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Farming systems research in Nepal: Concepts, design, and methodology for enhancing agricultural productivity and sustainability

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Abstract. Farming Systems Research (FSR) plays a crucial role in enhancing agricultural productivity, sustainability, and livelihoods in Nepal. This article provides a comprehensive review of FSR in Nepal, focusing on concepts, design, and methodology for optimizing farming systems. Integrated farming systems have emerged as a key strategy for small and marginal farmers to improve livelihood security and meet household needs for nutrition and income. By integrating various components such as crops, livestock, and agroforestry, farmers can enhance resource use efficiency, diversify income sources, and improve resilience to climate change impacts. FSR in Nepal combines scientific research, community engagement, and local knowledge to enhance agricultural sustainability and improve livelihoods for small-scale farmers. Nepal Agriculture Research Council (NARC) plays a crucial role in developing a national research agenda and allocating resources to address the diverse technological needs of farmers. By integrating diverse perspectives, utilizing innovative technologies, and engaging stakeholders, FSR addresses agricultural system complexities and contributes to food security, environmental sustainability, and rural development.

Keywords: *Bio-intensive farming system, climate change resilience, integrated farming system, livelihood security, and resource use efficiency*

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1. Introduction

Farming systems research (FSR) and development is the strategy that can address the need to raise the standard of living for small-scale farmers and the demand for increasing food production requirements in developing countries (Shaner et al., 1982). The integrated farming process, also known as integrated agriculture, is a system that combines the production of crops, livestock, and other organisms in a mutually beneficial way (Pokharel et al., 2018). Such an interactions between different agricultural components while reducing negative environmental impacts.

Designing farming systems in relevant ways is crucial for providing farmers with a comprehensive grasp of the conditions in which they work (Norman et al., 1995). The system is, in fact, complicated, and several factors influence the farming systems. The farmer or farming family is the operator of the farming system, and it depends on their livelihood, including their economic, social, and cultural well-being. It is required to take into consideration several determinants of farming systems (Table 1) (Maxwell, 1986).

There is a dire need to provide secure and resilient food systems, enhance economic opportunities for grass-roots communities, and create a sustainable environment in the world. The United Nations Organization has set Sustainable Development Goals (SDGs) for 2030 with a focus on eradicating poverty and hunger in all their forms (United Nations Global Compact, 2018).

The farming system is an intricate and interconnected network consisting of soil, plants, animals, tools, energy, labor, capital, and other resources. Farming families partially control the system, while political, economic, institutional, and social factors at various levels influence it (Behera & France, 2016; 2023). The industrial revolution necessitated changes in agricultural research and policy, leading to the need for more specialized agriculture. The increased specialization at the field, farm, and landscape levels raised environmental hazards and made biodiversity and ecosystem functions vulnerable to climate change.

Table 1. Determinants of farming systems

Natural		**Socio-economics**	
Physical	Biological	Exogenous	Endogenous
Climate Topography Soils Physical infrastructure	Crop alternatives Livestock alternatives Weeds Pests Diseases	Population Tenure Off-farm opportunities Social infrastructure Credit Markets Prices Technology Input supply Extension Saving opportunities	Family consumption Health and nutrition status Education Food preferences Risk aversion Attitudes/ goals

Methodologies in FSR are not homogenous, and their descriptive terminology also varies in the existing literature (Özkan, 1997). The FSR methodology consists of three interconnected, interdisciplinary activity areas: base-data analyses, research station studies, and on-farm studies. Plucknett et al. (1986) discuss the activity areas as follows:

Based data analysis (BDA) refers to the process of gathering, organizing, and examining data related to the various aspects that define the environment and farming practices in a specific location.

Research station studies (RSS) is a targeted research program that aims to produce components to enhance current systems or create new systems.

On-farm studies (OFS) include examining current systems, experimenting with technological adaptation, and evaluating the effects of new technology.

2. Farming systems research concepts

There are different farming systems, which include various approaches and methodologies focused on understanding and improving agricultural systems (Drinkwater et al., 2016). These are the concepts of a range of farming practices and research strategies.

1. Conservation agriculture systems: This includes resource-conserving methods like minimal tillage, cover crops, and crop rotations to enhance sustainability.

