

Table 1. Farming practices in the Interventions and Comparators.

Practice (code)	Practice (description)	No of mentions (intervention)	% (intervention)	No of mentions (comparator)	% (comparator)
OX	Organic farming	18	8%	0	0%
R121	Cultivation of Nitrogen fixing/protein crops	16	7%	3	5%
R14	Crop diversification	14	6%	1	2%
R15	Mixed cropping / intercropping	14	6%	0	0%
F44	Use of green manure	12	5%	1	2%
P11	Biological control	12	5%	1	2%
F46	Use of compost	11	5%	2	3%
P12	Mechanical control	11	5%	1	2%
R11	Crop rotation	9	4%	5	8%
F112	Ban on mineral fertilisers	9	4%	1	2%
P211	Ban on herbicides, haulm destructors and moss killers	6	3%	7	11%
P212	Ban on fungicides and bactericides	6	3%	1	2%
P213	Ban on insecticides and acaricides	6	3%	1	2%
I1	Low input systems	5	2%	1	2%
S24	No burning of crop residues	4	2%	1	2%
S26	Crop residue incorporated into the soil	4	2%	1	2%
A122	Feed from farm partial	4	2%	0	0%
S12	No tillage	3	1%	1	2%
W16	Sustainable water management on paddy rice fields (e.g. late drying up of paddy rice fields)	3	1%	1	2%
F213	Solid manure incorporation (within 6h)	3	1%	0	0%
L121	Creation of field margins	3	1%	0	0%
P214	Ban on Molluscicides	3	1%	0	0%
P215	Ban on Plant growth regulators	3	1%	0	0%
S22	Crop residues left on soil, leaving stubbles on the field	3	1%	0	0%
T1	Training	3	1%	0	0%
F41X	Use of specific mineral fertilizer types	2	1%	21	33%
F122	Max organic fertiliser input	2	1%	0	0%
F412	Organic-mineral fertilisers	2	1%	0	0%
L114	Maintenance and conservation of isolated trees	2	1%	0	0%
L117	Creation of trees in line	2	1%	0	0%
L312	Creation of silvopastoral systems	2	1%	0	0%
P31	Adoption of Integrated pest management principles (IPM)	2	1%	0	0%
R191	Cultivation of improved varieties	1	0%	3	5%
A51	Outdoor access for animals reared in stables	1	0%	1	2%
F33	Amendment with Lime	1	0%	1	2%
F421	Application of solid manure (various types)	1	0%	1	2%
A52	Provision of enrichment materials	1	0%	0	0%
A58	Improved space allowance per animal	1	0%	0	0%
A8	Livestock density limits at farm level	1	0%	0	0%

C1	Certification schemes	1	0%	0	0%
F11X	Ban on the use of fertilisers other than along water courses	1	0%	0	0%
F212	Split application (mineral fertilizers or manure)	1	0%	0	0%
G11	Minimum grazing period	1	0%	0	0%
G16	Rotational grazing	1	0%	0	0%
G24	Reseeding on grasslands	1	0%	0	0%
L192	Maintenance and conservation of terraces	1	0%	0	0%
L322	Creation of silvicultural systems	1	0%	0	0%
L41	Conservation of traditional orchards	1	0%	0	0%
O12	Conversion to organic farming practices	1	0%	0	0%
P22	Limitation in quantity of plant protection products other than along water courses.	1	0%	0	0%
R132	Long-term fallow	1	0%	0	0%
R17	Catch crops	1	0%	0	0%
S25	Green cover on permanent crops	1	0%	0	0%
Z21	Cultivation of rare/local crop species	1	0%	0	0%
R131	Short-term fallow	0	0%	3	5%
F121	Max mineral fertiliser input	0	0%	2	3%
L321	Maintenance of silvicultural systems	0	0%	1	2%
S11	Low tillage	0	0%	1	2%

Source: The Authors.

Most of the remaining practices are only mentioned once (2%), reflecting their marginal presence in the comparator systems analysed. These include practices such as outdoor access for livestock (A51), ban on mineral fertilizers (F112), soil amendment with lime (F33), application of solid manure (F421), green manure use (F44), biological and mechanical pest control (P11 and P12), restrictions on fungicides and insecticides (P212 and P213), crop diversification (R14), low or no tillage (S11 and S12), crop residue management practices (S24 and S26), and sustainable water management in paddy systems (W16).

Overall, these results indicate that the comparator systems used in the analysed studies are generally characterized by relatively simple or moderately diversified management practices, often centred on conventional input management, particularly mineral fertilization. While some comparators include elements associated with more sustainable farming practices—such as crop rotation, reduced pesticide use, or soil conservation measures—these practices appear only sporadically. Consequently, the comparator systems tend to represent baseline or transitional farming systems, which are then contrasted with the more complex and diversified agroecological practice packages that characterize the interventions in the full evidence library.

3.1.2. Interventions

The most frequently cited practices among the interventions primarily relate to agroecological strategies and sustainable farm management approaches.

The interventions show also a strong concentration around a limited number of practices, whereas many practices are only sporadically represented. The most frequently cited practices primarily relate to agroecological strategies and sustainable farm management approaches. In particular, organic farming is mentioned 18 times (8%), suggesting that conversion to or management under organic standards constitutes one of the main intervention strategies investigated in the literature.

While organic farming is often examined as an intervention in the literature, it is worth recalling that actually it consists in set of management practices, including among other ban of mineral fertilisers and synthetic pesticides plus other practices mentioned below, which can be applied individually. Cultivation of nitrogen-fixing crops (e.g., legumes) is the second most frequent practice, reported 16 times (7%), highlighting the importance attributed to biological mechanisms for improving soil fertility.

Practices aimed at increasing cropping system diversity also appear prominently. Crop diversification and mixed cropping are each mentioned 14 times (6%), indicating substantial attention to diversified production systems to enhance resilience and sustainability. Similarly, the use of green manure and biological control are reported 12 times each (5%), reflecting the relevance of organic soil fertility management and ecological pest control strategies in the interventions considered. Compost application and mechanical weed control follow closely, with 11 mentions each (5%), further emphasizing the role of organic inputs and non-chemical management practices.

A second group of practices relates to soil management and crop rotation strategies, which are moderately represented in the dataset. Both the ban on mineral fertilizers and crop rotation are mentioned nine times (4%), suggesting a notable but less dominant presence in the analysed interventions. Additionally, restrictions on synthetic pesticides, including bans on herbicides, fungicides, and insecticides, appear six times each (3%), indicating a recurring focus on reducing chemical inputs within agricultural systems. Low-input systems are reported five times (2%), further reflecting this emphasis on minimizing external inputs.

