



Innovations-led Farming is the Way Forward for Resilience, Sustainability and Improved Livelihood in Indian Arid Regions

O.P. Yadav

ICAR-Central Arid Zone Research Institute, Jodhpur 342 003, India

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Abstract: Arid regions are unique agricultural production and ecological systems characterized by challenging agro-climatic conditions and stressful environments for crops and livestock putting a ceiling on agricultural productivity. The inherent vulnerability of farming to stress conditions is further accentuated by climate change. This situation calls for improving productivity and strengthening resilience of farming to provide sustainable livelihoods for farming communities. This article highlights role of technological innovations to achieve this daunting task. Greater productivity, resilience, sustainability, and improved livelihood require not only multiple technological interventions but would also necessitate proper policy. Role of integrated farming, resilient crops and climate-smart livestock management are very vital in improving productivity and resilience of agricultural system. On the other hand, innovations in water management, sustaining soil health, precision agriculture, nature-friendly farming and use of digital tools will form foundation of enhanced sustainability. Engaging farmers in designing and testing of new technologies, delivering improved technologies at his doorsteps and enhancing their entrepreneurship skills, both at individual and community levels, hold the key to further enhance rural livelihood. While doing so, it is important to keep a constant and careful watch on changes occurring in the state of natural resources to ensure that there is no infidelity with combating desertification in agricultural lands.

Key words: Resilience, sustainability, livelihood, arid regions, farming, innovations.

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**Correspondence*

O.P. Yadav

opyadav21@yahoo.com

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Arid regions, located in north-western part of India, represent a very important agricultural production system covering 10% of country's total cropped area. Seven per cent of human population and 11% of livestock population of nation is dependent on this area for supply of food and fodder. Characteristically, arid regions offer challenging agro-climatic conditions for crops and livestock as they are highly prone to severe drought due to low rainfall (150-400 mm) and its irregular distribution (more than 40% CV). Regions also experience high summer temperatures often reaching beyond 45°C. High annual evaporation (up to 2000 mm) further intensify water scarcity. Almost all (99%) native soils are

severely deficient in nitrogen and nearly 50% are deficient in available phosphorous with low organic carbon content (<0.20%). These agro-climatic and edaphic conditions not only put a ceiling on agricultural productivity but also increase vulnerability of farming to stress conditions which is further accentuated by climate change. This situation advocates for strengthening resilience of farming, improving productivity and enhancing livelihood options.

Interestingly, arid regions have witnessed remarkable changes during last few decades in farming and society. Enhanced availability of water through canals and tubewells are forming novel and unprecedented opportunities in terms of choice of new field and horticultural crops. However, use of inefficient irrigation methods and cultivation of water-guzzling crops in coarse and sandy soils with high water infiltration rates (up to 30 mm per hour), poor water retention capacity (10-12% moisture on volumetric basis at field capacity) and high evaporation rate (up to 2000 mm per year) may lead to accumulation of salts in soil profile causing soil salinization. This would harm crops, disrupt soil structure, and reduce fertility eventually leading to desertification. Non-judicious and inefficient use of water is not sustainable as water resources are only finite threatening future generations' ability to meet their water needs for agriculture, domestic and industrial uses underlining the need of sustainability.

More than two third of human population in arid regions count on farming for their livelihood. Output of agricultural research must be translated into better methods of farming by bridging the gap between scientific knowledge and on-farm application through collaboration, stakeholder engagement and effective dissemination strategies. This translation is crucial for enhancing crop productivity, boosting farmer incomes, improving food security, and creating sustainable livelihoods for farming communities. The purpose of this article is to highlight potential innovations for further enhancing resilience and sustainability of farming and community livelihood.

Role of Innovations

Farming communities and researchers are sources of innovation in arid zone

farming. Farmers often develop innovative and locally adapted methods for water conservation and soil management and cultivate a combination of drought-tolerant crops. Farmer-centric innovations often stem from the need to manage scarce water resources and unpredictable and challenging climatic conditions. *Tanka* (cistern) and *khadin* (cultivation using run-off water) are two outstanding innovations, created by communities, in water conservation for domestic and farming purposes, respectively. Similarly, farmers' practices of adopting minimum tillage, conserving volunteer vegetation species during off-season and maintaining *orans* (sacred grooves) are examples of managing soil quality in arid eco-system. Such innovation-driven view of arid landscape is no lesser than a picture postcard. There are several other farmer-centric innovations but it's beyond the scope of this note to highlight all of them here.

