A CONCEPTUAL FRAMEWORK FOR DEVELOPING A DECISION SUPPORT SYSTEM FOR AGRO-ECOLOGICAL TRANSITION

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ABSTRACT

Agroecology presents a promising approach to agriculture, with the potential to restore soil health and sequester carbon, thereby contributing to climate change mitigation. However, farmers face considerable uncertainty when transitioning from conventional practices and selecting appropriate agro-ecological methods. This study develops a conceptual framework that synthesises the critical factors and their interdependencies required for a decision support system (DSS) to facilitate this transition. The framework consists of a data flow diagram and an adjacency matrix to guide the design of practical, farmer-centric DSS tools. A systematic literature review identifies relevant factors and considerations for DSS development, with the data analysed through an iterative thematic coding process. The resulting codes and their relationships inform the construction of the conceptual framework. Future research should focus on validating this framework in real-world settings to support the development of effective DSS solutions for agro-ecological transition.

Keywords: Agroecology, Decision Support Systems, Transition

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1 INTRODUCTION

Climate change is projected to bring a tide of challenges in global agriculture: lower crop yields, higher food prices and declining household incomes. [1], accompanied by more frequent and intense extreme weather events [2]. Rising temperatures are expected to severely impact the cultivation of key food crops that supply much of the world's dietary energy [3]. Even a slight increase of 1°C could result in yield declines of about 6% for wheat, 7.4% for maize, 3% for rice, and 3.1% for soybeans, posing a serious threat to global food security [3]. A drop in food production is likely to drive prices even higher, worsening existing food security challenges [4]. In urban areas, high food costs remain one of the leading causes of food insecurity, as many households cannot afford enough nutritious food [5]. Concurrently, intensive farming practices are resulting in the unsustainable degradation of soils, decreasing its long-term food production capabilities [6]. Soil health is deteriorating due to multiple processes, including loss of organic content, increased greenhouse gas emissions, excessive fertiliser use, soil erosion, pollution, rising acidity, salinisation, and a reduction in genetic variation within soil ecosystems [6] It is, therefore, clear that a change in the agricultural industry is essential to secure food production, but the direction of this change remains uncertain.

Agroecology offers a holistic remedy that enhances the resilience of farming systems, safeguards the environment and sustains food production[7], yet farmers attempting this transition confront a flood of information and a steep knowledge barrier, leading to difficulties in determining which agro-ecological practices best fit their unique priorities and contexts. The inherent complexity of biological interactions and environmental variability magnifies this challenge.

Decision Support Systems (DSS) can help stem that tide by distilling complex data into guidance that is tailored for practical use. Tools like Decision Support System for Agrotechnology Transfer (crop simulation), Hydrologic (water management tool), Agricultural Production Systems Simulator (nutrient management) and InfoCrop (pest management) [8] illustrate DSS potential. Adoption has, however, been limited, which has been attributed to the lack of farmer involvement in DSS development [8]. The existing models lack comprehensive integration [8], as is demanded by agroecology, which highlights the research need. However, before an agroecology transition, DSS can be developed; the elements of such a model need to be determined.

Therefore, this study aims to develop a conceptual framework that synthesises the factors and interdependencies required for a DSS that can navigate agro-ecological transition. Such a framework will consist of a data flow diagram and an adjacency framework to guide the design of practical, farmer-focused DSS tools.

1.1 Terminology

This section defines two key terms: agroecology and decision support systems, as they are used in this paper, and provides the rationale for these definitions.

1.1.1 Agroecology

The definition of agroecology has changed significantly over time. Initially, in the 1980s, it was primarily defined as "the application of ecological concepts and principles to the design and management of sustainable agroecosystems, or the science of sustainable agriculture", focusing on the farm level [9], [10]. Since then, its scope has expanded to include the broader food system, framing agroecology as a "way of building relationship- based market systems that are equitable, just and accessible for all" [10], and as a means of "confronting the economic and political power structures of the current industrial food system" [10], [11].

These shifts reflect agroecology's three core dimensions as described by [10], [11]:

1. Scientific: applying ecological principles in sustainable agroecosystem design
2. Practical: incorporating local, empirical, and indigenous farming knowledge
3. Social change: challenging, advocating for alternative social structures and influencing policy change.

Each dimension has received varying levels of emphasis across agroecology's history, as shown in [11]. Table 1 was synthesised by combining the periods and historical focuses, as presented in [11], with the corresponding aspect of agroecology from [10], to illustrate how the focus has shifted over time.

Table 1: Aspects of agroecology that were focused on during different historical periods in the term's existence [10], [11]

Period	Historical focus	Corresponding aspects
1980's	Farm-level sustainability	Scientific & practical
1900's	Relationship-based market systems	Social change
2010's	Economic and political power structures	Social change

While the importance of integrating all three dimensions is widely acknowledged [10], [12], this study retains the original farm-level emphasis. It therefore centres on the scientific and practical aspects of agroecology. Broader sociopolitical factors, such as policy, governance and structural power dynamics, are only considered to the extent that they directly affect the farmer's decision-making. These external factors, which often fall beyond a farmer's control, lie beyond the scope of this research.