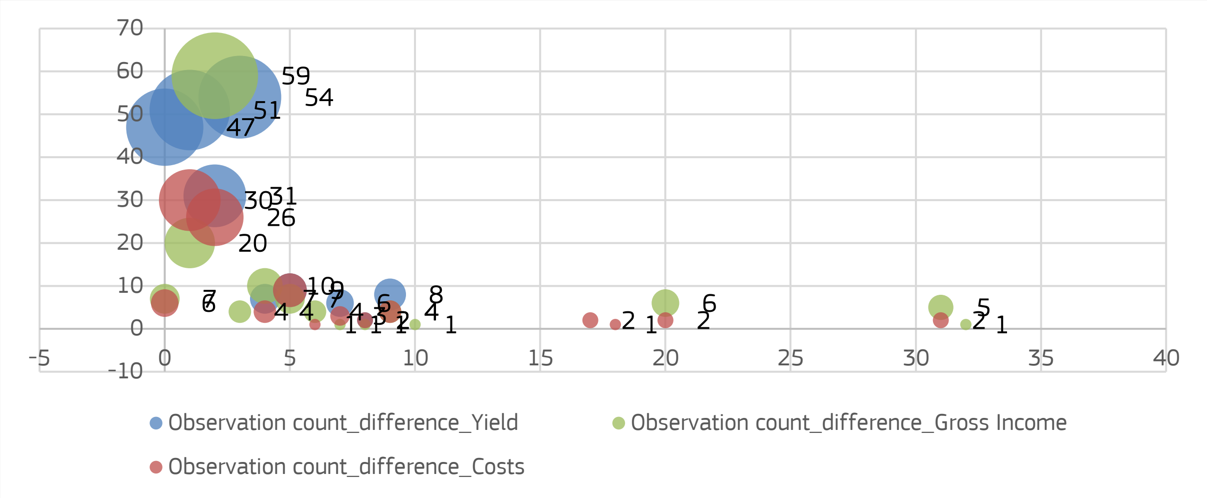
A number of practices appear with relatively low frequencies. Feed from farm, no burning of crop residues, and incorporation of crop residues into the soil are each mentioned four times (2%). Meanwhile, solid manure incorporation, creation of field margins, bans on molluscicides and plant growth regulators, no-tillage practices, crop residue management, farmer training, and sustainable water management are each reported three times (1%).

Several additional practices appear only once or twice (0–1%) across the dataset. These include measures such as limits on organic or organo-mineral fertilizers, the adoption of specific machinery or application techniques, the establishment of agroforestry elements (e.g., tree planting or silvopastoral systems), pasture management strategies, livestock welfare measures (e.g., outdoor access or livestock density regulations), certification schemes, and soil fertility practices such as catch crops or green cover.

Taken together, these results suggest that the body of literature included in the full evidence library, and in the following meta-analysis, is strongly concentrated on a core set of agroecological and input-reduction approaches, particularly organic farming, and individual practices such as crop diversification, and soil fertility management through organic amendments. In contrast, a wide range of more specialized or context-specific practices are only marginally represented, appearing in relatively few studies. This distribution indicates that the existing evidence base focuses predominantly on a limited number of widely recognized sustainability strategies, while many other potentially relevant agricultural practices remain comparatively underrepresented in the analysed interventions.

As shown in Figure 2, the number of observations decreases sharply as the difference in the number of practices between intervention and comparator systems increases. The vast majority of primary studies compare farming systems that differ by only a small number of practices, typically between zero and three. Beyond this range, the number of available observations drops rapidly, and only a few cases compare systems with larger differences in the number of practices (e.g., differences greater than ten). This pattern indicates that the empirical evidence base is largely concentrated on comparisons between relatively similar farming systems, while studies examining more substantial transitions toward complex agroecological systems remain comparatively scarce.

Figure 2. Bubble graph showing the decreasing number of observations as the number of practices increase.



Source: Authors' elaboration

It is important to note, however, that figure 1 only reflects the numerical difference in the number of practices attributed to comparator and intervention systems, without accounting for the qualitative nature or transformative potential of individual practices. In particular, some practices such as organic farming (which is in fact a farming approach entailing different individual practices) may represent deeper stages of agroecological transition than others and could therefore have disproportionately larger effects on system performance. Consequently, a simple count of practices cannot fully capture the level of agroecological complexity or transition embodied in the farming systems under comparison. This limitation suggests the need for future research to develop more refined indicators of agroecological transition or system complexity, capable of weighting practices according to their ecological and systemic significance rather than relying solely on their numerical count.

3.2. Effects on Yield

The random-effects meta-analysis for yield (n = 76) detected a significant positive overall effect, corresponding to an estimated 14.3% (CI: 3.0% - 26.8%) increase in yield under more complex, agroecology-oriented intervention systems versus simpler or less complex comparator systems. The magnitude of between-study heterogeneity was significantly high ($p < 0.01$), confirming that yield responses vary greatly across contexts and that pooled results must be interpreted in the presence of substantial underlying variability. Visual inspection of the funnel plot, together with Egger's regression test ($p = 0.33$), provided no evidence of publication bias.

The Fail-safe N Analysis indicated that 42 null-effect studies would need to be added to the dataset to render the overall effect nonsignificant ($p > 0.05$), reinforcing the robustness of the yield result. Normality checks (histogram, Q–Q plot, Shapiro–Wilk $p = 0.094$) showed no significant deviation from distributional assumptions.

