Policy Paper

Abiotic Stress Resilience in Indian Agriculture: A Policy Framework

ICAR-National Institute of Biotic Stress Management, Raipur, Chhattisgarh
ICAR-National Institute of Abiotic Stress Management, Baramati, Maharashtra
ICAR-National Academy of Agricultural Research Management, Hyderabad, Telangana
Indian Society of Agricultural Economics, Mumbai, Maharashtra

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Authors:
Bhaskar B. Gaikwad, Senior Scientist, ICAR-NIASM, Baramati
N. P. Kurade, Principal Scientist, ICAR-NIASM, Baramati
Santosha Rathod, Senior Scientist, ICAR-NIASM, Baramati
Nobin Chandra Paul, Scientist, ICAR-NIASM, Baramati
Navyasree Ponnaganti, Scientist, ICAR-NIASM, Baramati
K. Ravi Kumar, Scientist, ICAR-NIASM, Baramati
Sachin S. Pawar, Principal Scientist, ICAR-NIASM, Baramati
Pratap S. Khapte, Scientist, ICAR-NIASM, Baramati
Sushil S. Changan, Scientist, ICAR-NIASM, Baramati
A. Amarender Reddy, Joint Director, ICAR-NIBSM, Raipur
K. Srinivas, Principal Scientist, ICAR-NAARM, Hyderabad
Nalini Ranjan Kumar, Principal Scientist, NIAP, New Delhi
Anjani Kumar, Senior Research Fellow, IFPRI, New Delhi
Gopal Lal, Director, ICAR-NAARM, Hyderabad
P. K. Rai, Director, ICAR-NIBSM, Raipur
K. Sammi Reddy, Director, ICAR-NIASM, Baramati

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- ICAR-National Institute of Biotic Stress Management
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- ICAR-National Institute of Abiotic Stress Management
  Baramati-413115, Maharashtra, INDIA.
  Phone: 02112-258000, Website: http://niam.res.in
- ICAR-National Academy of Agricultural Research Management
  Hyderabad-500030, Telangana, INDIA.
  Phone: 040-24015070, Website: http://naarm.org.in
- Indian Society of Agricultural Economics
  Mumbai-400063, Maharashtra. INDIA.
  Phone: 022-40143951, Website: https://www.isaeindia.com

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Bhaskar B. Gaikwad
N. P. Kurade
Santosha Rathod
Nobin Chandra Paul
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Indian Society of Agricultural Economics, Mumbai, Maharashtra

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भारतीय कृषि अनुसंधान परिषद्
कक्ष क्र. 101, कृषि अनुसंधान भवन-II, पूसा, नई दिल्ली-110 012, भारत
INDIAN COUNCIL OF AGRICULTURAL RESEARCH
Room No. 101, Krishi Anusandhan Bhawan-II, Pusa New Delhi-110 012, India

डॉ. ए. के. नायक
Dr. A. K. Nayak
FNASc, FNAAS, FISSS, FARRW
उप महानिदेशक (प्राकृतिक संसाधन प्रबंधन)
Deputy Director General (Natural Resource Management)

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Foreword

With abiotic stresses intensifying and reshaping the country's production and productivity landscape, Indian agriculture stands at a critical moment. Abiotic stresses such as drought, heat, salinity, flooding, cold, and soil degradation pose mounting pressures on national food security and farmer incomes. The challenges of climate variability, resource constraints, and the increasing complexity of farming in diversifying environment need immediate attention to address these in a coordinated, science-led and systems-oriented policy response that integrates technological advancement, evidence-based planning and institutional synergy for execution.

This document, "Abiotic Stress Resilience in Indian Agriculture: A Policy Framework," prepared by Bhaskar B. Gaikwad, N. P. Kurade, Santosha Rathod, Nobin Chandra Paul, Navyasree Ponnaganti, K. Ravi Kumar, Sachin S. Pawar, Pratap S. Khapte, Sushil S. Changan, Mukeshkumar P. Bhendarkar, A. Amarender Reddy, K. Srinivas, Nalini Ranjan Kumar, Anjani Kumar, P. K. Rai, and K. Sammi Reddy, synthesizes the understanding of the team and the deliberations of the Brainstorming Workshop on Biotic and Abiotic Stress Management and Policy Issues in Indian Agriculture held on 21–22 July 2025 at ICAR-NIBSM, Raipur.

This document outlines a strategic framework for enhancing India's preparedness for abiotic stresses through integrated research, climate-resilient technologies, improved soil and water management, data-driven monitoring systems, and strengthened institutional coordination. It emphasizes the need to scale stress-tolerant varieties, modernize irrigation, restore degraded lands, and leverage digital and precision tools that should lead to anticipatory and adaptive decision-making.

This document will serve as a valuable resource for policymakers, researchers, development agencies, and state departments in shaping long-term strategies for resilient agriculture. The recommendations presented here offer actionable pathways to reduce vulnerability, safeguard productivity, and promote sustainable growth across India's farming systems.

I congratulate the authors for their effort in bringing out this policy framework that will help advance informed dialogue and decisive actions toward building a climate-resilient and secure agricultural future for the country.

(A.K. Nayak)

Ph. : +91-11-25848364 Fax : +91-11-25848366 E-mail : ddgnrm.icar@gmail.com, ak.nayak@icar.org.in Website : www.icar.org.in

Executive Summary

Indian agriculture faces growing challenges from abiotic stresses such as drought, heat, salinity, waterlogging, cold, and nutrient deficiencies, as well as from the combined effects of these stresses. Together, they threaten food security, farmer livelihoods, and the sustainability of agricultural systems. With about 68% of India's cultivated area still drought-prone and nearly 146.7 Mha (44% of the total land area) degraded, abiotic stresses continue to cause yield gaps exceeding 50% of the potential output, leading to major economic losses.

