

Article

A Comprehensive Literature Review and Conceptual Framework for Developing Conservation Agriculture in Arid Regions: Analyzing the Interaction of Institutional, Environmental, and Technical Factors

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Abstract: Conservation agriculture is a promising approach to the sustainability of agricultural production systems, especially in arid and semi-arid countries and has gained growing attention. But the process of developing and establishing this system in nations like Iraq has several problems, the most important of which is the one-dimensional perspective of the elements affecting it. The objective of this study is to offer a complete literature review and to build a conceptual framework for a systematic analysis of the evolution of conservation agriculture, concentrating on the interplay of institutional, environmental and technological elements in dry areas. This is a complete narrative evaluation that uses qualitative content analysis approach by in-depth examination of reputable local and foreign sources from 2005 to 2025. During the assessment, three major subsystems were identified (institutional-political, environmental-ecological and technical-mechanical) as the core elements of the development of conservation agriculture. Each subsystem, either alone or in interrelationships and feedback loops, affects the success or failure of this system. The main challenges noted include poor institutional coordination, inadequate supporting policies, lack of suitable equipment and technology, lack of enough training and competent extension services, and environmental constraints due to water shortages and soil erosion. The analysis of interrelationships and feedback processes performed in the proposed conceptual framework indicates that for the successful development of mechanised conservation agriculture in arid regions, an integrated and systematic approach is needed that considers all influencing factors simultaneously and in their interaction. This framework may provide a foundation for policy formation, planning and evaluation of programs for the development of conservation agriculture in dry locations especially in Al-Qadisiyah Governorate in Iraq.

Keywords: Conservation agriculture, mechanization, systematic analysis, institutional factors, environmental factors, technical factors, arid regions.

Introduction

The agricultural industry in arid and semi-dry areas of the globe (Iraq included) has been confronting many challenges throughout the last decades. The decline of water resources, the worsening of soil quality, the increase of salinity, the soil erosion and the impact of climate change have been a severe problem for the sustainability of agricultural output and food security [1]. The decrease in the flow of the Tigris and Euphrates rivers and the growing demand for natural resources have made the need for contemporary and sustainable techniques in the management of agricultural systems more important than ever before [2]. In this regard, the conservation agriculture has become one of the most significant sustainable agricultural systems that has attracted the attention of scholars, policy-makers and international organisations. Conservation agriculture is a holistic management method with three fundamental principles: limited tillage, permanent organic cover on soil surface and crop rotation and companion planting [3]. This approach creates the ideal environment for improving soil fertility, organic matter and biodiversity by lessening disruption to the natural soil structure and its vital processes [4]. Conservation agriculture is a world-wide idea and it is practised on more than 160 million hectares of agricultural land throughout the world. [5]. International reports indicate that developing conservation agriculture can effectively contribute to reducing the degradation of natural resources, improving water use efficiency, and enhancing food security [6]. Despite its potential benefits, the development and establishment of conservation agriculture in developing countries, particularly in arid regions like Iraq, still faces numerous constraints. These constraints can be categorized into three main groups:

- a) **Institutional-political obstacles:** weak organizational coordination, limited supportive policies, lack of economic incentives, and an inefficient education and extension system [7].
- b) **Environmental constraints:** limited water resources, soil vulnerability to erosion, climatic pressures, high temperatures, low rainfall, and increased soil salinity [8].
- c) **Technical-mechanical constraints:** high initial costs, lack of technical services, unsuitability of agricultural machinery for small farms, and inadequate practical training [9].

A review of completed studies shows that most research addressed each of the institutional, environmental, or technical dimensions separately, while only a few focused on a simultaneous and systematic analysis of these factors [10]. While conservation agriculture development is a multidimensional and systematic process shaped by the continuous interaction of institutional, environmental, economic, and technical-mechanical subsystems [11], from a systems dynamics perspective, conservation agriculture is capable of creating a set of positive feedback loops that, in the long term, enhance the sustainability and resilience of agricultural production systems [12]. However, the success of this approach depends on the availability of the necessary technical, educational, and institutional resources [13]. Based on a literature review, and considering the existing research gap in the simultaneous and systematic analysis of the factors influencing the development of mechanized conservation agriculture in arid regions, this article was prepared with the following objectives:

- A comprehensive review of the literature related to the institutional, environmental, and technical-mechanical dimensions influencing the development of conservation agriculture.
- Identifying and clarifying the interrelationships and feedback mechanisms among the three aforementioned subsystems.
- To present a comprehensive conceptual framework for a systematic analysis of mechanized conservation agriculture development in arid regions.