2. Reduced- or low-input farming systems: This system minimizes off-farm resources, tightens nutrient and energy cycles, and promotes internal resources such as biological pest controls and green manures.

3. Integrated farming systems: A combination of conventional and organic production methods for ecological balance and mechanical pest control practices.

4. Alternative livestock production systems: This management system emphasizes lower-confinement housing and intensive rotational grazing practices for sustainable livestock farming.

5. Organic agriculture: Ecological production management practices, avoiding synthetic fertilizers, and promoting biodiversity conservation.

6. Ecologically based farming systems: Environmental pest management focuses on nutrient cycling and renewable resource utilization to improve soil health and water quality.

7. Food systems: The use of a commodity chain approach for analysis linking food production to consumption.

These concepts highlight the diversity of approaches within farming systems research, each with its own distinctive focus on sustainability, resource conservation, and holistic agricultural practices.

3. Farming system research designs

Farming systems research includes a variety of methodologies and approaches aimed at understanding and improving agricultural systems. Some strategic designs, such as Marbleseed (2024), include:

1. Conservation agriculture systems: Sustainable practices like minimal tillage, cover crops, and crop rotations are utilized to enhance soil health and sustainability.

2. Integrated farming systems: The combination of different agricultural practices to promote ecological balance and sustainable production.

3. Agroforestry and silvopasture: The integration of trees and shrubs into farming systems to provide environmental, economic, and social benefits, such as carbon sequestration and increased water retention in soils.

4. Alternative livestock/Grass-based systems: The practice of utilizing perennial pastures and intensive rotational grazing practices for sustainable livestock management.

5. Urban farming: Producing food in urban areas, contributing to local food systems and sustainability.

These designs highlight the diverse approaches within farming systems research, each tailored to specific goals and contexts to enhance agricultural sustainability and productivity. The whole farm system design process involves setting goals, assessing water management, infrastructure needs, and equipment considerations to design a diverse, healthy, and sustainable farm, which requires many years of planning, experimenting, learning, and continually reinventing.

4. Methodologies of farm design

There are different methods and techniques targeted at understanding and improving agricultural systems. Some key methodologies include:

1. Multidisciplinary whole-farm approach: Involves integrating various disciplines to analyze and address the complexities of farming systems effectively (Behera & France, 2023).

2. Systems analysis: Utilizes a holistic approach to evaluate scenarios and solve problems within farming systems, considering the interconnections between different components (Norman et al., 1995).

3. Reductionist techniques: Focus on specific objects within the system, employing methods that provide clear and specific answers to well-defined questions, especially suited for non-human behavior aspects of the system (Norman et al., 1995).

4. Incorporation of different perspectives: Emphasizes the importance of integrating diverse viewpoints to ensure both rigor and relevance in farming systems research (Norman et al., 1995).

5. Geographic information systems (GIS): Utilized as a tool to integrate large amounts of data into a single framework for better analysis and decision-making in agricultural systems (Norman et al., 1995).

6. Community development and policy reform programs: Employ sophisticated techniques to promote decentralized planning, grassroots participation, and empowerment in designing solutions for farming systems (Norman et al., 1995).

7. On-farm evaluation: Involves testing new technologies on farms to assess their practicality and effectiveness in real-world agricultural settings (Norman et al., 1995).

8. Farmer and expert involvement: Emphasizes the importance of engaging farmers and experts in the design, testing, and dissemination of solutions to ensure relevance and effectiveness (Norman et al., 1995).

These methodologies highlight the diverse approaches and strategies used in designing and implementing farming systems research to address the complexities and challenges faced by agricultural systems.

5. An overview of research on farming systems in Nepal

The Nepal Agricultural Research Council (NARC) has been authorized by the Government of Nepal (GON) as the main organization responsible for conducting agricultural research in order to achieve the national goals of enhancing agricultural production and productivity. The national agricultural research system, formerly under the Department of Agriculture (DOA) and later under the National Agricultural Research and Service Center (NARSC), is currently under the authority of the National

Agricultural Research Council (NARC) following its independence in 1991. The center's primary goal is to develop relevant agricultural technologies for farmers, with the Department of Agriculture (DOA) and the Department of Livestock (DLS) in charge of distribution.

