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Technology Transfer in Dryland Ecosystems: Issues and Strategies

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ABSTRACT: Dryland agriculture in India, covering about 51% of cultivated land, faces challenges such as low rainfall, high temperatures, and soil degradation, which hinder productivity. Farmers in these regions deal with environmental fluctuations, wind erosion, poor soil fertility, low yields, and reliance on traditional technologies. As a result, rainfed farmers are particularly vulnerable to price risks due to their dependence on markets for inputs and outputs, unlike subsistence farmers. Technology transfer in drylands addresses challenges like low rainfall, high temperatures, and water scarcity through innovations such as drought-resistant crops, efficient irrigation, soil conservation, and water management techniques like rainwater harvesting. Sustainable livestock practices and climate-resilient tools, including weather forecasting and climate-smart agriculture, enhance community resilience. Transfer of technology through Participatory extension approaches, ICAR-CRIDA Farmer First programme and Model village initiatives, digital extension approaches, gender sensitive technology transfer and livestock-based technology transfer are a few of the strategies adopted in drylands for enhancing the technology adoption and are discussed in this paper.

Keywords: Agricultural productivity, dryland agriculture, drought, participatory extension approach, technology transfer

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Introduction

Dryland agriculture in India presents unique challenges due to the arid and semi-arid conditions, which account for about 51% of India's cultivated area. These regions experience low rainfall, high temperatures, and significant soil degradation, which constraints productivity. Out of total cultivated area of around 140.30 million hectares in India, only 60.86 million ha. is irrigated and the remaining 79.44 million ha. is rainfed. Rainfed crops account for 48 percent area under food crops and 68 percent of the area under non-food crops. Rainfed areas are generally endowed with fragile resource base and low productivity. Droughts and famines are the general features of dryland agriculture. The annual rainfall in the semi-arid and arid regions ranges between less than 350 mm to 800 mm, and has a high coefficient of variation. They are subjected to climate change through extreme weather events, a decrease of water availability and decrease in agricultural productivity. The common constraints faced by the farmers in the dryland areas include environmental fluctuation, wind erosion, less-fertile soil, lower yield and use of traditional technologies. (Ramakrishna and Rao, 2008). Thus, rainfed farmers are further exposed to price risks as they heavily depend on markets for purchasing inputs and selling outputs, unlike subsistence farming. Together, these stressors have the immense potential to threaten the sustainability of the livelihoods of a large number of agricultural households. In addition to the impending climate change, drylands are also affected by various other inherent biotic and abiotic limitations such as water scarcity, prolonged droughts, the late onset of monsoons, wind and soil erosion, and pests and disease infestations (Reddy *et al.,* 2021).

Farmers' awareness about dryland technologies is very good, but needs to be translated to adoption. This requires more concerted efforts in establishing mechanisms and traits including ready availability ease of use, low cost, low labour requirement and time requirements of different technologies and their components. Intercrops, row ratios, spacing, conservation furrows, fertilizer and chemical recommendations are by far, easily, readily and most adopted technologies by farmers in studies by Ravi Shankar *et al.,* 2012 and 2019. Interplay of different socio-economic factors and decision making processes leads to adoption behaviour of farmers. Therefore, for continuous adoption, additional working mechanisms need to be put in place such as extending hand holding for few more years, forming groups for ease of operation and improving farmers confidence to enable them continue with the practices even when projects from outside transition. Farmers should be advised to realize that returns are more than investments in the long run especially in Natural Resource Management (NRM) activities in drylands.

According to Spencer (1967), "technology transfer means a reasonable inter-flow of information and technologies to achieve the objectives of a project or business." The flow of technological information should be at both national and international levels, including diffusion of technology within (domestic) and among (international transfer) nation-states. Technology transfer is a kind of natural or spontaneous process, from people to people, and one field to another, with the ultimate aim of promoting human welfare. In the field of agriculture, food production is enhanced through the effective transfer of modern farming technology. Technology transfer in agriculture is vital for enhancing farmers' productivity and income (Table 1). It fosters the development of mechanisms that facilitate the adoption and integration of new technologies, especially among small-scale farmers. Technology transfer in dryland envisages various agricultural, water management, and climate adaptation innovations to address the unique challenges