The innovation of this article lies in its systematic methodology and simultaneous attention to institutional, environmental, and technical-mechanical dimensions, as well as its focus on the interrelationships and feedback loops among them [14].

Materials and Methods

This research is a comprehensive narrative review employing a qualitative content analysis methodology. Since the main objective of the article is to review the available literature, identify the

various dimensions of conservation agriculture, and present a conceptual framework based on the integration of previous studies' findings, this type of review can adequately address the research questions. This study is a narrative review, however the search, selection and analysis of sources followed a systematic method as nearly as feasible to the norms of systematic reviews. To identify related sources, a search was undertaken in well-known scientific databases, including Scopus, Web of Science, ScienceDirect, SpringerLink, Wiley Online Library, Google Scholar, SID, Noormags, and Civilica. The keywords for the search were: conservation agriculture, agricultural mechanisation, institutional factors, environmental factors, technical factors, systematic analysis, arid regions, sustainable development, in Persian and English: Conservation Agriculture, Mechanised Conservation Agriculture, No-till Farming, Sustainable Agriculture, Institutional Factors, Policy, Environmental Factors, Arid Regions, Systems Analysis, and Feedback Loops. International papers were searched throughout the period 2005–2025. The inclusion criteria of the study included: articles and research that directly addressed the topic of conservation agriculture and mechanisation; works that dealt with institutional, policy, environmental or technical-mechanical dimensions; studies conducted in arid and semi-arid regions; articles that employed reliable scientific methodologies; and sources published in scientific-research journals, reference books and reputable international reports. The exclusion criteria were: articles that only addressed the agricultural or production aspects of a specific crop, without considering the institutional and systemic dimensions of development; studies whose geographical scope did not match the objective of the article; and articles that did not have sufficient scientific quality. The sources were selected and analysed in five stages:

1. Search and elimination of replicates.
2. Screening by inclusion and exclusion criteria.
3. Qualitative assessment of the whole text of articles and identification of reputable sources.
4. Analysis of the inferential content (open, crucial and selective coding) to extract the ideas of the three subsystems, and to uncover interrelationships and feedback loops.
5. Provision of a complete conceptual framework for mechanised conservation agricultural development.

Results

General Review of Conservation Agriculture and its Three Dimensions

The literature review revealed that conservation agriculture is a current and sustainable method to manage agricultural systems and is based on three basic ideas, which are limited tillage, the retention of the vegetation cover and plant residues on soil surface and changing the cropping patterns. The goal is to reach a sustainable balance between agricultural production and the protection of precious resources [15], [16]. It increases the fertility, organic matter and biodiversity of soil. This is achieved by reducing the disturbance of the natural structure of soil and supporting its biological activity [17]. After the literature research, the development of mechanised conservation agriculture is made up of three primary subsystems with distinct core components:

- **Institutional-political sub-system:** institutional and organisational structures, supporting and incentive policies, the agricultural extension and education system, rules and regulations on land ownership and leasing and research and development initiatives. [18].
- **The environmental-ecological subsystem:** This includes water resources (quantity and quality), soil characteristics (texture, fertility, organic matter, erosion resistance), climatic conditions (temperature, rainfall, drought), soil biodiversity and microbial activity, and climate change and its impacts [19].
- **The technical-mechanical subsystem:** This includes specialized machinery and equipment (direct seeders, deep plows, row planting machines, residue management tools), farmers' technical knowledge and skills, technical services and support, mechanization infrastructure, and modern technologies [20].

In the technical-mechanical area, four main challenges were identified: high initial costs for purchasing specialized equipment [21] a lack of technical services and unavailability of maintenance

and spare parts [22], the unsuitability of machinery for small farms [23], and insufficient practical training and knowledge among farmers [24]. Approximately 70% of small farms in sub-Saharan Africa rely solely on manual labor, while access to mechanical power sources is limited to 10% [25]. The experience of leading countries like Brazil demonstrates that the successful development of a technical-mechanical subsystem requires the design of machinery suited to farmers' conditions [26]. In the environmental sphere, conservation agriculture, through mechanisms such as increasing soil water retention capacity, reducing runoff, enhancing rainwater infiltration and groundwater storage, enriching soil organic carbon, increasing microbial diversity, and improving nutrient cycling, can reverse soil degradation and enhance soil fertility [27]. Numerous studies have shown that conservation agriculture techniques can provide a range of benefits, including.