Climate change is intensifying these challenges. By 2050, India is projected to experience a rise in mean temperatures by 1.5 to 2.5°C across agricultural regions, along with altered monsoon patterns showing 10 to 15% variability in rainfall distribution. These shifts may lead to a 26% increase in the risk of rice production failure at the district level, a 21.6% reduction in rainfed rice yields under high-emission scenarios, and an expansion of salinity-affected areas by an additional 2 to 3 Mha.

This policy paper presents a comprehensive, evidence-based framework to strengthen abiotic stress resilience in Indian agriculture. Drawing on recent scientific research, government programmes, and global best practices, it outlines integrated strategies that combine technology development, institutional support, policy reforms, and farmer empowerment. The framework emphasizes preventive risk management, climate-smart agriculture, precision-based interventions, and active participation of all stakeholders aligned with India's commitment to sustainable development and climate action.

Key Recommendations:

- Establish a unified National Abiotic Stress Management Mission with dedicated funding adequate over five years for field-level implementation

- Promote climate-resilient crop varieties and stress-tolerant germplasm along with corrective measures to cover at least 50% of vulnerable areas by 2030.
- Expand irrigation coverage to 60 Mha with a strong focus on water-use efficiency and sustainable resource management.
- Develop district-level Climate Risk Atlases to enable targeted and region-specific interventions.
- Strengthen soil health management to restore about 5 Mha of degraded land by 2030.
- Integrate evidence-based policy evaluation frameworks for better decision-making.
- Establish 1000 climate-smart villages in vulnerable districts to promote participatory adaptation and community-led resilience.

1. Background

Agriculture remains the backbone of India's food, nutritional and livelihood security, supporting nearly half the population and contributing about 18.3% to the national GDP. As a multi-sectoral system covering crops, horticulture, livestock, fisheries and forestry, it plays a central role not only in food supply but also in employment, rural incomes and ecological stewardship. Despite its demographic importance, the sector's share in GDP has gradually declined with economic diversification, while more than 47% of the population still depends on agriculture for livelihood, increasing overall exposure to production and income shocks. The socio-institutional fabric further shapes vulnerability: over 85% of Indian farmers are small or marginal, many facing limited education, indebtedness and poor access to irrigation, inputs and credit. Institutional intermediaries such as KVKs are pivotal for technology dissemination, but they are often under-resourced, and many promising innovations struggle to scale due to unstable financing.

Current Vulnerabilities

India cultivates ~180.11 Mha, of which 43 Mha are fully irrigated, 23 Mha partially irrigated and 68% of the cultivated area remains drought-prone (DA&FW, 2023). Such a large dependence on rainfed agriculture heightens susceptibility to weather variability. Simultaneously, about 146.7 Mha ~ 44% of the country's total land area is degraded, largely through water erosion that removes nutrients, lowers soil productivity and accelerates reservoir siltation (Bhattacharyya et al., 2015). Soil fertility challenges further aggravate the situation. Imbalanced fertilizer use and an overreliance on subsidized NPK formulations have reduced soil organic matter and led to widespread deficiencies of micronutrients such as zinc, boron and sulfur (Das et al., 2022). Results from the Soil Health

Card Mission indicate that more than 70% of soils are either acidic or alkaline and that 55–60% contain low soil organic carbon, pointing to systemic nutrient imbalances and declining soil health. Mechanization levels in India is still limited (≈47% compared with over 75% in several developed agricultural economies) (Singh, 2020). Mechanization levels also remain skewed (generally lesser in abiotically stressed areas), hampering timeliness and field efficiency leading to higher yield penalties particularly during shortened or unpredictable weather windows and labour shortage scenarios. About 69% of India's landholdings are marginal (<1 ha), and fragmented ownership combined with low access to capital, limits the adoption of climate-resilient and resource-efficient technologies (Das et al., 2022). While livestock, poultry and fisheries now contribute >35% to agricultural GDP (2021–22), supporting infrastructure, veterinary services, cold chains and extension systems is frequently inadequate. Rising input costs, market volatility and inconsistent extension support further contribute to chronic stress on farm viability. In essence, the current status of the sector reflects a convergence of ecological degradation, resource constraints and institutional bottlenecks that collectively reduce the system's adaptive capacity.

2. The Abiotic Stress Challenge

Agricultural productivity in India is significantly constrained by interacting abiotic and biotic stresses. Abiotic stresses like drought, heat, cold, salinity, flooding, acidity and erosion, create yield gaps that frequently exceed 50% of potential productivity, while biotic stresses from pests, diseases and weeds add another 20–30% loss (Anderson et al., 2016). Climate change is intensifying these pressures by increasing the frequency and severity of heat waves, prolonged dry spells, erratic rainfall, cyclones and other extreme events (DA&FW, 2023). Land degradation—particularly water erosion remains the dominant environmental constraint across many regions and accounts for a major share of India's degraded geographical area, contributing to nutrient loss, reduced productivity and siltation of water bodies (NAAS, 2017). Importantly, these stresses are not static. They vary across space and time, shifting with monsoon patterns, agroecological conditions and seasonal cycles causing yield reduction and losses and is not limited to the tabulated overview as given under Table1 (stress type-wise), 2 (crop-wise).

