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Assessing Nature-Positive Practices: An Application of The Economics of Ecosystems and Biodiversity (TEEB) for Agriculture and Food Evaluation Framework

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Technical Report

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Introduction

To inform policy and investment that aim to promote nature-positive practices, it is critical to go beyond single metrics such as yield and profitability and comprehensively understand the social, economic, and environmental impact of practices. In this study, using the TEEB for Agriculture and Food (TEBAgriFood) Evaluation Framework (TEEB 2018) to assess four agricultural practices with high potential to contribute positively to biodiversity outcomes is a starting point for identifying the documented main costs and benefits, both visible and “hidden”, of the sustainable management approaches, and their impacts and dependencies on the various types of capitals including biodiversity. The results illuminate the potential co-benefits and tradeoffs in multi-dimensional outcomes that matter to society and shed light on gaps in data and information.

Assessment Framework

Rapid review of existing frameworks

To select the assessment framework, we first conducted a review of existing frameworks of sustainable agricultural management using the Google search engine and Google Scholar. Additional frameworks were also proposed by the research team. For this review, we used the search terms (Sustainable) AND (Agriculture OR Farming) AND (Evaluation OR Assessment) AND (Framework). Our search yielded 3,390,000 results, of which we conducted a rapid title and abstract review on 50 papers and frameworks. The rapid review was restricted to English papers and publicly available frameworks. Based on the rapid title and abstract review, 12 frameworks were considered. We then assessed each framework for its relevancy to our study based on the following criteria:

- Framework addresses four key impact areas:
  - Biodiversity.
  - Ecosystem services.
  - Climate change mitigation and climate resiliency.
  - Human well-being (including considerations of gender equality and social equity).
- Framework can be used on multiple spatial scales (i.e. local, regional, national).
- Frameworks are relevant to global agricultural sites (for example, national government assessment frameworks would not be considered).
- Framework can be used across multiple biomes or ecosystems, or considers comparators for differences in landscape assessments.

Our four key impact areas were chosen based on the main tenets of sustainable agriculture, namely the goals of creating more sustainable, equitable, and resilient farming systems while sustaining economic viability.

All considered frameworks as well as their reasons for exclusion can be viewed in Table 1.

Table 1: Each assessed framework, their data requirements, and reasons for exclusion.

Framework/Paper	Overview	Data requirements	Reason(s) for exclusion
TEEBAgriFood Evaluation Framework (TEEB 2018)	-The framework focuses on stocks, flows, outcomes, and impacts. -Stocks and outcomes are centered around four capital categories: produced capital, natural capital, human capital, and social capital.	-Indicator statistics*.	Not excluded; chosen framework Incorporating a comprehensive natural capital base that includes biodiversity and ecosystem services puts the TEEBAgriFood Evaluation Framework in line with other initiatives such as the Millennium Ecosystem Assessment (MA 2005) and the Intergovernmental

			Platform on Biodiversity and Ecosystem Services (IPBES 2018).
SAFE framework (Van Cauwenbergh et al. 2007)	-Hierarchical framework aimed at spatial and temporal assessment of the product life cycle. -Levels of hierarchical analysis flow from the sustainability goal into principles (environmental, social, etc.), criteria, indicators, and reference values.	-Indicator statistics*.	Considered for our final framework assessment method. -Team unfamiliar with framework.
CRA assessment framework (Zong et al. 2022)	-The framework is composed of four key dimensions: agricultural productivity, farmer income, climate adaptability, and the green development level. -The framework largely focuses on climate change impacts on agroecosystems, and agricultural mitigation and adaptation strategies.	-Indicator statistics*. -Survey questionnaires.	-Biodiversity and ecosystem services are not prioritized as impact areas. -National only spatial scale. -No biome/ecosystem classification.
Evaluation Framework for Circular Agriculture: A Pathway to Sustainable Farming (Rodino et al. 2023)	-Framework is focused on assessing circularity in sustainable agriculture systems. -Less of a guidance framework and more of a literature review.	NA	-Framework is limited to circular agricultural practices. -Incompatible format for our study.
A framework for evaluating the sustainability of agricultural production systems (Stockle et al. 1994)	-The framework evaluates sustainability based on nine attributes: profitability, productivity, soil quality, water quality, air quality, energy efficiency, fish and wildlife habitat, quality of life, and social acceptance. -Each attribute is coupled with “quantifiable constraints”, values to better understand hurdles in sustainability.	-Indicator statistics*.	-Ecosystem services and climate change mitigation/resiliency are not prioritized as impact areas. -No biome/ecosystem classification.
The IDEA method - version 4 (Zahm et al. 2018)	-The framework consists of 12 goals to achieve strong sustainability and agricultural multifunctionality. -Agricultural sustainability is broken down into five main properties including: an ability to produce goods and services, autonomy, robustness, territorial embeddedness, and global responsibility. -Indicators of sustainability are given hierarchical aggregations.	-Indicator statistics*.	-Ecosystem services are not prioritized as an impact area. -No biome/ecosystem classification.
Sustainable Agriculture Matrix (SAM)	-SAM was developed to assess a country’s agricultural sustainability to promote accountability and inform national policy. -Over 150 countries have been assessed and scored (ranging from 0-100) based on three indicator dimensions: environmental, economic, and social.	-Indicator statistics*. -National government data. -Trade statistics.	-Impact areas are only relevant to the national scale.

A framework for guiding sustainability assessment and on-farm strategic decision making (Coteur et al. 2016)	-The framework serves as an on-site guide for sustainable assessment and farm-specific decision-making. -The framework is two-dimensional, combining a complex sustainability assessment with farmer's strategic decision-making.	-Assessment is heavily reliant on farmer input. -Indicator statistics*.	-Framework is farm-specific (the farmer conducts the assessment) and is not applicable to broader management practices.
Response-Inducing Sustainability Evaluation (RISE)	-The framework uses an indicator-based methodology to assess and inform sustainability at the farm level. -Focuses on three key areas: economic, environmental, and social sustainability	-Assessment relies on voluntary participation. -Indicator statistics*.	-Assessment only relevant to a farm spatial scale.
LCA4CSA framework (Acosta-Alba, Chia and Andrieu 2019)	-The framework is based on Life Cycle Assessment (LCA) with the purpose of guiding stakeholders to the best climate-safe agricultural options. -The assessment process is broken down to five steps: 1. Definition and delimitation, 2. Selection of CSA principles, 3. Selection, design, and calculation of indicators, 4. Reference values, 5. Presentation and interpretation of results	-Assessment is heavily reliant on farmer/stakeholder input. -Indicator statistics*.	-Ecosystem services and key human well-being aspects are not prioritized as impact areas.
Multi-attribute Assessment of the Sustainability of Cropping Systems (MASC) framework (Sadok et al. 2009)	-The framework focuses on three key areas: economic, environmental, and social, and is meant as a sustainability assessment tool for cropping systems.	-Indicator statistics*.	-Ecosystem services, climate change mitigation/resiliency, and key human well-being aspects are not prioritized as impact areas. -No biome/ecosystem classification.
Sustainability Assessment of Food and Agriculture systems (SAFA) (FAO 2014)	The framework aims to assess sustainability goals in food and agricultural supply chains across four dimensions: economic, social, environmental, and governance. -The framework can be accessed as an assessment through online software containing 118 indicators of sustainability quality.	-Online tool available in English, French and Spanish.	-Ecosystem services are not prioritized as impact areas.

*Numerous frameworks have specific data requirements for social, environmental, and economic indicators. As such, indicator data requirements are listed as "Indicator statistics". Each assessed framework tended to have data requirements surrounding the chosen indicators of assessment. These generally centered around three key areas: Environmental, Social, and Economic. Though not explicitly stated in each framework, many of these indicators had implied levels of data effort that remained unanimous across each framework. For example, environmental statistics tended to focus on habitat and biotic quality (biodiversity, water, soil, etc.) which could be assumed to have similar ecological monitoring methods. Likewise, social parameters such as farmer health and empowerment would require equivalent monitoring methods across all frameworks. Other caveats that came up in our review fell under stakeholder input and the assessed level of the agricultural cycle. Certain frameworks, namely those that focused on site or farm-level assessments relied on input from local farmers or stakeholders for assessment development. Most of the frameworks we analyzed concentrated their assessment on the production systems of sustainable agriculture, though certain frameworks like TEEBAgriFood and SAM also considered the impacts of trade and consumption cycles.Ultimately, the TEEBAgriFood Evaluation Framework (hereafter the TEEBAgriFood Framework) was chosen for our study. We chose the TEEBAgriFood Framework for several reasons. First and foremost, the Framework considered each of our study's key impact areas. The diversity of impact areas allows for greater adaptation of assessment, allowing our team to better scrutinize sustainable management practices from multiple angles (Social, Environmental, and Climatic). Secondly, TEEBAgriFood Framework has a wide classification system for regional biomes, which allows the framework flexibility when assessing global management practices, as our team is focused on multiple global landscapes, this aspect of the Framework allows us to better classify, compare, and contrast elements of differing global ecosystems and biomes. Third, the TEEBAgriFood Framework includes a comprehensive guide for users interested in sustainable management assessments, giving our team a clearer assessment pipeline and presentation for results. Lastly, multiple members of the research team expressed familiarity with the TEEBAgriFood Framework, which helped in our decision to choose it over other considered frameworks.

The TEEBAgriFood Framework

The TEEBAgriFood Framework (TEEB 2018) identifies and characterizes all relevant elements of agri-food systems (Figure 1). By providing key definitions and associated measurement concepts and boundaries, the TEEBAgriFood

Framework establishes what aspects of agri-food systems may be included within a holistic evaluation framework. The choice of assessment methods will depend on the focus and purpose of any given assessment, the availability of data, and the scope of analysis. Since not all components receive the same type of evaluation and measurement, it is relevant to distinguish as to whether a component is being assessed descriptively, quantitatively or in monetary terms.

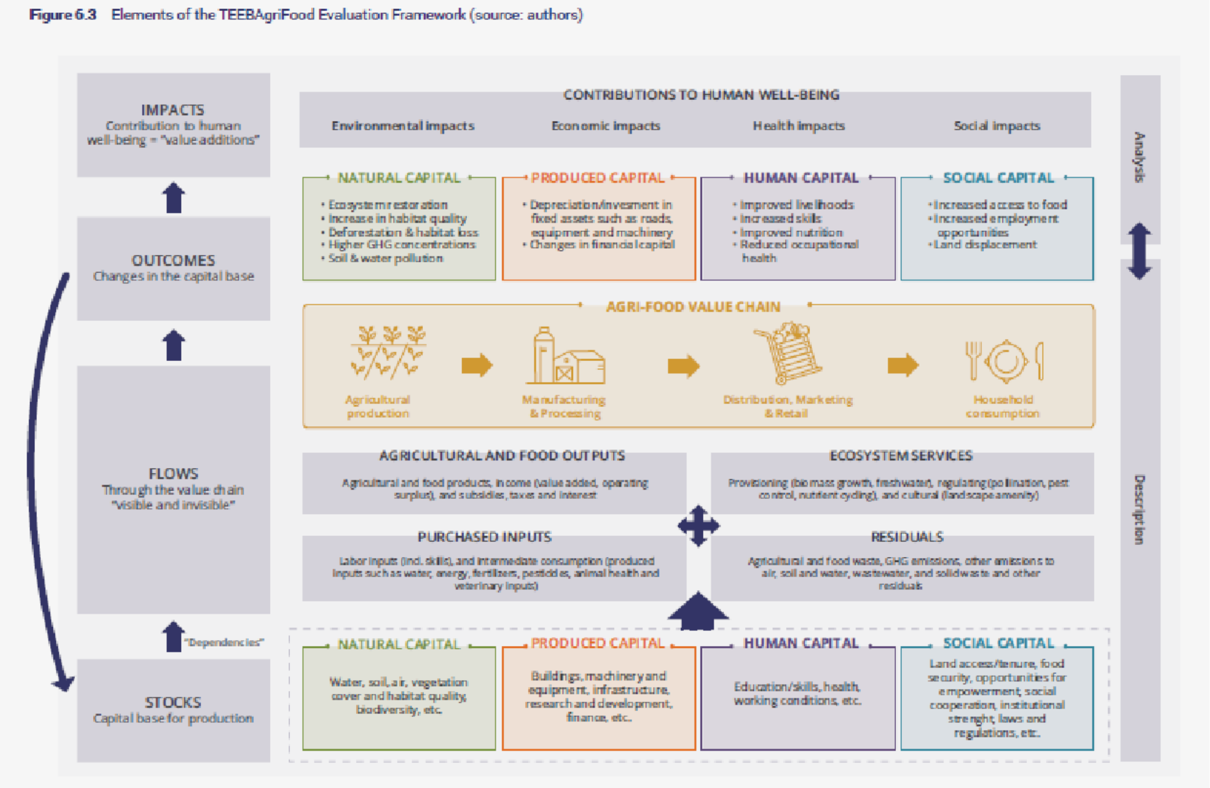


Figure 1. Elements of the TEEBAgriFood Evaluation Framework (Source: TEEB 2018).

The Framework includes four elements - stocks, flows, outcomes and impacts- which capture the set of interactions. The stocks of eco-agri-food systems comprise the four different "capitals" – produced capital, natural capital, human capital and social capital. These stocks underpin a variety of flows encompassing production and consumption activity, ecosystem services, purchased inputs and residual flows. The dynamics of an eco-agri-food system lead to outcomes that are reflected in the Framework as changes in the stocks of capitals, both quantitatively and qualitatively. In turn, these outcomes will have impacts on human well-being.

There are three guiding principles of the TEEBAgriFood Framework (TEEB 2018). The first guiding principle is universality: To consistently and clearly answer the question: "What should be evaluated?" a universal framework is needed. While each assessment may be different in scope and methods, to assure completeness within -and comparability across - assessments, it is important that the elements considered and evaluated in each assessment are defined and described in a consistent manner to allow drawing conclusions from comparisons across different scenarios or strategies.

The second guiding principle is comprehensiveness: both in terms of encompassing the entire value chain, and in terms of including all stocks, flows, outcomes, and impacts within an agri-food system to ensure that all hidden costs and benefits are part of each assessment.

The third guiding principle is inclusiveness in supporting multiple approaches to assessment, including in quantitative and qualitative terms. The evaluation of impacts in the TEEBAgriFood Framework stems primarily from an economic perspective and the accounting-based nature of the framework directly supports analysis in line with economic theory and the valuation of impacts on human well-being in monetary terms. However, while many flows and stocks can be measured in monetary terms, this is not possible for all aspects of human well-being. Thus, the framework should allow for a plurality of value perspectives and assessment techniques, such as multi-criteria analysis. Furthermore, the principle of inclusiveness extends to developing a common information base that underpins not only economic analysis but also other associated lines of measurement and inquiry.

The TEEBAgriFood Framework helps in understanding the true costs and benefits of different agricultural practices, leading to better decision-making and more sustainable outcomes. The full potential of the TEEBAgriFood Framework is only realized when all stakeholders use it to guide decision-making toward a more sustainable and equitable global agrifood system. The TEEBAgriFood Framework is designed to be used by a diverse range of stakeholders involved in or affected by agri-food systems. In addition to research use for comprehensively studying the impacts of agricultural practices and informing policy and practice, policymakers can use the framework to help design and evaluate policies and regulations that promote sustainable agricultural practices and food systems; the private sector (e.g., food and beverage companies, retailers and distributors) can use the framework to assess and improve the sustainability of their supply chains, reduce negative environmental impacts, and enhance social benefits or to source sustainably produced goods and promote sustainable consumption among consumers; financial institutions and investors can use the framework to evaluate the sustainability risks and opportunities associated with investments in the agriculture and food sectors; and development agencies can use the framework to guide investments and technical assistance in agriculture and rural development.