Similarly, strategic research innovations through institutional arrangements have led to development of efficient techniques of water harvesting and utilization; identification of suitable cropping and farming systems; creation of climate-smart cultivars of adapted field crops, grasses, horticultural crops and trees to provide a range of choices to farmers. Determination of nutrient requirements, and pest and disease management of crops have further helped in realizing higher productivity. Consequently, several need-based and cost-effective technologies were developed and transferred to farmers and stake-holders. Their adoption and success in challenging conditions of arid regions to enhance productivity and stability in production is like a page of fantasy novel.

Similarly, there exist several other innovations. Livestock can utilize marginal lands and they play a pivotal role in resilience and livelihood. Innovations in management of livestock and rangelands as per carrying capacity of later have led to optimization of resource use and minimization of climatic impact on production eventually impacting livelihood in arid production environments. Advancement in the development of several solar gadgets have been vital in harnessing solar energy for use in agriculture and society providing enabling solutions like solar water pumps for irrigation, solar dryers for food

preservation, and solar-powered farm for crop production and electricity generation.

Development of indicators having several biophysical parameters of desertification has helped in quantifying the extent and severity of land degradation. It is quite satisfying to note that several innovations promoted sustainable land and water management which checked desertification in arid regions to a large extent, despite challenging agro-climatic conditions and high biotic pressures on limited base of natural resources.

Way Forward

Resilience, sustainability and improved livelihood cannot rely on a single technological intervention. Moreover, technology, practice and policy must work together. Climate-smart technologies on management of water and soil will make a difference only when right choice is made of crops, cultivars and seeds and vice-versa. Farmer-centred innovations can further build the capacity of farming communities to adapt to climate change, resource scarcity, and other emerging challenges, ensuring long-term food security and livelihood. By involving farmers in the development of improved technologies, there is greater probability of their acceptance and a higher chance of long-term sustainability of the innovations.

An integrated approach, combining traditional wisdom with modern scientific innovations, holds the key in developing resilient and sustainable arid farming. While previous innovations would continue to contribute in their own established way, there are new opportunities to explore and create new innovations for arid agri-eco-system. Key future areas of innovations having a potential role in enhancing resilience, sustainability and improved livelihood are enlisted here.

Enhancing resilience

Integrated farming: Integrated farming with a combination of annual and perennial components is the central point for building resilience in addition to its several other advantages. Already several relevant models are in place with selected combinations of annual and perennial species, but it is not enough. Number of farming situation for arid zone might be as many as number of farming families. It is practically impossible to

evaluate every permutation and combinations of constituent components. The foremost question that remains is the allocation of land resources to various components for different farming situations. A decision supporting system (DSS) needs to be worked out for this purpose considering availability of resources and farmer's requirement. Interestingly, sufficient data bases exist at national level to develop the required DSS. Else, the gaps in the data can be plugged. The DSS with up to 75% predictability may be considered as sufficient.

The components of water and soil management; high-value, low-volume spice, aromatic and medicinal crops; and water efficient food, fodder and horticultural crops should be integrated in farming. With such strategic planning, more resilient systems need to be built to create a diversified and income- and employment-generating farming systems contributing to economic, social, and environmental benefits.

For promoting integrated farming at landscape level, farmers are to be exposed to a whole range of tested and validated choices available for the region in real-time situation. "Seeing is believing" is important for farmers as it emphasizes the value of visual evidence, especially in adopting new technologies. Visible results are more persuasive than abstract information influencing decisions on new farming techniques. Establishment of the Integrated Farming Cafeteria is one such initiative at ICAR-CAZRI that is largely serving this purpose. Farmers can easily identify the component that can be added in his existing farming situation to make production at his farm level more resilient and of greater magnitude.

Traditional agro-forestry is an integral part of farming. Both annual crops and perennial components of prevalent agro-forestry system have lower water, carbon and energy footprints and greater ecosystem services. The advantages of annual crops in terms of low environmental footprint and benefits of perennial species, like *khejri*, for higher eco-system services are to be monetized. Generation of such data is need of hour as deliberations are on to implementing measures to compensate farming community for raising crops that are helpful in mitigating the effects of climate change and in adapting to

changing climate conditions. Full compatibility of crops with trees and a tree-geometry wide enough to allow mechanized operations are a must for creating and upscaling agro-forestry models. Developing and promoting superior genotypes of multipurpose trees with faster growth rate within traditional agroforestry systems are also vital. Though the importance of quality planting material (QPM) for agro-forest species is widely recognized, the actual supply of QPM has long been inadequate presenting a significant and persistent challenge. The corrective measures are urgently needed to enhance supply of QPM of agro-forest species.