Agro-ecological transition, as used in [13], refers to the process of moving from conventional industrial agriculture towards more sustainable, biodiversity-based farming systems. This definition will be applied to this study.

1.1.2 DSS

A DSS (Decision Support System) is a computerised system for assisting decision-making processes, which integrates databases, modelling tools and multicriteria analysis methodologies to analyse and rank a set of alternatives, thereby enabling decision-makers to consider complex and interacting factors [14]. According to [14], DSS applications in agriculture have been increasing in the last decades, and the advantages of using a DSS are improved understanding of the process, identifying unexpected situations, improving communication, decisions and use of data and resources, as well as cost savings.

1.2 Paper structure

This paper is organised as follows: Section 2 outlines the research methodology. In particular, Section 2.1 describes the data gathering process, Section 2.2 details the data analysis procedures, and Section 2.3 explains how the validation for this study was performed. Section 3 presents the findings of the research, followed by the synthesised conceptual framework presented in Section 4. The paper concludes with Section 5, which summarises the key conclusions and Section 6, which offers recommendations for further research.

2 RESEARCH METHODOLOGY

2.1 Data gathering

For data gathering, a Systematic Literature Review (SLR) was applied since it uses

> *"…explicit, systematic methods to collate and synthesise findings of studies that address a clearly formulated question " [15].*

This method has been chosen for its comprehensiveness, to ensure all possible rigour and completeness in the resulting data. The aim of this SLR is to synthesise a conceptual framework integrating factors and interdependencies. The conceptual framework could be used in the

future to develop DSS models for agro-ecological transition, addressing the complexity of the problem and a gap in the literature.

The literature search was conducted between January and May 2025, and the following steps were used in this study [16].

1. Protocol: Define research question, scope, protocol and criteria for inclusion and exclusion (Section 2.1.1).
2. Search: Develop search string, select databases, conduct systematic searches (Section 2.1.2).
3. Appraisal: Select studies using inclusion/exclusion criteria and assess quality (Section 2.1.3).
4. Synthesis: extract and classify relevant data (Section 3).
5. Analysis: Evaluate synthesised data to extract a meaningful answer to the research question (Section 2.2) and Validation (Section 2.3).
6. Reporting: Reporting the study's findings in a transparent and detailed manner, and discussing the implications, limitations and suggestions for future research (Sections 4 and 5).

2.1.1 Protocol

The research protocol that was followed during this study is shown in Table 2.

Table 2: Research protocol followed in the SLR.

Purpose of the study	To identify the factors and their interdependencies involved in developing DSS models for agro-ecological transition, addressing a gap in the literature by integrating these elements into a conceptual framework, whether standalone or embedded in existing models or frameworks.
Keywords/search string	(DSS OR "decision support system*") AND (Agroecolog*) AND (transition* OR transformation*) AND (model* OR framework* OR factor*)
Search databases	ScienceDirect, Scopus, Springer, IEEE Xplore and Web of Science
Inclusion criteria	• Peer-reviewed, English-language studies on DSS in agriculture • Focus on agroecology practices involving the transition/transformation process • Present or discuss models/frameworks or defined factors for decision support • Full text available with transparent, reproducible methodology. • Articles published after 2005
Exclusion criteria	• Duplicates • Narrow Focus • Land-related topics • Climate change and sustainability (Broad) • Publication Type Issues • Tangential or brief keyword references • Full text unavailable
Quality assessment criteria	Studies should be published in English, and repeatable and reputable scientific research methods should have been followed, with adequate methodological transparency.

The inclusion criteria align closely with the objective of the study, and the reasoning behind the exclusion criteria is given below.

- Narrow focus: studies focused on isolated practices or technologies without a holistic or systems perspective, as required for agroecology.
- Land-related topics: studies related to land topics that are tangentially relevant but not of direct interest to the SLR's core focus.
- Climate change and sustainability: Broad sustainability or climate topics lacking a direct connection to agroecology.

- Publication type issues: non-peer-reviewed or insufficiently analytical formats (e.g. opinion pieces, data-only papers).
- Tangential or brief keyword references: studies that mention relevant terms superficially without addressing core research questions.

2.1.2 Search

To ensure that the SLR is conducted comprehensively and rigorously, multiple databases were selected based on their relevance, coverage and disciplinary scope. IEEE Xplore's comprehensive database of peer-reviewed literature in electrical engineering and computer science [17] makes it a promising resource for information on decision support systems and technological applications relevant to agroecology transitions. Scopus and Web of Science are widely acknowledged as authoritative multidisciplinary databases with high-quality resources, enabling broad coverage [18], while ScienceDirect and Springer provide extensive access to peer-reviewed journal articles and book chapters in environmental science, agriculture, and systems design [19], [20]- central to agroecology and DSS domains.