The National Agricultural Research Center (NARC) is responsible for overseeing the Field Station Representatives (FSRs) at its Regional and Area-Specific Agricultural Research Stations (R/ARSs). The responsibility for national planning and coordination of FSR at NARC is entrusted to the Outreach Research Division (ORD). Regional Agricultural Research Stations (RARSs) carry out Farming Systems Research (FSR) by addressing the most important issues specific to the region. The purpose of establishing Agricultural Research Stations (ARSs) is to carry out Farming Systems Research (FSR) that caters to the unique requirements of clients in the designated area (Sharma et al., 2021). Each research and ARS facility under the National Agricultural Research Center (NARC) has a multidisciplinary outreach research section. Both R and ARS are responsible for the agro-ecological domain, where on-farm research sites are established to conduct research focused on the specific issues and potentials of each area. Thus, an on-farm or outreach research site serves as the focal point for field activities in the context of Farming Systems Research (FSR) conducted by each Research and Agricultural Research Service (R/ARS). The diagram below (Figure 1) illustrates the hierarchical structure of the agricultural research systems in Nepal.

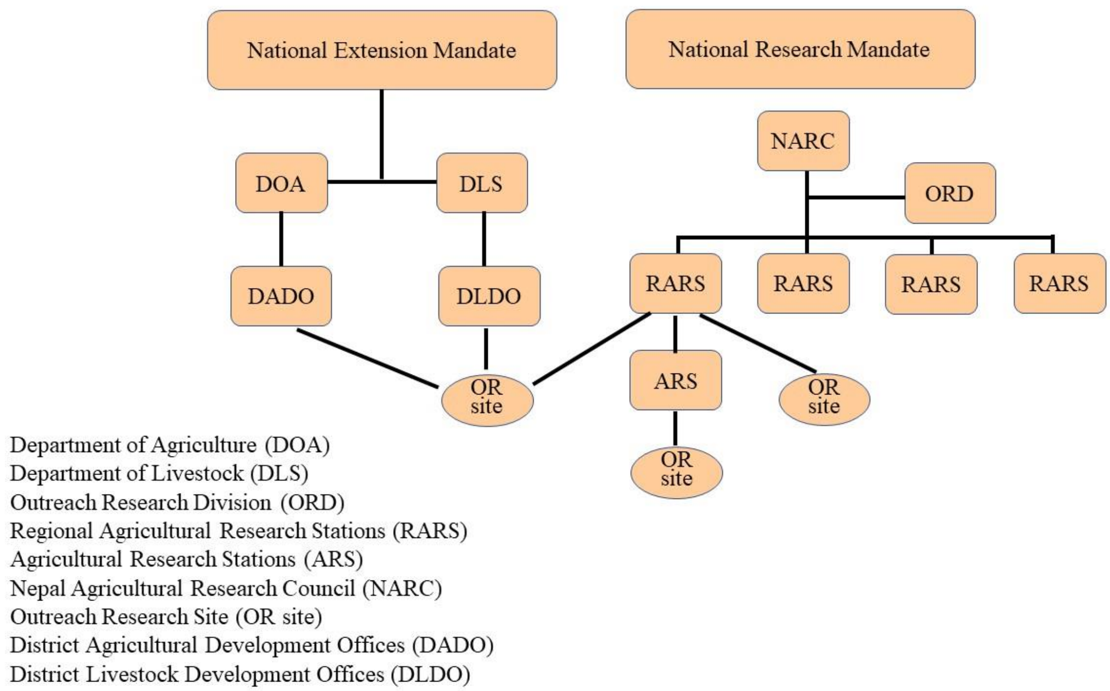

Figure 1. Organizational chart for agricultural research, extension, and outreach FSR activities in Nepal (Gauchan & Yokoyama, 1999)

Overall, farming systems research in Nepal is a dynamic field that aims to enhance agricultural sustainability, productivity, and livelihoods by integrating various disciplines, methodologies, and local practices to address the country's diverse agricultural landscape.