Applying the TEEBAgriFood Framework: Four case studies

Methods

To assess the selected agricultural management practices using the TEEBAgriFood Framework, we conducted a critical literature review of various case studies of minimum and no-tillage, “biocontrol” - biological pest management (specifically ‘conservation’ biological pest management, or the natural recruitment and enhancement of pest predators), agro-silvo-pastoralism, and micro-irrigation. Using Google Scholar, we conducted our review for zero/minimum/no-tillage using the search terms: (Sustainable OR Regenerative) AND (Agri* OR Agro* OR Farm*) AND (Till*) AND (Nature OR Biodiversity OR Ecosystem) yielding 113,000 results. For biological pest management, we used the terms: (Sustainable OR Regenerative) AND (Agri* OR Farm*) AND (Pest OR Invasive) AND (Bio* OR Natural OR Ecological OR Avian OR Bird) AND (Management OR Control OR Reduction) AND (Nature OR Biodiversity OR Ecosystem) yielding 93,400 results. For agro-silvo-pastoralism, we used the terms: (Sustainable OR Regenerative) AND (Agri* OR Agro* OR Farm*) AND (Silvo*) AND (Pasto*) AND (Nature OR Biodiversity OR Ecosystem) yielding 15,800 results. For micro-irrigation, we used the terms: (Sustainable OR Regenerative) AND (Agri* OR Agro* OR Farm*) AND (Micro-irrigation) AND (Nature OR Biodiversity OR Ecosystem) yielding 10,800 results. Only primary research case studies representing the four practices within specific research sites were included in the assessment, as such no previous reviews or systematic evaluations were included. Studies were chosen so that they represented our outcomes of interest, namely: Biodiversity, Ecosystem services, Climate change mitigation and climate resiliency, and Human well-being. Studies were first reviewed at a title and abstract level prior to inclusion (or exclusion) to the final assessment. We selected 20 studies for each of the four practices, resulting in 80 assessed studies to be analyzed under the TEEBAgriFood Framework. Members of the research team also provided additional studies to fill knowledge gaps presented in the TEEBAgriFood framework. Our final assessment totaled 82 studies.

The TEEBAgriFood Framework organizes information under four qualifiers: *Descriptive information available, Qualitative information available, Monetized information available,* and *Not included in study.* While qualitative and monetized information is rather straightforward for our research, we decided to qualify all quantitative information under the descriptive category and refer to it as ‘quantitative information’ going forward as we believed this to be more precise.

To support the application and implementation of the Framework and the associated discussions, the TEEBAgriFood study provided a stylized version of the Framework in the form of a checklist or table that can be used by researchers and decision makers to consider the relevant interactions and to ensure awareness of those aspects excluded from an assessment. The table for tillage can be viewed here, biological pest control can be viewed here, agro-silvo-pastoralism can be viewed here, and micro-irrigation can be found here.

Due to the diverse methodologies and calculations performed across each study, we did not include each paper’s reported values in our table. Instead, narrative descriptions are given for each result with a legend delineating if the referenced study included qualitative, detailed (quantitative), or monetized information. Certain studies provided multiple types of information on a given element of agri-food systems. For our purposes, priority was given to including quantitative information over qualitative information if similar results were reported (e.g., a numerical value of increase vs. the study noting better quality/quantity with no value attached). Our results are presented under our four broader categories of interested impact areas: Biodiversity, Ecosystem services, Climate change mitigation and climate resiliency, and Human well-being. However, each category has representation within the TEEBAgriFood Framework. Biodiversity outcomes were reflected under stocks and outcomes in the *Natural capital* section of the TEEBAgriFood Framework. Biotic effects and ecosystem services are reflected within stocks and outcomes in *Natural capital*, and flows under *Ecosystem service* and *Residuals.* Social and economic outcomes can be found under stocks and outcomes within *Produced capital, Human capital,* and *Social capital*. Further social and economic outcomes can be found within flows of *Agricultural and food outputs* and *Purchased inputs*. Finally, climatic outcomes are represented under *Ecosystem services* and *Residual* flows within the TEEBAgriFood Framework.

Results

Study locations, range, and agricultural system information

The table for tillage can be viewed here, biological pest control can be viewed here, agro-silvo-pastoralism can be viewed here, and micro-irrigation can be found here.

The majority of our selected studies took place in Europe (Tillage: 7 studies, Pest Management: 11 studies, Agro-silvo-pastoralism: 7 studies, Micro-irrigation: 2 studies, Total: 27 studies), followed by Asia (Tillage: 3 studies, Pest Management: 5 studies, Agro-silvo-pastoralism: 1 study, Micro-irrigation: 16 studies, Total: 25 studies), Latin America and the Caribbean (Tillage: 4 studies, Pest Management: 2 studies, Agro-silvo-pastoralism: 10 studies, Micro-irrigation: 0 studies, Total: 16 studies), Africa (Tillage: 3 studies, Pest Management: 1 study, Agro-silvo-pastoralism: 2 studies, Micro-irrigation: 1 study, Total: 7 studies), North America (Tillage: 4 studies, Pest Management: 1 study, Agro-silvo-pastoralism: 0 studies, Micro-irrigation: 1 study, Total: 6 studies), and lastly Oceania with one tillage study taking place in Australia (**Figure 2**). The majority of studies took place at a local scale, representing one study site, or multiple sites within a singular agricultural landscape (Tillage: 11 studies, Pest Management: 11 studies, Agro-silvo-pastoralism: 14 studies, Micro-irrigation: 13 studies, Total: 49 studies), followed by studies at a regional scale, representing numerous study sites across a larger geographic gradient, such as multiple adjacent districts or landscapes (Tillage: 10 studies, Pest Management: 9 studies, Agro-silvo-pastoralism: 5 studies, Micro-irrigation: 7 studies, Total: 31 studies), only one of our tillage studies represented research at a national scale, containing numerous agricultural districts across the country (Mazumder et al. 2023), there was also one study that took place across two countries (Amézquita et al. 2004). **Figure 3** presents the global coverage of our studies.

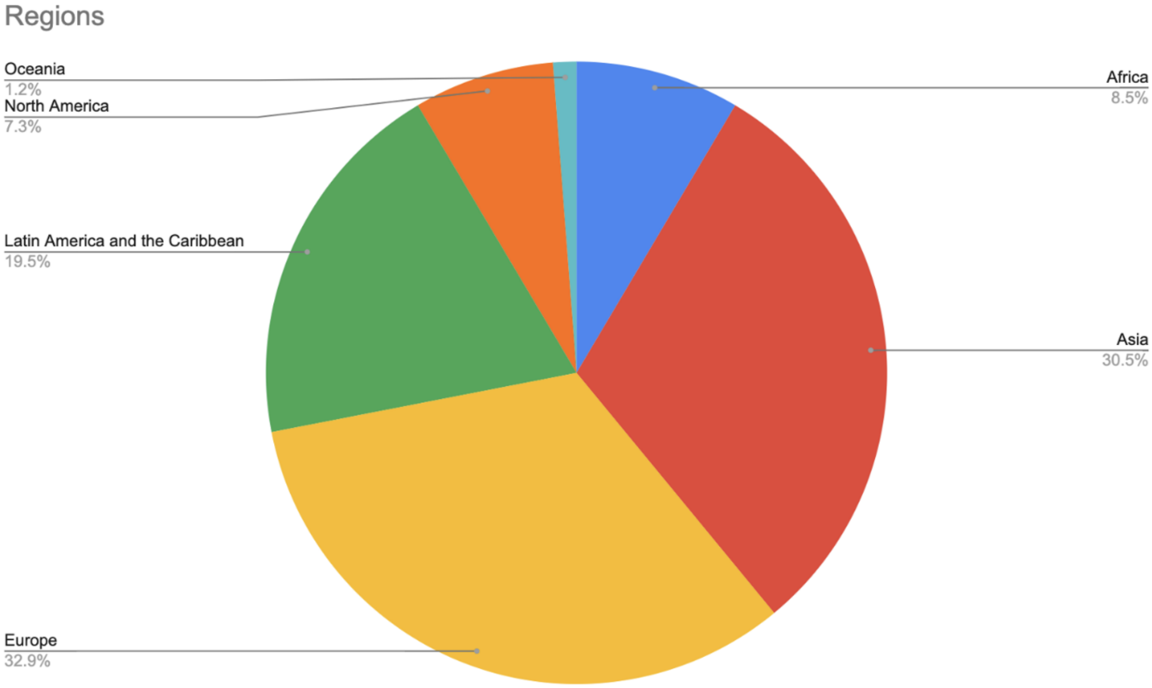


Figure 2: The regional distribution of our 82 selected studies.

A total of 48 different crop species were represented within the reviewed literature, with wheat being the most frequent study crop (30% of the studies), followed by maize (18% of the studies), and soybean (12% of the studies). Within agro-silvo-pastoral studies, cows were the most represented pastoral species (75% of all studies), followed by sheep (25% of all studies). Most of the studied agricultural systems utilized more than one crop in their fields, often represented by different crop rotations, seasonal planting and harvesting variations, or various cover crops. studies.

For studies focusing on minimum and no-tillage, nearly all case study sites utilized comparators of no-tillage or minimum tillage against conventional tillage systems to study the effects of each. Variations of tillage management included comparator sites of land abandonment (García-Orenes et al. 2013), fields with monoculture crops vs. crop rotations (Bedano et al. 2019; Figuerola et al. 2012; Bedano et al. 2016), or differences in herbicide/pesticide/fungicide treatments (Bedano et al. 2019; Figuerola et al. 2012; Bedano et al. 2016; LaCanne and Lundgren 2018; Mazumder et al. 2023).

For studies focusing on biological pest management, four beneficial predator taxa were identified: arthropods (including ground insects, flying insects, and spiders) (Pywell et al. 2015; Tschumi et al. 2016; Hatt et al. 2017; Boetzl et al. 2020; Martin et al. 2015; Redlichet al. 2018; Krauss et al. 2011; Woltz, Isaacs and Landis 2012; Otieno et al. 2011; Daelemans et al. 2023; Sharma et al. 2018; Birkhofer et al. 2016), birds (Karp et al. 2013; García et al. 2018; Bichier and Greenberg 2007; Machar et al. 2017; Maas et al. 2019; Yahya et al. 2024), bats (Karp et al. 2013; Maas et al. 2019), and frogs (Xu et al. 2011; Sharma et al. 2018). Conservation management strategies included agroforestry of fields with semi-natural habitats (Martin et al. 2015; Karp et al. 2013; Bichier and Greenberg 2007; Maas et al. 2019; Otieno et al. 2011), fields with organic treatments (Krauss et al. 2011; Xu et al. 2011; Birkhofer et al. 2016), and fields with habitat enhancements (Pywell et al. 2015; Hatt et al. 2017). Strategies for predator recruitment were also seen in numerous studies. Practices included the planting of flower and buckwheat strips within fields (Tschumi et al. 2016; Hatt et al. 2017; Woltz et al. 2012), and the installation of avian perches (Machar et al. 2017; Sharma et al. 2018).

Agro-silvo-pastoral studies would often have comparisons of different pastoral management types, such as between agro-silvo-pastoral systems , silvo-pastoral systems, traditional pastoral systems, degraded pastures, or natural forests (Mosquera et al. 2012; Ripamonti et al. 2023; Cassani et al. 2022; Marçal et al. 2022).

Micro-irrigation would often be seen through drip irrigation (Liao et al. 2019; Vaibhav and Makwana 2018; Surendran, Jayakumar and Marimuthu 2016; Sengupta et al. 2023; Chandrakanth et al. 2013; Asadi, Kouhi and Yazdanpanah 2012), sprinkler irrigation (Sachan and Patel 2023), a combination or comparison of both (Borsato et al. 2019; Ghazzawy, Sobaih and Mansour 2022; Kumar et al. 2013; Namara, Nagar and Upadhyay 2007; Sengupta et al. 2023; Sharma, Mehra and Kathuria 2012; Spehia and Verma 2019; Suryavanshi and Buttar 2016; Rathore et al. 2014; Fentabil et al. 2016; Grewal, Lohan and Dagar 2021). In one case micro-irrigation was used as supplementary to rain-fed crops (Marino et al. 2018).

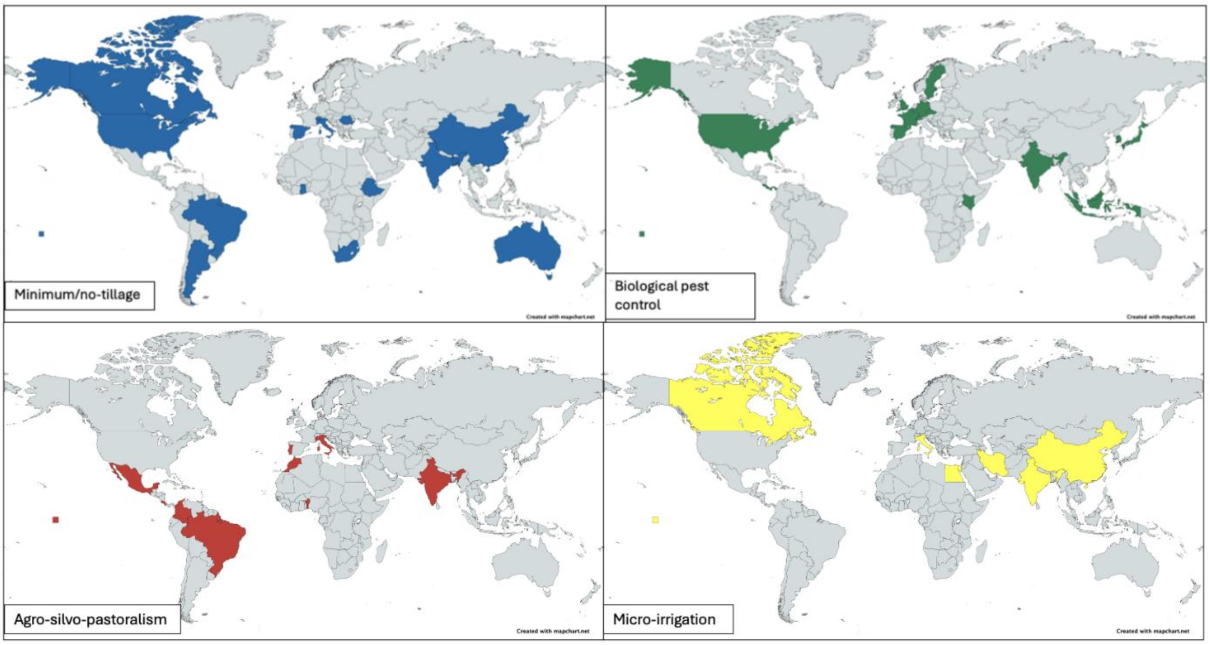


Figure 3: Global coverage of our studies.

The top left map represents the coverage of our minimum and no-tillage studies. The top right map represents the coverage of our biological pest control studies. The bottom left map represents the coverage of our agro-silvo-pastoral studies. The bottom right map represents the coverage of our micro-irrigation

Results by impact area

No-Tillage

Biodiversity outcomes: Only four of the 22 studies reviewed explicitly described *Biodiversity* outcomes as a result of minimum and no-tillage. One study showcased qualitative stocks and outcomes (Mazumder et al. 2023), with the other three being quantitative (García et al. 2019; Fiorini et al. 2020; Bedano et al. 2016). The trend observed was positive, with each no-tillage treatment showing a higher abundance and diversity of macroarthropods and other soil invertebrates within fields as compared to other treatments (García et al. 2019; Fiorini et al. 2020; Bedano et al. 2016). Though no studies examined the off-site effects of minimum and no-tillage on biodiversity in detail, *Mazumder et al. 2023* found that about a fourth of interviewed agro-ecosystem professionals see the potential for the practice to contribute to biodiversity effects. In the same study, 58.8% of farmers reported medium-level effects of conservation farming practices (including minimum and no-till) on the surrounding environment, while 12.9% reported low-level effects, and 7.7% reported high-level effects (Mazumder et al. 2023).

Biotic effects and ecosystem services outcomes: Eighteen of our 22 studies reported biotic effects and ecosystem service outcomes due to minimum and no-tillage. The majority of studies outlined positive effects on soil health as a result of minimum and no-tillage. Most studies reported quantitative information on *Soil* stocks and outcomes (Conyers et al. 2019; Bedano et al. 2016; Bedano et al. 2019; Teodor et al. 2009; Islam and Reeder 2014; LaCanne and Lundgren 2018; Simon et al. 2018; García-Orenes et al. 2013; Fiorini et al. 2020; Seitz et al. 2018; Figuerola et al. 2012) with two (Adam and Abdulai 2023; Mello et al. 2021) providing qualitative results. One study presented similar qualitative results for stocks and outcomes to *Other emissions to air, soil, and water*; *Wastewater*; and *Solid waste and other residuals* (Mello et al. 2021). No-tillage practices were shown to help lower soil bulk density, which ultimately helps in improving soil porosity and compaction (Islam and Reeder 2014; Fiorini et al. 2020; Bedano et al. 2016; Simon et al. 2018). An increase in soil nitrogen, carbon, and humus was found in fields under minimum and no-tillage (Islam and Reeder 2014; Bedano et al. 2019; Teodor et al. 2009). Soil organic matter increased under both minimum and no-tillage systems when compared to conventional tillage (Mello et al. 2021; LaCanne and Lundgren 2018; Seitz et al. 2018; Figuerola et al. 2012; Adam and Abdulai 2023). A similar trend was observed with improvements to particulate organic matter in soils under minimum and no-tillage management (Bedano et al. 2019; LaCanne and Lundgren 2018). Soil microbial biomass and micro-aggregation were shown to be higher under continuous no-till (Conyers et al. 2019; García-Orenes et al. 2013; Islam and Reeder 2014), however strategic use of minimum-tillage was shown not to affect micro-aggregates negatively (Conyers et al. 2019). The improvements to biological activity and chemical compositions due to minimum and no-tillage systems ultimately lead to improved soil respiration, fertility, and greater generation of new soil (Bedano et al. 2019; Islam and Reeder 2014; Teodor et al. 2009).