The search string was carefully designed to capture core concepts relevant to the design of DSS for the transition to agroecology, and consists of 4 key components, which are combined by Boolean operators, for clarity, and asterisk truncation, to allow variations:

- (DSS OR "decision support system*")- to capture all relevant literature referring to decision support systems.
- (Agroecolog*)- The term "agroecology" has been chosen for the search string, as it encompasses a wide range of other terminology that prioritise management of biodiversity [21].
- (transition* OR transformation*)- to capture shifts, changes or transformations in agricultural systems, addressing the dynamic process of change towards agro-ecological practices.
- (model* OR framework* OR factor*)- to focus on studies that identify standalone factors, as well as factors embedded in frameworks or models.

As the search was conducted, filters were applied to exclude all articles published before 2005, given the technological developments over the last 20 years, as well as a filter to limit the results to articles in English.

2.1.3 Appraising the literature

The literature was screened using the inclusion and exclusion criteria as discussed in Section 2.1.2. Figure 1 presents the PRISMA literature selection and reduction process, providing a detailed view of the number of articles that were excluded during the screening process, as per the reasons defined in section 2.1.1.

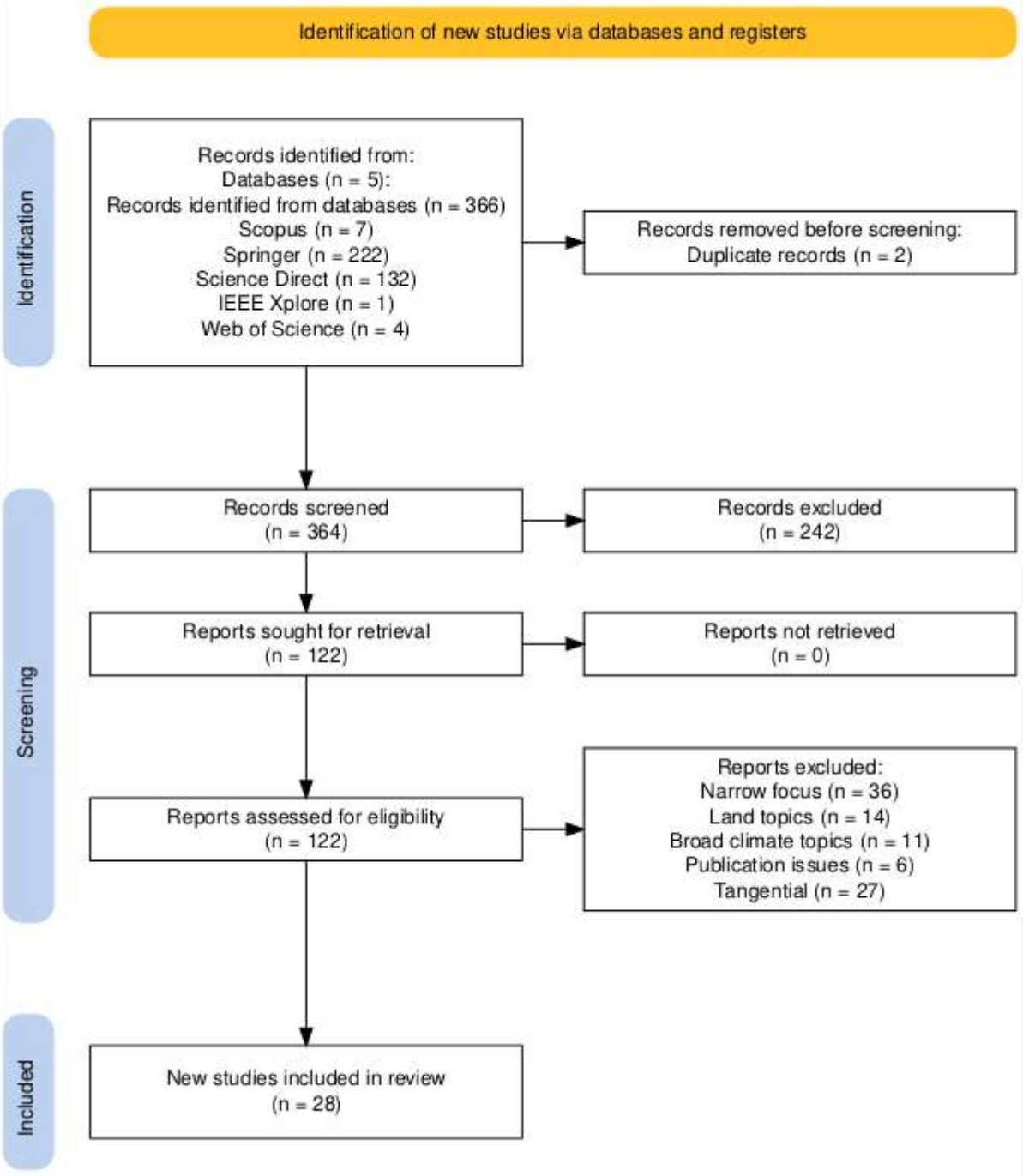


Figure 1: PRISMA literature selection and reduction process followed.