Nepal has implemented a modified approach for FSR to align with the country's specific local agro-ecological, socioeconomic, and institutional conditions. The process is centered on the farmers, and their input is incorporated at every stage, leading to the generation of technology that is driven by need. This approach involves a continual exchange between farmers, researchers, and extension services, which facilitates improved connections and the flow of information in both directions (Nepali et al., 2022). Furthermore, it uses agroecological methods to divide geographical regions into uniform zones for the purpose of conducting Farming Systems Research (FSR). The wide range of climate, landforms, and farming techniques in Nepal makes it unsuitable to devise a universal planning formula for agricultural growth (Pathak, 2021). The establishment of a distinct agro-ecological zone in each location facilitates the recognition of agricultural potentials and enables optimal utilization (Baral et al., 2021). In the past, several studies have been conducted to establish and demarcate agro-climatic and agro-ecological zones for diverse locations, including Tarai and Hills, as well as districts in Nepal. Currently, in Nepal, the agro-eco-zoning method primarily relies on agro-ecological factors such as climate, altitude, land types, hydrology, soils, vegetation, and others (Luintel et al., 2021). Commonly used factors for FSR and analysis include land types, hydrology, and soil-based agro-eco-zones in the Terai region, as well as climatic and altitude-based factors in the hills and mountains. The FSR technique implemented in Nepal, as outlined by Nepali et al. (2022), consists of the following steps (Figure 2):

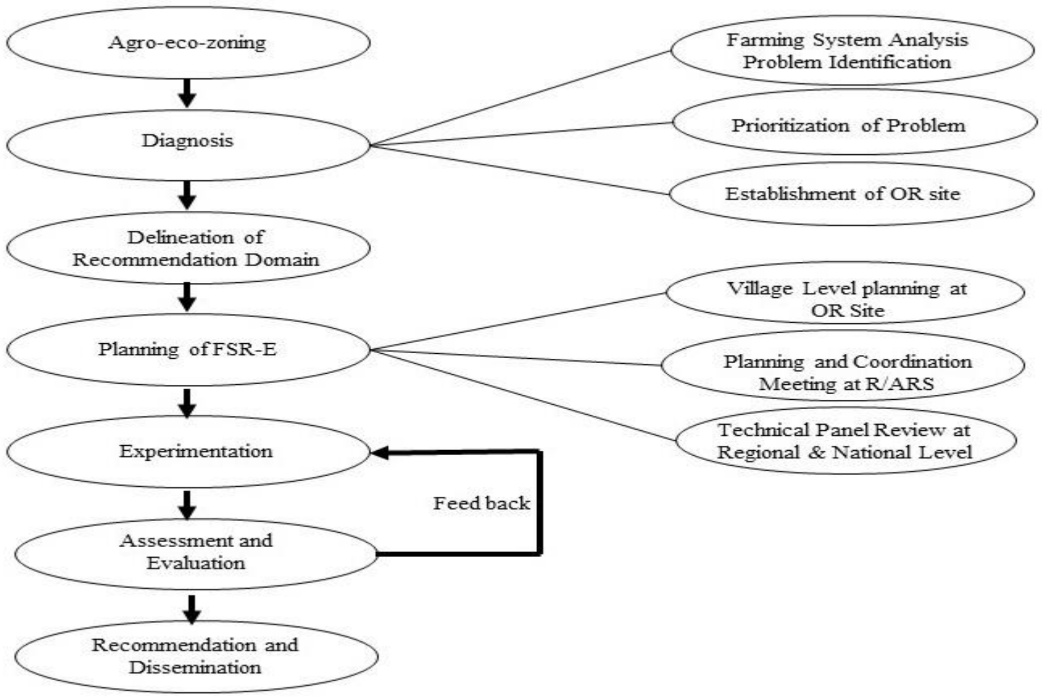

Figure 2. Steps in farming systems research approach followed in Nepal (Nepali et al., 2022)

In Nepal, farming systems research is a comprehensive field that covers multiple aspects of the country's agriculture. The research conducted in Nepal is centered on comprehending and enhancing farming techniques in order to augment agricultural sustainability and productivity. In Nepal, crucial components of farming systems study encompass the following:

1. Agroecological zonation: Identifying different agroecological zones in Nepal to tailor farming systems research to specific environmental conditions (Gauchan & Yokoyama, 1999).