Studies in Arid Regions (Iraq and Iran)

A review of research conducted in arid regions shows that Iraq, despite benefiting from the Tigris and Euphrates rivers, has faced challenges in recent years related to climate change, including rising temperatures, declining rainfall, the construction of numerous dams in upstream countries, overexploitation of water resources, and poor management of these resources [28]. According to the findings of Abdul Wahid *et al.*, the period between 2003 and 2023 witnessed a significant increase in surface temperatures in Iraq. Furthermore, more severe droughts, increased soil salinity, and declining water quality have led to reduced productivity and efficiency in the agricultural sector. In the field of local studies in Iran, a study by Khamoshi and Taheri Hajivand showed that the "market and infrastructure" motive is the cornerstone and root of all other motives, and that the success of conservation agriculture development programs depends largely on the development of infrastructure and agricultural input markets [29]. Another study by Khamoshi and Taheri Hajivand also showed that structural-institutional and policy-program factors are the most significant obstacles to the development of this system [30]. A study by Latifi *et al.* showed that disseminating awareness at both the national and local levels, along with formulating appropriate supportive policies, has the greatest impact on promoting the acceptance of conservation agriculture [31]. As Latifi *et al.* demonstrated, using an interpretive structural modeling methodology, developing this system is a phased and systematic process that begins with a thorough analysis of the current situation and continues through capacity building, resource allocation, the establishment of appropriate institutional structures, and the formulation of effective policies [32].

Main Obstacles and Drivers for Development

Based on a comprehensive literature review, the main obstacles and drivers for developing mechanized conservation agriculture in arid regions are categorized in Table 1:

Table 1. Main obstacles and motives of developing mechanized conservation agriculture in arid regions

Category	Main motives	Main obstacles
Institutional-political	Reforming institutional structures, formulating supportive policies, developing educational and guidance programs, and establishing credit facilities.	Weak organizational coordination, limited supportive policies, lack of economic incentives, a weak education and guidance system, and contradictory policies.
Environmental	Integrated management of water and soil resources, preservation of vegetation cover, increase in soil organic matter, reduction of erosion, carbon fixation	Limited water resources, soil vulnerability to erosion, climatic pressures, rising temperatures, low rainfall, and increased soil salinity.
	Developing compatible local technologies, designing machines	High initial costs, lack of technical services, unsuitability of machinery