2.2 Data Analysis

The factors involved in designing a DSS to facilitate the transition to different agro-ecological systems were identified through an iterative process of qualitative coding and thematic refinement using Atlas.TI software (version 23), thereby following the qualitative synthesis methodology as established by [22], to protect the nuance and contextual understanding of the data, relevant quotations were revisited within their original source document, and the entire section was reviewed to minimise the risk of loss or data misinterpretation. A thematic iterative coding analysis methodology was chosen to systematically identify, code and

interpret patterns and relationships relevant to the adoption of agro-ecological practices at the farm level, as explained in

> *"Coding is an iterative, systematic, and meticulous process. Researchers often rely on both manual methods and qualitative data analysis software such as NVivo, ATLAS.ti, or MAXQDA. Each data extract is reviewed systematically, with relevant segments assigned concise codes" [23].*

The software enabled efficient management of the diverse data collected, particularly in terms of segmenting, coding and organising text across multiple sources. The process began by importing all references identified in Section 2.1.3. A bottom-up, inductive coding approach was initially applied, whereby relevant quotations were manually highlighted and assigned descriptive codes, which were either newly assigned or added to an existing code, allowing for the development of a comprehensive and growing codebook. To ensure rigour, coding decisions were documented throughout the process and incorporated into the code definitions, as each code represents an identified factor. The codes have been organised into code groups during the analysis phase, which is described in Section 2.3.

Relationships among factors were identified within quotations containing multiple factors (codes) and subsequently into three relationship types (detailed in Table 4). Each relationship type was assigned a specific code. A code co-occurrence table generated in ATLAS.ti was then validated by cross-referencing it with the relationship codes associated with each quotation, during which adjustments were made as necessary to ensure that the co-occurrence table accurately portrays relationships instead of simple code overlap.

2.3 Validation

The PRISMA framework validates the SLR conducted in this study, as it adheres to the following requirements:

1. Complete, transparent reporting that is in adherence to the PRISMA checklist [15].
2. This study has included a PRISMA flow diagram (Refer to Figure 1).
3. Measures have been taken to prevent bias and ensure that a pre-planned methodology was followed (Section **Error! Reference source not found.**).
4. The rationale and methodology in conducting the review, as well as the synthesised results (Sections 2 and 4, respectively), have been reported.

3 FINDINGS

The factors that were identified from the literature are presented in this section, and have been organised into four code groups, each reflecting their role within a future DSS:

- **Design requirements (Purple):** Functional and operational specifications that define how a DSS processes inputs to generate outputs.
- **Inputs (Orange):** Information required from the user to tailor the model's response.
- **Dual role factors (Yellow):** Factors that serve as both inputs and outputs, where the current state serves as an input, and the system returns improvement recommendations as output.
- **Outputs (Blue):** The resulting outputs or outcomes generated by the model.

Table 3 presents the factors involved in designing a DSS to facilitate the transition to a different agro-ecological system, their definitions, as used and developed during the iterative coding process, the desired DSS response, and the sources from where these factors have been found.

Table 3: Factors identified from the literature

Identified factor	Definition	How a DSS Should Respond	Sources
Adaptability	Adaptability & vulnerability of farming systems towards: •Environmental changes •Extreme weather •Flexible cropping •Early warning systems (improved response time) •Resilience •Wetland management	Support iterative reconfiguration and scenario adjustment in response to environmental or systemic change.	[8], [24], [25], [26]
Biodiversity	Diverse species & ecological interaction, to achieve polyculture and integration through multi-species management.	Identify opportunities and strategies to enhance on-farm biodiversity.	[24], [26], [27], [28]
Forecasting	Predictions & estimates for weather, climate & disaster (primary use), agronomy, pest & disease, weed population, socioeconomic & ecological scenarios.	Integrate external forecasts (e.g., weather, pest pressure) and simulate decision outcomes accordingly.	[24], [26], [29], [30], [31]
Information flow	Sharing agricultural data to improve response times, communication & record-keeping.	Allow data sharing and updates from multiple sources to ensure responsiveness and traceability.	[7], [8], [24], [25], [27], [28]
Outcome Measurement	Methods to quantify agricultural outcomes, as well as challenges experienced with measurements, which prominently feature challenges with measuring environmental impact.	Accept observed outcomes to support ongoing calibration and iterative improvement.	[7], [24], [25], [28], [29], [32], [33], [34], [35], [36], [37]
Participatory research	To co-design solutions with farmers, integrate local knowledge, farmer awareness, preferences, and tradition, and use on-farm experimentation.	Incorporate farmer input and validation loops to ensure contextual accuracy and trust.	[21], [24], [26], [27], [29], [33], [34], [38]
Priority	Priorities from literature and the incorporation of stakeholder opinions for agricultural decision-making and strategy.	Accept farmer-stated priorities and internally rank practices based on contextual fit and scientific evidence.	[24], [26]
Resource conservation	Practices to sustain resources.	Recommend context-specific opportunities to conserve natural resources.	[21], [24], [26], [31]
Species Interactions and Dependencies	Interactions and dependencies between species and systems.	Account for ecological synergies and interdependencies in the recommendation engine.	[24], [26], [28]
Disease resistance	Genetic traits enhancing resistance to diseases.	Capture species-level resistance traits to improve recommendation accuracy.	[7], [24]
Farmer capacity	Factors that are of importance to the individual farmer, like their ability to perform tasks, access capital, achieve self-sufficiency & make independent decisions	Tailor recommendations to the farmer's labour, financial, and operational capacity.	[8], [24], [26], [28], [39]
GIS	Geographic Information Systems for spatial analysis in agriculture.	Geolocate inputs and link them to relevant spatial datasets and constraints.	[8], [24], [28], [29], [30], [31], [37]
Social & Governance Structures	Relevant structures, at centralised (government) level, decentralised (community) level, and other sustainability-incentivising structures.	Incorporate regulatory and policy constraints that directly affect decisions.	[7], [24], [25], [26], [27], [28], [37], [40]