Table 1: Estimated yield losses due to abiotic stresses in India

Abiotic Stress Type	Area Affected (Million ha)	Yield Loss (%)	Primary Affected Crops	References
Drought	~68 % of cultivated area drought-prone (95 Mha)	30 to 50	Rice, wheat, pulses, coarse cereals	Deptt. of Agriculture & Farmers Welfare (2023); Anderson, Johansen, & Siddique (2016)
Heat Stress	~ 45 to 60 Mha in Indo-Gangetic and central plains vulnerable	15 to 25	Wheat, mustard, chickpea, vegetables	IPCC (2022); IJOEAR (2024)
	Heat stressed areas	50 25-35	Livestock (milk) Poultry (Egg)	
Salinity & Alkalinity	~ 6.73 Mha salt-affected land (CSSRI data)	20 to 40	Rice, wheat, cotton, sugarcane	Tyagi (2016, CSSRI); Prevention Web (2023)
Waterlogging & Flooding	~8 to 12 Mha chronically waterlogged (CWC & IIWM)	25 to 45	Rice, pulses, vegetables	Central Water Commission (2012, 2023); Ahmed (2012)

Cold Stress / Frost	~5 to 8 Mha in northern and hill regions	10 to 30	Wheat, potato, vegetables, horticultural crops	DA&FW (2023); IPCC (2022)
Nutrient Deficiency / Poor Soil Health	~ 120to140 Mha degraded or nutrient-deficient (37 % of total land)	10 to 20	All major crops	NAAS (2017); Das et al. (2022)

Table 2: Crop-specific yield reductions due to abiotic stresses

Crop	Baseline Yield (t ha^{-1})	Projected / Observed Yield (2030s – 2080s)	Yield Loss (%)	Key Stress Factors	Reference
Rice (Irrigated)	2.2 (1976 to 2005 baseline)	-3 % (2020); -2 to -5 % (2050–2080 RCP 2.6–8.5)	-2 to -5 %	Heat, drought, rainfall variability	Kumar et al., 2019
Rice (Rainfed)	2.13 (1976 to2005 baseline)	-20 % (2050); -47 % (2080 RCP 8.5)	-20 to -47 %	Drought, heat, salinity	Kumar et al., 2019
Rice (North India)	6.3 to 7.7 (range)	Decline to 6.0 by 2050 (Approx.)	-5 to -15 %	High temp. during reproductive stage	Singh et al., 2017
Wheat (Projected)	3.2 to 3.5	-8 to -19 % (2050); -18 to -41 % (2080 RCP 4.5–8.5)	-8 to -41 %	Terminal heat, moisture stress	Kumar et al., 2019
Wheat (2022 Heatwave)	3.3 (2021 to 22 avg.)	-10 to -25 % (Punjab–Haryana)	-10 to -25 %	Terminal heat, early maturity	CRIDA, 2022; CGIAR, 2022
Maize	2.9 to 3.0	-10 to -18 % (2022 heatwave Punjab–MP)	-10 to -18 %	Heat, drought, FAW attack	CRIDA, 2022
Chickpea (Pulses)	0.9 to 1.1	-19 to -35 % (heat & drought episodes)	-20 to -35 %	Heat, drought	CRIDA, 2022
Sugarcane	70 to 80	-20 to -37 % (drought, salinity, waterlogging)	-20 to -37 %	Drought, salinity, waterlogging	SBI, 2024
Vegetables (Horticultural Crops)	Variable (10 to 25)	-25 to -50 % (heat, frost, flooding)	-25 to -50 %	Heat, cold, flooding	CRIDA, 2021; IPCC, 2022
Green Gram (Moong)	0.8 to 1.0	-15 to -20 % (2022 heatwave)	-15 to -20 %	Heat, whitefly infestation	CRIDA, 2022

Spatial extent of the abiotic stresses

The spatial extent of the major abiotic stresses as listed in Table 3 and 4 reverify the important of addressing it on priority. The spatiotemporal variability of the abiotic stresses make it increasingly difficult for farmers and institutions to rely on traditional knowledge alone for risk management. It also underscores the need for advanced modelling frameworks capable of integrating weather, soil, water and crop data to track stress dynamics and generate location-specific advisories. As climate extremes intensify and stress interactions become more complex, building such predictive and adaptive capacities becomes central to India's broader strategy for climate resilience and sustainable agricultural growth.

Table 3: State-Wise Distribution of Major Abiotic Stresses.

State/Region	Primary Abiotic Stress	Major Crops Affected	Projected 2050 Impact
Rajasthan	Drought, Heat, Salinity	Pearl Millet, Pulses, Mustard	Increased temperature, yield reduction
Maharashtra	Drought, Heat	Cotton, Soybean, Pulses	Increased drought frequency, heat stress
Punjab & Haryana	Waterlogging, Salinity, Heat	Rice, Wheat	Salinity expansion, groundwater issues
Uttar Pradesh	Waterlogging, Salinity, Frost	Rice, Wheat, Sugarcane	Rainfall variability, heat stress
Bihar	Flooding, Drought, Heat	Rice, Wheat, Maize	Heat stress, rainfall extremes, yield loss
Tamil Nadu	Drought, Salinity (coastal)	Rice, Pulses, Cotton	Drought vulnerability, water scarcity
Gujarat	Salinity (coastal), Drought	Cotton, Groundnut, Wheat	Salinity, erratic rainfall
Odisha	Flooding, Cyclones, Salinity	Rice, Pulses	Cyclone damage, coastal vulnerability
Madhya Pradesh	Drought, Heat	Rice, Wheat, Pulses, Oilseeds	Rainfall variability, heat stress
North-East States	Flooding, Soil Acidity, Erosion	Rice, Maize, Horticulture	Heavy rainfall, soil degradation
Himalayan States	Cold Stress, Frost, Erosion	Wheat, Potato, Horticulture	Erratic snowfall, frost damage