Seven of our studies presented flows relating to *Regulating ecosystem services*. Three studies included qualitative information (Islam and Reeder 2014; Mazumder et al. 2023; LaCanne and Lundgren 2018), four reported quantitative results (Islam and Reeder 2014; Carretta et al. 2021; Mitchell, Bennett and Gonzalez 2014; Adam and Abdulai 2023) and one study included monetized information (Zhang et al. 2016). Fields utilizing minimum and no-tillage had greater biological pest management and disease control than fields with conventional tillage (Mitchell et al. 2014; Islam and Reeder 2014; LaCanne and Lundgren 2018). No-till systems were found to be more effective than conventional tillage management in preventing wind and water erosion and can be instrumental in reducing the effects of water runoff during heavy rains (Islam and Reeder 2014; Carretta et al. 2021; Mello et al. 2021; Astatke, Jabbar and Tanner 2003; Adam and Abdulai 2023). Additionally, minimum and no-till practices enhanced fields through greater moisture retention and water stability within soils (Simon et al. 2018; Teodor et al. 2009; Fiorini et al. 2020; Islam and Reeder 2014; Bedano et al. 2016; Adam and Abdulai 2023). Reduction of water runoff and soil erosion from no-till agriculture prevented the leaching of solids and pollutants into waterways, owing to lower rates of eutrophication and healthier waters (Islam and Reeder 2014; Carretta et al. 2021; Mello et al. 2021). Wet aggregate stability was also found to decrease in soils following tillage treatments, taking upward of years to recover to their previous value under no-tillage (Conyers et al. 2019). Effects on *Water* were the second most reported stocks and outcomes, comprising results of five studies. Two studies presented quantitative outcomes (Conyers et al. 2019; Adam and Abdulai 2023), with the rest showing quantitative results (Islam and Reeder 2014; Simon et al. 2018; Teodor et al. 2009; Bedano et al. 2016). Two studies reported effects on *Provisioning effects*, with one presenting qualitative information (Conyers et al. 2019) and the other quantitative (Fiorini et al. 2020). In interviews with farmers using minimum and no-tillage within their fields, 69.5% reported medium-level effects on ecosystem services (no mention of directionality but presumably positive), 9.4% of high-level effects, and 4.3% of low-level effects (Mazumder et al. 2023). Only two studies reported stocks and outcomes of *Vegetation cover and habitat quality*, both presenting qualitative information (Mazumder et al. 2023; Astatke et al. 2003). Minimum and no-tillage systems benefitted surrounding environments, enhancing vegetation cover (Mazumder et al. 2023; Astatke et al. 2003).

There was no reported information for stocks or outcomes of *Air* or *'Other'*, and no studies presented monetized information. None of our studies presented any results for *Manufacturing and processing; Distribution, marketing and retail;* and *Household consumption*, with every study focusing solely on stocks and outcomes of *Agricultural production*. No assessed study presented flows related to *Cultural ecosystem services* and each of the flows within *Regulating and Provisioning* services was within the *Agricultural production* cycle, with no results for *Manufacturing and processing; Distribution, marketing and retail;* and *Household consumption.*

Social and economic outcomes: Thirteen of our 22 studies reported outcomes related to human social dynamics and economics. Two studies reported stocks and outcomes of *Food security* within *Agricultural production*, both being qualitative results (Mazumder et al. 2023; Astatke et al. 2003). Food security and stability were outlined as a major positive outcome of minimum and no-tillage systems, with farmers reporting greater food availability and access from the practice (Mazumder et al. 2023). Minimum tillage fields could be harvested sooner than fields with conventional tillage systems, allowing farmers to avoid potential food shortages and increase their market revenue thanks to early-harvest crops (Astatke et al. 2003; Teodor et al. 2009). One study reported qualitative stocks and outcomes of *Food security* within *Household consumption* (Adam and Abdulai 2023). Minimum tillage practices increased household dietary diversity and decreased household food insecurity (Adam and Abdulai 2023). Two studies reported *Health* outcomes, both being qualitative results (Mazumder et al. 2023; Mello et al. 2021). No-till systems can contribute to better quality drinking water in urban populations, as compared to conventional tillage, there is reduced pollutant runoff into waterways (Mello et al. 2021). Adoption and perception of sustainable tilling practices were influenced by several factors including a farmer's age, gender, and level of education. Younger farmers, those with higher levels of education, and female-dominated households tended to gravitate more toward sustainable tilling practices in their farms (Mazumder et al. 2023; Ntshangase, Muroyiwa and Sibanda 2018; Adam and Abdulai 2023). Farmers reported their psychological health to be positively affected by using minimum and no-tillage systems, with 71.3% claiming medium-level effects, 10.0% claiming high-level effects, and only 0.9% claiming low-level effects (Mazumder et al. 2023). One study showcased results on *Opportunities for empowerment* (Mello et al. 2021). In a program aimed at participatory management strategies in no-tillage fields along the Brazilian Itaipu watershed, farmers reported higher autonomy in decision-making and greater productivity in their work and harvests (Mello et al. 2021). Two studies presented qualitative flows of *Labor inputs* (Astatke et al. 2003; Ntshangase et al. 2018) and one presented quantitative flows (Adam and Abdulai 2023). Labor from oxen, draft power, and weeding requirements was reduced in long-term minimum tillage systems compared to conventional tillage and newly established minimum tillage systems (Astatke et al. 2003; Adam and Abdulai 2023). However, minimum and no-tillage practices have been shown to require higher labor inputs during the early stages of agricultural production, especially if farms are transitioning from more conventional tillage systems (Ntshangase et al. 2018; Adam and Abdulai 2023).

Eleven of our assessed studies presented flows relating to *Agricultural and food products*. Most studies presented quantitative results (Islam and Reeder 2014; Mello et al. 2021; Figuerola et al. 2012; Astatke et al. 2003; Bedano et al. 2019; Teodor et al. 2009; Conyers et al. 2019; Simon et al. 2018; Adam and Abdulai 2023), with two studies containing qualitative results (Ntshangase et al. 2018; Cariappa et al. 2024). Yields tended to be higher in most minimum and no-tillage fields in comparison to similarly planted fields using conventional tillage practices (Ntshangase et al. 2018; Islam and Reeder 2014; Mello et al. 2021; Figuerola et al. 2012; Zhang et al. 2016; Teodor et al. 2009; Astatke et al. 2003; Simon et al. 2018; Conyers et al. 2019; Adam and Abdulai 2023). No-tillage in corn fields of Ohio increased yields by 36% - 44% (Islam and Reeder 2014). Within agricultural fields in the Argentinean Pampas, fields utilizing good no-tillage (intensive crop rotation, nutrient replacement, reduced herbicides and insecticides use) had 24.7% higher yields of soybeans, and 149.9% higher yields of maize when compared to fields using poor no-tillage practices (high crop monoculture, low nutrient replacement, increased use of herbicides and insecticides) (Figuerola et al. 2012). However, at two sites, tillage effects were beneficial to crop production and yield (Conyers et al. 2019; Simon et al. 2018). One study presented quantitative results of *Agricultural and food waste* (Mitchell et al. 2014), with no-tillage owing to lower pest damage to soybean leaves. Five studies covered *Income* flows within *Agricultural production*, including two with monetized information (Sijtsma et al. 1998; Cariappa et al. 2024), two with quantitative flows (Mello et al. 2021; Teodor et al. 2009), and one with qualitative flows (Mazumder et al. 2023). In general, production costs were lower in minimum and no-tillage systems as compared to other practices (Mazumder et al. 2023; Sijtsma et al. 1998; Mello et al. 2021; Teodor et al. 2009), but we refrain from extrapolating geographic production cost patterns from these four studies that occurred in Bangladesh, Canada, Brazil, and Romania. Higher profitability of climate regulation services was also observed in minimum and no-till systems, in some cases, this came in the form of carbon credit qualification (Zhang et al. 2016; Cariappa et al. 2024). Two studies reported quantitative flows relating to *Income* within the *Distribution, marketing and retail cycle* (LaCanne and Lundgren 2018; Teodor et al. 2009). Farmers were able to receive an organic premium when selling their produce for their engagement in no-till, and some farmers were able to sell products quicker thanks to an earlier harvest cycle from no-till practices (LaCanne and Lundgren 2018; Teodor et al. 2009). Five studies presented flows relating to *Intermediate consumption*, with four containing quantitative information (Mello et al. 2021; Figuerola et al. 2012; Teodor et al. 2009; Sijtsma et al. 1998) and the other being qualitative (LaCanne and Lundgren 2018). Many farms practicing minimum and no-tillage were able to reduce their consumption of fuels, insecticides, herbicides, and fertilizers, owing to greater savings on production (Sijtsma et al. 1998; LaCanne and Lundgren 2018; Mello et al. 2021; Figuerola et al. 2012; Teodor et al. 2009).

No studies presented stocks or outcomes covering *Education/skills, Land access/tenure; Social cooperation; Institutions; Laws and regulations;* or *'Other'*. The results of all fell under the *Agricultural production* cycle, with no quantitative or monetized information. None of our assessed studies showed results for *Produced capital*. This includes stocks and outcomes comprising *Buildings; Machinery and equipment; Infrastructure; Finance;* and *'Other'*. No study presented flows relating to *Subsidies, taxes and interest*, and no results were reported under *Manufacturing and processing*.

Climatic outcomes: We found four studies presenting flows to *GHG emissions*, with two presenting qualitative results (Mello et al. 2021; Mazumder et al. 2023) and two presenting quantitative results (Zhang et al. 2016; Fiorini et al. 2020). Minimum and no-tillage practices contributed to lower greenhouse gas emissions and greater sequestration potential than other tilling practices (Zhang et al. 2016; Mazumder et al. 2023; Islam and Reeder 2014). Soil organic carbon was also higher in soils under no-till management (Fiorini et al. 2020). Reduced pollutant runoff from no-till systems can also minimize eutrophication in waterways, ultimately limiting the greenhouse gas emissions from eutrophication caused by more conventional tillage practices (Mello et al. 2021). In calculating the ecosystem service value of climate regulation, no-tillage followed by minimum tillage showed greater economic values than other tillage systems (Zhang et al. 2016). All studies presented results of the *Agricultural production* cycle, with no results for *Manufacturing and processing; Distribution, marketing and retail;* and *Household consumption.*

Table 1: Stocks/Outcomes and Flows for Minimum Tillage

Value Chain		Agricultural production
Stocks/Outcomes		
Natural Capital	Water (incl. quantity, quality)	- Greater moisture retention and water stability within soils. - Reduction of water runoff.
	Soil (incl. quantity, quality)	- Lower soil bulk density, improving soil porosity and compaction. - Increase and improvements in soil nitrogen, carbon, humus, microbial biomass, respiration, fertility, organic matter and particulate organic matter.
	Air	NA
	Vegetation cover and habitat quality	- Enhanced vegetative cover.
	Biodiversity	- Higher abundance and diversity of macroarthropods and other soil invertebrates.
	Other	NA

*No results for *Manufacturing and processing; Distribution, marketing and retail;* or *Household consumption*

Value Chain		
Stocks/Outcomes		
Produced Capital	Buildings	NA
	Machinery and equipment	NA
	Infrastructure	NA
	Research and development	NA
	Finance	NA
	Other	NA

Value Chain		Agricultural production	Household consumption
Stocks/Outcomes			
Human Capital	Education / skills	NA	NA
	Health	- Improved psychological effects.	- Lower drinking water treatment costs for urban populations.
	Working conditions (decent work)	NA	NA
	Other	NA	NA

*No results for *Manufacturing and processing* or *Distribution, marketing and retail.*

Value Chain		Agricultural production	Household consumption
Stocks/Outcomes			
Social Capital	Land access / tenure (private, public, and communal)	NA	NA
	Food security (access, distribution)	- Positive impact on food availability, security and food access.	- Household food insecurity decreased. - Increased dietary diversity.
	Opportunities for empowerment (gender and minority)	- Farmers reported higher decision-making autonomy.	NA
	Social cooperation (incl. networks / unions)	NA	NA
	Institutions	NA	NA
	Laws and regulations (e.g. child labor)	NA	NA
	Other	NA	NA

*No results for *Manufacturing and processing* or *Distribution, marketing and retail.*

Value Chain		Agricultural production	Distribution, marketing and retail
Flows			
Agricultural and food outputs	Agricultural and food products	- Higher crop yields.	NA
	Income: value added, operating surplus	- Lower production costs. - Higher profitability of climate regulation services.	- Farmers received an organic premium. - Farmers were able to sell products quicker thanks to an earlier harvest cycle.
	Subsidies, taxes and interest	NA	NA

*No results for *Manufacturing and processing* or *Household consumption.*

Value Chain		Agricultural production
		Flows
Purchased inputs	Labor inputs (incl. skills)	- Labor from oxen, draft power, and weeding requirements was reduced. - Higher labor inputs during the early stages of agricultural production, especially if farms are transitioning from more conventional tillage systems.
	Intermediate consumption (produced inputs such as water, energy, fertilizers, pesticides, animal health, and veterinary inputs)	- Farms can reduce their consumption of fuels, insecticides, herbicides, and fertilizers, owing to greater savings on production.

*No results for *Manufacturing and processing; Distribution, marketing and retail;* or *Household consumption*

Value Chain		Agricultural production
		Flows
Ecosystem services	Provisioning (e.g. biomass growth, freshwater)	- Water stability increased.
	Regulating (e.g. pollination, pest control, nutrient cycling)	- Improved biocontrol of pests and diseases. - Enhanced protection against wind and water erosion. - Higher ecosystem service values of climate regulation.
	Cultural (e.g. landscape amenity)	NA

*No results for *Manufacturing and processing; Distribution, marketing and retail;* or *Household consumption*

Value Chain		Agricultural production
		Flows
Residuals	Agricultural and food waste	- Lower pest damages to soybean leaves.
	GHG emissions	- Reduced GHG emissions. - Greater sequestration potential. - Greater amount of soil organic carbon.
	Other emissions to air, soil, and water	- Reduced leaching of solids and pollutants such as nitrogen and phosphorus into waterways.
	Wastewater	- Reduced leaching of solids and pollutants such as nitrogen and phosphorus into waterways.
	Solid waste and other residuals	- Reduced leaching of solids and pollutants such as nitrogen and phosphorus into waterways.

*No results for *Manufacturing and processing; Distribution, marketing and retail;* or *Household consumption*

Biological pest control

Biodiversity outcomes: Biodiversity stocks and outcomes were the most reported *Natural capital*, comprising results from 11 studies. Ten of those studies included quantitative outcomes (Machar et al. 2017; Birkhofer et al. 2016; Karp et al. 2013; Krauss et al. 2011; Tschumi et al. 2016; Pywell et al. 2015; Woltz et al. 2012; Otieno et al. 2011; Daelemans et al. 2023; Sharma et al. 2018) while one provided a qualitative outcome (Boetzl et al. 2020). However, no studies reported any outcomes of off-farm biodiversity. Landscape complexity, presence of natural or semi-natural habitats, and greater forest cover were positively correlated to higher abundance and diversity of pest predator species at multiple agricultural sites (Birkhofer et al. 2016; Karp et al. 2013; Pywell et al. 2015; Daelemans et al. 2023; Woltz et al. 2012). Farms that practiced various forms of conservation management also showed a higher diversity and abundance of beneficial on-farm predator species (Krauss et al. 2011; Daelemans et al. 2023; Sharma et al. 2018; Pywell et al. 2015). On-field manipulation practices such as flower or buckwheat strip treatments or avian perch installations also enhanced recruitments of diverse insect and raptor predators respectively within fields (Tschumi et al. 2016; Woltz et al. 2012; Machar et al. 2017). Conversely to natural species recruitment methods, the use of pesticides on fields decreased predator abundance within fields (Otieno et al. 2011). Selection of crop type also showed an effect on field biodiversity, with predator assemblages changing alongside a change in crop type (Boetzl et al. 2020).