2. The evolution of farming systems research in Nepal: Highlighting the distinctive qualities of Nepalese agriculture and the country's progress in this field (Gauchan & Yokoyama, 1999).

3. Farming systems complexity: Farming in Nepal's Middle Hills has evolved into a complex system, with farmers relying on crops, livestock, and forests for their livelihood, demonstrating the diverse nature of agricultural practices in the region (Nepali et al., 2022).

4. Current status and future agenda: Assessing the current status of farming systems research in Nepal and outlining future agendas to address challenges and improve agricultural systems in the country (Gauchan & Yokoyama, 1999).

5. Case studies: Detailed case studies, such as the Newar people's land use in Kathmandu District, provide insights into Nepal's specific farming practices and land management strategies (Kurokawa, 2000).

6. Major types of farming system

A farming system is a group of individual farm systems that share similar characteristics, such as resource bases, enterprise patterns, household livelihoods, and restrictions. These farming systems can benefit from similar development strategies and interventions. This system has the capacity to include a small number of households or a large number of homes, ranging from a few dozen to millions. According to Rajbhandari (2016), the main factors considered in farming systems are as follows:

1. The local area possesses a range of natural resources, such as water, land, forests, and pastures. Climate, including factors like height and temperature, plays a crucial role. Geographical terrain, as well as farm size, ownership, and organization, are all significant factors to consider.

2. The primary focus is on the prevailing agricultural practices and household livelihoods, encompassing various aspects such as cultivation, animal husbandry, forestry, aquaculture, hunting and gathering, processing, and off-farm activities. This analysis takes into consideration the key technologies employed, including the use of chemical or organic inputs, cultivation techniques, types of crop varieties or livestock breeds, irrigation methods, and sources of energy. These factors collectively determine the level of production intensity and the integration of different activities such as crop cultivation, animal rearing, agro-forestry, fisheries, and other related endeavors.

The key types of agricultural systems important in the context of Nepal are subsistence farming, conventional farming, alternative farming, organic farming, agroecological farming, and bio-intensive farming (Rajbhandari, 2016).

6.1. Subsistence farming system

Subsistence farming is an agricultural practice in which farmers cultivate crops and rear livestock primarily for personal consumption rather than for commercial purposes. Small-scale farmers in developing countries frequently engage in this form of agriculture. This farming system is based on traditional knowledge and technologies, using resources that are locally available, such as different types of seeds, organic fertilizers, plants with natural pest or worm control properties, animal power, and manual tools. Its purpose is to meet the nutritional and livelihood needs of the household. This approach frequently incorporates the following practices:

- Enhancing soil organic matter through organic recycling
- Implementing zero tillage as a suitable tillage method
- Incorporating organic manure, such as farmyard manure or compost
- Incorporating cover crops, green manure crops, or fallow periods into crop rotations
- Implementing agro-forestry practices to reduce soil erosion

6.2. Conventional farming system

Conventional farming is an agricultural practice that relies extensively on the application of synthetic fertilizers, pesticides, and other chemical substances to achieve maximum crop productivity. The mainstream conventional farming system (CFS), also known as the petrochemical-based farming system, was established in Nepal approximately 50 years ago. This system was initiated in 1965/66 with the introduction of chemical fertilizers from India and the former USSR (Union of Soviet Socialist Republics) as part of an aid project. After the 1970s, the chemical farming system caused the self-sufficient Nepalese organic farming system to become dependent on imported chemical fertilizers and foreign crop varieties. Concurrently with the advent of chemical fertilizers, there was also a promotion of the introduction and distribution of high-yielding types of food crops such as paddy rice, maize, and wheat. The extensive dependence on synthetic chemical fertilizers and pesticides in agriculture is causing significant repercussions on both public health and the environment.

6.3. Alternative farming system

Alternative farming systems differ from conventional farming in their use of inputs, crop varieties, and management practices. These systems often emphasize sustainability, biodiversity, and local food systems. The alternative farming system aims to achieve maximum crop yields while using the least amount of land, making optimal use of organic inputs, and resorting to safe chemical inputs only in emergencies. This approach also focuses on improving soil health and protecting livestock, fisheries, agro-forestry, and pastures as sub-systems. The objective of the approach is to achieve long-term sustainability within a closed system. It has demonstrated efficacy on both small-scale and commercial farms. Implementing carefully tailored alternative cropping systems, together with suitable cultivation techniques, has the potential to significantly reduce the frequency and severity of diseases, insect pests, and weeds. Moreover, alternative agriculture encompasses several practices, such as biodynamic agriculture, organic farming, permaculture, biointensive farming, and natural farming. Additionally, these practices help to preserve soil resources, improve soil health, and protect the environment by reducing nitrate leaching. They also contribute to the development of nutrient and water-use efficiencies (Gangwar & Prasad, 2005).