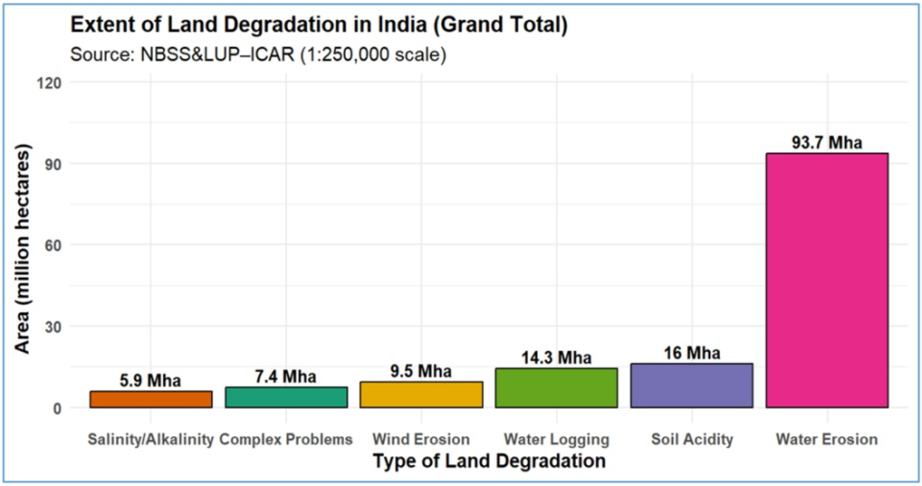
Source: (Rao et al., 2022; Sahana & Mondal, 2023; Balaganesh et al., 2020; Tesfaye et al., 2017; Jha et al., 2021)

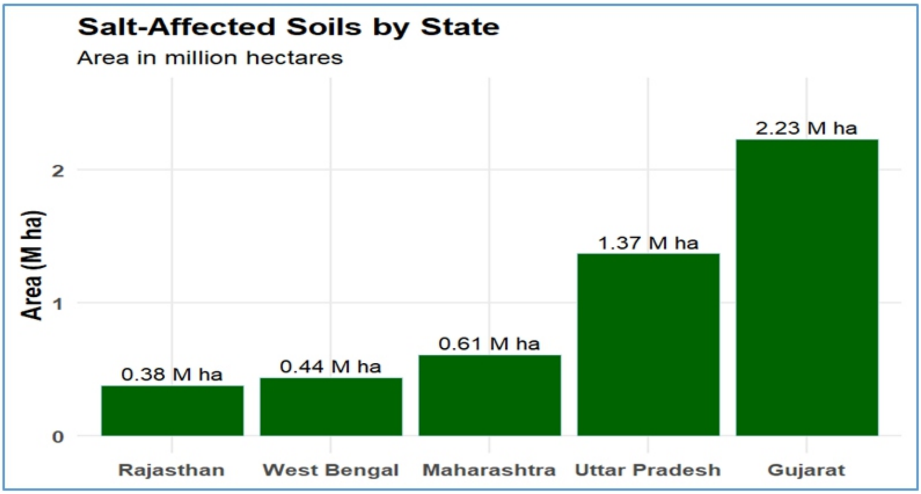
Table 4: Area affected by different abiotic stresses in India.

Abiotic Stress Type	**Area (Mha)**	**References**
Drought-prone Area	68	Tyagi et al., 2020
Waterlogging	14	Kumar & Sharma, 2020
Degraded Land	147	Bhattacharyya et al., 2015; Kumar & Sharma, 2020
Salinity & Alkalinity	6.7–7.3	Kumar & Sharma, 2020; Arulmathi & Porkodi, 2020
Nutrient Deficiency	widespread but not mapped as a distinct area	Bhattacharyya et al., 2015; Kumar & Sharma, 2020

Edaphic Stresses

The total land area affected by degradation in India is estimated at 146.8 Mha, reflecting a major constraint to sustainable agricultural productivity. Water erosion is the most dominant form, accounting for 93.7 Mha, followed by soil acidity (16.0 Mha) and waterlogging (14.3 Mha). Other forms such as wind erosion (9.5 Mha), salinity/alkalinity (5.9 Mha) and complex degradation issues (7.4 Mha) also contribute significantly. (Bhattacharyya et al., 2015; Mythili and Goedecke, 2016; CSSRI, 2016). The predominance of water erosion highlights the critical need for soil and water conservation strategies, particularly in rainfed and hilly regions, while problems like salinity and acidity require region-specific