Resilient crops: Development and delivery of climate resilient cultivars of field crops, grasses and horticultural crops hold the key for built-in resilience. The crop and grass species cultivated in arid regions are inherently adapted to abiotic and nutrient stress environments. Large inherent variation exists in genetic resources of each species for adaptive traits to further enhance adaptation level. Future research should place greater emphasis on development of cultivars having tolerance/escape to multiple abiotic and biotic stresses.

All arid crops are excellent genomic resources for isolation of candidate genes responsible for tolerance to climatic stresses and their possible deployment in other crops. Sequencing their genome might uncover several genes that might be useful for taking adaptation to the next level not only in arid crops but also for other food crops. Use of adapted germplasm and marker-assisted selection should be integrated in the ongoing breeding programme on pearl millet, moth bean, clusterbean, cumin and isabgol. Such efforts are urgently needed.

Development and deployment of early maturing cultivars with duration as per moisture availability pattern during rainy season is critically important to enhance resilience under drought. Extra-early varieties bred in pearl millet, mothbean and mung bean with a duration of 65-70 days have been largely adopted in arid regions bringing in a tremendous improvement in their productivity. The simple reason for a large-scale adoption of improved cultivars is their remarkable ability to reduce risk of crop failure in rainfed situation due to early withdraw of seasonal rains in arid areas. However, such innovation has largely

excluded clusterbean, the most important annual industrial crop of arid areas. Greater efforts are obviously needed in this direction in clusterbean.

It is also well recognized that, early maturing cultivars have significant yield penalties due to negative association between earliness and yield potential. Such negative nexus needs to be broken. This requires strategic use of germplasm, handling of larger populations in segregating generations, backcrossing and molecular-assisted breeding to create unique combinations of genes governing earliness, adaptation and yield.

Crops of arid regions have good adaptations to succeed in low-nutrient soil conditions. There are reported differential response of various genotypes to a given amount of nutrients. This is largely an unaddressed issue in crop improvement programmes of arid crops. Understanding the genetic basis of adaptation to low nutrients conditions can be a novel area of research to develop new crops with low nutrient demand with acceptable level of productivity. This aligns well with the larger objective of reducing dependence of crops on chemical fertilizers without compromising with productivity. It is also to be recognized that the crops of arid region face other biotic and abiotic stresses. Therefore, new crop cultivars must fulfil all other criterion prescribed in the national coordinated system to qualify for release and deployment at the farmers' field.

Climate-smart livestock management: Livestock productivity is low in arid regions due to heat stress from prevailing temperature and nutritional stress arising from shortage of both quantity and quality in fodder resources. This leads to decreased milk production, lower body mass, reduced feed intake, compromised immune function and increased susceptibility to diseases. Therefore, ameliorating nutritional and climatic stresses in livestock through proper feed, fodder and housing management is most important. The key areas include:

- Decoding of adaptation mechanism to stress environments of local breeds of small and large ruminants is required. A multidisciplinary approach, analysing behavioural traits like shade-seeking, morphological adaptations such as light hair colour and elongated ears, physiological

changes including increased respiration and altered hormone levels, and genomic basis is critical for understanding genetic mechanism of climate-resilient breeds.

- Research interventions are to be explored for improving semi-intensive and intensive housing management to reduce direct solar radiation, improve air circulation, select appropriate roofing materials and designs that minimize heat absorption.
- New alternative fodder and feed resources are to be explored in view of shrinking of grazing resources to augment green fodder and dry stover supply.
- Value addition of local fodder resources for increasing digestible protein and energy contents to meet the higher maintenance requirements under stress.
- In absence of formal production and supply of grass seed, participatory seed production of new fast-growing cultivars of grasses should be a top priority. Farmers should be given a leading role in producing and sharing quality seeds of new grass varieties.
- During migration of herds for the period March-June from arid areas to Haryana, Punjab and Uttar Pradesh in the offseason, regular availability of clean and fresh water for livestock is vital for all physiological functions and to combat dehydration from heat stress. Also, real-time monitoring of livestock health is very critical.