Identified factor	Definition	How a DSS Should Respond	Sources
Tools & Technology	Tools, including equipment, technology & infrastructure used to support agricultural activities- this includes information and decision-making tools.	Assess existing tools and technologies in use and adapt outputs accordingly.	[7], [24], [25], [26], [30], [31], [35], [38], [40], [41]
Topography	Physical features and land characteristics of a site, e.g. slope, altitude, field lengths, drainage, boundary management, terracing, alley cropping, contour bunds, raised beds, tied ridges, hillside farming, etc.	Incorporate topographical constraints into practical recommendations.	[7], [8], [24]
Trade opportunities	Prospects and market opportunities for trading & selling agricultural products.	Assess market access and opportunity levels to guide viable crop or product selection.	[24], [28], [39]
Animal Healthcare	Practices to maintain & improve animal health.	Identify improvement opportunities based on current practices.	[24]
Animal integration	Strategies for integrating & managing livestock.	Assess integration levels and suggest context-appropriate improvements.	[7], [24], [28], [31], [39]
Animal selection	Selection of animals based on morphology, body condition, and suitability.	Evaluate selection criteria and propose refinements.	[24]
Breeding	Processes to improve livestock or crop genetics, including advanced techniques and outcomes like high survival rates.	Analyse breeding strategies and suggest improvements or alternatives.	[7], [24], [25]
Chemical usage	Pesticides, insecticides, inorganic fertiliser, etc.	Evaluate chemical dependency and suggest safer or more sustainable alternatives.	[7], [24], [28], [30], [40]
Cover plants & Legumes	Used to improve soil health and nitrogen fixation.	Evaluate incorporation levels and recommend soil-enhancing strategies.	[24]
Crop diversification	Strategies like intercropping to enhance resilience and productivity.	Assess current species mix and suggest diversification strategies.	[7], [24]
Crop health	Monitoring and managing crop vitality.	Recommend targeted practices to improve or maintain crop vitality.	[7], [24]
Crop timing	Crop cycles, including life cycles, growing seasons, rotation, succession, flowering periods, pruning, etc.	Align crop cycles with climate, variety, and market demands for optimal outcomes.	[24], [28], [29]
Disease management	Strategies to prevent and control diseases in general.	Suggest context-specific disease prevention and control strategies.	[7], [24]
Diversify income	Its aim is to buffer agricultural systems.	Assess income streams and propose feasible on-farm diversification options.	[24]
Hygiene	Hygienic practices to maintain animal health, including proper disposal of dead animals.	Evaluate hygiene practices and recommend improvements.	[24]
INM	Integrated Nutrient Management to optimise nutrient use and soil fertility.	Evaluate nutrient strategies and suggest integrated, precision-based improvements.	[8], [24]
IPM	Integrated Pest Management for sustainable pest control.	Recommend pest control approaches that balance efficacy with sustainability.	[24]