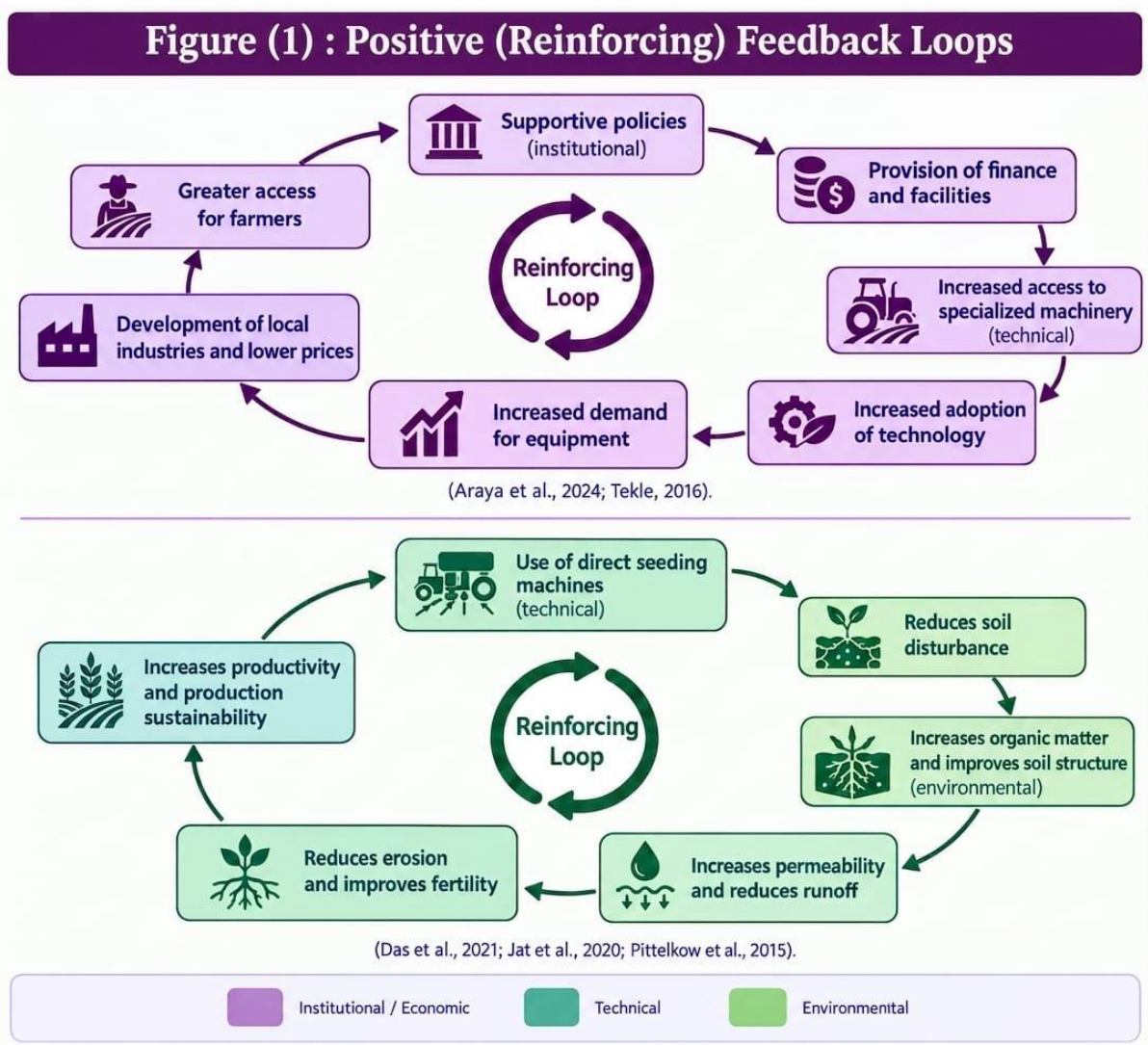
Category	Main motives	Main obstacles
Technical - Mechanical	suitable for small farms, developing a mechanization service network, and enhancing technical knowledge.	for small farms, poor practical training, lack of specialized equipment
Structural- market	Developing the input market and infrastructure, establishing an input distribution network, and strengthening the communication and information infrastructure.	Weak communication and information infrastructure, lack of inputs

Interrelationship Analysis and Feedback Loops

A literature review reveals complex interrelationships and multiple feedback loops among the three subsystems mentioned. Understanding these relationships is a prerequisite for designing effective policies and strategies for the development of sustainable conservation agriculture [33]. According to Meadows, a system is a set of interconnected elements that function in such an organized way that the whole is greater than the sum of its parts.