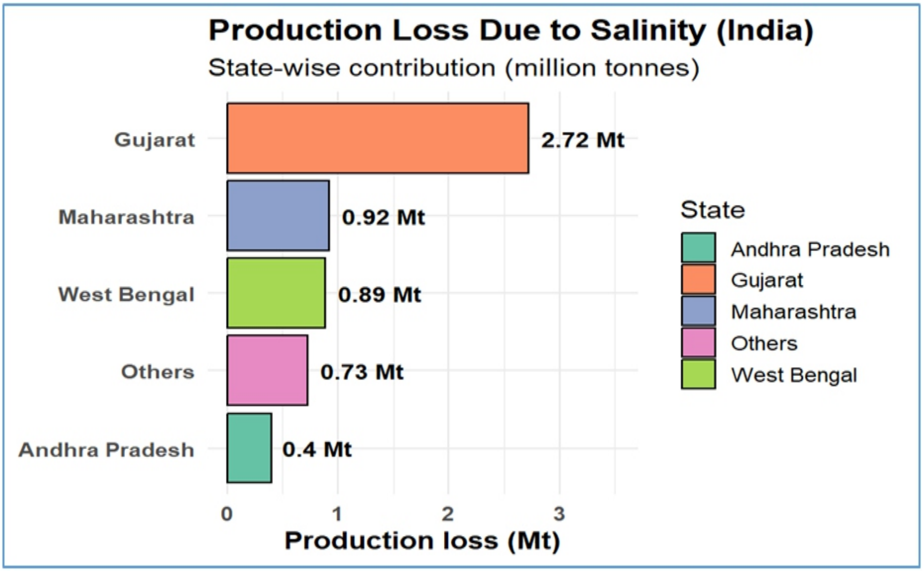


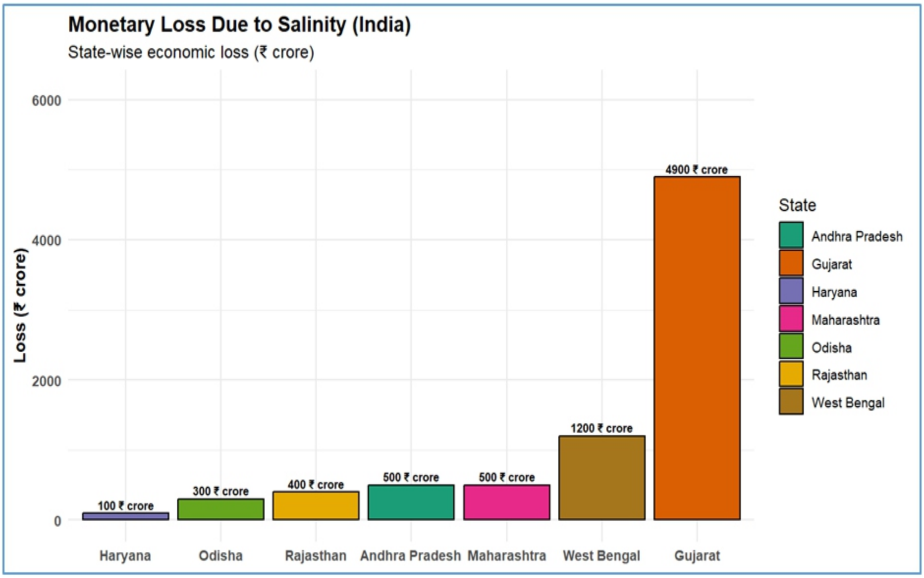
reclamation and nutrient management interventions. India has about 6.73 million ha of salt-affected soils, with nearly 75% of the salt-affected area is concentrated in Gujarat (2.23 Mha), Uttar Pradesh (1.37 Mha), Maharashtra (0.61 Mha), West Bengal (0.44 Mha) and Rajasthan (0.38 Mha).

Production and Monetary Losses Due to Salinity

Salinity poses a significant challenge to agricultural productivity in India. According to estimates from ICAR-CSSRI, salinity leads to a loss of nearly 5.66 million tonnes of crop production annually at the national level, which corresponds to an economic loss of around Rs. 80,000 million (Rs. 8,000 crore) (Sharma et al. 2016). A state-wise analysis shows that Gujarat experiences the maximum production loss (2.72 M t), followed by Maharashtra (0.92 M t), West Bengal (0.89 M t) and Andhra Pradesh (0.40 M t). In monetary terms as well, Gujarat incurs the highest loss of about Rs. 49,000 million, followed by West Bengal (Rs. 12,000 million), Maharashtra and Andhra Pradesh (each Rs. 5,000 million (Approx.), Rajasthan (Rs. 4,000 million), Odisha (Rs. 3,000 million) and Haryana (Rs. 1,000 million). The adverse effects are also evident across crop types:

pulses sustain the greatest losses in Gujarat, followed by Rajasthan and West Bengal, while oilseed losses are highest in Gujarat, with smaller impacts observed in West Bengal, Rajasthan, and Maharashtra (ICAR-CSSRI, 2016).





Abiotic stress impacts Cross pronounced by other sectoral challenges

The cross sectoral challenges additionally amplify the impact of current abiotic stress challenge. They become more pronounced by fragmented policies, poor resource management, and limited technology integration as tabulated below that shows the core threat across crops, livestock, and fisheries sectors.

Table 5: Impact of current abiotic stress challenges intensified by other categories of challenges

Category of Challenge	Common Challenges & Impacts Across Sectors	Sector-Specific Examples
1. Mechanization and Labor Constraints	• National mechanization level ~47%; Punjab–Haryana (~75%) far exceed smallholder states. • Fragmented landholdings (~1 ha average) and declining rural labor (<40% workforce) limit timely operations. • Custom-hiring services, FPO machinery pools, and women's mechanization initiatives remain underdeveloped. • Repair, training, and service infrastructure are inadequate.	- **Crops:** Low mechanization (<45%) delays harvests, especially in pulses and millets. - **Livestock/Fisheries:** Minimal mechanized feeding, cooling, or aeration systems.
2. Infrastructure and Technology Gaps	• Poor storage, processing, and cold chain infrastructure across sectors. • Weak adoption of precision agriculture, IoT, and digital tools due to cost and training barriers.	- **Crops:** 10–15% post-harvest losses due to weak logistics. - **Livestock:** Poor cooling facilities reduce milk quality. - **Fisheries:** Inadequate cold chains and hatchery systems.
3. Policy and Institutional Gaps	• Sectoral programs operate in silos — e.g., PMKSY (irrigation), NMSA (watershed), IWMP (soil) lack integration. • Disconnected input and sustainability policies — fertilizer subsidy not aligned with soil health goals. • Absence of national land-use policy, weak coordination between weather advisories, insurance (PMFBY), and extension. • Limited coverage of weather-index insurance and credit for climate-proofing smallholders.	- **All sectors:** Fragmented governance leads to inefficient stress management and limited cross-sectoral convergence.
4. Market and Value Chain Issues	• Price volatility, lack of MSP for horticulture and animal products, weak cold chains, and poor aggregation reduce profitability.	- **Horticulture & Fisheries:** Price crashes and perishability losses. - **Livestock:** Milk and meat marketing unorganized.

5. Knowledge and Extension Gaps	• Research–adoption divide: stress-tolerant varieties and conservation practices not widely used. • Weak feedback loops between farmers, KVKs, and R&D systems. • Limited awareness of sustainable soil and water management.	- **Crops:** Poor uptake of climate-resilient genotypes. - **Livestock:** Low awareness of cooling and nutritional stress mitigation. - **Fisheries:** Limited capacity on water quality and climate-risk management.
6. Socio-Economic Vulnerabilities	• 86% of farms under 2 ha; low income, limited insurance, and low adaptive capacity. • Gender inequities in mechanization and credit access persist.	- **All sectors:** Small and marginal producers most exposed to shocks; women farmers under-supported.