faced by communities in these arid regions. The use of drought-resistant crops, combined with water-efficient irrigation systems, is central to improving agricultural productivity, as outlined by the Food and Agriculture Organization (FAO) in its 2019 report on climate-smart agriculture. However, adoption of these technologies is often hindered by high costs and limited access to financing for small-scale farmers. Efforts to manage scarce water resources include rainwater harvesting, insitu and exsitu soil and water conservation measures and aquifer recharge. Sustainable livestock management practices such as feed management, drought-tolerant fodder crops have also been introduced to combat overgrazing and maintain pasture health, as reported by the International Fund for Agricultural Development (IFAD). Regarding climate resilience, weather forecasting tools and renewable energy sources like solar and wind play a critical role. The Intergovernmental Panel on Climate Change (IPCC) underscores the need for these technologies to help communities better adapt to unpredictable climate patterns. However, many of these technologies require significant upfront investments, which can be futile without proper financing mechanisms.

Table 1: Technology transfer in dryland ecosystems

Category	Technologies/ Innovations	Benefits	Challenges	References
Agricultural innovations	-Drought-resistant crops -Water-efficient irrigation (e.g., drip systems) -Soil conservation (mulching, terracing)	- Increased crop yields -Efficient water use -Reduced soil erosion	- Limited access to technologies -High initial costs	FAO (2019)
Livestock management	-Feed management -Drought-tolerant fodder crops	-Prevents overgrazing -Maintains soil and pasture health	-Limited pasture availability -Low livestock productivity	IFAD (2021)
Climate-technologies	-Climate-smart agriculture -Weather forecasting tools -Renewable energy (solar, wind)	-Better adaptation to climate variability -Reduced dependence on fossil fuels	-Unpredictable climate patterns -Costs of technology	IPCC (2022)
Capacity building & sharing	-Training programs and workshops -Digital platforms for information dissemination	-Enhanced local expertise -Real-time access to information	-Low digital literacy in some areas -Poor network infrastructure	UNDP (2018)
Indigenous knowledge integration incorporating traditional land management practices	-Culturally appropriate solutions -Sustainable practices	-Often overlooked in policy-making	Validation and capturing evidences.	UNESCO (2020)
Policy & infrastructure support	-Subsidies -Infrastructure development (roads, water storage)	-Easier technology adoption -Support for local economies	-Policy gaps -Weak governance in some regions	World Bank (2019)

Capacity building through training programs and digital platforms enhances local expertise and empowers communities to make informed decisions (UNDP, 2018). Incorporating indigenous knowledge into technology transfer initiatives is also vital for appropriate and sustainable solutions, as UNESCO points out in its publications. Finally, policy support and infrastructure development remain essential for the widespread adoption of technologies in dryland areas. The World Bank (2019) emphasizes the importance of government subsidies and investment in infrastructure such as roads and water storage facilities to support local economies. Despite these efforts, policy gaps and weak governance in some regions continue to pose challenges.

Transfer of Technology through Participatory Extension Approach

The participatory extension approach is a significant departure from the traditional top-down transfer of technology model. In the past, agricultural innovations were often disseminated from researchers to extension agents and finally to farmers. This linear approach often failed to consider the diverse needs and contexts of farming communities, leading to limited adoption and impact. Transfer of technology models, non-participatory generally constrained in the dissemination of Natural Resource Management (NRM) technologies being a critical issue for dryland areas. Acceleration of NRM technology necessitates

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empowering farmer communities through participation (Omer Hinde, 2022). The participatory approach, as advocated by Chambers in 1989, recognizes that farmers are not passive recipients of technology but active agents of change. It emphasizes engaging farmers in all stages of the technology transfer process, from identifying problems and needs to developing, testing, and adapting solutions.

The participatory approach also emphasizes the importance of local knowledge and farmer-to-farmer learning. Farmers possess a wealth of knowledge and experience about their local environments and farming systems which can help adapt technologies to specific conditions and ensure their successful adoption. Participatory extension programmes often involve activities such as farmer to farmer extension, farmer field schools, on-farm demonstrations, and community meetings where farmers can share their knowledge, learn from each other, and collectively experiment with new technologies. This process of co-learning and knowledge exchange empowers farmers and promotes a sense of ownership and responsibility for the technologies being introduced.