Biotic effects and ecosystem services outcomes: Nineteen of our studies reported results relating to *Regulating ecosystem service* flows. Seventeen of our papers reported quantitative flows (Karp et al. 2013; Pywell et al. 2015; Tschumi et al. 2016; Redlich et al. 2018; Perrot et al. 2021; Hatt et al. 2017; Boetzl et al. 2020; García et al. 2018; Krauss et al. 2011; Bichier and Greenberg 2007; Maas et al. 2019; Woltz et al. 2012; Otieno et al. 2011; Martin et al. 2015; Daelemans et al. 2023; Xu et al. 2011; Birkhofer et al. 2016) while four reported qualitative flows (Machar et al. 2017; Yahya et al. 2024.; Martin et al. 2015; Karp et al. 2013). As expected, all studies reported outcomes relating to biological pest control. Similar to the trend seen in predator recruitment, predation rates were higher in fields with greater landscape or crop complexity, presence of natural or semi-natural habitats, and forest cover (Pywell et al. 2015; Perrot et al. 2021; Martin et al. 2015; Karp et al. 2013; Tschumi et al. 2016; Redlich, Martin and Steffan-Dewenter 2018; Boetzl et al. 2020; Daelemans et al. 2023; Xu et al. 2011). Likewise, organically managed fields had higher pest predation rates and lower pest infestation rates than fields with more conventional methods of pest control (insecticides, rodenticides, etc.) (Krauss et al. 2011; Xu et al. 2011; Birkhofer et al. 2016). Fields with manipulations such as the flower or buckwheat strip treatments and avian perch installations also showed increased pest predation (Machar et al. 2017; Tschumi et al. 2016; Hatt et al. 2017). The site with raptor perches installed was found to be equally effective as fields applied with rodenticide in suppressing rodent infestations (Machar et al. 2017). When natural predators were excluded or restricted from field sites, there were markable increases in pest infestations and growth when compared to areas where predators were capable of foraging (Redlich et al. 2018; Karp et al. 2013; García et al. 2018; Bichier and Greenberg 2007; Maas et al. 2019; Woltz et al. 2012). A higher abundance of pollinator species was found in fields with close proximity to semi-natural patches. Pollinator numbers decreased in fields treated with pesticides but showed an increase in those treated with fertilizers, both organic and inorganic (Otieno et al. 2011).

Fields promoting management strategies to enhance the biocontrol of pests showed several benefits to their natural environment as well. We found three studies that reported quantitative stocks and outcomes for *Vegetation cover and habitat quality* (Krauss et al. 2011; Sharma et al. 2018; Xu et al. 2011). Vegetation surrounding organic fields showed significantly higher species richness and cover than natural habitats maintained near conventional fields (Krauss et al. 2011). Greater habitat quality within fields also promoted better living conditions and growth for frogs (Sharma et al. 2018; Xu et al. 2011). One study reported quantitative effects on *Soil* (Martin et al. 2015). Soil nitrogen was higher in conventional fields than in organic fields, causing a larger build-up of pest insects (Martin et al. 2015).

No studies reported stocks and outcomes related to *Water; Air;* or *'Other'*. Likewise, no flows were reported for *Other emissions to air, soil, and water; Wastewater;* or *Solid waste and other residuals*. There was no monetized information available from any study. *Agricultural production* was the only represented cycle, with no results coming from *Manufacturing and processing; Distribution, marketing and retail;* and *Household consumption.*

Social and economic outcomes: Twelve of our 20 studies reported social and economic outcomes, though all were related to crop yields and crop damages. Eight studies presented quantitative flows relating to *Agricultural and food products* (Pywell et al. 2015; Boetzl et al. 2020; Karp et al. 2013; Maas et al. 2019; Yahya et al. 2024; Sharma, Shera and Sangha 2018; Xu, Fujiyama and Xu 2011; Birkhofer et al. 2016). Natural pest management in fields neighboring natural habitats showed increased crop yields (Karp et al. 2013; Pywell et al. 2015). In bean fields with semi-natural habitats, yields were increased by 25% - 35% (Pywell et al. 2015). Within forested coffee fields, bird-mediated pest control of borers doubled the amount of berries saved from pest damage (Karp et al. 2013). Similar effects were observed in one study of organic fields, showing higher yields than conventionally managed plots (Birkhofer et al. 2016). However, the inverse was seen in the grain yield of the *Sharma et al. 2018* study, with lower yields being reported in fields practicing conservation agriculture compared to more traditional agricultural practices, though the conservation agriculture plots maintained higher yields than untreated fields (Sharma et al. 2018). Edge effects were found to be detrimental to yields, however, predator increases in field centers were correlated to higher crop yields (Boetzl et al. 2020). Yields were also significantly lower in fields that restricted access to predator species (Maas et al. 2019). Four studies reported quantitative flows of *Agricultural and food waste* (García, Miñarro and Martínez-Sastre 2018; Bichier and Greenberg 2007; Maas et al. 2019; Yahya et al. 2024). In plots inaccessible to predator species, there was a significant increase in pest damage to crops, including damage to leaves, fronds, crowns, shoots, fruits, flowers, and the wooded parts of trees (Yahya et al. 2024.; García et al. 2018; Bichier and Greenberg 2007; Maas et al. 2019). Methods promoting biocontrol pest mediation showed numerous economic benefits. Four studies covered *Income* flows within *Agricultural production*, including three results with monetized information (Maas et al. 2019; Karp et al. 2013; Sharma et al. 2018), and one with qualitative information (Pywell et al. 2015). Farmers saved money in costs related to preventative crop damages from pests (Maas et al. 2019; Karp et al. 2013). In coffee fields of San Antonio, Costa Rica, bird-mediated pest services were estimated to save farmers $3,500–$9,400 USD per year (Karp et al. 2013). Practices such as creating wildlife habitats within fields showed no monetary losses or detriments to nutritional energy yields (Pywell et al. 2015). In a cost-effective analysis, fields promoting natural pest reduction showed higher returns than fields with more traditional farmer practices (Sharma et al. 2018). The biocontrol method was also significantly cheaper and just as effective in pest control than the application of rodenticides (Machar et al. 2017). The same study presented quantitative intermediate consumption flows, as farmers utilizing avian perches were shown to save money on rodenticide purchases (Machar et al. 2017).

None of our assessed studies showed results for *Produced capital, Human capital,* or *Social capital*. This includes stocks and outcomes comprising *Buildings; Machinery and equipment; Infrastructure; Finance; Education/skills; Health; Working conditions; Land access/tenure; Food security; Opportunities for empowerment; Social cooperation; Institutions; Laws and regulations;* and *'Other'*. Flows relating to *Subsidies, taxes and interest,* and *Labor inputs* were also absent in our studies. All studies presented results of the *Agricultural production* cycle, with no results for *Manufacturing and processing; Distribution, marketing and retail;* and *Household consumption.*

Climatic outcomes: None of our biological pest control studies reported any outcomes relating to climatic impacts.

Table 2: Stocks/Outcomes and Flows for Biological Pest Control

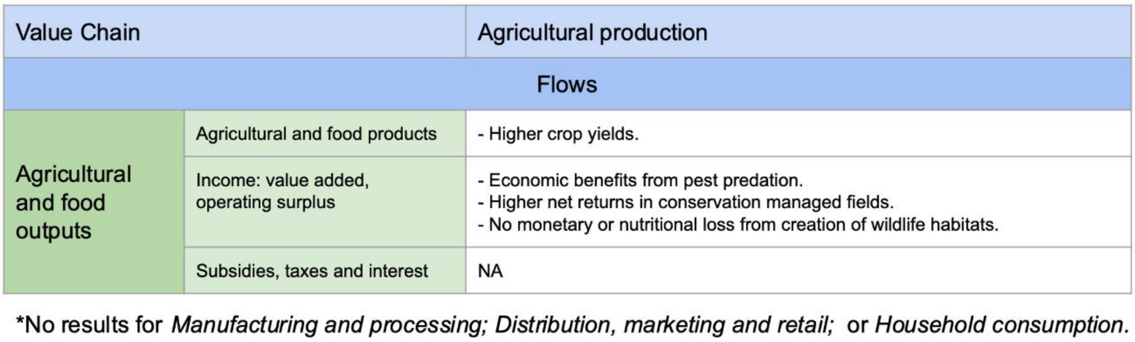
Value Chain		Agricultural production
Stocks/Outcomes		
Natural Capital	Water (incl. quantity, quality)	NA
	Soil (incl. quantity, quality)	- Higher soil nitrogen.
	Air	NA
	Vegetation cover and habitat quality	- Higher species richness and the vegetation cover of non -crop species in organic fields. - Better habitat quality accounted for larger predators.
	Biodiversity	- Higher abundance and diversity of pest predator species in fields with greater landscape complexity, presence of natural or semi -natural habitats. - On-field manipulation practices enhanced recruitments of diverse insect and raptor predators.
	Other	NA

*No results for *Manufacturing and processing; Distribution, marketing and retail;* or *Household consumption*

Value Chain		
Stocks/Outcomes		
Produced Capital	Buildings	NA
	Machinery and equipment	NA
	Infrastructure	NA
	Research and development	NA
	Finance	NA
	Other	NA

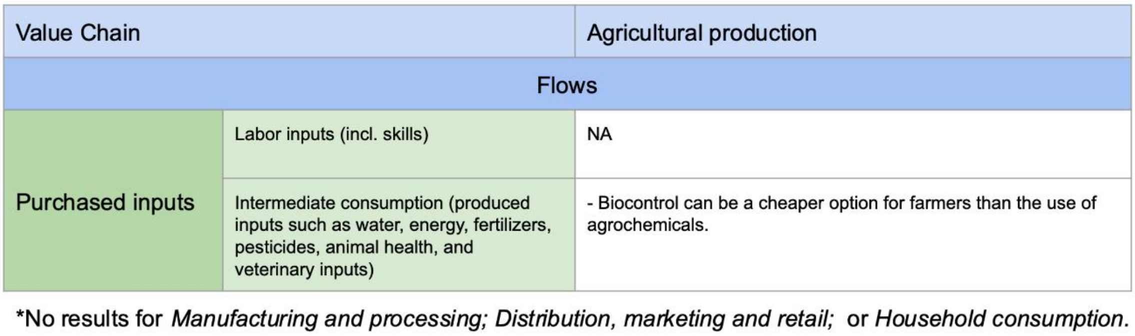
Value Chain		
Stocks/Outcomes		
Human Capital	Education / skills	NA
	Health	NA
	Working conditions (decent work)	NA
	Other	NA

Value Chain		
Stocks/Outcomes		
Social Capital	Land access / tenure (private, public, and communal)	NA
	Food security (access, distribution)	NA
	Opportunities for empowerment (gender and minority)	NA
	Social cooperation (incl. networks / unions)	NA
	Institutions	NA
	Laws and regulations (e.g. child labor)	NA
	Other	NA



Value Chain		Agricultural production
Flows		
Agricultural and food outputs	Agricultural and food products	- Higher crop yields.
	Income: value added, operating surplus	- Economic benefits from pest predation. - Higher net returns in conservation managed fields. - No monetary or nutritional loss from creation of wildlife habitats.
	Subsidies, taxes and interest	NA

*No results for *Manufacturing and processing; Distribution, marketing and retail;* or *Household consumption.*



Value Chain		Agricultural production
Flows		
Purchased inputs	Labor inputs (incl. skills)	NA
	Intermediate consumption (produced inputs such as water, energy, fertilizers, pesticides, animal health, and veterinary inputs)	- Biocontrol can be a cheaper option for farmers than the use of agrochemicals.

*No results for *Manufacturing and processing; Distribution, marketing and retail;* or *Household consumption.*

Value Chain		Agricultural production
Flows		
Ecosystem services	Provisioning (e.g. biomass growth, freshwater)	NA
	Regulating (e.g. pollination, pest control, nutrient cycling)	- Infestations decreased with natural habitat integration. - Organically managed fields had higher pest predation rates and lower pest infestation rates. - Fields with manipulations such as the flower or buckwheat strip treatments and avian perch installations showed increased pest predation. -Increases in pest infestations and growth when natural predators were excluded or restricted from field sites. -Pollinator numbers decreased in fields treated with pesticides but showed an increase in those treated with fertilizers.
	Cultural (e.g. landscape amenity)	NA

*No results for *Manufacturing and processing; Distribution, marketing and retail;* or *Household consumption*.

Value Chain		Agricultural production
Flows		
Residuals	Agricultural and food waste	- In plots inaccessible to predator species, there was a significant increase in pest damage to crops, including damage to leaves, fronds, crowns, shoots, fruits, flowers, and the wooded parts of trees.
	GHG emissions	NA
	Other emissions to air, soil, and water	NA
	Wastewater	NA
	Solid waste and other residuals	NA

*No results for *Manufacturing and processing; Distribution, marketing and retail;* or *Household consumption*.

Agro-silvo-pastoralism

Biodiversity outcomes: Six of the studies reported biodiversity results. Three of those studies presented quantitative stocks and outcomes (Gonçalves et al. 2012; A Re et al. 2014; Bagella et al. 2013), and three reported qualitative stocks and outcomes (Bagella et al. 2014; Bagella et al. 2016; Cassani et al. 2022). Vascular plant biodiversity was found to be heavily affected by land-use changes within agro-silvo-pastoralism systems, with grazing activities and conversion to sustainable pasture use increasing richness and Shannon indices (Bagella et al. 2013; Bagella et al. 2016). Silvo-pastoral systems also saw higher fauna biodiversity as compared to natural forests and intensive agricultural systems, (Gonçalves et al. 2012; Bagella et al. 2016; Cassani et al. 2022). Silvo-pastoral with native vegetation also saw higher biodiversity values than monocultured or intensive silvopastoral systems (Cassani et al. 2022). Landscape heterogeneity was also found to have positive effects on biodiversity conservation, as agro-silvo-pastoralism systems with more varied land uses and habitats resulted in higher species richness (Gonçalves et al. 2012; Bagella et al. 2014). Effects of grazing pressure on biodiversity was inconsistent, with one study presenting negative effects to small mammals (Gonçalves et al. 2012), while another presented positive results to biodiversity from moderate and intense cattle grazing (A Re et al. 2014).

Biotic effects and ecosystem services outcomes: Thirteen of our studies reported biotic effects and ecosystem service outcomes in regards to agro-silvo-pastoralism systems (Amézquita et al. 2004; Cassani et al. 2022; Ripamonti et al. 2023; Bagella et al. 2013; Wick, Tiessen and Menezes 2000; Marçal et al. 2022; Xavier et al. 2014; Deniz et al. 2019; Durana, Murgueitio and Lopera-Marín 2023; d'Angelo et al. 2000; Gonçalves et al. 2012; Bagella et al. 2016; Mosquera et al. 2012). Stocks and outcomes relating to *Soil* were among the highest reported results, with six studies presenting qualitative information (Amézquita et al. 2004; Ripamonti et al. 2023; Bagella et al. 2013; Wick, Tiessen and Menezes 2000; Marçal et al. 2022; Xavier et al. 2014). Soils were generally healthier in agro-silvo-pastoralism systems, showing greater soil organic matter, greater nutrient content including higher quality nitrogen accumulation and overall greater nitrogen stocks, lower soil bulk density, higher soil macroporosity, decreased pH, higher levels of fertility, and better biochemical indicators of soil quality when compared to other management types (Ripamonti et al. 2023; Wick, Tiessen and Menezes 2000; Marçal et al. 2022; Xavier et al. 2014). Soils under agro-silvo-pastoralism management were also found to have greater carbon stocks as compared to natural tropical forests and degraded pastures (Amézquita et al. 2004). Pure pastoral fields had higher incidence of bare soils compared to agro-silvo-pastoral fields (Ripamonti et al. 2023). However soil acidification was observed to increase with higher stocking rates of sheep, and stocking rates were shown to be highest under agro-silvo-pastoralism management (Bagella et al. 2013; Sandoval et al. 2023). One study presented qualitative stocks and outcomes of *Water*, showcasing lower water usage in native agro-silvo-pastoral fields when compared to more intensive agro-silvo-pastoral fields or those under monocultured management (Cassani et al. 2022). Stocks and outcomes relating to *Air* also had a single study reporting quantitative information, showing that agro-silvo-pastoral fields tended to have better humidity conditions (Deniz et al. 2019). *Vegetation cover and habitat quality* had six of our studies reporting stocks and outcomes, with four studies showcasing quantitative results (d'Angelo et al. 2000; Ripamonti et al. 2023; Amézquita et al. 2004; Bagella et al. 2013), and two reporting qualitative results (Durana, Murgueitio and Lopera-Marín 2023; Goncalves, de Medeiros and Albuquerque 2021). The relationship between agro-silvo-pastoralism and vegetation cover and quality is complex and does not show a consistent positive or negative relationship, rather different studies presented various effects that management and grazing activity may have on natural landscapes. For example, agro-silvo-pastoralism may lead to greater plant diversity and vegetation cover, but this also may lead to a reduction of grassland area (Durana, Murgueitio and Lopera-Marín 2023; Ripamonti et al. 2023; Amézquita et al. 2004). Land-use changes from the conversion of extensive agro-silvo pastures to semi-extensive agro-silvo-pastures has also led to a decrease in woodland areas, and a marked increase in landscapes of artificial pastures. This land degradation was observed most in pasture amendments occurring in unsuitable areas (d'Angelo et al. 2000). Mediterranean biodiversity may also be threatened from landscape simplification as agro-silvo-pastures prioritize biodiverse nutritional pastures for grazing (Gonçalves et al. 2012). With regards to livestock, plant assemblages under cattle grazing were found to be more diverse than sheep grazed grasslands (Bagella et al. 2013).