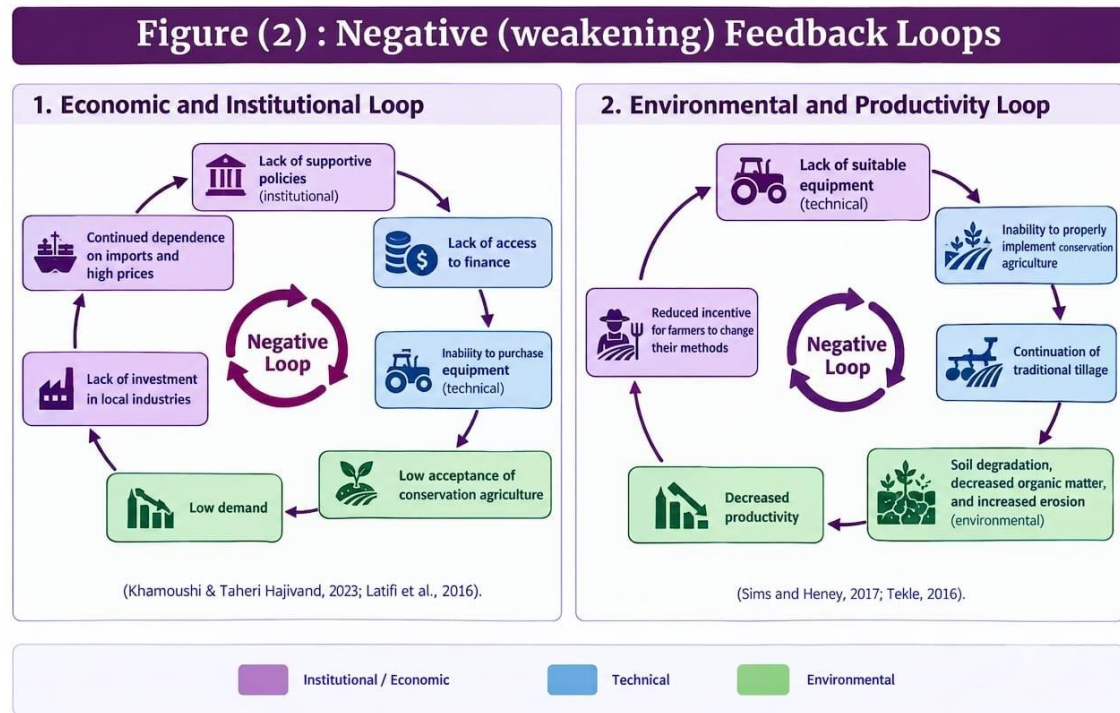
Positive (Reinforcing) Feedback Loops

Success in any one subsystem can reinforce the others for example in figure (1):



Negative (weakening) feedback loops

Weaknesses in any of the subsystems can generate negative feedback loops that hinder development for example in figure (2):



Balancing feedback loops

Two main types of balancing feedback loops have been identified as shown in figures (3) and (4):

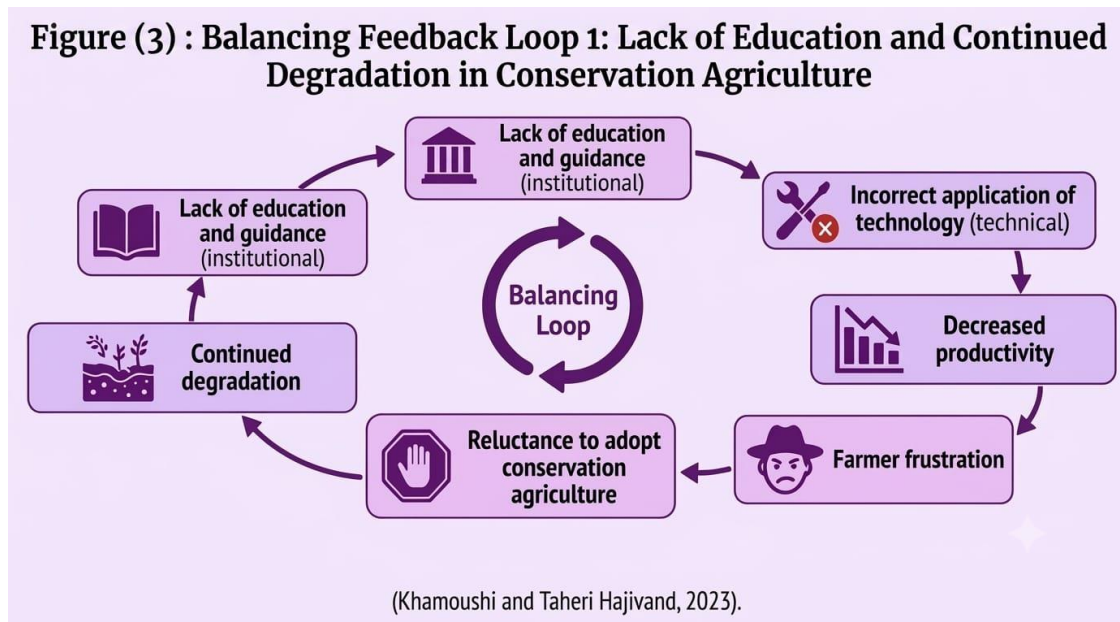
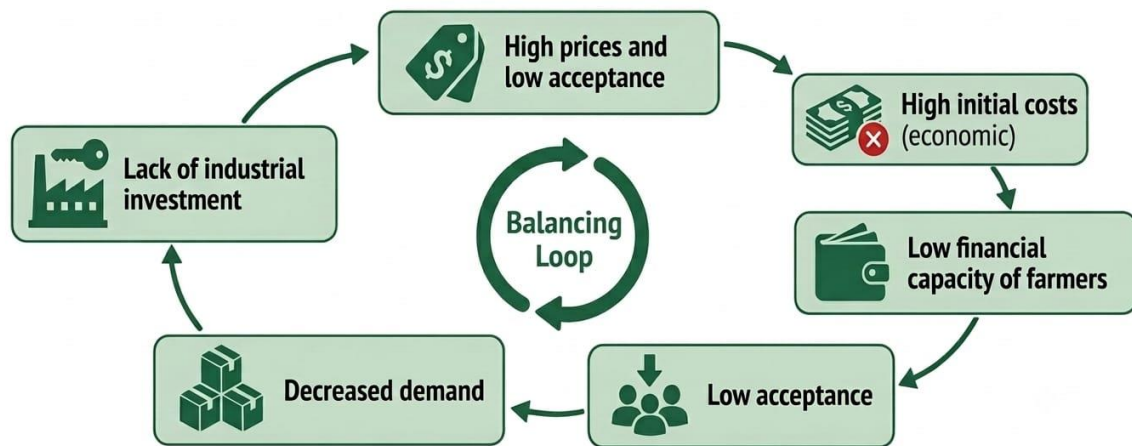