Impact of farmer participation approach on the development of rainfed areas

Widespread initiatives of participatory extension approach worldwide have been developed and significant one being the Participatory Integrated Climate services for Agriculture (PICSA) pioneered by Dorward *et al.,* 2015, which addresses climate change challenges, have been successfully implemented in Zimbabwe and Kenya. Wijeratne and Silva, 2024 suggested multi stakeholder participation in building climate resilience for climate smart agriculture. Another popular approach prevalent in Egypt to achieve food security: Participatory Extension and Advisory Services (PEASS), promoted for integrating need oriented advisory services for smallholders (Emad *et al.,* 2022). Farmer participatory watershed development approach responds to needs and priorities of farmers and is believed to reverse land degradation (Pretty, 1995). Farmer participation as recorded from watershed development project in Ethiopia has revealed that factors which significantly contributed to participation were age, education, distance from watershed, farm size and dependency ratios of farmers (Mekonen and Teklu, 2023), that suggest the extent of participation would be influenced by diversified community's demographic and socio-economic status.

ICAR - CRIDA Initiatives

Farmer FIRST Programme (FFP)

Farmer FIRST is a farmer centric approach leading to collaboration and co-learning is an ICAR initiative. It is a frontline extension system approach that focuses on farmers, farmers' innovations, farmers' resources and knowledge, and science and technology. It is a participatory approach that integrates all components of a farm to develop the farm beyond productivity and profitability. The underlying basic concept of FFP approach focussed on local knowledge systems, when managed over a period leads to innovation and a key to sustainable development. The main focus and aspects covered are technology assemblage components of soil and water conservation, crops and cropping systems, horticulture, small farm mechanization and socio-economic aspects in an environment of convergence and multi -institutional linkages.

The approach has adequately created an impact benefitting 400 farm families and farms through effective utilisation of harvested water and loss of soil with construction of effective check dams and water harvesting structures; demonstration of new varieties of pigeon pea leading to cent percent seed replacement in villages, increased yield by 32 percent over local farmer practice; diversification with vegetables and floriculture improved income of farmers; enhanced food and nutritional security with adoption of backyard poultry from inclusion of eggs in the diet by introduction of Srinidhi, a low-input-backyard poultry technology, besides backyard poultry also found to supplement the earnings of poor farmers and landless laborers. The protein diet with eggs obtained from backyard poultry provided the adequate energy in the diet that met Basal Metabolic Rate requirements in all categories of people in the family. Livestock development with sheep farming and fodder production technology enhanced the livestock-based livelihood of farm households.

CRIDA Model Village Project

CRIDA has developed many dryland agricultural technologies for enhancing the yield, increasing the income and improving the overall livelihood of the farmers. A Model Village Approach is concerted and holistic packaging, delivery and implementation of demand driven interventions. Model Villages serve as miniature self-sufficient, sustainable and equitable units. This project was started by ICAR-CRIDA in the year 2023 in Gaddamallaiahguda village, Yacharammandal, Ranga Reddy district of Telangana. Intervention of proven dryland technologies in different theme areas viz., soil health and nutrient management, crops and cropping systems, farm energy management, livestock health and nutrient management, knowledge management, training and capacity building etc. were introduced in the Model village. Other interventions like workshops, demonstration of nano urea spraying, distribution of seed kits, animal camp, farmer-scientist interface meetings, establishment of custom hiring centers for farm machinery, World Soil Day celebrations etc. were successfully organized to the farmers of Model village.

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Of particular importance here for discussion is on Integrated Farming Systems (IFS) approach in drylands. IFS approach is multifunctional, contributing to food security and livelihood enhancement. Promotion of the IFS model through effective combination of one or more enterprises with crop components such as livestock, poultry, goats, or bees (depending on the availability of resources) and effective recycling of waste for sustainable natural resource development have been found to be more profitable and environmentally sustainable. In semi-arid areas, with a predominance of small and marginal farmers – who have limited finances and limited access to resources such as land, water, inputs, credit and technology – farmer is now being encouraged to adapt to the IFS model on a small scale to earn a decent income from each of the enterprises that is sufficient to meet livelihood needs.

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Technology Transfer through Digital Extension in Drylands

Digital agricultural extension

Globally, digital extension initiatives are upending newly emerging, data-rich approaches in agriculture (Nettle *et al.,* 2018), replacing conventional farmer extension agent engagements with intricate, back-end data collection and analysis procedures (Eastwood *et al.,* 2019). Thus, digital agricultural extension can enable a break from the cycle of low production, vulnerability, and poverty, particularly for smallholders (Davis *et al.,* 2018). Digital agricultural extension utilizes digital tools and services to effectively deliver such information. Extension workers commonly employ Short Message Service (SMS), Interactive Voice Response (IVR), interactive radio, and low-cost video to reach a large number of farmers quickly and provide extension services such as timely reminders, alerts, weather forecasts, and best practices to enhance productivity (Table 2). Traditional extension methods, which involve face-to-face information sharing, are time-consuming, costly, and may not yield the desired benefits for the farming community. However, digital technology can significantly expand the reach of extension services. Providing farmers with accurate information is crucial for enabling them to make informed decisions and realize their full potential. Information providers need to maintain strong connections with farmers throughout the cropping cycle. Digital technologies facilitate the creation of farmer networks and maintain connections with service and advisory providers.