Eight studies reported flows relating to *Ecosystem services*, with five reporting quantitative information (Mosquera et al. 2012; Marçal et al. 2022; Xavier et al. 2014; Wick, Tiessen and Menezes 2000; Deniz et al. 2019), and three reporting qualitative information (Bagella et al. 2016; Durana, Murgueitio and Lopera-Marín 2023; Amézquita et al. 2004). The cycling of nitrogen and other nutrients was higher under agro-silvo-pastoralism than other pastoral managements (Xavier et al. 2014; Wick, Tiessen and Menezes 2000). Carbon stocks and carbon increase was also higher in agro-silvo-pastures than in native forests, conventional pastures, degraded pastures, and monoculture pastures (Mosquera et al. 2012; Marçal et al. 2022; Amézquita et al. 2004). Due to the integration of more vegetation cover, agro-silvo-pastoralism systems can provide more shade and thermal protection than other pastoral management systems (Deniz et al. 2019). The better vegetation and habitat quality in agro-silvo-pastoralism also assists in the natural regulation of grass-sucking insects (Durana, Murgueitio and Lopera-Marín 2023). Though not specified, Mediterranean cork oak silvo-pastoral systems were also reported as having improved ecosystem services (Bagella et al. 2016).

No flows were reported for *Other emissions to air, soil, and water; Wastewater;* or *Solid waste and other residuals*. There was no monetized information available from any study. *Agricultural production* was the only represented cycle, with no results coming from *Manufacturing and processing; Distribution, marketing and retail;* and *Household consumption.*

Social and economic outcomes: Eleven of our studies reported social and economic outcomes. Three studies presented stocks and outcomes pertaining to *Human capital,* all of which were qualitative (Amézquita et al. 2004; Boughalmi and Napoléone 2017; Durana, Murgueitio and Lopera-Marín 2023). With regards to *Working conditions*, farmers under agro-silvo-pastoral management showed improvements to quality of life and working conditions over conventional pastoral management systems, mainly due to conventional farmers feeling geographic and social isolation, and noted improper work conditions (Boughalmi and Napoléone 2017). Farmers self-sufficiency was also higher under agro-silvo-pastoral management as compared to conventional systems (Amézquita et al. 2004). *Health* stocks and outcomes were more positive under agro-silvo-pastoral management as well, again due to conventional farms being more socially isolating to farmers than those in agro-silvo-pastoral fields (Boughalmi and Napoléone 2017). Farmers in Agro-silvo-pastures were also less likely to have exposure to toxic substances (Durana, Murgueitio and Lopera-Marín 2023). Two studies reported quantitative flows and outcomes of *Social capital*, both fitting under the *Other* value chain (Amézquita et al. 2004; Boughalmi and Napoléone 2017). Farmer's family living conditions were reported to be improved under agro-silvo-pastoral, and "farming practices" in general were also improved (Amézquita et al. 2004; Boughalmi and Napoléone 2017). There were also two studies presenting *Finance* and *Other* flows and outcomes within Produced capital (Sandoval et al. 2023; Hessa et al. 2024). Within *Other*, Hessa et al. 2024 presented quantitative information reporting that agro-silvo-pastoral farms can provide more food resources to cattle from crops compared to silvopastoral farms (Hessa et al. 2024). Under monetized *Finance* information, agro-silvo-pastoral systems were shown to have higher establishment costs when compared to other management systems (Sandoval et al. 2023).

Within *Agricultural and food outputs*, nine papers presented flows relating to *Agricultural and food products* with seven papers having quantitative information (Boughalmi and Napoléone 2017; Hessa et al. 2024; Bagella et al. 2013; Xavier et al. 2014; Sandoval et al. 2023; Ripamonti et al. 2023; dos Santos et al. 2020), and two presenting qualitative information (Durana, Murgueitio and Lopera-Marín 2023; Cassani et al. 2022). In general, livestock weights were higher in agro-silvo-pastoral farms as compared to other farm managements (Hessa et al. 2024; Xavier et al. 2014; Sandoval et al. 2023), though in one case, weight gain of cattle was 20% lower in agro-silvo-pastoral farms than conventional farms (Amézquita et al. 2004). Stocking rates were also found to be higher in agro-silvo-pastoral farms, with sheeps showing higher rates and heavier grazing than cattle (Sandoval et al. 2023; Bagella et al. 2013). In general, animals were found to have better health indicators in agro-silvo-pastoral systems (Cassani et al. 2022). This can be seen reflected in production quality, as agro-silvo-pastoral farms had better organic quality meats than conventional systems (Boughalmi and Napoléone 2017), and managed to maintain similar yields of milk production (Durana, Murgueitio and Lopera-Marín 2023). Agro-silvo-pastoral systems also maintained higher crop and livestock diversity than other pastoral or monocultured systems (Boughalmi and Napoléone 2017; Cassani et al. 2022). However, in one case, the diversification of an agro-silvo-pastoral system through tree legume integration resulted in reduced animal performance (dos Santos et al. 2020). Five papers had flows relating to *Income* within *Agricultural production,* one with quantitative information (Boughalmi and Napoléone 2017), two with qualitative information (Amézquita et al. 2004; Durana, Murgueitio and Lopera-Marín 2023), and two with monetized information (Sandoval et al. 2023; Gupta et al. 2022). Agro-silvo-pastoral farms were more profitable than compared conventional farms, and presented better economic efficiency (Amézquita et al. 2004; Gupta et al. 2022; Boughalmi and Napoléone 2017; Durana, Murgueitio and Lopera-Marín 2023). In the only paper that presented monetized information under *Distribution, marketing and retail,* it was noted that sales for meats were highest in an agro-silvo-pastoral system due to the increased amount of livestock and the improved quality of meats (Sandoval et al. 2023*).* Additionally, there is potential for additional profit within agro-silvo-pastoral systems through their reduction of avoided methane emissions, with an estimated US $6.12 saved per cattle, alongside a microclimatic regulation valuation of US $2,026 per hectare (Sandoval et al. 2023).

Two papers presented flows under *Purchased inputs.* One paper showcased qualitative information relating to *Labor inputs*, with results supporting lower maintenance and renovation costs under agro-silvo-pastoral management (Sandoval et al. 2023). Two studies had flows relating to Intermediate consumption, with one presenting quantitative information (Cassani et al. 2022), and one presenting monetized information (Durana, Murgueitio and Lopera-Marín 2023). Systems under agro-silvo-pastoral management saved costs on fuels, insecticides, fertilizers, and other external supplies (Durana, Murgueitio and Lopera-Marín 2023; Cassani et al. 2022). These systems also benefited from reduced electric energy consumption (Cassani et al. 2022).

Climatic outcomes: Only one paper presented quantitative information flows to *GHG emissions.* Methane emissions were found to be lowest in agro-silvo-pastoral management when compared to other systems (Sandoval et al. 2023).

Table 3: Stocks/Outcomes and Flows for Agro-silvo-pastoralism

Value Chain		Agricultural production
Stocks/Outcomes		
Natural Capital	Water (incl. quantity, quality)	- Water usage usage is lower in native silvopastoral systems compared to in intensive silvopastoral and monoculture systems.
	Soil (incl. quantity, quality)	- Increase in bare soil, soil carbon stocks, soil organic matter, soil fertility, and other biochemical indicators - Decreased pH
	Air	- Humidity conditions better under agro-silvo-pastoralism systems.
	Vegetation cover and habitat quality	- Increase in plant diversity and vegetation cover - Reduction in grassland areas
	Biodiversity	- Higher biodiversity
	Other	NA

*No results for *Manufacturing and processing; Distribution, marketing and retail;* or *Household consumption*

Value Chain		Agricultural production
Stocks/Outcomes		
Human Capital	Education / skills	- Farmer educational level higher than in conventional-systems farms.
	Health	- Farmers reported better quality of life. - Lower exposure to harmful substances.
	Working conditions (decent work)	- Farmers reported better quality of life.
	Other	- Farmer self-sufficiency higher than in conventional-systems farms

*No results for *Manufacturing and processing; Distribution, marketing and retail;* or *Household consumption*.

Value Chain		Agricultural production
Stocks/Outcomes		
Social Capital	Land access / tenure (private, public, and communal)	NA
	Food security (access, distribution)	NA
	Opportunities for empowerment (gender and minority)	NA
	Social cooperation (incl. networks / unions)	NA
	Institutions	NA
	Laws and regulations (e.g. child labor)	NA
	Other	- Family living conditions higher than in conventional-systems farms.

*No results for *Manufacturing and processing; Distribution, marketing and retail;* or *Household consumption*.

Value Chain		Agricultural production
Stocks/Outcomes		
Produced Capital	Buildings	NA
	Machinery and equipment	NA
	Infrastructure	NA
	Research and development	NA
	Finance	- Higher costs occur for the establishment of silvopastoral systems.
	Other	- Agro-silvo-pastoral farms provide more food resources from crops compared to silvopastoral farms.

*No results for *Manufacturing and processing; Distribution, marketing and retail;* or *Household consumption*

Value Chain		Agricultural production	Distribution, marketing and retail
Flows			
Agricultural and food outputs	Agricultural and food products	- Higher milk and meat yields. - Higher crop and livestock diversity. - Better livestock health, including weight gain.	- Higher income from milk sales.
	Income: value added, operating surplus	- More economically efficient - Higher profitability of climate regulation services.	NA
	Subsidies, taxes and interest	NA	NA

*No results for *Manufacturing and processing* or *Household consumption*.

Value Chain		Agricultural production
Flows		
Purchased inputs	Labor inputs (incl. skills)	- Maintenance and renovation lower
	Intermediate consumption (produced inputs such as water, energy, fertilizers, pesticides, animal health, and veterinary inputs)	- Farms can reduce their consumption of fuels, electricity, fertilizers, and insecticides owing to greater savings on production.

*No results for *Manufacturing and processing; Distribution, marketing and retail;* or *Household consumption*

Value Chain		Agricultural production
Flows		
Ecosystem services	Provisioning (e.g. biomass growth, freshwater)	NA
	Regulating (e.g. pollination, pest control, nutrient cycling)	- Greater nutrient cycling. - Improved the natural regulation of the grass-sucking insects. - Increase in carbon stocks.
	Cultural (e.g. landscape amenity)	NA

*No results for *Manufacturing and processing; Distribution, marketing and retail;* or *Household consumption*

Value Chain		Agricultural production
Flows		
Residuals	Agricultural and food waste	- Reduced pasture depletion.
	GHG emissions	- Lower methane emissions.
	Other emissions to air, soil, and water	NA
	Wastewater	NA
	Solid waste and other residuals	NA

*No results for *Manufacturing and processing; Distribution, marketing and retail;* or *Household consumption*

Micro-irrigation

Biodiversity outcomes: None of our micro-irrigation studies reported any outcomes relating to biodiversity.

Biotic effects and ecosystem services outcomes: Eighteen of our 20 studies reported biotic effects and ecosystem service outcomes in regards to micro-irrigation systems. Seventeen of those studies presented quantitative stocks and outcomes of *Water* (Asadi, Kouhi and Yazdanpanah 2012; Bahinipati and Viswanathan 2019; Borsato et al. 2019; Chandrakanth et al. 2013; Kumar et al. 2013; Namara, Nagar and Upadhyay 2007; Sengupta et al. 2023; Sharma, Mehra and Kathuria 2012; Suryavanshi and Buttar 2016; Rathore et al. 2014; Liao et al. 2019; Fentabil et al. 2016; Sachan and Patel 2023; Brar et al. 2022; Grewal, Lohan and Dagar 2021; Vaibhav and Makwana 2018; Surendran, Jayakumar and Marimuthu 2016). The most reported benefit of micro-irrigation is its potential of saving water, higher water use efficiency, and overall greater water productivity when compared to other systems (Bahinipati and Viswanathan 2019; Borsato et al. 2019; Bahinipati and Viswanathan 2019; Kumar et al. 2013; Namara, Nagar and Upadhyay 2007; Sengupta et al. 2023; Sharma, Mehra and Kathuria 2012; Suryavanshi and Buttar 2016; Rathore et al. 2014; Liao et al. 2019; Sachan and Patel 2023; Brar et al. 2022; Grewal, Lohan and Dagar 2021; Vaibhav and Makwana 2018; Surendran, Jayakumar and Marimuthu 2016). The addition of mulch film was also shown to benefit drip irrigation systems' water use efficiency (Liao et al. 2019). When examining crop cultivation structure, a conventional structure, as opposed to an alternating row structure, was found to have the greatest water use efficiency (Asadi, Kouhi and Yazdanpanah 2012). When comparing drip vs. sprinkler irrigation, transpiration rates were higher in sprinkler systems (Rathore et al. 2014), whereas water filled pore space was higher under drip irrigation (Fentabil et al. 2016). However, some studies reported greater water use efficiency in drip systems, whereas others reported it greater under sprinklers (Borsato et al. 2019; Kumar et al. 2013). Three papers reported stocks and outcomes relating to *Soil,* with two presenting quantitative information(Sengupta et al. 2023; Surendran, Jayakumar and Marimuthu 2016), and one presenting qualitative information (Liao et al. 2019). Micro-irrigation treatments saw both improvements and detriments to soil chemistry and quality, with both drip and sprinkler irrigation reducing harmful arsenic content, though also potentially reducing soluble solids, organic acids and vitamin C content (Sengupta et al. 2023; Liao et al. 2019). In regards to post harvest benefits, drip irrigation treatments had better soil nutrient status and greater NPK (nitrogen, phosphorus, potassium) values when compared with flood irrigation (Surendran, Jayakumar and Marimuthu 2016).

Only one study presented quantitative flows to *Regulating* ecosystem services. Under micro-irrigation treatments, crops showed greater nitrogen uptake as well as better photosynthetic rates (Rathore et al. 2014). One study presented quantitative flows under *Wastewater*, positing that micro-irrigation can prevent groundwater pollution due to its lower relience on fertilizers (Spehia and Verma 2019).

No study presented stocks or outcomes relating to *Air*; *Vegetation cover and habitat quality*; or *Other.* For ecosystem services, no paper presented flows to *Provisioning* or *Cultural*. No flows were reported for *Agricultural and food waste*; *Other emissions to air, soil, and water;* or *Solid waste and other residuals*. There was no monetized information available from any study. *Agricultural production* was the only represented cycle, with no results coming from *Manufacturing and processing; Distribution, marketing and retail;* and *Household consumption.*

Social and economic outcomes: All 20 of our studies reported social and economic outcomes. Under *Produced capital*, Three studies reported stocks and outcomes relating to *Machinery and equipment,* with two presenting monetized information (Asadi, Kouhi and Yazdanpanah 2012; Suryavanshi and Buttar 2016), and one presented qualitative information (Bahinipati and Viswanathan 2019). Machinery costs were inconsistent among studies, with one study reporting materials and operational costs as higher under micro-irrigation (Asadi, Kouhi and Yazdanpanah 2012), and another reporting that system costs were lower than that of conventional irrigation systems (Suryavanshi and Buttar 2016). Micro-irrigation systems also influenced farm infrastructure, as farmers using the practice were more likely to add column pipes into irrigation structures (Bahinipati and Viswanathan 2019). Also under *Produced capital*, four studies presented quantitative information regarding *Infrastructure* (Bahinipati and Viswanathan 2019; Chandrakanth et al. 2013; Kumar et al. 2013; Namara, Nagar and Upadhyay 2007). Under micro-irrigation, farmers were able to increase their area of irrigation while enhancing irrigation frequency (Bahinipati and Viswanathan 2019). Additionally, micro-irrigation allowed farmers to cultivate an area of 1.13 to 1.20ha under the same amount of irrigation required for a 1ha farm under conventional irrigation (Kumar et al. 2013). However, farms under drip irrigation had a higher probability of well failure (Chandrakanth et al. 2013), and initial costs of construction were higher for both drip and sprinkler irrigation when compared to other irrigation strategies (Kumar et al. 2013). In a comparison of cost efficiency, higher priced micro-irrigation systems were found to have better irrigation uniformity than low-cost micro-irrigation systems (Namara, Nagar and Upadhyay 2007). Lastly under *Produced capital*, one study presented quantitative information to stocks and outcomes to *Finance*, showing that capital investments are higher for micro-irrigation systems when compared to other irrigation managements (Namara, Nagar and Upadhyay 2007). One study produced results under *Social Capital*. The same study had quantitative information for *Food security*, as well as qualitative information for *Other* (Spehia and Verma 2019). With regards to food security, micro-irrigation was shown to help in diversifying food products, allowing farmers to grow more cash-rich produce like vegetables and floricultural crops (Spehia and Verma 2019). These same micro-irrigation facilities also broadened employment opportunities in rural villages (Spehia and Verma 2019).