Figure (4) : Balancing Feedback Loop 2: Economic and Institutional Cost Barriers to Conservation Agriculture Acceptance



(Araya et al., 2024; Johansen et al., 2012).

The External Environment of the System

The development of conservation agriculture is also influenced by multiple external factors that affect the performance of the system as a whole [34] , These factors include: climate change (rising temperatures, decreasing rainfall, drought), market shifts (volatility in input and output prices), macroeconomic policies (inflation rate, exchange rate, tariffs), political and security conditions (political stability, international cooperation), and technological developments (remote sensing, Internet of Things, artificial intelligence).

The Conceptual Framework of the Research

Foundations for Forming the Framework

Based on a comprehensive literature review and the systems analysis conducted, it has been shown that the development of mechanized conservation agriculture in arid regions is a complex, multidimensional process influenced by the simultaneous interaction of three main subsystems: institutional-political, environmental-ecological, and technical-mechanical [35]. A review of previous studies revealed that most available research addressed these factors in a one-dimensional or two-dimensional manner, while few studies focused on a simultaneous and systematic analysis of all three dimensions and their interrelationships [36]. Hence, the proposed conceptual framework aims to address this research gap by systematic approach and investigation of the interrelationships of subsystems.

The Comprehensive Systems Model

The systems model with five major components is the conceptual framework for this research:

Part One: System inputs The key inputs needed for the establishment and growth of mechanised conservation agriculture are:

1. Institutional-Policy Inputs (Supportive legislation, finance facilities, education and extension activities .
2. Technical-Mechanical Inputs (specialised machinery, technical know how and expertise, support services).
3. Environmental-Natural Inputs (Water resources, Soil quality, Climatic condition, Plant residues.
4. Human-Financial Inputs (investment, involvement of farmer, skilled labour).

Part Two: System Processes • The collection of decisions, interactions, and actions that turn inputs into outputs.

1. Institutional-administrative processes (policies, inter-institutional cooperation, legislation, development of educational programs).
2. Technical-Practical Processes (low tillage in field preparation, direct planting, residue management). Training of farmers, construction of model farms, transfer of technical know-how etc throughout the course of education and extension.
3. Decision making and participation processes (farmer adoption of technology, mechanisation service networks engagement)

Part Three: Systemic outputs and outcomes - The outcomes of the system installation in four dimensions are:

1. Productive outcomes (Higher yields, Less volatility in yield, Sustainable production).
2. Environmental outcomes (better soil quality, more organic matter and carbon sequestration, reduced erosion, better water usage efficiency).
3. economic outcomes (reduction of cost of production, growth of net income, growth of factor efficiency).
4. Socio-institutional results (increase of farmers' awareness and knowledge, development of local institutions, improvement of rural people's lives, increase of food security).

Part four: Learning Cycles and Feedback Loops There are three categories of these:

1. Positive (Reinforcing) Feedback: Successful productive and economic outputs increase confidence and motivation among farmers, resulting in more demand for training and equipment, better inputs and ultimately, higher performance [37].
2. Corrective Feedback: When faults are found in outputs, it leads to root causes identification, process or input modification and system performance improvement [38].
3. Policy Feedback: Success and problems of implementation provide feedback to policy makers and lead to revisions and improvements of supporting policies and enhanced institutional inputs.

Part Five: External Environment of the System- These are aspects that are external to the system that impact the overall working of the system.