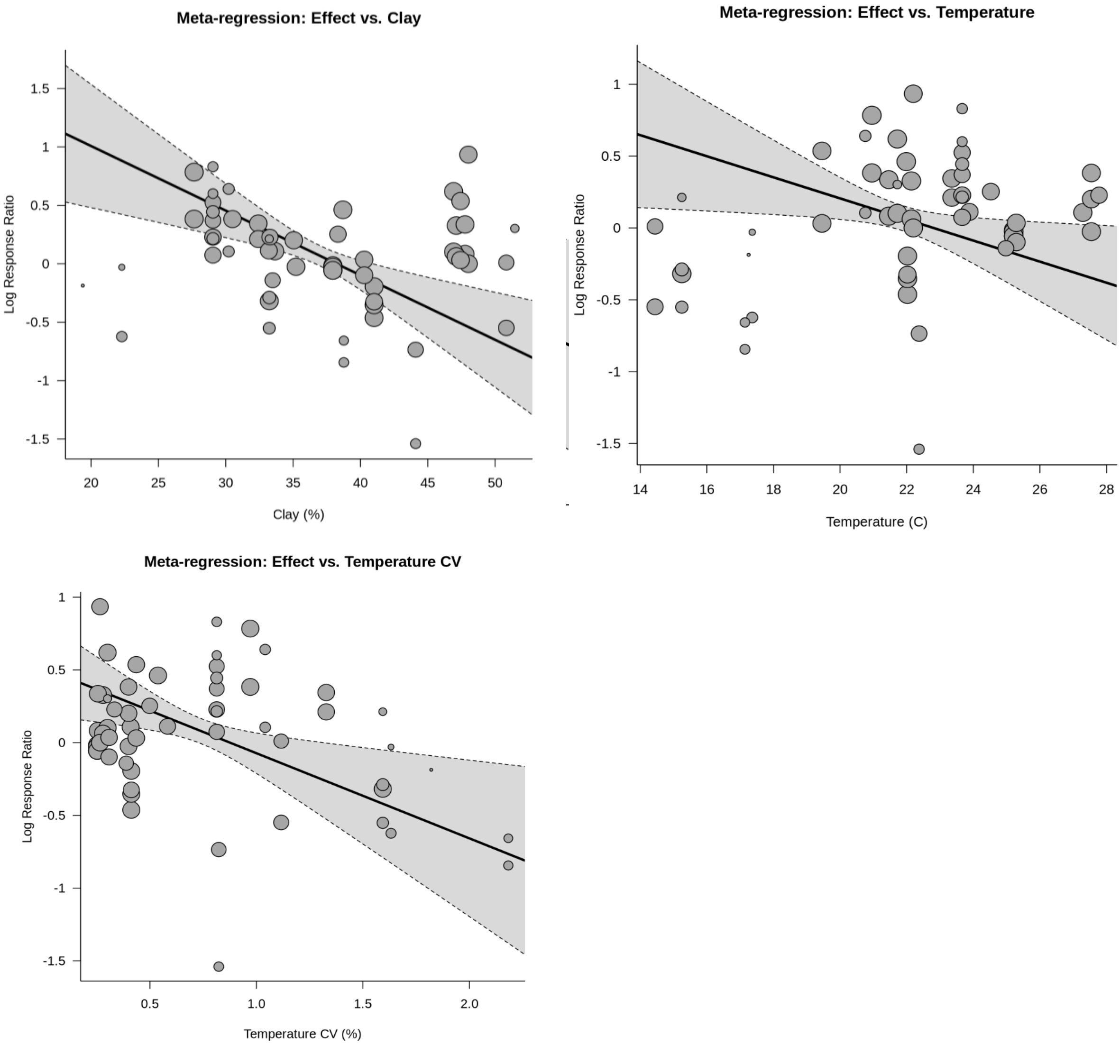
To investigate the pronounced heterogeneity, a mixed-effects meta-regression was conducted using biophysical and contextual moderators. This model (n = 57) explained 38.4% of the between-study variance (R^2) and showed a highly significant overall moderator effect ($p < 0.01$).

Among the tested variables:

1. Clay content was a significant negative moderator (estimate = –0.0553, p = 0.0004).
2. Temperature (estimate = –0.0734, p = 0.0230) and temperature CV (estimate = –0.5854, p = 0.0065) both negatively moderated yield responses.

These results indicate that yield responses tend to be more positive in cooler, more stable climates and less clay-rich soils.

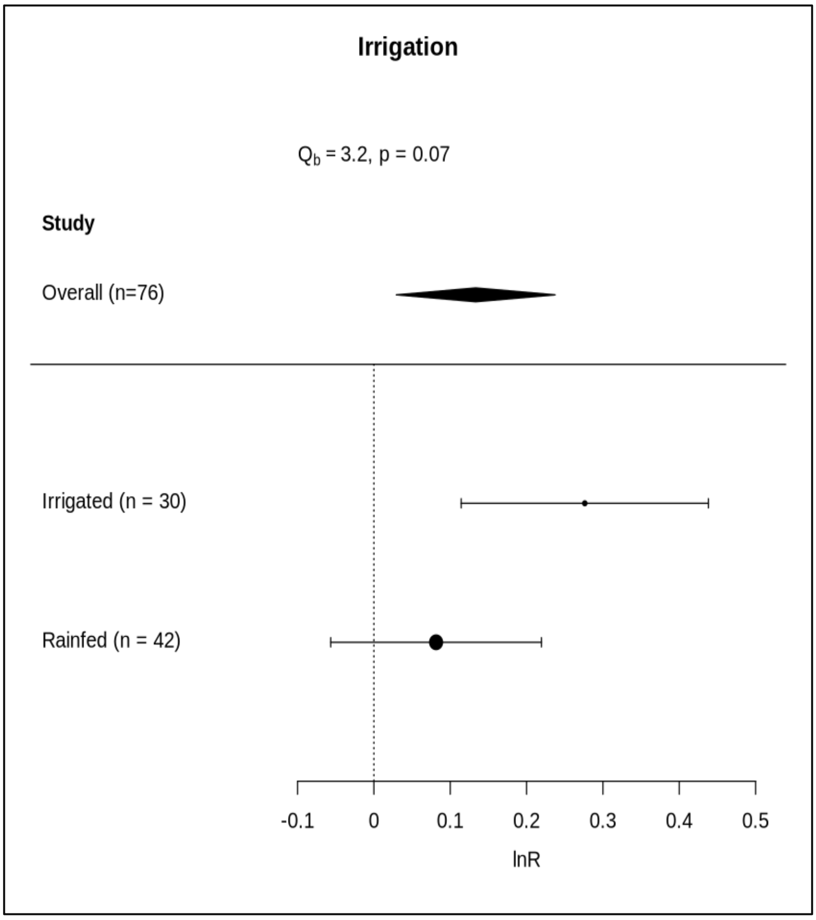
Figure 3. Meta-regression results showing significant negative moderation of yield responses by clay content (upper-left panel), mean temperature (upper-right panel), and temperature variability (CV) (bottom-left panel). Yield advantages were greater in cooler and more stable climates and in soils with lower clay content.