Under *Agriculture and food outputs,* 16 papers presented flows to *Agricultural and food products,* with 16 showcasing quantitative information (Asadi, Kouhi and Yazdanpanah 2012; Borsato et al. 2019; Chandrakanth et al. 2013; Ghazzawy, Sobaih and Mansour 2022; Kumar et al. 2013; Marino et al. 2018; Namara, Nagar and Upadhyay 2007; Sengupta et al. 2023; Sharma, Mehra and Kathuria 2012; Spehia and Verma 2019; Suryavanshi and Buttar 2016; Rathore et al. 2014; Liao et al. 2019; Surendran, Jayakumar and Marimuthu 2016; Sachan and Patel 2023; Brar et al. 2022), and two with qualitative information (Liao et al. 2019; Surendran, Jayakumar and Marimuthu 2016). In numerous cases, micro-irrigation practices led to higher crop yields compared to conventional irrigation systems (Chandrakanth et al. 2013; Kumar et al. 2013; Marino et al. 2018; Namara, Nagar and Upadhyay 2007; Sharma, Mehra and Kathuria 2012; Suryavanshi and Buttar 2016; Surendran, Jayakumar and Marimuthu 2016; Sachan and Patel 2023; Brar et al. 2022). Though in one case, furrow irrigation led to higher yields than micro-irrigation, however those benefits were minimal (Liao et al. 2019). Within micro-irrigation management, higher yields were also obtained when irrigation efforts increased (Asadi, Kouhi and Yazdanpanah 2012; Ghazzawy, Sobaih and Mansour 2022; Spehia and Verma 2019). Comparisons of yield results from drip and sprinkler irrigation were mixed, with one study showing better yields from drip irrigation (Ghazzawy, Sobaih and Mansour 2022), whereas other reported higher yields under sprinkler irrigation (Namara, Nagar and Upadhyay 2007; Borsato et al. 2019), however, it's noted that the choice of which management to use also depends on groundwater quality (Namara, Nagar and Upadhyay 2007). Within drip irrigation, conventional cropping structures produced higher yields when compared to an alternating row structure (Asadi, Kouhi and Yazdanpanah 2012). When examining crop health, micro-irrigation conferred various benefits over conventional systems such as greater shoot lengths and flower bud abscission of pistachio trees (Marino et al. 2018), better quality date palm (sucrose, purity, and percent extractable sugar) (Ghazzawy, Sobaih and Mansour 2022), improved leaf area, faster carbohydrate production, and efficient transport of photosynthates to the head of broccoli and cauliflower (Sengupta et al. 2023), and lastly, improved stomatal resistance, conductance, shoot length, and increased days of flowering in mustard seed (Rathore et al. 2014). However, in cherry crops, micro-irrigation may have led to a reduction of fruit quality (Liao et al. 2019). Other benefits of micro-irrigation included better crop water demand (Kumar et al. 2013), and less moisture stress (Surendran, Jayakumar and Marimuthu 2016).

Also within *Agriculture and food outputs,* nine studies presented flows to *Income*, including four with quantitative information under the *Agricultural production* cycle (Kumar et al. 2013; Rathore et al. 2014; Grewal, Lohan and Dagar 2021; Vaibhav and Makwana 2018), five with monetized information under the *Agricultural production* cycle (Surendran, Jayakumar and Marimuthu 2016; Namara, Nagar and Upadhyay 2007; Kumar et al. 2013; Asadi, Kouhi and Yazdanpanah 2012; Chandrakanth et al. 2013), and two with monetized information under the *Distribution, marketing and retail* cycle (Suryavanshi and Buttar 2016; Chandrakanth et al. 2013). In most cases, the cost-benefit ratio and net returns were greater in micro-irrigation systems than conventional irrigation systems (Kumar et al. 2013; Surendran, Jayakumar and Marimuthu 2016; Namara, Nagar and Upadhyay 2007; Suryavanshi and Buttar 2016; Chandrakanth et al. 2013). The economic status of farmers adopting micro-irrigation was also improved (Vaibhav and Makwana 2018). However, initial investment costs for micro-irrigation infrastructure were higher than conventional systems (Kumar et al. 2013). Despite this, one study found that overall system costs were lower in micro-irrigation systems (Asadi, Kouhi and Yazdanpanah 2012), and another study noted that well costs were also lower in these systems compared to conventional irrigation (Chandrakanth et al. 2013).

Under *Purchased inputs*, two studies presented flows to *Labor inputs*, one with quantitative information (Grewal, Lohan and Dagar 2021) and the other showcasing monetized information (Vaibhav and Makwana 2018). There were massive savings attributed to labor costs in micro- irrigation (Grewal, Lohan and Dagar 2021), and there was also a notable reduction of weeding costs in one study (Vaibhav and Makwana 2018). Also within *Purchased inputs,* six studies presented flows relating to *Intermediate consumption*. Of these, four presented quantitative information (Sharma, Mehra and Kathuria 2012; Surendran, Jayakumar and Marimuthu 2016; Brar et al. 2022; Vaibhav and Makwana 2018), two presented qualitative information (Sharma, Mehra and Kathuria 2012; Spehia and Verma 2019), and one presented monetized information (Suryavanshi and Buttar 2016). The use, and subsequently the costs, of fertilizers and pesticides were reduced under micro-irrigation systems (Sharma, Mehra and Kathuria 2012; Brar et al. 2022; Vaibhav and Makwana 2018; Spehia and Verma 2019). Electrical usage and costs were also lower under micro-irrigation, owing them to be more energy efficient thanconventional irrigation methods (Surendran, Jayakumar and Marimuthu 2016; Sharma, Mehra and Kathuria 2012). Additionally, micro-irrigation showed a monetary advantage due to its water saving capabilities (Suryavanshi and Buttar 2016).

Climatic outcomes: Only two studies reported quantitative information flows to *GHG emissions* (Borsato et al. 2019; Fentabil et al. 2016). Within one studied system, the energy-use efficiency was lower in micro-irrigation than conventional irrigation, which in turn may have led to higher greenhouse gas emissions (Borsato et al. 2019). When comparing the two main micro-irrigation practices, it was found that micro-sprinkler irrigation had significantly lower N2O emissions than drip irrigation (Fentabil et al. 2016).

Table 4: Stocks/Outcomes and Flows for Micro-irrigation

Value Chain		Agricultural production
Stocks/Outcomes		
Natural Capital	Water (incl. quantity, quality)	- Better water use efficiency. - Better groundwater retention. - Better water productivity.
	Soil (incl. quantity, quality)	- Reduction in chemical contents. Both harmful and beneficial.
	Air	NA
	Vegetation cover and habitat quality	NA
	Biodiversity	NA
	Other	NA

*No results for *Manufacturing and processing; Distribution, marketing and retail;* or *Household consumption*

Value Chain		Agricultural production
Stocks/Outcomes		
Produced Capital	Buildings	NA
	Machinery and equipment	- System costs lowered but material and operational costs higher.
	Infrastructure	- Higher well failures - Higher production cost due to construction of irrigation infrastructure. - Less uniformity of irrigation due to infrastructure.
	Research and development	NA
	Finance	- High capital investment requirements.
	Other	NA

*No results for *Manufacturing and processing; Distribution, marketing and retail;* or *Household consumption*

Value Chain		
Stocks/Outcomes		
Human Capital	Education / skills	NA
	Health	NA
	Working conditions (decent work)	NA
	Other	NA

Value Chain		Agricultural production
Stocks/Outcomes		
Social Capital	Land access / tenure (private, public, and communal)	NA
	Food security (access, distribution)	- Help in crop diversification.
	Opportunities for empowerment (gender and minority)	NA
	Social cooperation (incl. networks / unions)	NA
	Institutions	NA
	Laws and regulations (e.g. child labor)	NA
	Other	- More job opportunities.

*No results for *Manufacturing and processing; Distribution, marketing and retail;* or *Household consumption*

Value Chain		Agricultural production	Distribution, marketing and retail
Flows			
Agricultural and food outputs	Agricultural and food products	- Higher crop yields. - Better quality crops.	NA
	Income: value added, operating surplus	- Greater net profit. - Better cost-benefit ratio. - Lower system costs.	- Greater net returns.
	Subsidies, taxes and interest	NA	NA

*No results for *Manufacturing and processing* or *Household consumption.*

Value Chain		Agricultural production
Flows		
Purchased inputs	Labor inputs (incl. skills)	- Lower labor inputs and costs.
	Intermediate consumption (produced inputs such as water, energy, fertilizers, pesticides, animal health, and veterinary inputs)	- Farms can reduce their consumption of fuels, electricity, and fertilizers, owing to greater savings on production.

*No results for *Manufacturing and processing; Distribution, marketing and retail;* or *Household consumption*

Value Chain		Agricultural production
Flows		
Ecosystem services	Provisioning (e.g. biomass growth, freshwater)	NA
	Regulating (e.g. pollination, pest control, nutrient cycling)	- Better nitrogen uptake. - Greater photosynthesis
	Cultural (e.g. landscape amenity)	NA

*No results for *Manufacturing and processing; Distribution, marketing and retail;* or *Household consumption*

Value Chain		Agricultural production
Flows		
Residuals	Agricultural and food waste	NA
	GHG emissions	- N2O emissions under micro-sprinkler irrigation were significantly lower than drip irrigation.
	Other emissions to air, soil, and water	NA
	Wastewater	- Reduced leaching of fertilizer pollutants into groundwater.
	Solid waste and other residuals	NA

*No results for *Manufacturing and processing; Distribution, marketing and retail;* or *Household consumption*

Discussion

Utilizing a comprehensive and universal assessment framework provides a common basis to compare assessments, a tool for decision makers to understand what information is missing (blind spots), and a means to identify areas of further research (TEEB 2018).

We conducted a critical literature review to obtain our assessed papers. It is important to note that this study does not represent a systematic approach to understanding the outcomes of the four sustainable agricultural management practices selected for the assessment. Our peer-reviewed studies represented single or multi-site agricultural systems engaging in the specific nature-positive agriculture practices. We did not include grey literature, reviews, or overviews of the practices themselves. Publication bias may lead to under-reporting of linkages or effects that are non-significant. Furthermore, we focused our assessment on ‘conservation’ biological pest management, as our papers outlined the natural recruitment and enhancement of pest predators. Other forms of biological pest management can include the importation or augmentation of pest species; however, these were not included in the present study. Though our results do not represent a comprehensive analysis of these two practices, we believe they can be viewed as representative of research trends and outcomes as a subsequent analysis of literature reviews produced similar outcome reporting.

Our results indicate numerous benefits in promoting the four sustainable agricultural management practices. These benefits were observed across a wide range of crop types, biomes, and spatial scales, suggesting that different applications of our chosen sustainable practices can be incredibly malleable within various agroecosystems. Outside of our selected papers, an examination of the agroecological potential of various sustainable agricultural practices, reduced tillage, biological pest control, and micro-drip irrigation each scored as high potential for integration into modern field management (Wezel et al. 2014).

Nearly every study outlined the benefits to soil health for sustainable tillage compared to conventional tillage systems. Improvements to soil health ultimately led to other positive ecosystem outcomes, such as improved soil biodiversity, improved water stability, better greenhouse gas retention and sequestration, and reduced waste and pollutants in natural ecosystems. Outside of our study, soil health and subsequent ecosystem service benefits of minimum and no-tillage have been well-represented within sustainable agriculture studies (Lal 2013; Roger-Estrade et al. 2010; Wezel et al. 2014; Altieri and Rosset 1996). In studies examining crop yields, sustainable tillage practices showed consistently higher yields compared to field systems with conventional tillage; this economic benefit can also be observed in several other tillage systems not represented in our sample studies (Lal 2013). No-tillage can also reduce labor costs for farmers, as it can make use of cheaper equipment, reduce fuel consumption, and reduce the use of fertilizers and pesticides. However, it is important to note sustainable tillage, and subsequently, its perceived benefits, were often paired with other farm practices like cover-cropping or reduced chemical treatments. As minimum and no-till practices frequently see challenges in weed control in fields, cover crops can be beneficial in smothering weed species (Lal 2013; Wezel et al. 2014).

Studies focused on biological pest control have exemplified the benefits of biological pest control to provide a safer, cheaper, and more ecologically friendly alternative to pesticides for farmers interested in more organic practices. Nearly every study showed improvements in pest management from biological control, owing to increased crop yield and higher farm income from avoided pest damages. Natural habitat integration within fields and farms with more organic practices saw a higher abundance and biodiversity of pest predators, and thus higher predation rates of pests. This pattern of pest reduction due to diverse landscapes is well reflected in literature outside of our analysis as well (Bianchi, Booij and Tscharntke 2006; Gurr, Wratten and Luna 2003; Wyckhuys et al. 2022b). Our study highlighted the benefits of numerous natural predatory species across a broad range of agroecosystems, emphasizing the geographic malleability of different farms to enhance natural pest control. Though not emphasized in our selected studies, the adoption of biological pest management practices can save farmers money on pesticides (Bianchi, Booij and Tscharntke 2006; Gurr, Wratten and Luna 2003; Wyckhuys et al. 2022a). Reduction of pesticide use could also prove beneficial to farmers health. Exposure to various pesticides be it through inhalation or consumption of pesticide treated crops has been linked to cancer, hormone disruptions, asthma, and various birth defects (Kim, Kabir and Jahan 2017), though this observation also was not present in any of our assessed studies. Another aspect of biological pest management not covered within our papers is its benefits on a farm's carbon footprint. Pesticide use in agriculture contributes to significant anthropogenic GHG emissions; farmers reducing their pesticide use in favor of biological pest control can therefore curb emissions from their fields (Wyckhuys et al. 2022a; Wyckhuys et al. 2022b). Agroforestry fields or those with natural habitat integration for biological pest control can also aid in carbon sequestration (Gurr, Wratten and Luna 2003). The promotion of biological field control came in a range of practices. Certain studies took place within agroforestry systems or fields with integrated semi-natural habitats, while others utilized field manipulation practices such as perch installations to promote the recruitment of avian predators, or the planting of flower strips to enhance the abundance and biodiversity of arthropod predators and pollinators. Ultimately, each farm's chosen sustainable practice may depend on the location's natural predators.

Numerous positive nature outcomes were tied to agro-silvo-pastoral practices. Similarly to no tillage, a prominent number of studies showcased benefits to soil health and productivity. These benefits were often attributed to the presence of native vegetation found in agro-silvo-pastoral systems. Agro-silvo-pastoral studies also represented the only management type which reported positive *Air* outcomes. Though there was some inconsistency regarding its effects on biodiversity, the integration of natural habitats into pasture lands in general showed positive effects to local wildlife and vegetation. More so than the other examined practices, multiple benefits to *Human* and *Social capital* were reported on in agro-silvo-pastoral management. Farmers were generally healthier and more productive within these systems. This outcome was also well reflected in cattle as well, with numerous studies showing improved animal conditions such as greater weight gain and stocking rates. However, one study warned that these improved stocking rates may have detrimental effects to soil characteristics and overall pasture productivity (Ripamonti et al. 2023). Improved animal health often correlated with financial gains, with several studies showing positive income from production, as well as saved costs in multiple consumables (agro-chemicals, fuels, general renovations etc.). Results related to climate regulation were sparse but still positive, one study examined lower methane emissions in agro-silvo-pastoral systems, and another found that total carbon storage was increased under this management practice. One study noted that the presence of natural trees combined with the better health indicator of livestock may also make these systems more resilient to climate change (Hessa et al. 2024). Pastoral systems are well reported to be at high abandonment risks due to mismanagement, often leaving degraded landscapes with depleted ecosystem services (Bagella et al. 2013; Bagella et al. 2016). This further emphasizes the need for influential and successful sustainable management of these areas.