Identified factor	Definition	How a DSS Should Respond	Sources
Long-term planning	The timeframe of long-term strategies, for example, land ownership/tenure duration is highly relevant for considering perennials.	Align recommendations with the stated planning horizon and land tenure strategy.	[24]
Nutrient management	Practices to enhance soil fertility and nutrient uptake, including nitrogen fixation, organic fertilisers, precision application, and addressing uptake complexities.	Assess nutrient strategies and propose scientifically validated improvements.	[7], [24], [29], [32], [39]
Organic fertiliser	Use of natural fertilisers like earthworm castings and organic manure.	Evaluate usage and suggest natural alternatives where applicable.	[24], [28], [39]
Organic pest management	Natural pest control methods like beneficial insects, biopesticides, organic chemicals, sterile insect techniques, trapping/confusing pests, transgenic insects and vector control techniques.	Suggest sustainable biological pest control methods.	[7], [24]
Pest management	Strategies to control pests and weeds.	Recommend integrated, context-sensitive pest and weed control strategies.	[7], [24], [28], [30]
Planting patterns	Arrangements to optimise crop growth and resource use.	Optimise planting configurations based on spatial and ecological inputs.	[24]
Raised Beds, Mulch & Shelters	Mulch protects soil and enhances agricultural outcomes, structures and raised beds protect crops from soil contact & waterlogging.	Recommend protective practices based on local soil and climatic conditions.	[24]
Risk & Insurance	Uncertainties faced & mitigations taken, which includes insurance.	Evaluate risk exposure and suggest mitigation strategies, including insurance.	[7], [8], [24], [26], [28], [39]
Seed planning	Selection, treatment, distribution, and delivery of seeds.	Support seed selection, treatment, and distribution based on local suitability.	[7], [24], [25], [35]
Soil characteristics	Soil properties like pH, runoff, temperature, colloidal minerals, texture/structure & productivity.	Integrate soil data to tailor practice recommendations.	[7], [24], [28], [35]
Soil health	Overall soil condition & fertility, microorganisms that contribute to soil health, and carbon sequestration practices.	Assess soil condition and suggest biologically informed improvements.	[7], [24], [29], [35], [39]
Soil moisture management	Aims to optimise water infiltration and soil-crop water balance.	Evaluate water balance and recommend moisture optimisation practices.	[7], [8], [24], [39]
Stress	Environmental pressures on plants and animals.	Diagnose stressors and propose adaptive response strategies.	[7], [24]
Tillage	Soil preparation methods.	Assess tillage methods and recommend regenerative or conservation alternatives.	[24], [31], [35]
Tree integration	Incorporating trees into agriculture.	Evaluate agroforestry practices and recommend improvements.	[7], [24], [39]
Varietal selection	Choosing crop varieties to optimise performance.	Assess crop variety suitability and suggest better-aligned alternatives.	[7], [24], [25]
Water management	Water optimisation strategies for delivery systems & scheduling, storage mechanisms & groundwater access.	Propose optimal water delivery and scheduling strategies.	[7], [24], [26], [31], [35], [39]
Quality Standards	Standard of agricultural products.	Estimate the quality of outputs based on current and proposed practices.	[21], [24]

Identified factor	Definition	How a DSS Should Respond	Sources
Viability	Farming venture profitability & financial sustainability.	Simulate financial outcomes to assess profitability and sustainability of the venture.	[7], [8], [21], [24], [25], [28], [31], [32], [37], [39]
Yield	Quantity of agricultural output	Simulate yield outcomes to support comparison of alternative practices.	[7], [8], [24], [29], [35], [39], [42]

4 CONCEPTUAL FRAMEWORK

This section presents the factors, as well as the relationships between them, as obtained from the thematic iterative coding analysis performed on the data obtained through the SLR.

Together, the data flow diagram (Section 4.1) and the adjacency matrix (Section 4.2) form a conceptual framework, as they illustrate the relationships between the factors or concepts under investigation, in accordance with the requirements for a conceptual framework outlined in [43]. This framework can inform the development of a decision support system (DSS) to facilitate the transition to agroecology.

4.1 Data Flow Diagram

Data flow diagrams are used to simplify designing DSSs, as they provide a view that simultaneously presents a high-level, while mapping the detailed factors [44]. Each factor in Table 3 was assigned to one of the four categories required for a data flow diagram: Input, Output, Design Requirements and Dual Role (factors that function as both inputs and outputs). The data flow diagram was then constructed by grouping the factors according to these categories and depicting the movement and processing of data through the model with directional arrows. Figure 2 presents the data flow diagram for a DSS model facilitating the transition to agroecology.

This data flow diagram can be used in the design of a future DSS. There is a clear emphasis on the need for collaborative research and stakeholder participation, as reflected in design requirements (top centre of the figure) such as "Participatory research". Important model inputs (positioned on the left side of the figure) include "Priority," where users specify their goals or areas of concern; "Farmer capacity"; and "GIS" data, which requires the farm's geo-location. Additionally, "Topography" (capturing site-specific features such as erosion, historical chemical use, and other relevant conditions) and "Trade opportunities" are critical components. Together, these elements significantly enhance the ability to tailor model outputs to the unique context of each user.

In addition to providing recommendations on agricultural practices for factors in the "Dual role" category (bottom centre), the model's output (top right) should also forecast the quality standards of the agricultural products, the financial viability of the venture- both short- and long- term-and the expected yield, presented in a format that allows users to compare projected future states with the current baseline.