Source: Authors' elaboration

To complement the continuous moderators, categorical subgroup analyses were performed. Water management type (irrigated, rainfed) was not a significant moderator (p=0.1682), indicating considerable overlap in yield effects across irrigation strategies. Although irrigation type did not significantly explain heterogeneity, the subgroup estimates showed that irrigated systems frequently displayed more positive yield effects than rainfed or mixed systems (**Figure 4**).

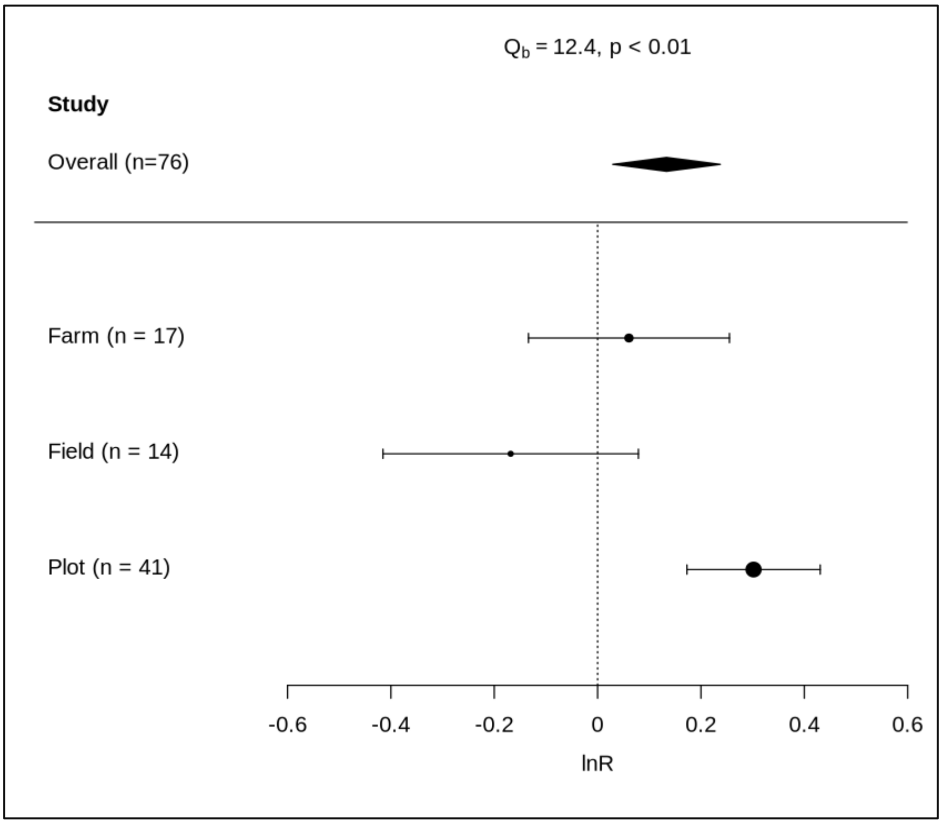
Figure 4. Subgroup analysis of irrigation strategies. Although the moderator was not statistically significant (p = 0.1682), irrigated systems showed more positive yield responses than rainfed systems.



Source: Authors' elaboration.

Spatial scale had a statistically significant moderator effect (p < 0.01). In particular, plot-scale observations showed a significantly more positive yield response compared to field, farm, or farm-scale observations (Fig. 5). This pattern is consistent with the expectation that small-plot trials often reflect more controlled conditions and may better express treatment effects, whereas landscape-scale outcomes integrate larger ecological and management variability. However, further analysis based on a larger data pool would be needed to confirm this.

Figure 5. Yield effects across spatial scales (plot, field, farm). Spatial scale was a significant moderator ($p < 0.01$). Plot-level studies exhibited the strongest positive yield effects relative to field- and farm-scale observations.



Source: Authors' elaboration.

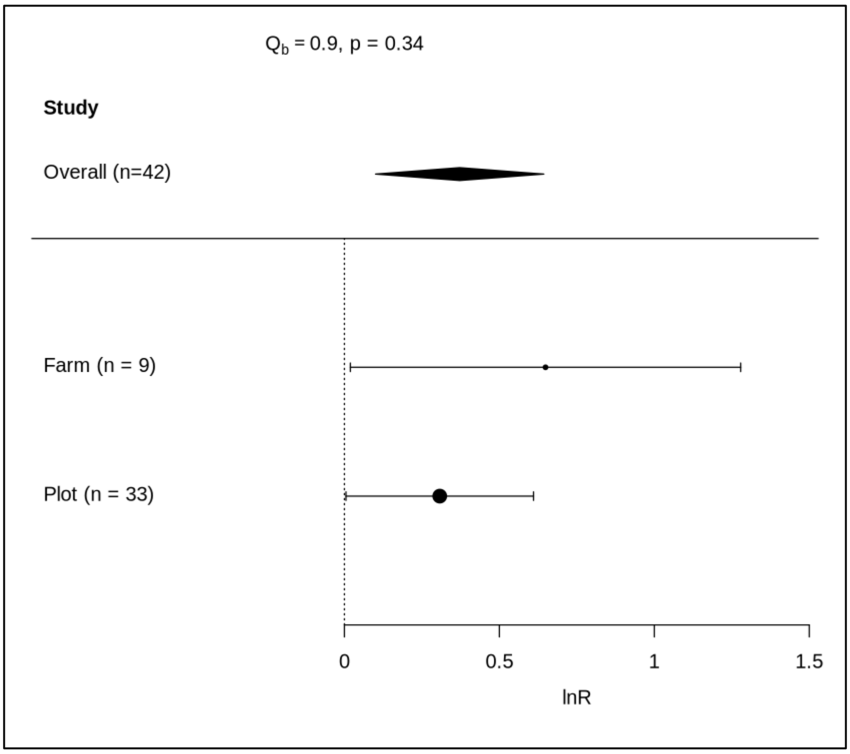
3.3. Effects on Gross income

The random-effects meta-analysis for gross income (n = 42) indicated a significant overall increase of 44.5% associated with the intervention systems compared to conventional controls (CI: 9.7%-90.3%). Heterogeneity was significantly high ($p < 0.01$), mirroring the variability observed in the yield analysis and suggesting that economic benefits vary substantially across contexts. Unlike the yield metric, the gross-income synthesis showed indications of publication bias. Egger's regression test detected statistically significant funnel-plot asymmetry ($p = 0.04$), pointing toward potential small-study or reporting effects. The fail-safe N analysis further supported this concern, showing that 29 null-effect studies would be needed to raise the overall p-value above 0.05 which indicate moderate vulnerability of the income results to file-drawer bias.