Enhancing sustainability

Smart water and soil management are main drivers of sustainability of farming in arid regions where water scarcity and fragile soils present major challenges to agricultural productivity and resilience. Smart farming technologies and techniques help optimize resource use, reduce water waste, and improve sustainability and resilience to climatic stresses.

Managing water: Water availability has increased in the region. Sustainable farming requires balancing the expansion of irrigated agriculture with careful water and soil management. Over-relying on irrigation to support water-intensive farming on naturally poor fertility soils can deplete water resources

and cause long-term soil damage through salinization.

Improving water-use efficiency through micro-irrigation in arid areas has been one of the greatest success stories in modern agriculture. Sprinkler and drip irrigation systems, combined with the government's policy of supporting the *diggi* (lined farm pond) system, have empowered farmers through science and innovation by enabling cultivation on undulating soils of high-value crops in the Indira Gandhi Nahar Pariyojana (IGNP) and Narmada Canal (NC) command area. Micro-irrigation significantly boosted water use efficiency by directly delivering water to plant roots, minimized losses from evaporation, runoff, and deep percolation. This technology allows farmers in arid areas to save water and energy, leading to increased crop yields, larger cultivated areas and improved farmer income eventually resulting in greater resilience and sustainability in agriculture. Future research should focus on improving the water productivity through automated irrigation methods and by including water-efficient crops and cultivars in different cropping and farming systems.

There is a plenty of underground saline water in arid regions which remains unused except its conjunctive use, up to some extent, by mixing it in fresh water in solar-diggi system in canal command areas. The use of saline water needs to be explored further without impacting soil health by choosing salt-tolerant crops and applying irrigation at most tolerant growth stage of crop. These strategies, along with managing soil drainage, can increase water-use efficiency and mitigate negative impacts like soil salinization.

High amount of water evaporation from *diggi* system is a concern in arid areas. Water budgeting indicated losses up to 60% from open surface. Solar radiation and desiccating winds are main drivers of evaporation. A combination of low-cost floating physical covers, biological methods and chemical treatments needs to be tried to reduce water evaporation from *diggi* ponds.

Due to climate change, arid regions are experiencing frequent and high-intensity rainfall events, underlining need to determine the potential of runoff water in providing

life-saving irrigation to crops during drought, recharging groundwater, and mitigating the effects of soil erosion and flooding.

Integration of technology and policy is an absolute necessity in water management. While technology provides the necessary tools for increasing efficiency and real-time monitoring, policy creates the long-term vision, regulatory structure, societal motivation and judicious water use by influencing behaviour and infrastructure. Holistic planning supported by technology like GIS and digital mapping would allow the coordinated development of water management strategies. Demand-side management of water is also extremely important. Incentivization, through improved economics and marketing, of water efficient millets, legumes and horticultural crops would promote their cultivation in arid regions resulting in sustainability of farming.

Sustaining soil health: Arid soils have a very high sand content and are thus possess several inherent limitations. The soils have low organic carbon, poor water holding capacity, low nutrient content and low cation exchange capacity, all of which are intricately linked and impinge on each other. All these edaphic factors influence microbial activity. Organic carbon is often considered the most important because it significantly influences all the other factors.

Practices like adding organic matter, implementing conservation tillage, allowing vegetation cover, practicing crop rotation with diverse root structures and applying mulch to the soil surface will contribute to improve soil health and water access. Integrated farming, discussed above, is critical to sustaining soil health by fostering a closed-loop system where the farm's components recycle nutrients, enhance organic matter, and build soil structure.

New alternative strategies are being developed to enhance soil water and nutrient retention that include application of liquid natural clay (LNC), nano-clay, and superabsorbent polymers (both natural and synthetic) for enhancing soil ability to retain water and nutrients and to boost yield. Use of organic resources, native minerals and other interventions should also be explored. While, deficiency of N and P in arid soils are adequately acknowledged, tracking of secondary and micronutrients like sulphur (S), zinc (Zn), iron

(Fe) and boron (B) and subsequent interventions are equally necessary in view of a high priority of developing biofortified crops.