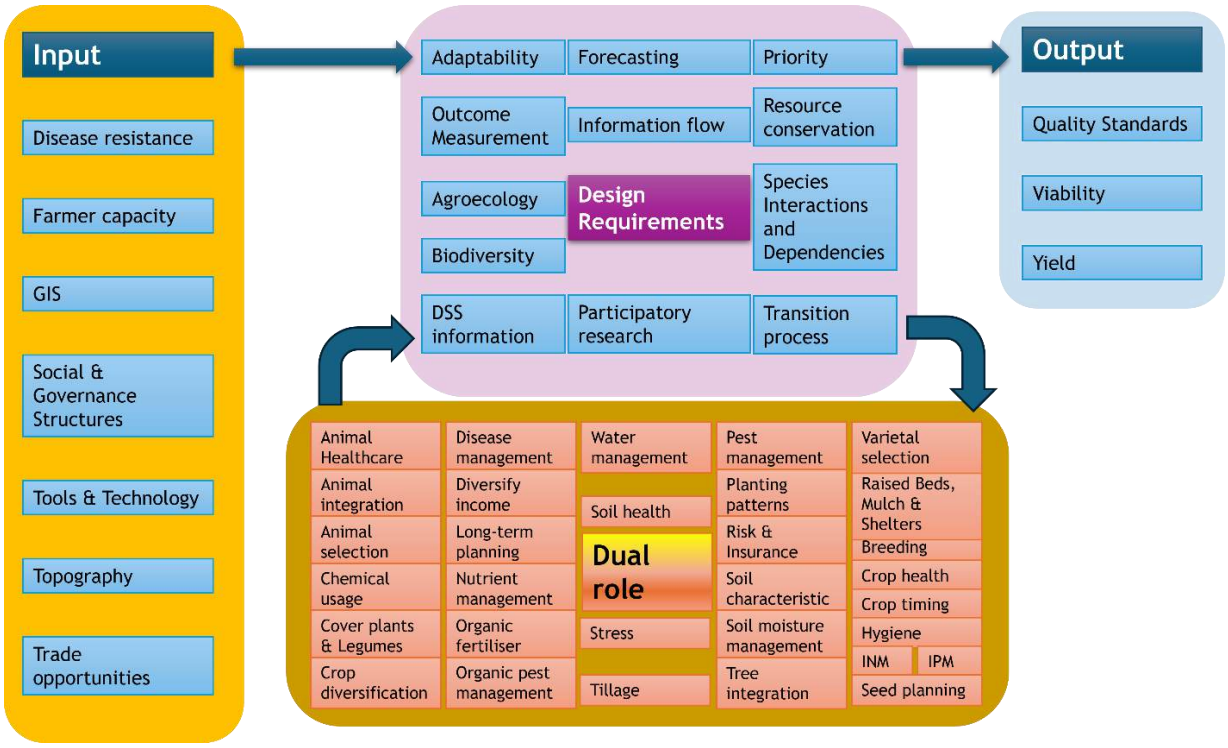


Figure 2: Data flow diagram for a future DSS model facilitating the transition to agroecology.

4.2 Adjacency matrix- Interdependencies and relationships between factors

Semantic relationships were observed from the identified factors and quotations, as found in the sources in the last column of Table 3. The key used in the adjacency matrix is presented in Table 4.

Table 4: Definitions and symbols for factor relationships or interdependencies

Relationship type	Symbol used	Colour used	Definition
Influences	I	Green	Both factors exert an influence on each other in a bidirectional relationship.
Is associated with	A	Blue	Factors are generally associated with each other, no directionality specified.
Opposing effect	O	Light red	One factor has an opposing or negative effect on the other, directionality specified on the table.

Figure 3 and Figure 4 shows the resulting adjacency matrix, which displays the relationships between factors. Blank rows and columns have been removed from the table in the interest of simplification. The colour key, displayed to the right of the table, includes two sub-categories:

1. The "Data flow role" corresponds to the established code groups, applied to the first row and column, and retains the same colour scheme as in Table 3.
2. The "Relationship" sub-category indicates the colour and symbol assigned within the matrix, excluding the first row and column, to represent each relationship type. The relationship definitions are presented in Table 4.

The directionality is indicated in the table, which should be interpreted by first considering the row variable, followed by the column variable. For example, adaptability, located in the first row, has an opposing effect on risk, indicating that as adaptability increases, risk decreases.

Figure 3: Adjacency matrix part 1

Factor Relationships	Animal Healthcare	Animal integration	Animal selection	Breeding	Chemical usage	Crop diversification	Crop health	Crop timing	Disease management	Diversify income	INM	Nutrient management	Organic fertiliser	Organic pest management	Pest management	Planting patterns	Risk & Insurance	Seed planning	Soil characteristics	Soil health	Soil moisture management	Stress	Tillage	Tree integration	Varietal selection	Water management	Colour code
Adaptability			I			I							A	O				I			A					Data flow role
Biodiversity							A	A					A					I								Design requirement
Forecasting													A		A											Input
Information flow		A											I	I	I											Dual Role
Outcome Measurement																										Relationship Type
Participatory research							I						A		O					O						Influences (I)
Priority																A										Is associated with (A)
Resource conservation																										Opposing effect (O)
Species Interactions and Dependencies					I								I								A					
Disease resistance							A																A			
Farmer capacity						I									O											
GIS	I												A												I	
Social & Governance Structures				A																						
Tools & Technology	I	I		I		I	I		A		A	A		A	I			I					A		I	
Topography						I							I							I			I		I	Total number of links:
Trade opportunities																										
Viability											I										I		I	I		
Yield																I										190
Animal Healthcare		A						A																		
Animal integration															O		I									
Breeding		I	I																				A			
Chemical usage							A						A			A									A	
Cover plants & Legumes										I			A	I						O						
Crop diversification						I														I			A			
Crop health			A			I																				
Crop timing		A								I				I												
Disease management															O					O	A		A			
Diversify income															O											
Hygiene	A	A																								
INM										A						I				I						
IPM													A													
Long-term planning																					A					
Nutrient management		A		A				I																		
Organic fertiliser										A																
Organic pest management	A												A													
Pest management															O					O	A		A			
Planting patterns										I																
Raised Beds, Mulch & Shelters																	I	I	O							
Risk & Insurance														I												
Seed planning							A																			
Soil characteristics										I						I									I	
Soil health					I														I							
Soil moisture management																									A	
Stress			I																I							
Tillage				A											O	I	A	I	A	A						
Tree integration										I				I	O	I	I									
Varietal selection	I	A				I				I					O	I				O						
Water management			A							I								I		I		I				