To better understand the sources of heterogeneity, a series of moderator analyses were conducted. A multivariate mixed-effects meta-regression including soil texture, soil organic carbon, pH, rainfall, temperature, agroecological performance score, and climatic variability indicators explained 20% of the between-study variance ($R^2 = 20.18\%$), but none of the individual moderators were statistically significant when considered jointly. This indicates that environmental and pedoclimatic gradients do not systematically structure the variation in gross-income responses and suggests that economic outcomes are likely influenced by factors not captured in the dataset—such as input costs, labour availability, local market access, or farmer-level management decisions.

Beyond continuous environmental gradients, categorical subgroup analyses were also undertaken to determine whether gross-income effects varied according to spatial scale or irrigation strategy. The spatial-scale model tested differences among plot-scale experiments, field-scale observations, and broader farm or landscape evaluations (**Figure 6**). The results indicated that spatial scale was not a significant moderator ($p = 0.4871$), with no subgroup differing significantly from the overall pooled estimate. This finding contrasts with the yield metric, where plot-level observations showed systematically stronger treatment effects. For gross income, by contrast, the magnitude of economic gains appears consistent across experimental, field, and real-farm conditions, suggesting that the income benefits observed in smaller plot trials tend to translate to operational farm contexts.

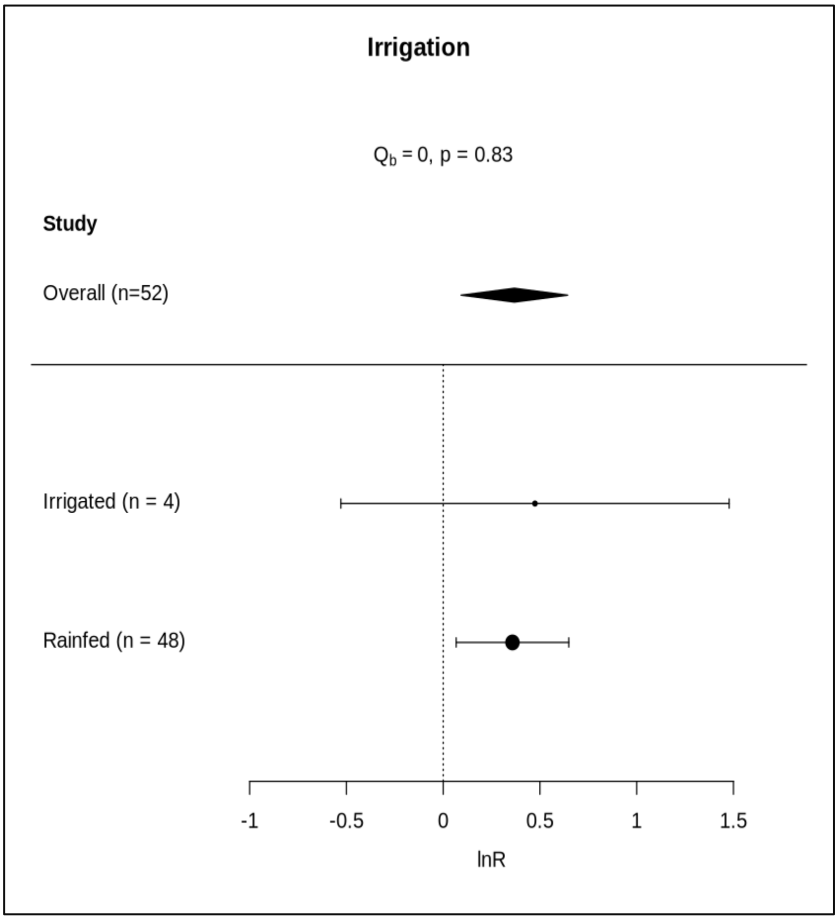
Figure 6. Subgroup analysis of spatial scale for gross-income effects. No significant moderation by scale, indicating that income benefits observed in plot observations are consistent at field and farm levels.



Source: Authors' elaboration.

Similarly, the analysis of water management and irrigation type found no significant moderation of income outcomes ($p = 0.96$) (Fig. 7). This suggests that, unlike yield—which can be strongly constrained by water availability—farm-gate income is more heavily shaped by market and cost structures than by irrigation regime when moving towards more agroecological approaches. In practical terms, this means that economic performance appears broadly resilient across water-management contexts, and that the income benefits associated with intervention systems are not limited to irrigated settings. However, this interpretation warrants some caution: if irrigation costs (e.g., infrastructure investment, energy, water fees) are not captured in the income measure used here, the null result may partly reflect an incomplete accounting of production costs rather than a true absence of effect. Future analyses that incorporate full input costs would help clarify whether irrigation regime influences income net of these expenditures.

Figure 7. Gross-income responses by irrigation regime. Irrigation type was not a significant moderator, suggesting that economic gains are broadly independent of water-management context.



Source: Authors' elaboration.

Overall, the analysis demonstrates that while more complex, agroecology-oriented intervention systems are associated with substantial gross-income gains, the evidence base for this outcome is more heterogeneous and more sensitive to publication bias than the corresponding yield results. The absence of significant moderating effects from environmental variables, spatial scale, or irrigation highlights that the economic drivers of intervention performance remain only partially understood and likely depend on socio-economic and managerial factors that extend beyond biophysical site characteristics.

3.4. Effects on Production costs

The meta-analysis of production costs drew on n = 19 observations that reported sufficient statistical information for effect-size calculation. The random-effects model estimated a statistically significant average reduction in production costs of –36.46% under intervention systems compared with conventional controls. This corresponds to a log response ratio of –0.4534 (SE = 0.1652, p = 0.0061, 95% CI: –0.7772 to –0.1297), indicating that, across the evidence base, more complex, agroecology-oriented intervention systems are generally associated with substantial cost savings for farmers. The model also identified very high heterogeneity among the included observations, reflected in a $p < 0.01$, suggesting that the magnitude of cost reductions varies widely across contexts.

In contrast to both yield and gross income, the meta-analysis on production costs showed a publication bias. Egger's regression test indicated significant funnel-plot asymmetry ($p < 0.01$), implying a systematic tendency for studies reporting negative or favourable cost reductions to be over-represented relative to those finding neutral or cost-increasing results. This interpretation is reinforced by the fail-safe N analysis, which estimated that 16 null-effect studies would be needed for the overall cost-reduction effect to lose statistical significance—demonstrating that the apparent strength of the cost signal is sensitive to potential file-drawer bias. Nevertheless, after accounting for publication bias, the direction of the effect remained consistently negative, indicating that cost savings are a recurrent feature across intervention systems, even if their magnitude may be overstated due to reporting bias.