As was expected, the majority of studies within micro-irrigation touched on elements of water productivity. In nearly all cases, drip and sprinkler irrigation allowed farms to save water while increasing productivity, and in many cases, increasing crop production. As noted in numerous studies, this benefit towards water use efficiency could serve as crucial in drought prone regions, or those with limited access to groundwater. Unfortunately, other aspects within *Natural capital* were non-existent in our studies. This presents a significant research gap, as even when explicitly searching for biodiversity outcomes, we found no results within micro-irrigation presenting either on-farm or off-farm effects to biodiversity. Likewise, none of our assessed papers showcases any outcomes to vegetation outside of farmed crops. Instead, much of the literature seemed to be more focused on how micro-irrigation may assist in production rather than presenting its benefits or effects to nature. It is also possible that this practice is far more site-specific in its sustainable influence, which could explain why we're not seeing broader and more substantial biotic effects of micro-irrigation.

However, numerous data gaps emerged when applying the management practices to the TEEBAgriFood Framework. Knowledge from the *Agricultural production* cycle was well represented across our reviewed studies, but we found information on *Manufacturing and processing; Distribution, marketing and retail;* and *Household consumption* severely lacking. Only five of our 82 studies outlined flows to *Distribution, marketing and retail*, and two showed results of *Household consumption*. This would suggest that while the effects of minimum and no-tillage, biological pest management, agro-silvo-pastoralism and micro-tillage are well-researched in agricultural production, much more work must come forth to understand their impact on the other aspects of the agri-food system. As the TEEBAgriFood Framework is comprehensive in its representation of stocks and flows pertaining to the entire value chain, we believe this data gap is not an issue of the framework itself, but rather a potential bias within research literature towards production.

Produced capital was also a major gap in our study. As these stocks and outcomes center around the production of machinery, infrastructure, buildings, etc., it isn't surprising they weren't a focal point of our four management approaches. The one exception to this was under micro-irrigation, with several studies reporting impacts to machinery and on-farm infrastructure. However, significant knowledge and data gaps occurred in both *Human* and *Social capital*. We only observed three tillage studies outlining impacts on *Health* and *Working conditions* (*Human capital*) and three with outcomes relating to *Food security* and *Opportunities for empowerment* (*Social capital*). Likewise, social results within micro-irrigation was incredibly sparse. Human well-being and equity exist among the main signifiers of good sustainable agricultural management; as such it is concerning that there was such a large data gap pertaining to these studies.

Though our review captured positive on-farm effects on natural and human/social capital, there was a lack of focus on off-site impacts save for a few instances. Due to the deleterious effects caused by conventional agriculture, it is crucial to highlight the benefits sustainable agriculture may provide to both people and nature outside of farm systems. For natural capital in particular, more time must be put forward in each study region to understand better how sustainable practices affect nature outside of farm systems. Likewise, a broader effect on human and social capital may not be well represented in studies only examining the agricultural production cycle, further emphasizing the need for research on the numerous other agricultural cycles. A literature synthesis like this, applying the TEEBAgriFood Framework, helps to draw a more comprehensive picture of the multi-dimensional performance of alternative management practices.

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Bibliography

Acosta-Alba, I., E. Chia, and N. Andrieu. 2019. "The LCA4CSA framework: Using life cycle assessment to strengthen environmental sustainability analysis of climate smart agriculture options at farm and crop system levels." *Agricultural Systems* 171:155–170.

Adam, B., and A. Abdulai. 2023. "Minimum tillage as climate-smart agriculture practice and its impact on food and nutrition security." *PLOS ONE* 18(12):e0287441.

Altieri, M.A., and P. Rosset. 1996. "Agroecology and the conversion of lárge-scale conventional systems to sustainable management." *International Journal of Environmental Studies* 50(3–4):165–185.

Astatke, A., M. Jabbar, and D. Tanner. 2003. "Participatory conservation tillage research: an experience with minimum tillage on an Ethiopian highland Vertisol." *Agriculture, Ecosystems & Environment* 95(2):401–415.

Bedano, J.C., A. Domínguez, R. Arolfo, and L.G. Wall. 2016. "Effect of Good Agricultural Practices under no-till on litter and soil invertebrates in areas with different soil types." *Soil and Tillage Research* 158:100–109.

Bedano, J.C., F. Vaquero, A. Domínguez, M.P. Rodríguez, L. Wall, and P. Lavelle. 2019. "Earthworms contribute to ecosystem process in no-till systems with high crop rotation intensity in Argentina." *Acta Oecologica* 98:14–24.

Bianchi, F. j. j. a, C. j. h Booij, and T. Tscharntke. 2006. "Sustainable pest regulation in agricultural landscapes: a review on landscape composition, biodiversity and natural pest control." *Proceedings of the Royal Society B: Biological Sciences* 273(1595):1715–1727.

Bichier, P., and R. Greenberg. 2007. "Bird predation on insects reduces damage to the foliage of cocoa trees (Theobroma cacao) in western Panama." *Journal of Tropical Ecology* 23:715–719.

Birkhofer, K., F. Arvidsson, D. Ehlers, V.L. Mader, J. Bengtsson, and H.G. Smith. 2016. "Organic farming affects the biological control of hemipteran pests and yields in spring barley independent of landscape complexity." *Landscape Ecology* 31(3):567–579.

Boetzl, F.A., M. Schuele, J. Krauss, and I. Steffan-Dewenter. 2020. “Pest control potential of adjacent agri-environment schemes varies with crop type and is shaped by landscape context and within-field position.” *Journal of Applied Ecology* 57(8):1482–1493.

Cariappa, A.A.G., N.C. Konath, T.B. Sapkota, and V.V. Krishna. 2024. “Evaluating the potential and eligibility of conservation agriculture practices for carbon credits.” *Scientific Reports* 14(1):9193.

Carretta, L., P. Tarolli, A. Cardinali, P. Nasta, N. Romano, and R. Masin. 2021. “Evaluation of runoff and soil erosion under conventional tillage and no-till management: A case study in northeast Italy.” *CATENA* 197:104972.

Conyers, M., V. van der Rijt, A. Oates, G. Poile, J. Kirkegaard, and C. Kirkby. 2019. “The strategic use of minimum tillage within conservation agriculture in southern New South Wales, Australia.” *Soil and Tillage Research* 193:17–26.

Coteur, I., F. Marchand, L. Debruyne, F. Dalemans, and L. Lauwers. 2016. “A framework for guiding sustainability assessment and on-farm strategic decision making.” *Environmental Impact Assessment Review* 60:16–23.

Daelemans, R., E. Hulsmans, E. Laenen, S. Remy, T. Beliën, and O. Honnay. 2023. “Direct and indirect effects of management and landscape on biological pest control and crop pest infestation in apple orchards.” *Journal of Applied Ecology* 60(1):181–192.

FAO 2014. Sustainability Assessment of Food and Agriculture systems (SAFA) guidelines Version 3.0. Food and Agriculture Organization of the United Nations, Rome, Italy. https://www.fao.org/3/i3957e/i3957e.pdf

Figuerola, E.L.M., L.D. Guerrero, S.M. Rosa, L. Simonetti, M.E. Duval, J.A. Galantini, J.C. Bedano, L.G. Wall, and L. Erijman. 2012. “Bacterial Indicator of Agricultural Management for Soil under No-Till Crop Production.” *PLOS ONE* 7(11):e51075.

Fiorini, A., R. Boselli, S.C. Maris, S. Santelli, A. Perego, M. Acutis, S. Brenna, and V. Tabaglio. 2020. “Soil type and cropping system as drivers of soil quality indicators response to no-till: A 7-year field study.” *Applied Soil Ecology* 155:103646.

García, D., M. Miñarro, and R. Martínez-Sastre. 2018. “Birds as suppliers of pest control in cider apple orchards: Avian biodiversity drivers and insectivory effect.” *Agriculture, Ecosystems & Environment* 254:233–243.

García, M., M. Repullo, R. Carbonell- Bojollo, and R. Ordóñez-Fernández. 2019. “COMPARATIVE BIODIVERSITY BETWEEN NO-TILL AND CONVENTIONAL TILL ON A CROP ROTATION.” *AGROFOR* 3.

García-Orenes, F., A. Morugán-Coronado, R. Zornoza, and K. Scow. 2013. “Changes in Soil Microbial Community Structure Influenced by Agricultural Management Practices in a Mediterranean Agro-Ecosystem.” *PLOS ONE* 8(11):e80522.

Gurr, G.M., S.D. Wratten, and J.M. Luna. 2003. “Multi-function agricultural biodiversity: pest management and other benefits.” *Basic and Applied Ecology* 4(2):107–116.

Hatt, S., T. Lopes, F. Boeraeve, J. Chen, and F. Francis. 2017. “Pest regulation and support of natural enemies in agriculture: Experimental evidence of within field wildflower strips.” *Ecological Engineering* 98:240–245.

Islam, R., and R. Reeder. 2014. “No-till and conservation agriculture in the United States: An example from the David Brandt farm, Carroll, Ohio.” *International Soil and Water Conservation Research* 2(1):97–107.

Karp, D.S., C.D. Mendenhall, R.F. Sandí, N. Chaumont, P.R. Ehrlich, E.A. Hadly, and G.C. Daily. 2013. “Forest bolsters bird abundance, pest control and coffee yield.” *Ecology Letters* 16(11):1339–1347.

Kim, K.-H., E. Kabir, and S.A. Jahan. 2017. “Exposure to pesticides and the associated human health effects.” *Science of The Total Environment* 575:525–535.

Krauss, J., I. Gallenberger, and I. Steffan-Dewenter. 2011. “Decreased Functional Diversity and Biological Pest Control in Conventional Compared to Organic Crop Fields.” *PLOS ONE* 6(5):e19502.

LaCanne, C.E., and J.G. Lundgren. 2018. “Regenerative agriculture: merging farming and natural resource conservation profitably.” *PeerJ* 6:e4428.

Lal, R. 2013. “Enhancing ecosystem services with no-till.” *Renewable Agriculture and Food Systems* 28(2):102–114.

Maas, B., Y. Clough, and T. Tscharntke. 2013. “Bats and birds increase crop yield in tropical agroforestry landscapes.” *Ecology Letters* 16(12):1480–1487.

Maas, B., S. Heath, I. Grass, C. Cassano, A. Classen, D. Faria, P. Gras, K. Williams-Guillén, M. Johnson, D.S. Karp, V. Linden, A. Martínez-Salinas, J.M. Schmack, and S. Kross. 2019. “Experimental field exclosure of birds and bats in agricultural systems — Methodological insights, potential improvements, and cost-benefit trade-offs." *Basic and Applied Ecology* 35:1–12.

Machar, I., J. Harmacek, K. Vrublova, J. Filippovova, and J. Brus. 2017. "Biocontrol of Common Vole Populations by Avian Predators Versus Rodenticide Application." *Polish Journal of Ecology* 65(3):434–444.

Martin, E.A., B. Reineking, B. Seo, and I. Steffan-Dewenter. 2015. "Pest control of aphids depends on landscape complexity and natural enemy interactions." *PeerJ* 3:e1095.

Mazumder, M.S.U., Md.S. Ali, M. Moonmoon, and F.Z. Toshi. 2023. "Effects of conservation farming practices on agro-ecosystem services for sustainable food security in Bangladesh." *Food Security* 15(3):673–692.

Mello, I., F. Laurent, A. Kassam, G.F. Marques, C.M.P. Okawa, and K. Monte. 2021. "Benefits of Conservation Agriculture in Watershed Management: Participatory Governance to Improve the Quality of No-Till Systems in the Paraná 3 Watershed, Brazil." *Agronomy* 11(12):2455.

Mitchell, M.G.E., E.M. Bennett, and A. Gonzalez. 2014. "Agricultural landscape structure affects arthropod diversity and arthropod-derived ecosystem services." *Agriculture, Ecosystems & Environment* 192:144–151.

Ntshangase, N.L., B. Muroyiwa, and M. Sibanda. 2018. "Farmers' Perceptions and Factors Influencing the Adoption of No-Till Conservation Agriculture by Small-Scale Farmers in Zashuke, KwaZulu-Natal Province." *Sustainability* 10(2):555.

Otieno, M., B.A. Woodcock, A. Wilby, I.N. Vogiatzakis, A.L. Mauchline, M.W. Gikungu, and S.G. Potts. 2011. "Local management and landscape drivers of pollination and biological control services in a Kenyan agro-ecosystem." *Biological Conservation* 144(10):2424–2431.

Perrot, T., A. Rusch, C. Coux, S. Gaba, and V. Bretagnolle. 2021. "Proportion of Grassland at Landscape Scale Drives Natural Pest Control Services in Agricultural Landscapes." *Frontiers in Ecology and Evolution* 9. Available at: https://www.frontiersin.org/articles/10.3389/fevo.2021.607023 [Accessed March 28, 2024].

Pywell, R.F., M.S. Heard, B.A. Woodcock, S. Hinsley, L. Ridding, M. Nowakowski, and J.M. Bullock. 2015. "Wildlife-friendly farming increases crop yield: evidence for ecological intensification." *Proceedings of the Royal Society B: Biological Sciences* 282(1816):20151740.

Redlich, S., E.A. Martin, and I. Steffan-Dewenter. 2018. "Landscape-level crop diversity benefits biological pest control." *Journal of Applied Ecology* 55(5):2419–2428.

Rodino, S., R.-E. Pop, C. Sterie, G. Andreea Daniela, and E. Dumitru. 2023. "Developing an Evaluation Framework for Circular Agriculture: A Pathway to Sustainable Farming." *Agriculture* 13:2047.

Roger-Estrade, J., C. Anger, M. Bertrand, and G. Richard. 2010. "Tillage and soil ecology: Partners for sustainable agriculture." *Soil and Tillage Research* 111(1):33–40.

Sadok, W., F. Angevin, J.E. Bergez, C. Bockstaller, B. Colomb, L. Guichard, R. Reau, A. Messéan, and T. Doré. 2009. "MASC, a qualitative multi-attribute decision model for ex ante assessment of the sustainability of cropping systems." *Agronomy for Sustainable Development* 29(3):447–461.

Seitz, S., P. Goebes, V.L. Puerta, E.I.P. Pereira, R. Wittwer, J. Six, M.G.A. van der Heijden, and T. Scholten. 2018. "Conservation tillage and organic farming reduce soil erosion." *Agronomy for Sustainable Development* 39(1):4.

Sharma, S., P.S. Shera, and K.S. Sangha. 2018. "Impact of Bio-Intensive Integrated Pest Management Practices on Insect Pests and Grain Yield in *Basmati* Rice." *Journal of Biological Control*:137–141.

Sijtsma, C.H., A.J. Campbell, N.B. McLaughlin, and M.R. Carter. 1998. "Comparative tillage costs for crop rotations utilizing minimum tillage on a farm scale." *Soil and Tillage Research* 49(3):223–231.

Simon, A., T. Rusu, F. Chetan, C. Chetan, and P.I. Moraru. 2018. "IMPACT OF MINIMUM TILLAGE SYSTEMS IN CONSERVATION OF WATER IN THE SOIL IN THE CASE OF PEA CROPS." *AgroLife Scientific Journal* 7(1). Available at: https://agrolifejournal.usamv.ro/index.php/agrolife/article/view/220 [Accessed April 9, 2024].

Stockle, C.O., R.I. Papendick, K.E. Saxton, G.S. Campbell, and F.K. van Evert. 1994. "A framework for evaluating the sustainability of agricultural production systems." *American Journal of Alternative Agriculture* 9(1–2):45–50.

Teodor, R., P. Gus, I. Bogdan, P. Moraru, A.I. Pop, D. Clapa, D. Marin, I. Oroian, and L. Pop. 2009. "Implications of minimum tillage systems on sustainability of agricultural production and soil conservation." *Journal of Food Agriculture and Environment* 7:3 3 5-3 3 8.

The Economics of Ecosystems and Biodiversity (TEEB) (2018). TEEB for Agriculture & Food: Scientific and Economic Foundations. Geneva: UN Environment.

Tschumi, M., M. Albrecht, J. Collatz, V. Dubsky, M.H. Entling, A.J. Najar-Rodriguez, and K. Jacot. 2016. “Tailored flower strips promote natural enemy biodiversity and pest control in potato crops.” *Journal of Applied Ecology* 53(4):1169–1176.