The matrix is not symmetrical because some relationships are unidirectional, while others lack specified directionality due to the absence of that information in the literature that has been reviewed for this study. As seen in Figure 3 and Figure 4, there is a total of 190 relationships and interdependencies between the identified factors. There is a total of 105 "Influence" relationships, 69 "Association" relationships and 16 relationships that have opposing effects on each other. The adjacency matrix is a crucial component to incorporate into a future DSS, as the fundamental philosophy of agroecology depends on the relationships and interactions between different biological and non-biological parts of a farming ecosystem, encompassing both mutually beneficial exchanges and trade-offs within the ecosystem.

Figure 4: Adjacency matrix part 2

Factor Relationships	Biodiversity	Forecasting	Information flow	Outcome Measurement	Participatory research	Priority	Resource conservation	Disease resistance	GIS	Social & Governance Structures	Tools & Technology	Topography	Trade opportunities	Quality Standards	Viability	Yield	Colour code
Adaptability									I								Data flow role
Biodiversity							I										Design requirement
Forecasting																	Input
Information flow									A								Dual Role
Outcome Measurement																	Relationship Type
Participatory research			A	I					I			I				I	Influences (I)
Priority																	Is associated with (A)
Resource conservation															I		Opposing effect (O)
Species Interactions and Dependencies	A																
Disease resistance																	
Farmer capacity															I		
GIS		I															
Social & Governance Structures										I							
Tools & Technology			I	I			I		I		I					I	
Topography							I										Total number of links:
Trade opportunities															I		
Viability																	
Yield		A															190
Animal Healthcare																	
Animal integration	A																
Breeding								I									
Chemical usage										A						A	
Cover plants & Legumes																	
Crop diversification																	
Crop health																	
Crop timing													I			I	
Disease management																	
Diversify income														A			
Hygiene																	
INM					A												
IPM															I	I	
Long-term planning						A											
Nutrient management													I	I	I		
Organic fertiliser																	
Organic pest management	A																
Pest management																	
Planting patterns																	
Raised Beds, Mulch & Shelters													I				
Risk & Insurance														A			
Seed planning																	
Soil characteristics																	
Soil health				I												I	
Soil moisture management																	
Stress																	
Tillage										A	I						
Tree integration	A					I						I		A		I	
Varietal selection																I	
Water management							A						I			I	

5 CONCLUSION

An SLR was performed to gather data on factors to consider during the transition to an agro-ecological approach to agriculture. Multiple factors have been identified from interdisciplinary sources. The following groups were used to classify these factors: Input (e.g., Farmer Capacity and Disease Resistance), Design Requirements (E.g., Adaptability and Biodiversity), Output (E.g., Quality Standards, Yield), and Dual Role (E.g., Animal Healthcare and Tillage). All factors have been brought together in the conceptual framework, which can be seen as a star

chart, guiding navigation through these waves of change amidst the storms of complexity and serving as a starting point for developing a future DSS.

6 FUTURE RESEARCH

The following limitations were identified during this study: Firstly, the conceptual framework is grounded on a synthesis of existing literature. The limited scope of only five databases may have excluded grey literature and studies indexed in other important regional or specialised databases. Future research should consider expanding the range of databases to improve the breadth of coverage.

Second, the interdisciplinary nature of agroecology and decision support system (DSS) design introduces a high degree of heterogeneity in study methods, contexts, and findings. This complexity is reflected in the large volume and diversity of the 190 identified relationships within the framework, which pose significant challenges for effective visualisation and generalisation.

Third, the conceptual framework remains unvalidated in real-world farming contexts. Future work should focus on empirical testing of the conceptual framework across diverse agro-ecological settings to assess its practical applicability, usability, and effectiveness. Additionally, co-design approaches that actively involve farmers and end-users in the development and refinement of the conceptual framework could enhance relevance and adoption.

In summary, this conceptual framework provides a foundational anchor for the emerging field of agro-ecological DSS design, derived exclusively from literature findings. The next critical step is to translate the conceptual framework into operational DSS models and validate them through participatory and applied research.

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