To explore the sources of heterogeneity in the cost reductions, a meta-regression incorporating soil properties, climate variables, and agroecological intensity was performed. However, in contrast to yield—which showed several significant biophysical predictors—the cost dataset revealed no significant moderators, and none of the environmental or agronomic covariates meaningfully explained variability in cost outcomes. This suggests that production costs are influenced less by pedoclimatic conditions and more by farm-level management choices, input substitution pathways, or economic and institutional environments that are not captured in the dataset.

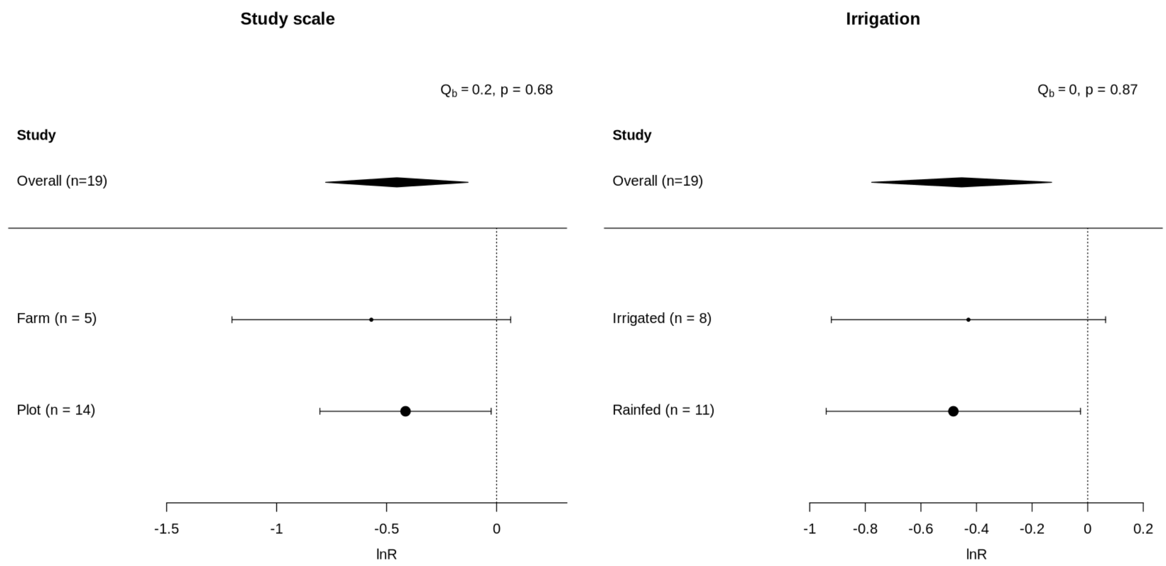
The absence of significant moderators is consistent with the idea that cost reductions in agroecological systems often derive from reduced reliance on external inputs (e.g., synthetic fertilizers, pesticides, irrigation energy), whose use varies more with management strategy than with inherent environmental conditions. This contrasts with yield responses, which are strongly shaped by soil and climate gradients, and with gross income, where market factors dominate. Also, farm-level management choices are in turn affected by, and adopted in response to, pedoclimatic conditions, so results may also suggest that as the effects of the latter can be mitigated, in terms of costs, by adopting more agroecological practices that better adapt the systems to the external conditions. However, given the more limited numbers of observations on costs, results should be interpreted with caution.

To complement the continuous moderators, subgroup analyses were conducted to determine whether the magnitude of cost changes varied across spatial scale (plot, field, farm) or water management systems (irrigated, rainfed, mixed) (**Figure 8**). There is no evidence that spatial scale significantly modifies the cost outcome, with subgroup estimates clustering around the overall negative effect and p-values far from significance. This suggests that, unlike yield—which tends to show stronger treatment effects at the plot scale—cost reductions observed in small experimental plots generally translate to real-farm operational contexts.

Similarly, the water-management moderator showed no significant differences among irrigated, rainfed, or mixed systems. Although specific cost components (e.g., pumping energy, irrigation inputs) may vary with water availability, the overall cost reductions induced by intervention systems did not differ significantly by irrigation strategy. This aligns with the expectation that many agroecological practices reduce input expenditure regardless of water regime—for example, through improved nutrient cycling, biological pest control, or the substitution of purchased inputs with on-farm resources.

Overall, the production-cost analysis demonstrates that intervention systems are associated with substantial and statistically significant reductions in production costs, although the evidence base is more affected by publication bias than the other metrics. Unlike yield or income, cost responses do not appear to be systematically structured by environmental gradients, spatial scale, or irrigation regime. This suggests that the economic efficiency gains of agroecological transitions arise primarily from management-driven reductions in input use, which operate consistently across diverse environmental settings.

Figure 8. Subgroup analyses of production-cost effects across spatial scales (left panel) and irrigation regimes (right panel). No significant moderation was detected for either factor, indicating that cost reductions associated with intervention systems remain consistent across plot- and farm-scale observations



Source: Author's elaboration

The VIF analysis highlighted differences in collinearity structures across the studied metrics. While multicollinearity was not a concern for the Costs (maximum VIF = 3.05) and Yield (maximum VIF = 4.98) models (Table 2), the initial Gross Income model exhibited severe collinearity, primarily driven by soil pH (VIF = 10.76). Soil pH was highly correlated with mean annual precipitation (r = -0.86) and precipitation variability (r = 0.728), reflecting well-documented soil leaching and acidification processes under higher rainfall regimes (Table 3).

By excluding pH from the Gross Income dataset, we successfully mitigated this multicollinearity. The maximum VIF among the remaining covariates in the Gross Income model was reduced to 6.08 (for clay content), which is well below the standard threshold of 10 (Table 3, rightmost colum). Conversely, because pH did not cause problematic collinearity in the Costs (VIF = 2.14) or Yield (VIF = 2.69) datasets, it was safely retained in those models to preserve its potential explanatory power.

3.5. Collinearity analysis

The VIF analysis highlighted differences in collinearity structures across the studied metrics. While multicollinearity was not a concern for the Costs (maximum VIF = 3.05) and Yield (maximum VIF = 4.98) models (**Table 2**), the initial Gross Income model exhibited severe collinearity, primarily driven by soil pH (VIF = 10.76). Soil pH was highly correlated with mean annual precipitation (r = -0.86) and precipitation variability (r = 0.728), reflecting well-documented soil leaching and acidification processes under higher rainfall regimes (**Table 3**, left column).