1. Climate change (greater heat, less rain, drought).
2. Market developments (volatility of prices of inputs and products).
3. Macro economic policy (inflation, tariffs, currency rate)
4. Political and security situation (stability of political climate, international cooperation).
5. Improvement of technology (better mechanisation and management of agriculture).

Main Components of the Framework

The suggested conceptual framework shows that five primary components need to be dealt with simultaneously to successfully establish mechanised conservation agriculture in dry regions:

Component 1: Institutional Coordination and Integrated Policies Coordination between relevant institutions and creation of supporting and integrated policies are among the most critical requirements for development. Applied studies in Iran have shown that structural and institutional factors are the most significant obstacles to the development of conservation agriculture.

Component 2: Access to Appropriate Technology and Equipment — Implementation of the concepts of this system is likely to be difficult without access to specialised apparatus and equipment. Developing locally produced equipment adapted to local conditions is a key solution in this area. The market and infrastructure drivers are fundamental to development and play a pivotal role in ensuring access to appropriate equipment.

Component 3: Sustainable Management of Natural Resources – Given the arid conditions of the region, conservation agriculture must be accompanied by a comprehensive approach to water and soil

management. Increasing soil organic matter, reducing erosion, and improving water use efficiency are among the most important objectives of this component.

Component 4: Farmer Empowerment and Participation – Conservation agriculture cannot succeed without the active participation and empowerment of farmers through education and extension services. Studies have shown that disseminating knowledge at the national and local levels has the greatest impact on promoting the acceptance of conservation agriculture.

Component 5: Adaptation to Local Conditions and Climate Change – Conservation agriculture development solutions must be adapted to local conditions (climatic, educational, economic, and social) and resilient to climate change. Adapting to climate change is an indispensable necessity to ensure the sustainability of agriculture in arid regions.

Discussion

The literature review revealed that the development of mechanized conservation agriculture in arid regions is a complex, multidimensional phenomenon influenced by the simultaneous interaction of three subsystems: institutional-political, environmental-ecological, and technical-mechanical. This finding is consistent with previous studies, including those by Giller *et al.*, Kassam *et al.*, and Lal, all of which emphasized the systemic nature of conservation agriculture. The unique aspect of this research is that a framework is provided to investigate the interactions and feedbacks of all three subsystems in dry circumstances, and to compare the system dynamics to linear models. Research in Iraq and Iran indicates that conservation agricultural programs are one-dimensional. Most efforts were geared on addressing technological issues and equipment distribution, leaving institutional and regulatory framework for acceptance and sustainability of technology unattended. This might explain the low attractiveness and sustainability of dry land conservation agriculture.

The review demonstrated that the challenges to conservation agriculture in the arid areas are the institutional and political constraints. Conservation agriculture will have difficulty thriving without sound institutional structures, ongoing supporting policies and a robust education and extension system, even if the requisite technology and suitable environmental conditions are available. The key hurdles to conservation agriculture dissemination in Iraq are lack of coordination of agencies, policies and supporting economic incentives, and poor teaching and extension methodologies.

Technical-mechanical areas need suitable technology and equipment. The results show that high initial cost, lack of professional support, insufficient machinery and lack of practical training are the constraints for smallholder and desert area farmers' access and proper use of such equipment. The design and development of small farm equipment and mechanisation service network in Brazil and others has led in engagement and technical localisation.

The research identified interrelations and feedbacks between the three subsystems. The conceptual framework suggests that these links might be positive or negative feedback loops. Good starting points initiate a self-reinforcing development path in favour of the conservation agricultural system. That's the whole point of positive feedback loops. Negative loops are important because they highlight how a small failure in one part of the system can lead to the failure of the entire system.

This model differs from previous models in four important ways:

1. Three dimensional analysis of simultaneity (institutional, environment and technological).
2. Study of positive and negative feedback.
3. External environment (climate, market, macro-economic policy) mirrored
4. DRY ZONE APPLICATION (Specially formulated for dry environments & problems).

Conclusion

This study was carried out to provide a complete literature review and a conceptual framework for a holistic analysis of the evolution of mechanised conservation agriculture with an emphasis on the interplay of institutional, environmental and technological elements in dry areas. The primary

conclusions of the research based on comprehensive analysis of relevant local and foreign sources may be summarised under five main areas:

The first axis: Relevance and Status of Conservation Agriculture Conservation agriculture is a contemporary and sustainable method to management of agricultural systems. It is based on three basic principles: minimum tillage, maintenance of vegetation cover and plant residues on the soil surface, and diversification of cropping patterns. It is a major contributor to soil and water resource conservation, enhanced production efficiency and increased resilience of agricultural systems to environmental stressors.