It should be recognized that the improvement of soil health in arid regions is an extremely challenging task as wind erosion is a severe process of land degradation in the region. Any single intervention would have only a small impact and therefore multiple interventions affecting soil physical, chemical and biological properties are needed. Sand dune stabilization technology has proved effective impacting many such properties of soil. Surface-sealing with natural gums and enhancing glomalin production through arbuscular mycorrhizal fungi (AMF) can be explored to help stabilize sand and restore soil health in arid regions. Natural gums offer a direct, physical solution to prevent sand movement, while glomalin can provide a long-term, biological mechanism for improved soil structure and health.

Arid microbiome: Role of microbiome is extremely important in arid farming because it enables crops to adapt to harsh, water-scarce, and nutrient-poor conditions. The microbial communities perform vital functions that enhance plant resilience, improve soil health, and reduce reliance on chemical inputs. Microbial diversity of arid regions is unique. Results so far have clearly established the role of microbes in promoting growth, reducing diseases and pests, enhancing nutrient uptake, fixing atmospheric nitrogen and boosting yields up to 10-15%. A more comprehensive collection of microbes is needed to enhance the understanding of microbial diversity and function across different vegetation, soil types, seasons and habitats including rhizosphere, phyllosphere and endosphere. An inclusive sampling strategy is required to capture the full spectrum of microbial diversity in varying ecological niches. Studying microbes from high-temperature and drought-prone regions provides a deep understanding of stress adaptation mechanisms. Next-generation sequencing and bioinformatics analyses can provide further insights into taxonomic composition and function. By isolating and analysing these microbes, unique molecular, physiological, and genetic mechanisms can be identified that underpin their resilience. Long-term studies on microbiome dynamics in different cropping systems should be planned

and put in place for identifying microbes as PGPR in augmenting crop production under moisture stress and in managing diseases and pests.

Precision agriculture and digital tools: In the last few years, several innovations have emerged in natural resources and plant health management that are primarily driven by advances in remote sensing, artificial intelligence (AI), Internet of Things (IoT) and automation. These technologies have a great potential to further improve productivity through precision farming using sensors, GPS, drones, and AI for real-time monitoring of soil moisture and nutrients to assess crop needs. The data-driven innovations would enable variable rate of fertigation using drip or sprinkler systems to deliver exact amounts of water and nutrients, thereby reducing waste, lowering costs, and promoting sustainable farming practices. Real-time information on crop health, weather, and market trends for farmers would provide valuable data for decision-making. Digital innovations can also help farmers access markets and financial services.

Initiatives in precision agriculture, especially involving cultivation of high value crops in polyhouses and net houses, are successfully leveraging technology to manage water, nutrients and improve yields in arid regions especially in peri-urban areas. But significant challenges remain in large-scale adoption and infrastructure. To make precision agriculture more widespread and effective, future efforts must focus on technological accessibility, capacity building of farmers, and robust financial and policy frameworks.

Future research should be on use of sensors and IoT-based technologies for digital agriculture tailored to specific crops to optimize resource use efficiency and enhance productivity. The development of precision planters and other automation-based machineries is also need of hour.

Natural farming: Natural farming is an interesting subject of deliberations in recent past. It advocates no use of any synthetic inputs (chemical fertilizers, pesticides and growth promoters), practising minimal soil disturbance and promoting biodiversity both under irrigated and rainfed conditions across crops. It also recommends homemade

microbial treatments like *Beejamrut* (for seeds) and *Jivamrut* (for soil) to provide nutrients and promote beneficial microorganisms. Cultivation of a variety of crops and integration of livestock are also recommended to create a balanced and resilient ecosystem. Four advocacies (minimal soil disturbance, promoting biodiversity, cultivation of a variety of crops and integration of livestock), out of these six, are largely followed in existing rainfed farming in arid areas as a part of adaptation process to prevailing harsh conditions.

Knowledge so far has established that deficiency of nutrients, especially N and P, in arid soils limits crop growth resulting in reduced yield, but their supplemental dose enhance yield substantially. Thus, a small investment in form of cost of external inputs give economic returns to farmers within 4-6 months with benefit cost ratio of up to 1.5. On the other hand, several meta-analyses across world have indicated a yield penalty of 10-30% in different crops under natural farming, at least in the initial years, in comparison to conventional farming. In view of this, long-term evaluation trials on natural farming have been established in various agro-climatic zones of country to quantify the role of homemade microbial treatments and other interventions on soil biology, nutrient dynamics, productivity and sustainability. Information on these aspects are of special value in arid farming because of inherently low nutrient contents in arid soils, low microbial activity in soil profile and greater oxidation of carbon due to high temperature.