3. Technologies for Stress Management in Indian Agriculture

India has developed a diverse set of climate-resilient, biological, and digital technologies for managing abiotic stresses. Following tables summarizes its Primary Function / Application; Key Benefits / Impact; Current Adoption / Status; Constraints / Gaps and Lead Implementing Agencies / Supporting Schemes by Government of India.

Table 6. Existing Technologies for Abiotic Stress Management in Indian Agriculture

Technology / Intervention	Primary Function / Application	Key Benefits / Impact	Current Adoption / Status	Constraints / Gaps	Lead Implementing Agencies / Supporting Schemes
Stress-Resilient Crop Varieties	Drought, flood, salinity and heat tolerance in cereals, pulses, oilseeds, millets.	• Yield stability (1–3 t/ha advantage). • Key examples: *Sahbhagi Dhan*, *Swarna-Sub1*, *HD-3086*.	Widely deployed in eastern, coastal, and semi-arid regions via ICAR–SAU networks.	Limited seed access, weak extension, regional adaptation issues.	ICAR, SAUs, National Innovations in Climate Resilient Agriculture (NICRA), National Food Security Mission (NFSM).
Plant Growth Regulators (PGRs)	Regulate plant physiology under drought, salinity, and heat stress.	• Improves root growth, antioxidant defense, and photosynthesis. • Salicylic acid enhances drought tolerance.	Used in cotton, fruits, and vegetables; trials expanding to cereals.	High cost, need for precise application, low farmer awareness.	ICAR institutes, State Horticulture Missions, RKVY (for input support).
Biofertilizers (*Rhizobium*, *Azotobacter*, Mycorrhiza)*	Enhance nutrient uptake, soil health, and stress resilience.	• Improve N fixation, P solubilization, soil structure; sustain yields under drought/salinity.	Expanding under organic and sustainable farming programs.	Quality inconsistency, limited shelf life, low extension outreach.	NMSA, Paramparagat Krishi Vikas Yojana (PKVY), RKVY, NMOOP, ICAR-NBSS&LUP.

Biopesticides (*Trichoderma*, *Bt*, neem extracts)*	Eco-friendly pest/disease control under stress conditions.	• Induce systemic resistance, protect stressed crops, reduce residues.	Used in horticulture, cotton, and pulses.	Slower action, product quality variation, limited training.	Central Insecticides Board & Registration Committee (CIBRC), ICAR-NBAIR, NMSA, NABARD bio-input projects.
Soil Test-Based Nutrient Management (STBNM)	Optimize fertilizer use based on soil diagnostics (4R principle).	• Enhances nutrient-use efficiency, reduces input costs, improves drought tolerance.	Implemented via Soil Health Card Scheme and KVK demonstrations.	Low lab coverage, awareness gaps, inadequate extension follow-up.	DAC&FW, ICAR-NBSS&LUP, SHC Scheme, RKVY.
Seed Treatment / Priming	Chemical/biological pre-sowing treatment for vigor and stress tolerance.	• Improves germination, seedling vigor, and pathogen resistance.	Common in cotton, maize, pulses; growing via private sector.	High cost, variable efficacy, low smallholder access.	State Seed Corporations, NSC, ICAR institutes, Seed Village Programme (MoA&FW).
Water Management Technologies (Drip, Sprinkler, Rainwater Harvesting)	Efficient irrigation and water conservation.	• 20–30 % yield increase, 25–50 % water savings.	Adopted under micro-irrigation projects; wider uptake in Gujarat, Maharashtra, Tamil Nadu.	High cost, maintenance, subsidy delays.	PMKSY, NMSA, State Micro-Irrigation Missions, NABARD RIDF.
Smart / Precision Irrigation (IoT, Sensors)	Automated, data-driven irrigation scheduling.	• Improves water efficiency, stabilizes yields, reduces energy use.	Pilots in select ICAR/KVK clusters; early adoption by FPOs.	High capital cost, technical know-how barriers.	ICAR-IIT-Kharagpur Precision Agri Lab, Digital India Agritech Mission, PMKSY Phase II pilots.
Mechanization (Farm Machinery, CHCs)	Improve timeliness and reduce labour drudgery.	• 10–20 % higher productivity; 15 % lower labour cost.	National mechanization ~45 %; CHCs expanding in most states.	Small landholdings, low repair networks, credit access limits.	Sub-Mission on Agricultural Mechanization (SMAM), Custom Hiring Centres Scheme, RKVY.
Precision Agriculture (IoT, GPS, AI, Drones)	Optimize resource use and stress monitoring.	• Water savings (~18 %), fertilizer accuracy (≈98 %), improved decision-making.	Drone spraying supported under GoI programs; pilots expanding in states.	High technology cost, limited training, smallholder scale barriers.	Digital Agriculture Mission (2021–26), ICAR–NAARM AI4Ag Initiative, MoA&FW Drone Subsidy Scheme.

India possesses a strong technological foundation for abiotic stress management—spanning resilient genetics, bio-inputs, nutrient and water precision tools, and mechanization. However, adoption remains uneven due to cost, quality assurance, and institutional gaps. Greater coordination among ICAR, DAC&FW, SAUs, and state missions, coupled with targeted credit, digital support, and localized extension, is essential to achieve scale and equity in stress-resilient farming.

4. Factors Influencing the Adoption and Non-Adoption of Abiotic Stress Management in Indian Agriculture

The adoption of technologies to manage stresses in Indian agriculture is crucial for India's food and livelihood security. Such stresses cause 51–82% of global yield losses, with India's rainfed systems being especially vulnerable (Yadav et al., 2023). Technologies like stress-tolerant varieties, precision farming, and improved water management offer resilience, but adoption depends on institutional, economic, technological, socio-cultural, environmental, and political factors. Farmer capacity is shaped by resource access, landholding size, knowledge, credit, and risk-bearing ability. Government programmes such as DPAP, DDP, and NWDPRA (1970–1990s) initiated integrated watershed approaches, later consolidated into IWMP (2009–10) and PMKSY (2015) to expand irrigation and improve water-use efficiency. NICRA developed digital vulnerability maps (cyclone, flood, drought, exposure and sensitivity indices) guiding national stress mitigation efforts.