Key drivers of e-extension in India

1. *Affordable Handsets and Data*: Lower costs of smartphones and mobile data have made e-extension more accessible to farmers, enabling them to use mobile apps and online platforms for agricultural information. Rural India had more than 425 million internet users, a whopping 44% more than urban India, which had 295 million people using the internet regularly, according to a report by Nielson.
2. *Government Support*: The Indian government has launched several initiatives promoting e-extension, including:
    - Digital Agriculture Mission (DAM): A Rs. 1.5 lakh crore initiative to enhance digital technologies in agriculture.
    - National Agriculture Extension Policy (NAEP): Focuses on using ICT tools to improve agricultural extension services.
    - Pradhan Mantri Krishi Sinchai Yojana (PMKSY): Provides irrigation related information through e-extension platforms.
3. *ICT Initiatives*: Government projects like BharatNet and the Digital India Program aim to provide rural broadband connectivity and digital literacy, crucial for the growth of e-extension services.
4. *Agri-Entrepreneurs*: Emerging agri-entrepreneurs are developing tailored e-extension solutions, such as mobile apps, expert platforms, and digital market places for farmers.
5. *Farmer Producer Organizations (FPOs):* FPOs facilitate e-extension by aggregating demand, providing training, and partnering with agri-entrepreneurs to create innovative solutions.

Table 2: Digital initiatives by Government of India

Initiative	Description
Farmers' Portal	Centralized platform for weather forecasts, market prices, crop advisories, and government schemes
mKisan Portal	Mobile app offering real-time agricultural information and advisories
Kisan Call Centres (KCC)	Toll-free, 24/7 access to agricultural experts
Kisan Suvidha App	App providing soil testing, pest control, and crop insurance services
Crop Insurance App	Allows farmers to apply for and manage crop insurance digitally
e-Krishi Samvad	Web-based platform for accessing agricultural information and resources
Soil Health Card (SHC) Portal	Provides farmers with nutrient information for better fertilizer application
e-NAM (National Agricultural Market)	Online platform for transparent and efficient selling of farm produce

Initiative	Description
Fertilizer Quality Control System (FQCS) Portal	Provides information on fertilizer quality
Participatory Guarantee System (PGS) Portal	Certifies organic products through farmer participation
India Digital Ecosystem of Agriculture (IDEA)	Framework for a federated farmers' database
Public-Private Partnerships	Collaborations with Digital Green and Microsoft for digital extension platforms
Microsoft Pilot Project	Pilot project in 100 villages across six states focusing on smart agriculture and post-harvest management

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Digital extension service providers in dryland areas

Bharath Agri: Operating primarily in Maharashtra, with services in Karnataka and Andhra Pradesh, Bharath Agri offers AI and ML-driven personalized farm advisories. It provides free weather-based pest and disease alerts and premium advisory services at INR 600 per acre per season, making advisory a revenue-generating service.

Big Haat: A pan-India e-commerce platform for agricultural inputs (seeds, agrochemicals, machinery) accessible via smartphones and a missed call service. Big Haat's agronomy team offers crop advisory and assists with purchase orders, complemented by a "Feet on Street" model for community engagement and education.

Digital Green: Active in states like Andhra Pradesh and Bihar, Digital Green uses video-based peer-to-peer learning, where farmers co-create digital content. Trained community resource persons produce and disseminate videos showcasing local best practices.

IFFCO Kisan Sanchar Ltd: Provides localized, voice-based advisories via mobile phones, using AI, ML, and IoT for data-driven interventions. It conducts digital profiling of farms and offers real-time personalized advice, including pest and disease diagnosis through reverse image mapping.

Kalgudi: A comprehensive web and mobile platform operating in multiple states, Kalgudi combines ML with field learning to deliver high-quality advisories. It supports farmers through training programs, farm activity reporting, and market linkages for FPOs and Self-Help Groups (SHGs).