The second axis: The main subsystems and their interdependence The development of mechanised conservation agriculture in arid regions is a multidimensional and complex phenomenon, and its success depends on the effective and simultaneous interaction of three main subsystems: the institutional-political (the fundamental and essential role), the environmental-ecological (the necessity of adopting conservation approaches in arid regions), and the technical-mechanical (the correct application of conservation agriculture principles).

Third Axis: Key Obstacles and Challenges The main obstacles for developing conservation agriculture in arid areas are: weak institutional coordination and lack of effective regulations; lack of supportive policies and lack of economic incentives; lack of appropriate equipment and technologies, especially for small farms; lack of effective education and extension services and low awareness of farmers; lack of financial resources and weak investment; problems of land ownership and leasing; and environmental pressures such as water scarcity, soil erosion and climate change.

Fourth Axis: Feedback Cycles and System Dynamics Positive (reinforcing) feedback cycles may lead to a self-reinforcing growth path, negative (weakening) feedback cycles can lead to the disruption of the whole system. The “market and infrastructure” driver has been highlighted as a major growth driver, and structural-institutional issues as the most important barriers.

fifth Axis: Integrated Approach and Conceptual Framework – The conceptual framework presented in this study demonstrates that the successful development of mechanised conservation agriculture in arid regions needs an integrated approach considering simultaneously and in mutual interaction all the factors that influence it, by systematically taking into account five key components (inputs, processes, outputs, feedback and external environment). This framework may be utilised as an analytical tool for policy formulation, planning and evaluation of conservation agricultural development projects in dry locations like Al-Qadisiyah Governorate in Iraq.

Policy and Implementation Recommendations

The results of this research have led to five main suggestions for policymakers, planners and implementers in the dry agricultural sector:

Recommendation 1: Reforming Institutional Structures and Establishing Inter-Institutional Coordination – Creating joint coordination councils between the Ministry of Agriculture, the Ministry of Water Resources, the Environment Authority, and other relevant institutions for the purpose of developing and implementing integrated programs for the development of conservation agriculture. In Iraq, for example, the creation of a Supreme Council for Conservation Agriculture with members of all relevant agencies may be a beneficial move. Laws of land ownership and leases should also be modified to permit farmers’ investments in soil fertility improvement.

Proposal 2: Formulate long-term support policies and develop local technologies – Design support packages that include direct subsidies, low-interest credit facilities, tax exemptions, and crop insurance to cover the transition period (the first 3 to 5 years). Support local producers to design and manufacture conservation agricultural equipment suitable for local conditions and small farms, and establish and strengthen a network of conservation agricultural mechanization service providers (rental and customized services).

Proposal 3: Strengthen the education and extension system and empower farmers – Invest in educational and extension programs for farmers, experts, and policymakers; establish model and

demonstration farms; organize specialized courses and practical training workshops; and utilize modern extension tools such as social media and local messaging applications. Proposed Indicator: Increase educational coverage to at least 50% of farmers in the targeted areas by 2028.

Proposal 4: Integrated Water and Soil Resources Management and Climate Change Adaptation – Design and implement integrated water and soil resources management programs with a climate-responsive approach; improve water use by increasing permeability and reducing evaporation; preserve vegetation cover and residues to reduce erosion; and provide special support to farmers in the initial years of implementation to compensate for potential declines in productivity.

Proposal 5: Farmer Participation Planning and Establishment of a Monitoring and Evaluation System – Design and implement development programs with the active participation of farmers and local communities, taking into account their needs, priorities, and constraints. Establish a continuous monitoring and evaluation system to track program progress, identify challenges, and adjust policies in a timely manner using key performance indicators such as cultivated area, number of participating farmers, soil organic matter increase, and improved water use efficiency.

In conclusion, Mechanised conservation agriculture in arid places is needed to meet the rising environmental issues of water shortages, soil erosion and climate change. However, this growth demands a systematic, integrated and participatory strategy where key players including policy makers, academics, promoters and farmers themselves connect and comprehend each other's linkages and feedback loops to pave the path for progress. The conceptual framework suggested in this research might be a roadmap for policy formation, planning and assessment of conservation agricultural development projects in dry locations including Al-Qadisiyah Governorate in Iraq however it has to be further validated and adapted locally.

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