Institutional Factors

Institutions like ICAR–NARS and SAUs have released 1,956+ stress-tolerant varieties (e.g. SUB1 rice, salinity-tolerant lines). Yet adoption remains low due to weak extension networks, limited coordination, and absence of centralized data. Schemes such as Rainfed Area Development (RAD) (7.13 lakh ha coverage) and PMKSY micro-irrigation (benefiting 22 lakh farmers) illustrate progress. FPOs and KVKs help bridge outreach gaps but have limited reach. Institutional effectiveness, extension contact, and market conditions strongly influence participation in watershed programmes. *Example studies:* NMSA promotes climate-resilient practices; ATMA improves dissemination.

Economic Factors

High initial costs limit adoption among 87% small and marginal farmers (avg 1.08 ha). Technologies like precision irrigation and drainage remain expensive despite subsidies. Strawponics in saline regions lowers costs and yields > 6 t/ha garlic (Yadav et al., 2023). Credit access remains weak. Adoption rises with low-cost innovations and targeted subsidy schemes (PMKSY, NABARD support).

Technological Factors

Adoption depends on complexity, cost, and local compatibility.

- Subsurface drainage increases rice–wheat yields by 328–465% (Haryana) but faces maintenance barriers (Mukhopadhyay et al., 2023).
- PSSD systems reduce salinity by 49% and raise pearl millet yield by 23.5% (Neha et al., 2022).
- Grafting vegetables improves stress tolerance, boosting yield 20–30%, but grafting is labourious and costly.
- Drip irrigation improves water-use efficiency but faces issues of poor dripper quality and maintenance (Hiremath & Makadia, 2021). Short-duration, stress-tolerant crops (e.g. summer mungbean) expanded from 4% to 22% area (2017–2022) (Ram et al., 2016). Biochar from pigeon pea stalk improves soil carbon (Venkatesh et al., 2022). However, IoT-based precision farming remains inaccessible to smallholders.

Socio-Cultural Factors

Traditional practices and risk aversion delay technology uptake. Peer influence boosts adoption by 10–15% (Bandiera & Rasul, 2006). Gender gaps persist, women contribute 70% of farm labour but have poor access to credit and machinery (Subathra et al., 2020). Education and farm size positively correlate with adoption (Singh et al., 2011). Engaging youth through training and entrepreneurship can accelerate technology diffusion.

Environmental Factors

Abiotic stress varies by zone, salinity affects 6.73 Mha causing 16.84 Mt yield loss (₹ 230 billion) annually (Basak et al., 2022). Drought affects 68% of cultivated land, with 33% chronically drought-prone (< 750 mm rainfall). Poor groundwater quality hinders salt leaching. Region-specific adaptation technologies are essential to sustain productivity.

Political Factors

Strong policy support and infrastructure investment enable scaling of stress-mitigation technologies. Custom-hiring centres, PPPs, and cooperative farming reduce costs for smallholders. Credit, subsidies, and training enhance adoption (NITI Aayog, 2023). Conservation programmes focusing on river basins and watersheds must integrate farm-level innovation clusters to improve adoption and diffusion.

Despite robust institutional and technological progress, adoption of abiotic stress management technologies in India remains uneven due to high costs, weak extension, fragmented policies, and socio-cultural barriers. Strengthening local institutions, integrating credit and knowledge systems, and promoting region-specific, affordable technologies are key to scaling climate-resilient agriculture.

5. Existing Agricultural Policies in India

The Indian government is implementing the inclusive framework of policies and programs to address abiotic stresses in agriculture. These initiatives address the multifaceted challenges posed by climate change, water scarcity, soil degradation, and other environmental stressors affecting agricultural productivity. These initiatives span across quality and timely inputs, water management, soil health, mechanization, sustainable practices, and insurance or financial support. The integrated approach combining technological innovation of NARS, financial assistance, and institutional support in the form of KVKs and State departments provides a robust foundation for climate-resilient agriculture. The success of these programs primarily depends on effective implementation, farmer participation, and continuous adaptation to emerging challenges.

Table 7: Existing Agricultural Policies of Government

Name of Scheme/ Programme	Beneficiary Criteria	Benefits Offered	Impact Observed	Current Status of Implementation	Constraints in Implementation
Pradhan Mantri Dhan-Dhaanya Krishi Yojana (PMDDKY)	Farmers in 100 selected "underperforming" / aspirational districts; priority to small & marginal farmers (embedded within the 36 sub-schemes across 11 ministries)	– Infrastructure improvement (irrigation, storage, post-harvest, cold chains) – Crop diversification support – Facilitation of long-term and short-term credit – Integration of 36 sub-schemes under one umbrella – Strengthening of value chains at panchayat / block levels	NA	Launched on 11th Oct., 2025	NA