Digital extension services have the potential to significantly transform Indian agriculture by delivering timely and accurate information to farmers. However, several challenges impede their adoption. Limited internet access affects around 70% of Indian households, with smart phone penetration at approximately 40%, particularly in remote and hilly regions where connectivity is often slow, unreliable, and costly. Additionally, low digital literacy among farmers restricts their ability to effectively utilize these services. Language barriers further complicate matters, as much of the available digital content is in English, which many farmers cannot comprehend. There is a pressing need for more localized, region-specific content in Hindi and other local languages to enhance accessibility and usability.

Technology Transfer in Dryland Ecosystem: Gender Issues

Women farmers are the backbone of agriculture and allied sectors in India, contributing to a major share in terms of labour. With the outmigration of men, there is a growing feminisation of agriculture in India, leading to an increasing number of women in different roles such as agricultural labourers, cultivators and entrepreneurs. This has contributed to an increased burden on women. Studies show that women carry out most of the back-bending tasks such as from preparing the land, selecting seeds, preparing and sowing to transplanting the seedlings, applying manure, fertilizers and pesticides, harvesting, winnowing and threshing (Pande, 2017). According to Oxfam India, women farmers produce 60-80 percent of food and 90 percent of dairy products (The Hindu Business Line, 2013). Though women represent half of the labor force in agriculture, women in agriculture and rural areas have less access than men to productive resources, training and information. Women have poor access to extension services and only less than 13 percent of Indian women own land (Sircar, 2016).

Women in agriculture face major barriers in accessing essential resources like information, training, inputs, and markets. These limitations reduce their influence in decision-making and restrict participation in collective groups, such as cooperatives and water user associations, leaving them largely excluded from critical agricultural decisions. According to FAO report, women can improve agricultural productivity by 20-30 percent, if offered the same level of training and resources as men (FAO, 2011).

According to Subathra *et al.,* 2020, the main challenges faced by women farmers in agriculture sector are the following:

- Women have unequal land rights and have limited access to use of productive resources.
- Women perform all un-mechanized agricultural tasks and perform multiple tasks which add more burdens to them.
- Women have little control over decision making process.

- Poor women farmers are less able to purchase technology to adapt to climate change due to lack of access to credit and agricultural services. They often have low productivity due to an inability to invest in things such as improved seeds and soil replenishment.
- Women farmers in agricultural sector suffer from high illiteracy rate among them. They do not know their legal rights.
- Women earn fewer wages, especially in joint, informal and private sector.
- Lack of market intelligence and inadequate information put women farmers under unfavourable situation with weak bargaining power with the buyers.

To address the existing inequality and recognize the contribution of women to the agriculture and allied sectors, a few strategies are given below:

- Improving access to inputs such as land and credit is a key step towards women's empowerment**.** It is important to recognize the labour work of women in the rural economy by accounting for it in monetary terms. More facilities need to be provided to poor rural women for land, agricultural and livestock extension services.
- Measures should be taken to enhance women's literacy.
- Creating awareness among women of their existing rights. Reducing discrimination through legal reforms is key to achieving gender equality in the long run.
- Encouraging women to participate in decision-making bodies that can help in bringing structural changes in gender relations in society.
- Inducting a sizeable number of well-trained women personnel in training and extension programmes of agricultural development agencies at all levels.

Women, as primary managers of natural resources for their families, face hardships from resource depletion and limited, gender-insensitive mechanization in agriculture. Equipment like harvesters and transplanters is often designed without considering women's needs, reflecting a broader oversight in agricultural research and technology development that marginalizes women as key contributors and beneficiaries. This lack of inclusivity hinders both women's productivity and overall agricultural advancement. Technological empowerment must be reinforced with social empowerment. This calls for gender sensitising at all levels and equipping women with new technological advances, knowledge of ecologically sound farming practices and management skills. To address this, one of the strategies is to recruit para-agricos, on the lines of para-vets, from rural areas, especially women school dropouts, can be trained in scientifically developed, sustainable technologies, provided with tool kits and inducted at grassroots level. The number of women professionals in the field of agriculture, veterinary science and allied areas are increasing. The professional-rural women linkages can be strengthened through formulation of gender sensitive, location specific, inter-disciplinary research with compulsory involvement of rural women in planning, technology re-assessment and evaluation process through participatory methods. More number of women have to be inducted into the formal extension system and provided with facilities like secure accommodation and transport, incentives for off campus activities and due recognition.