Van Cauwenbergh, N., K. Biala, C. Bielders, V. Brouckaert, L. Franchois, V. Garcia Cidad, M. Hermy, E. Mathijs, B. Muys, J. Reijnders, X. Sauvenier, J. Valckx, M. Vanclooster, B. Van der Veken, E. Wauters, and A. Peeters. 2007. “SAFE—A hierarchical framework for assessing the sustainability of agricultural systems.” *Agriculture, Ecosystems & Environment* 120(2):229–242.

Wezel, A., M. Casagrande, F. Celette, J.-F. Vian, A. Ferrer, and J. Peigné. 2014. “Agroecological practices for sustainable agriculture. A review.” *Agronomy for Sustainable Development* 34(1):1–20.

Woltz, J.M., R. Isaacs, and D.A. Landis. 2012. “Landscape structure and habitat management differentially influence insect natural enemies in an agricultural landscape.” *Agriculture, Ecosystems & Environment* 152:40–49.

Wyckhuys, K.A., W. Zhang, Y.C. Colmenarez, E. Simelton, B.O. Sander, and Y. Lu. 2022. “Tritrophic defenses as a central pivot of low-emission, pest-suppressive farming systems.” *Current Opinion in Environmental Sustainability* 58:101208.

Wyckhuys, K.A.G., M.J. Furlong, W. Zhang, and Y.D. Gc. 2022. “Carbon benefits of enlisting nature for crop protection.” *Nature Food* 3(5):299–301.

Xu, Q., S. Fujiyama, and H. Xu. 2011. “Biological pest control by enhancing populations of natural enemies in organic farming systems.” *Journal of Food Agriculture and Environment* 9:455–463.

Yahya, M.S., N.L. Ibrahim, N. Kamarudin, S.N. Ahmad, S.N. Atikah, R. Sanusi, A.R. Norhisham, M.M.M. Masri, and B. Azhar. “Higher avian biodiversity, increased shrub cover and proximity to continuous forest may reduce pest insect crop loss in small-scale oil palm farming.” *Journal of Applied Ecology* n/a(n/a). Available at: https://onlinelibrary.wiley.com/doi/abs/10.1111/1365-2664.14632 [Accessed March 28, 2024].

Zahm, F., A. Alonso Ugaglia, J.-M. Barbier, H. Boureau, B. del ’Homme, M. Gafsi, P. Gasselin, S. Girard, L. Guichard, C. Loyce, V. Manneville, A. Menet, and B. Redlingshofer. 2018. “Evaluating sustainability of farms: introducing a new conceptual framework based on three dimensions and five key properties relating to the sustainability of agriculture. The IDEA method version 4.” In *13th European IFSA Symposium ”Farming systems: facing uncertainties and enhancing opportunities”. Symposium Theme ”Agroecology and new farming arrangements”*. Chania, Greece. Available at: https://hal.science/hal-01851634 [Accessed March 5, 2024].

Zhang, X.-Q., C. Pu, X. Zhao, J.-F. Xue, R. Zhang, Z.-J. Nie, F. Chen, R. Lal, and H.-L. Zhang. 2016. “Tillage effects on carbon footprint and ecosystem services of climate regulation in a winter wheat–summer maize cropping system of the North China Plain.” *Ecological Indicators* 67:821–829.

Zong, X., X. Liu, G. Chen, and Y. Yin. 2022. “A deep-understanding framework and assessment indicator system for climate-resilient agriculture.” *Ecological Indicators* 136:108597.

Appendix: Assessed papers using the TEEBAgriFood Framework

Title	Citation	Management type	Country
Agricultural landscape structure affects arthropod diversity and arthropod-derived ecosystem services	Mitchell, Bennett and Gonzalez 2014	Minimum and no-tillage	Canada
Agroecological Transition for Sustainable Cattle Ranching with Silvopastoral Systems in the High Andean Slopes of Colombia	Durana, Murgueitio and Lopera-Marín 2023	Agro-silvo-pastoralism	Colombia
An analysis of resource conservation technology in improving farmer's livelihood: A case of micro irrigation system	Sachan and Patel 2023	Micro-irrigation	India
Animal performance in grass monoculture or silvopastures using tree legumes	dos Santos et al. 2020	Agro-silvo-pastoralism	Brazil
Applicability of micro irrigation system on cotton yield and water use efficiency	Asadi et al. 2012	Micro-irrigation	Iran
Assessment of extensive and oasis sheep farming systems sustainability in Morocco	Boughalmi and Napoléone 2017	Agro-silvo-pastoralism	Morocco
Bacterial Indicator of Agricultural Management for Soil under No-Till Crop Production	Figuerola et al. 2012	Minimum and no-tillage	Argentina
Bats and birds increase crop yield in tropical agroforestry landscapes	Maas, Clough and Tscharntke 2013	Biological pest management	Indonesia
Benefits of Conservation Agriculture in Watershed Management: Participatory Governance to Improve the Quality of No-Till Systems in the Paraná 3 Watershed, Brazil	Mello et al. 2021	Minimum and no-tillage	Brazil
Biocontrol of Common Vole Populations by Avian Predators Versus Rodenticide Application	Machar et al. 2017	Biological pest management	Czech Republic
Biological pest control by enhancing populations of natural enemies in organic farming systems	Xu, Fujiyama and Xu 2011	Biological pest management	Japan
Bird predation on insects reduces damage to the foliage of cocoa trees (Theobroma cacao) in western Panama	Bichier and Greenberg 2007	Biological pest management	Panama
Birds as suppliers of pest control in cider apple orchards: Avian biodiversity drivers and insectivory effect	García, Miñarro and Martínez-Sastre 2018	Biological pest management	Spain
Can micro irrigation adoption help in doubling farmers income: A case study of Himachal Pradesh, India	Spehia and Verma 2019	Micro-irrigation	India

Can Micro-Irrigation Technologies Resolve India’s Groundwater Crisis? Reflections from Dark-Regions in Gujarat	Bahinipati and Viswanathan 2019	Micro-irrigation	India
Carbon replacement and stability changes in short-term silvo-pastoral experiments in Colombian Amazonia	Mosquera et al. 2012	Agro-silvo-pastoralism	Colombia
Carbon Sequestration in Pastures, Silvo-Pastoral Systems and Forests in Four Regions of the Latin American Tropics	Amézquita et al. 2004	Agro-silvo-pastoralism	Colombia, Costa Rica
Case study: Impact analysis of Micro Irrigation System in Kodinar Region of Gujarat	Vaibhav and Makwana 2018	Micro-irrigation	India
Changes in Soil Microbial Community Structure Influenced by Agricultural Management Practices in a Mediterranean Agro-Ecosystem	García-Orenes et al. 2013	Minimum and no-tillage	Spain
Comparative Biodiversity Between No-till and Conventional Till on a Crop Rotation	García et al. 2019	Minimum and no-tillage	Spain
Comparative tillage costs for crop rotations utilizing minimum tillage on a farm scale	Sijtsma et al. 1998	Minimum and no-tillage	Canada
Conservation tillage and organic farming reduce soil erosion	Seitz et al. 2018	Minimum and no-tillage	Switzerland
Contrasting land uses in Mediterranean agro-silvo-pastoral systems generated patchy diversity patterns of vascular plants and below-ground microorganisms	Bagella et al. 2014	Agro-silvo-pastoralism	Italy
Decreased Functional Diversity and Biological Pest Control in Conventional Compared to Organic Crop Fields	Krauss, Gallenberger and Steffan-Dewenter 2011	Biological pest management	Germany
Direct and indirect effects of management and landscape on biological pest control and crop pest infestation in apple orchards	Daelemans et al. 2023	Biological pest management	Belgium
Earthworms contribute to ecosystem process in no-till systems with high crop rotation intensity in Argentina	Bedano et al. 2019	Minimum and no-tillage	Argentina
Economic Benefits from Micro Irrigation for Dry Land Crops in Karnataka	Chandrakanth et al. 2013	Micro-irrigation	India
Economic Feasibility of Micro-irrigation Methods for Wheat Under Irrigated Ecosystem of Central Punjab	Suryavanshi and Buttar 2016	Micro-irrigation	India

Economic-environmental assessment of silvo-pastoral systems in Colombia: An ecosystem service perspective	Sandoval et al. 2023	Agro-silvo-pastoralism	Colombia
Economics, adoption determinants, and impacts of micro-irrigation technologies: empirical results from India	Namara et al. 2007	Micro-irrigation	India
Effect of Good Agricultural Practices under no-till on litter and soil invertebrates in areas with different soil types	Bedano et al. 2016	Minimum and no-tillage	Argentina
Effect of micro-irrigation type, N-source and mulching on nitrous oxide emissions in a semi-arid climate: An assessment across two years in a Merlot grape vineyard	Fentabil et al. 2016	Micro-irrigation	Canada
Effects of conservation farming practices on agro-ecosystem services for sustainable food security in Bangladesh	Mazumder et al. 2023	Minimum and no-tillage	Bangladesh
Effects of long-term management practices on grassland plant assemblages in Mediterranean cork oak silvo-pastoral systems	Bagella et al. 2013	Agro-silvo-pastoralism	Italy
Effects of management options on mammal richness in a Mediterranean agro-silvo-pastoral system	Gonçalves et al. 2012	Agro-silvo-pastoralism	Portugal
Environmental and Economic Sustainability Assessment for Two Different Sprinkler and A Drip Irrigation Systems: A Case Study on Maize Cropping	Borsato et al. 2019	Micro-irrigation	Italy
Evaluating the potential and eligibility of conservation agriculture practices for carbon credits	Cariappa et al. 2024	Minimum and no-tillage	India
Evaluation of agroforestry systems viz-a-viz livelihood of farmers of Jammu	Gupta et al. 2022	Agro-silvo-pastoralism	India
Evaluation of runoff and soil erosion under conventional tillage and no-till management: A case study in northeast Italy	Carretta et al. 2021	Minimum and no-tillage	Italy
Evaluation Of The Sustainable Performance Of Native And Intensive Silvopastoral Systems In The Mexican Tropics Using The Mesmis Framework	Cassani et al. 2022	Agro-silvo-pastoralism	Mexico
Farmers’ Perceptions and Factors Influencing the Adoption of No-Till Conservation Agriculture by Small-Scale Farmers in Zashuke, KwaZulu-Natal Province	Ntshangase, Muroyiwa and Sibanda 2018	Minimum and no-tillage	South Africa

Forest bolsters bird abundance, pest control and coffee yield	Karp et al. 2013	Biological pest management	Costa Rica
Groundwater Use Dynamics: Analyzing Performance of Microirrigation System- A case study of Mewat District, Haryana, India	Sharma et al. 2012	Micro-irrigation	India
High biodiversity silvopastoral system as an alternative to improve the thermal environment in the dairy farms	Deniz et al. 2019	Agro-silvo-pastoralism	Brazil
Higher avian biodiversity, increased shrub cover and proximity to continuous forest may reduce pest insect crop loss in small-scale oil palm farming	Yahya et al. 2024	Biological pest management	Malaysia
Impact of Bio-Intensive Integrated Pest Management Practices on Insect Pests and Grain Yield in Basmati Rice	Sharma, Shera and Sangha 2018	Biological pest management	India
Impact of grazing on the agro-ecological characteristics of a Mediterranean oak woodland. Five years of observations at Monte Pisanu forest	A Re et al. 2014	Agro-silvo-pastoralism	Italy
Impact of minimum tillage systems in conservation of water in the soil in the case of pea crops	Simon et al. 2018	Minimum and no-tillage	Romania
Implications of minimum tillage systems on sustainability of agricultural production and soil conservation	Teodor et al. 2009	Minimum and no-tillage	Romania
Improving water productivity through micro-irrigation in arid Punjab regions	Kumar et al. 2013	Micro-irrigation	India
Land quality changes following the conversion of the natural vegetation into silvo-pastoral systems in semi-arid NE Brazil	Wick, Tiessen and Menezes 2000)	Agro-silvo-pastoralism	Brazil
Landscape structure and habitat management differentially influence insect natural enemies in an agricultural landscape	Woltz, Isaacs and Landis 2012	Biological pest management	USA
Landscape-level crop diversity benefits biological pest control	Redlich, Martin and Steffan-Dewenter 2018	Biological pest management	Germany
Local management and landscape drivers of pollination and biological control services in a Kenyan agro-ecosystem	Otieno et al. 2011	Biological pest management	Kenya
Low cost drip irrigation: Impact on sugarcane yield, water and energy saving in semiarid tropical agro ecosystem in India	Surendran et al. 2016	Micro-irrigation	India

Micro-irrigation and fertigation improves gas exchange, productivity traits and economics of Indian mustard (Brassica juncea L. Czernj and Cosson) under semi-arid conditions	Rathore et al. 2014	Micro-irrigation	India
Micro-irrigation in Drought and Salinity Prone Areas of Haryana: Socio-economic Impacts	Grewal et al. 2021	Micro-irrigation	India
Micro-irrigation strategies to improve water-use efficiency of cherry trees in Northern China	Liao et al. 2019	Micro-irrigation	China
Minimum tillage as climate-smart agriculture practice and its impact on food and nutrition security	Adam and Abdulai 2023	Minimum and no-tillage	Ghana
Mitigating land degradation in Mediterranean agro-silvo-pastoral systems: a GIS-based approach	d'Angelo et al. 2000	Agro-silvo-pastoralism	Italy
Nitrogen cycling in a Brachiaria-based silvopastoral system in the Atlantic forest region of Minas Gerais, Brazil	Xavier et al. 2014	Agro-silvo-pastoralism	Brazil
No-till and conservation agriculture in the United States: An example from the David Brandt farm, Carroll, Ohio	Islam and Reeder 2014	Minimum and no-tillage	USA
Organic farming affects the biological control of hemipteran pests and yields in spring barley independent of landscape complexity	Birkhofer et al. 2016	Biological pest management	Sweden
Outcomes of a comparison between pastoral and silvopastoral management on beef cattle productivity, animal welfare and pasture depletion in a Mediterranean extensive farm	Ripamonti et al. 2023	Agro-silvo-pastoralism	Italy
Participatory conservation tillage research: an experience with minimum tillage on an Ethiopian highland Vertisol	Astatke, Jabbar and Tanner 2003	Minimum and no-tillage	Ethiopia
Pest control of aphids depends on landscape complexity and natural enemy interactions	Martin et al. 2015	Biological pest management	South Korea
Pest control potential of adjacent agri-environment schemes varies with crop type and is shaped by landscape context and within-field position	Boetzl et al. 2020	Biological pest management	Germany
Pest regulation and support of natural enemies in agriculture: Experimental evidence of within field wildflower strips	Hatt et al. 2017	Biological pest management	Belgium

Potential Use of Quartzipisamment under Agroforestry and Silvopastoral System for Large-Scale Production in Brazil	Marçal et al. 2022	Agro-silvo-pastoralism	Brazil
Proportion of Grassland at Landscape Scale Drives Natural Pest Control Services in Agricultural Landscapes	Perrot et al. 2021	Biological pest management	France
Regenerative agriculture: merging farming and natural resource conservation profitably	LaCanne and Lundgren 2018	Minimum and no-tillage	USA
Replacing conventional surface irrigation with micro-irrigation in vegetables can alleviate arsenic toxicity and improve water productivity	Sengupta et al. 2023	Micro-irrigation	India
Soil type and cropping system as drivers of soil quality indicators response to no-till: A 7-year field study	Fiorini et al. 2020	Minimum and no-tillage	Italy
Sustainability of pistachio production (*Pistacia vera* L.) under supplemental irrigation in a Mediterranean climate	Marino et al. 2018	Micro-irrigation	Italy
Sustainable water use through multiple cropping systems and precision irrigation	Brar et al. 2022	Micro-irrigation	India
Tailored flower strips promote natural enemy biodiversity and pest control in potato crops	Tschumi et al. 2016	Biological pest management	Switzerland
The Role of Micro-Irrigation Systems in Date Palm Production and Quality: Implications for Sustainable Investment	Ghazzawy et al. 2022	Micro-irrigation	Egypt
The strategic use of minimum tillage within conservation agriculture in southern New South Wales, Australia	Conyers et al. 2019	Minimum and no-tillage	Australia
Tillage effects on carbon footprint and ecosystem services of climate regulation in a winter wheat–summer maize cropping system of the North China Plain	Zhang et al. 2016	Minimum and no-tillage	China
Traditional land uses enhanced plant biodiversity in a Mediterranean agro-silvo-pastoral system	Bagella et al. 2016	Agro-silvo-pastoralism	Italy
Weight gain of calves under sylvo-pastoral and agro-sylvo-pastoral farms	Hessa et al. 2024	Agro-silvo-pastoralism	Benin
Wildlife-friendly farming increases crop yield: evidence for ecological intensification	Pywell et al. 2015	Biological pest management	England

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