Table 2: Results of the collinearity analysis – yields and cost analyses

Variable	Variance Inflation Factors (VIF)	
	Yield analysis	Cost analysis
Clay	1.57	1.84
SOC	2.01	1.76ft column
pH	2.68	2.14
precipitation	4.98	2.36
temperature	3.97	1.38
AE score	2.05	1.29
Temperature CV	4.00	1.68
Precipitation CV	1.80	3.05

Source: Authors' elaboration

By excluding pH from the Gross Income dataset, we successfully mitigated this multicollinearity. The maximum VIF among the remaining covariates in the Gross Income model was reduced to 6.08 (for clay content), which is well below the standard threshold of 10 (**Table 3**, right column). Conversely, because pH did not cause problematic collinearity in the Costs (VIF = 2.14) or Yield (VIF = 2.69) datasets, it was safely retained in those models to preserve its potential explanatory power.

Table 3. Results of the collinearity analysis – gross income analysis.

Variable	Variance Inflation Factors (VIF)	
	Original	After removing pH
Clay	6.64	6.07
SOC	2.90	2.89
pH	10.76	-
precipitation	8.27	3.59
temperature	2.01	1.68
AE score	1.82	1.41
Temperature CV	1.38	1.38
Precipitation CV	6.83	4.73

Source: Author's elaboration

4. Discussion

4.1. The practice-based approach

The practice-based approach, counting the practices included in interventions and comparators to assess complexity of systems reveals a clear difference between comparator and intervention systems. Comparator systems generally include a limited number of practices, with an average of two coded practices per system, and are largely centred on conventional input management strategies, particularly mineral fertilisation. By contrast, interventions include substantially more practices, averaging 6.1 per system and reaching up to 33 in some cases. This difference suggests that the empirical literature included in the full evidence library typically compares relatively simplified baseline systems with more complex agroecological practice bundles.

This finding reflects a broader characteristic of agroecological transitions, which are rarely implemented through isolated technological changes but rather through integrated sets of management practices operating at the system level (Altieri and Nicholls 2020; Wezel et al. 2020; FAO 2013; Gliessman 2007). Previous studies have emphasized that agroecological performance often emerges from interactions among multiple practices, including diversification, soil fertility management, and ecological pest regulation, rather than from the isolated effect of a single intervention (Tamburini et al. 2020; HLPE-FSN 2019; Tittonell et al. 2020) (Duru et al. 2015; Kremen and Miles 2012).

The analysis of comparator practices further highlights that the baseline systems used in the literature frequently represent conventional or partially transitional farming systems, rather than purely intensive monoculture systems. For instance, practices such as crop rotation, short-term fallow, or restrictions on specific pesticides appear in several comparator systems. This suggests that many studies compare agroecological interventions not only with highly simplified conventional systems, but also with moderately diversified or partially improved farming systems. This observation is important for interpreting the magnitude of the estimated impacts reported in the meta-analysis, as it implies that agroecological interventions are often evaluated against already improved baselines rather than against purely conventional systems (Beillouin et al. 2021, 2019; Knapp and Van Der Heijden 2018).

At the same time, the distribution of practices among the interventions indicates that the empirical literature tends to concentrate on a core subset of agroecological strategies, particularly organic farming, crop diversification, nitrogen-fixing crops, organic soil amendments, and ecological pest control. These practices correspond closely to the widely recognized principles of agroecology, such as diversification, recycling of nutrients, and the reduction of external inputs (FAO 2018; Gliessman 2007; Altieri and Nicholls 2020).

However, many other practices included in comprehensive agricultural sustainability frameworks appear only marginally represented in the analysed studies. This suggests that the current evidence base may reflect a relatively narrow operationalization of agroecology in empirical research, focusing primarily on a limited set of well-established practices. As a result, other potentially relevant practices—particularly those related to landscape management, biodiversity conservation, or integrated livestock–crop systems—remain underexplored in the full evidence library, and in existing literature (Mabhaudhi et al. 2023).

It is also worth highlighting that since interventions often consist of bundles of practices, attributing observed outcomes to specific practices can be challenging. The effects reported in primary studies may reflect not only the individual contribution of each practice but also synergistic interactions among multiple practices implemented simultaneously (Duru et al. 2015; Therond et al. 2017). Consequently, practice-based coding approaches, such as the one adopted in this study using the JRC iMAP-FP classification, provide a useful way to better capture the structural complexity of agroecological interventions.

More broadly, the results reinforce the idea that agroecological transitions should be understood not simply as the adoption of alternative inputs or isolated technologies, but rather as system-level transformations involving multiple interacting practices and management strategies.

4.2. Methodological considerations: towards a geospatial augmented Meta-analytic framework

The meta-analytic framework applied in this study was designed to synthesize heterogeneous evidence on agroecological transitions while maintaining methodological rigor. By relying on random-effects models and outcome-specific diagnostics, the framework ensures that variability across farming systems, pedoclimatic contexts, and study designs is explicitly accounted for.

Overall, among the three metrics analysed, yield emerged as the most statistically robust outcome. This robustness reflects both the stronger empirical base for agronomic performance and the more standardized reporting of yield data across studies. Gross income also showed a significant and positive overall effect, indicating that more complex, agroecology-oriented intervention systems can meaningfully enhance farm-level economic returns. However, the robustness of this metric was weaker than that of yield. Moreover, the heterogeneity observed in gross-income outcomes was only partially explained by the tested moderators, implying that economic performance is shaped by socio-economic and managerial factors—such as market access, labour dynamics, or input-price structures—that were not captured in the available dataset. As a result, while the direction of gross-income effects is clearly positive, their magnitude should be interpreted cautiously.

Results on production costs, while still being statistically significative, showed weaker robustness due to the more limited number of observations (n=19). This narrower evidence base also limited the possibility to investigate the role of other factors potentially influencing cost reductions. Studies reporting cost reductions may also be overrepresented. Overall, the findings provide a strong indication that agroecological practices can reduce production costs; however, the relatively small number of observations warrants further research to confirm this effect.

This differentiated robustness underscores the importance of expanding high-quality economic data in future agroecological research.