Improving livelihood

A myriad of technologies have been developed for getting higher productivity of crops, cropping system and integrated farming in arid regions. At the same time, several innovations are also deployed to reduce cost of cultivation. Many of them have been demonstrated successfully at the farmers' field following cluster approach. Higher production from existing land resources through adoption of new technologies enables farmers to produce marketable surplus at his farm level providing him extra income and greater ability to absorb risk due to climatic vagaries. The development of entrepreneurship among farmers, supported by Self-Help Groups (SHGs), Farmer Producer Organizations (FPOs), and Farmer Producer

Companies (FPCs) holds the key to further enhance rural livelihood. There is strong need to develop business models for livelihood security by amalgaming suitable knowledge interventions. Such collective models offer farmers a unified platform to overcome the systemic challenges of fragmented landholdings, poor market access, and lack of credit by leveraging economies of scale. The key activities to augment livelihood options are:

- Diversifying income sources by integrating in the existing production system, improved cultivars of suitable field crops, horticultural crops, multipurpose trees, grasses and livestock.
- Establishing nurseries for production and supplying of healthy, resilient and quality planting material of local fruits and multipurpose agro-forestry trees
- Being part of seed village to produce and sale quality seed of improved cultivars of crops and local grasses
- Entrepreneurship development in value addition of local food grains, fruits and fodder
- Cultivation in peri-urban areas of high value vegetables in polyhouse and net-house
- Brackish water aquaculture in the areas where such water is available
- Manufacturing and marketing of small solar gadgets
- Production and supply of biofertilizers and biopesticides

Skill development and training programs are crucial for improving the livelihoods of arid farmers. By providing farmers with knowledge and modern techniques, these programs help increase productivity, build resilience, and enhance economic stability in regions. Capacity building through institutional arrangements in modern and sustainable practices of farming is vital for arid farmers to improve their socio-economic well-being.

Embarking upon cold arid regions

Cold arid regions, spanning over UT of Leh and parts of Himachal Pradesh and Uttarakhand, are very different and represent

the most challenging production system of country. This is due to a combination of high altitude, water scarcity, harsh winters, fragile ecosystems and underdeveloped infrastructure. Farmers in these regions are often smallholders with limited resources and capital to invest in modern technologies or adapt to climate-related risks. The reliance on farming and livestock for livelihood makes communities particularly vulnerable to climate shocks, potentially triggering migration and increasing financial hardship

In most of the region, especially UT of Leh, only one crop season is possible. The biggest challenge is very narrow window of farming of annual crops (June to Sept). On the other hand, the intensity of solar radiation is very high throughout year. Intense research is needed for extending the growing season through technological interventions (multipurpose solar agri-structures), introducing new climate-resilience crops (e.g. maize, mustard) and early maturing cultivars for food, fruit and fodder production improving overall farm productivity. An integrated approach having innovations in agro-forestry, forestry, horticultural crops, field crops, water management, and soil management is crucial for Ladakh to achieve the targeted carbon neutrality. Given its high-altitude, cold-desert climate and fragile ecosystem, this holistic strategy is essential for sequestering carbon, reducing greenhouse gas (GHG) emissions, and building resilience to climate change.

Monitoring and combating desertification in agricultural land

Close monitoring of desertification and state of natural resources (soil, water and vegetation) in arid areas should heavily rely on integrating advanced remote sensing technologies and GIS with on-the-ground observation and data collection. While remote sensing provides a large-scale view, on-the-ground data collection is critical for confirmation and more in-depth understanding. Such comprehensive watch helps detect early signs of land degradation, distinguish between natural and human-induced factors, and suggests effective management strategies especially in agricultural lands. Areas should also be identified that are at potential risk to extensive wind erosion, loss

of vegetation cover, building up of secondary salinity etc.

The high-resolution data and maps generated from 1:10000 scale would directly inform and enable the implementation of targeted strategies to combat desertification in agricultural lands. This would require detailed baseline data, customized land-use planning and site-specific management options to deal

with degradation in agricultural land. Hotspots for land degradation need to be identified for site-specific interventions through community participation and state governments.

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