Livestock-Based Technology Transfer in Drylands

Covering about 40% of the Earth's surface, drylands face challenges like low rainfall, high evaporation, and extreme temperatures, which impact livestock production—a key livelihood source for rural communities. Effective transfer of livestock-based technologies in these areas is crucial for improving productivity, food security, and sustainability, though barriers remain (Nirmala *et al.,* 2024). In dryland India, livestock not only supports livelihoods and nutrition but also holds cultural significance. Transferring livestock-based technologies in dryland ecosystems aims to enhance animal health, nutrition, and management practices through innovations like drought-resistant fodder, advanced breeding techniques, and tailored disease control (Srinivasa Rao *et al.,* 2010). Effective technology transfer can significantly increase productivity by improving milk and meat yields, thus boosting economic stability. It also promotes sustainable resource use through water conservation and feed optimization, which are vital for dryland sustainability (Pankaj *et al.,* 2023). Moreover, as climate change intensifies, these technologies help livestock systems adapt to varying conditions, supporting long-term resilience (Amrendra *et al.,* 2024).

Issues affecting the adoption of livestock based technologies

Lack of Local Relevance: Many technologies are developed without community input, resulting in solutions unsuited to the socio-economic and environmental conditions of dryland farmers. For example, methods that work in one region may not be practical elsewhere due to climate, culture, or resources (Pankaj *et al.,* 2019).

Limited Access to Information: Poor infrastructure, low literacy, and limited internet access restrict farmers' awareness and understanding of available technologies. Additionally, extension services often lack updated knowledge and resources to effectively inform farmers.

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Financial Constraints: Many technologies require upfront investment, which can be prohibitive for smallholder farmers who have limited access to credit or financial services.

Cultural Resistance: Deeply ingrained traditional beliefs can hinder the adoption of new practices, especially where livestock management is influenced by cultural taboos, as seen in swine and goat production (Pankaj and Ramana, 2013).

Inadequate Extension Services: Extension services, primarily through State Animal Husbandry Departments, are limited in scope, often focused on treatment rather than knowledge transfer. With minimal budget (0.4–1%), these services lack sufficient staffing and training, reducing their effectiveness.

Strategies for effective dissemination of livestock-based technologies

To address these challenges, the following strategies are recommended (Prasad *et al.,* 2024):

Participatory Research and Development: Engaging communities in research ensures technology relevance and effectiveness. Participatory Action Research (PAR) addresses the specific needs of local farmers (Rao *et al.,* 2012).

Tailored Communication Strategies: Using local languages, visual aids, and digital tools such as smartphones and radios can help bridge the information gap and foster awareness of climate adaptation practices (Pankaj *et al.,* 2015).

Financial Support and Microfinancing: Microloans and financial support, such as the Kisan Credit Card (KCC) for livestock farmers, enable farmers to invest in technologies, improving adaptive capacity.

Capacity Building and Training: Practical training programs focused on skills like disease management and resource optimization enhance farmers' ability to apply new technologies effectively. Need-based programs also support improved fodder production systems (Pankaj *et al.,* 2018).

Strengthening Extension Services: Increasing funding and using mobile technology can improve outreach and effectiveness of extension services, making technology transfer more accessible.

Promoting Farmer-to-Farmer Learning: Peer networks and Farmer Field Schools (FFS) facilitate collaborative learning, allowing farmers to share experiences and learn from each other's observations.

Utilizing Technology Platforms: Mobile applications and online resources provide farmers with timely information on best practices, market trends, and weather, aiding decision-making (Jagriti Rohit *et al.,* 2024).

Conclusion

Transfer of technologies in dryland ecosystems is critical for improving resilience and livelihoods, but it requires coordinated efforts from governments, development agencies, and local communities. While several challenges hinder effective technology transfer, implementing targeted strategies can significantly improve the situation. By focusing on participatory approaches, tailored communication, financial support, capacity building, and strengthening extension services, stakeholders can create a conducive environment for technology adoption. Participatory approaches in a collaborative and consortia approach in drylands can realize the goals towards achieving market-led extension in the future. FFP and Model village approaches offer participatory, action oriented and demand driven interventions which enable collaborative service providers to respond to multiple challenges faced by dryland farmers in integrated ways through enhanced partnerships. Gender sensitive transfer of technology will enhance the inclusiveness and sustainability of technology adoption. Knowledge transformation through digital extension can bring about changes in extension strategies in the future with the application of information and communication technologies. Multi-stakeholder participation through coordination and resource sharing can only shift farming into business and farmers into entrepreneurs.

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