4.3. Agronomic interpretation on yield outcomes

The yield responses observed in this meta-analysis are consistent with established agronomic theory. The significant moderating effects of soil texture, temperature, and climatic variability point toward clear biophysical mechanisms driving the performance of agroecological practices.

Soil texture emerged as one of the strongest moderators: yield advantages of agroecological systems decreased as clay content increased. Heavy soils are known to be more susceptible to structural constraints such as compaction, poor aeration, limited root penetration, and slower drainage. These constraints reduce the responsiveness of such soils to shallow or reduced tillage, which is common in many agroecological practices. Empirical evidence suggests that shallow tillage on heavy soils tends to depress yields (Ceriani et al. 2026). Therefore, the negative moderating effect of clay content observed in our analysis aligns with known soil–tillage interactions and highlights the need for context-specific tillage management when promoting agroecological transitions in clay-rich environments.

Temperature and temperature variability also had significant negative effects on yield responses. Higher temperatures increase evapotranspiration demand, accelerating soil moisture depletion and heightening plant water stress. These effects may be explained by the fact that agroecological practices often improve soil water retention over time through organic inputs, mulches, and root biomass accumulation, but these benefits may not fully counteract high evaporative demand in the short term—especially under erratic rainfall or temperature patterns. The significant role of temperature variability further suggests that agroecological systems are more sensitive to climatic instability during their establishment phase, when soil structure and biological activity are still developing. Under such unstable pedoclimatic conditions, yield responses are penalized regardless of the management strategy, but the effect is more visible when transitioning away from high-input buffers.

The agronomic relevance of water availability is also evident in the subgroup analysis on irrigation, which showed that irrigated systems experience substantially more positive yield effects than rainfed or mixed systems. Irrigation mitigates the water stress that would otherwise constrain the potential benefits of agroecological practices, especially in hot or variable climates. By buffering soil moisture and stabilizing plant water supply, irrigation allows the ecological processes fostered by agroecological practices—such as improved nutrient cycling, enhanced microbial activity, or better root–soil interactions—to express their full agronomic potential. In contrast, under rainfed conditions where water availability is uncertain, the benefits of diversified practices can be overshadowed by climatic limitations. This pattern reinforces the centrality of water management in agroecological transitions and suggests that integrated water strategies (irrigation, rainwater harvesting, mulching, soil cover, organic matter enhancement) can be critical for achieving stable yield gains in dry or variable climates.

Taken together, these findings confirm that the agronomic performance of agroecological interventions is strongly conditioned by biophysical context. The overall positive yield effect reflects the average benefit of diverse ecological processes. However, the magnitude of this benefit depends on whether underlying soil and climatic conditions enable or constrain those processes. Agroecological sets of practices perform best where soils are neither excessively heavy nor structurally degraded, where temperature and climatic variability are moderate, and where water availability is sufficiently buffered—either naturally or through irrigation. Nevertheless, it should be remarked that this evidence emerges from a merely economic analysis, while viability of agroecology should not be reduced to this dimension of economic sustainability.

This agronomic reading thus provides coherence to the meta-analytic results: agroecology tends to increase yields, but its success is amplified in favourable pedoclimatic conditions and attenuated where basic soil–water–temperature constraints limit crop development. The contextual sensitivity observed in this study highlights the importance of tailoring agroecological interventions to local biophysical realities rather than applying uniform prescriptions across heterogeneous agricultural landscapes. It also underscores the importance of continuously enlarging the knowledge base, adding observations covering not only different combination of practices, but also different soil types, agro-climatic zones and larger scope, i.e. farm and landscape scale.

5. Conclusions

To the author's knowledge, this study is one of the first quantitative meta-analysis of the effect of more complex, agroecology-oriented intervention systems versus simpler or less complex systems. It is also one of the first attempts to enhances a classical statistical meta-analysis by using the location of primary studies to retrieve information not reported in the study themselves, but available in geospatial datasets.

Results show that more agroecological farming has positive effects on yields, gross income and production costs. While results are statistically significant for each of the three examined metrics, their robustness is high for yields, medium for gross income and moderate for costs.

The analysis of how pedoclimatic conditions affect results further reinforces the idea that agroecological efficacy is not uniform but is highly sensitive to pedoclimatic gradients, thereby providing a more nuanced, site-specific roadmap for agricultural development in Africa and the Global South.

The methodology proposed, together with the new structured dataset made available, proved able to contribute to the JRC quantitative evidence library and contributes to fill the gap on robust, quantitative evidence on the socio-economic performance of agroecology which is often indicated as a barrier to widespread adoption by farmers and increased support by policy.

Future research should address some open questions emerging from this study. In particular, there's a need to have a better metric to measure the degree to which a farm adopts agroecology principles along a continuum, to move beyond binary "agroecology versus conventional" categorizations. This can be done by elaborating ad-hoc scores starting from individual farming practices.

Also, the present results are mainly based on observation at plot/field level. More evidence is needed to assess the effect of agroecology at farm and landscape scales. Future research shall also consider the institutional and territorial context in which the farm operates. This may include assessing the impact of short supply chains, participatory governance, and collective action on the economic viability of agroecological systems.

Another key research frontier lies in evaluating whether the identify relationships between application of agroecological practices and socio-economic effects is linear or there are "threshold effect", whereby differences are very little when few farming practices are applied while they increase substantially where the new system reaches a certain degree of complexity.

Moreover, the time dimension was not considered in this study. Previous literature suggests that longer implementation periods of agroecological practices are likely to be associated with greater benefits. This is an important element to be incorporated in future works, but requires that policy supports long-term studies, which are more costly and difficult to carry out Finally, this study focused on agronomic and socio-economic aspects at farm level, but acknowledges that agroecology is a broader and more complex concept that entails changes on social, environmental and economic aspects in the entire food systems.

These limitations notwithstanding, the results of this study encourage a shift in agricultural development strategies in the Global South from supporting conventional intensification toward fostering deep, multi-level agroecological transitions that are resilient to both climatic and socio-economic shocks.

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List of abbreviations and definitions

Abbreviations	Definitions
ΑΒΓ	Alpha Beta Gamma
CI	Confidence Intervals
CV	Coefficient of Variation
EC	European Commission
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
iMAP-FP	Integrated Modelling platform for Agro-economic and resource Policy analysis – Farming Practices
JRC	Joint Research Centre
NDICI	Neighbourhood, Development and International Cooperation Instrument
REML	Restricted Maximum Likelihood
SD	Standard Deviation
SE	Standard Error
SOC	Soil Organic Carbon
VIF	Variance Inflation Factors

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