6.3.1. Organic farming system

Organic agriculture is a sustainable farming approach that focuses on biodiversity, biological cycles, and soil activity using natural inputs like minerals and plant-derived products. It rejects synthetic fertilizers and pesticides, aiming to optimize land-animal-plant interactions, preserve natural nutrient and energy flows, and enhance biodiversity. Organic farmers prioritize human health and contribute to sustainable agriculture. The practice has a long history in Asia, with methods like intercropping, crop rotation, mulching, and livestock integration. Organic agriculture is unique in its use of natural, non-synthetic inputs, soil structure, and fertility. The production system's design incorporates a crop rotation plan, which embodies the fundamental principles that distinguish organic agriculture.

1. Increase the entire system's overall biological diversity.
2. Enhance soil microbial activity.
3. Sustain soil fertility over an extended period.
4. Reutilize plant and animal waste to replenish soil nutrients, thereby reducing reliance on finite resources.
5. At the local level, rely on sustainable resources in agriculturally structured systems.
6. Encourage the sustainable utilization of land, water, and air while reducing all types of pollution arising from agricultural activities.
7. Advocate for meticulous processing techniques for agricultural products to retain the organic integrity and essential characteristics of the product across all phases.
8. Establish oneself on an existing farm by going through a conversion process.

6.3.2. Agro ecological farming system

Agro-ecological farming systems (AEFS) are methods of organic farming that encourage the interactions between different parts of an agro-ecosystem to work together in a way that does n't require synthetic chemical fertilizers. Organic sustainable agriculture, organic bio-intensive farming, permaculture, and organic eco-technical farming are among the various forms in which they find application. Agroecological management ensures optimal nutrient recycling, organic matter turnover, closed energy flows, water and soil conservation, and balanced pest and natural enemy populations. Aligning modern agricultural systems with ecological principles is challenging, especially in the current agricultural development context.

6.3.3. Bio-intensive farming system

The bio-intensive farming system (BIFS) is a mixed farming approach that involves intensive farmer engagement, organic recycling, integrated plant nutrient management, and integrated organic pest management. To maintain soil fertility, it uses biopesticides, botanical pesticides, and biota. The system includes improved farmyard manure, compost, green manure, and bio-fertilizers. BIFS reduces farmers' dependency on chemical inputs, promoting high crop productivity and soil fertility. It differs from the green revolution in terms of socio-economic criteria, crop selection, research requirements, and local participation. The principles of the BIF system include the following (Rajbhandari, 2002):

1. Using scientific crop rotation techniques;
2. Using mixed cropping and farming systems;
3. Making the most of organic recycling;
4. Using participatory and sustainable ways to manage natural resources;
5. Using participatory research and extension methods;
6. Making sure that farm households can run their own businesses even when the economy or technology changes outside their control.

7. Conclusions

Farming systems worldwide face challenges such as supporting livelihoods, conserving biodiversity, offsetting emissions, and adapting to climate change. Traditional farming systems involve multiple crops and enterprises on a single farm, including land, labor, capital, and management. Farming Systems Research (FSR) is a multidisciplinary approach that can help smallholders and marginal farmers solve problems. FSR combines reduction of erosion, increased crop productivity, soil preservation, nutrient recycling, responsible land use, and environmental strengthening. Over time, FSR methodologies have evolved to meet farmers' priorities and resource availability. Scientists can apply FSR in individual or integrated farming systems, as well as in managing polycultural systems. Challenges include loss of diversity, soil degradation, greenhouse gas emissions, water quality, and sustainable bioenergy utilization to adapt to climate change. Research, extension, and development approaches to farming systems can effectively establish sustainable agriculture and meet sustainable development goals.

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