Mission for Self-Reliance in Pulses ("Self-Reliance in Pulses Mission")	Pulse growers across the country; states with potential for expansion of pulses cultivation in the 100 selected districts	– Improved productivity of pulses (via seeds, technologies) – Expanding area under pulses – Strengthening value chain: procurement, storage, processing – Reducing post-harvest losses – Possibly subsidies / incentives for pulses processing and quality improvement	NA	Launched on 11th Oct., 2025	NA
Pradhan Mantri Krishi Sinchayee Yojana (PMKSY)	All farmers; Small and marginal farmers get priority with 55% subsidy, others get 45%	End-to-end irrigation solutions; 55% subsidy for small/marginal farmers, 45% for others	NA	Operational since 2015; 83.46 lakh hectares covered under micro-irrigation	NA
Per Drop More Crop (PDMC)	Small and marginal farmers (priority), all farmers eligible	Financial assistance for drip and sprinkler irrigation; 83.46 lakh hectares covered	NA	Implemented under RKVY from 2022-23; Component of PMKSY	NA
Soil Health Card Scheme	All farmers across the country	Soil health information every 3 years; Customized fertilizer recommendations; Cost savings in fertilizer use	Net income increased by 9.38%; Benefit-cost ratio 1:1.98 in wheat; 20-30% reduction in urea and DAP use	Operational since 2015; 23.58 crore cards distributed; 8,272 soil testing laboratories	Delayed receipt of results; Poor infrastructure and human resources; Samples not collected in farmers presence; Lack of extension services
Pradhan Mantri Fasal Bima Yojana (PMFBY)	All farmers (voluntary since 2020); Previously mandatory for loan availing farmers	Crop insurance coverage; Farmers pay 1.5-5% premium, govt pays 95%+	Low claim ratios during normal seasons; Several states withdrew	Several states withdrew (Gujarat, Bihar, West Bengal, Andhra	Financial constraints of states; Low claim ratios; Delayed claim settlements; Lack of

			due to financial constraints	Pradesh, Telangana, Jharkhand); Maharashtra threatened withdrawal	awareness; Complex procedures; Official bias in loss assessment
PM-KISAN Samman Nidhi	Small and marginal farmers with cultivable land in their name; Family definition: husband, wife, minor children	₹6,000 annual income support in 3 installments of ₹2,000 each	Covers 9.51 crore farmers; Direct benefit transfer; Irregularities in beneficiary identification noted	Operational; 9.51 crore beneficiaries; Issues with beneficiary verification noted	Inadequate self-declarations; No mechanism to verify income tax payers; Multiple beneficiaries from same family; Minors receiving benefits
Digital Agriculture Mission	All farmers (target: 11 crore farmers by 2026-27)	Digital identity for farmers; Crop monitoring; Real-time advisories; ₹2,817 crore outlay	Pilots conducted in 6 states for Farmer IDs; 12 states for crop survey; 19 states signed MoUs	Approved September 2024; Implementation starting; 19 states signed MoUs	Fragmented landholdings; High initial costs; Lack of digital literacy; Inadequate rural infrastructure; Language barriers
National Mission for Sustainable Agriculture (NMSA)	All farmers, especially in rainfed areas with irrigation ≤30% of cultivated area	Integrated farming systems; Water use efficiency; Soil health management; Resource conservation	NA	Operational since 2014-15; Implementation through various components	NA
Sub-Mission on Agricultural Mechanization (SMAM)	All farmers, Self Help Groups, User Groups, Cooperative Societies, FPOs, Entrepreneurs; 50% allocation for small and marginal farmers; 30% for women	Subsidies 50-80% on agricultural machinery; Custom hiring centers; Training programs	Current mechanization: 47% overall; Wheat: 69%, Rice: 53%, Maize: 46%	Operational since 2014-15; Implemented across all states	NA

Paramparagat Krishi Vikas Yojana (PKVY)	Farmers in groups (20-hectare clusters); Maximum 2 ha per farmer	₹31,500 per hectare for 3 years; Organic certification; Cluster approach	8.41 lakh hectares under organic farming; 1.53 lakh hectares in NE region	Operational since 2015-16; 6211 clusters formed; Slow progress in fund utilization	Slow fund release; Non-compliance with new guidelines; Low actual expenditure vs budget estimates; States unable to provide required documents
National Mission on Natural Farming (NMNF)	Target: 1 crore farmers in 15,000 clusters	Support for chemical-free farming; Bio-input centers; Traditional practices promotion	Newly approved in 2024 - Impact data not yet available	Approved in 2024; Implementation beginning	Newly approved - Implementation constraints not yet identified
Mission Organic Value Chain Development for North Eastern Region (MOVCDNER)	Farmers in North Eastern states only	Organic cultivation support; Processing facilities; Collection units	1.53 lakh hectares; 189,039 farmers; 379 FPOs/FPCs; 394 collection units	Operational; ₹1,150.09 crore released as of June 2024	NA
Bharatiya Prakritik Krishi Paddhati (BPKP)	Farmers following natural farming practices	Zero-budget natural farming; On-farm biomass recycling; Livestock integration	NA	Component under PKVY; Implementation ongoing	NA
Kisan Credit Card Scheme	All farmers with cultivable land	Affordable credit; Flexible repayment; Comprehensive coverage	NA	Operational; Linked with PM-KISAN for streamlined access	NA
Micro Irrigation Fund	States availing micro-irrigation projects	₹5,000 crore fund; 3% interest subvention	NA	Established with NABARD; ₹5,000 crore fund available	NA

Modernization of Command Area Development and Water Management (M-CADWM)	States implementing Command Area Development projects	₹1,600 crore outlay; Underground piped irrigation; SCADA and IoT technology	Approved in 2025 - Impact data not yet available	Approved in 2025; Implementation beginning	Newly approved - Implementation constraints not yet identified
National Livestock Mission (NLM)	Individual farmers, SHGs, FPOs, state governments; across poultry, sheep, goat, piggery sectors	• Breed development & entrepreneurship support • Incentives for fodder seed production, feed & fodder units • R&D, extension, livestock insurance, innovation support • Strengthening feed/fodder supply chain	• Some improvements in breed multiplication farms • Greater awareness of fodder block units • Enhanced productivity in pilot areas (state-wise) (less publicly aggregated data)	Operational since 2014-15 under revised form from 2021–22	• Low adoption in remote areas • Insufficient extension reach • Inadequate coordination among state and central agencies • Difficulty in scaling infrastructure for feed/fodder • Insurance uptake low • Capital subsidy and credit limitations
Bharat Pashudhan (Digital Ecosystem for Livestock)	Livestock farmers and stakeholders linked via DAHD / NDDB network (poultry, cattle, etc.)	Digital platforms for livestock records, extension, traceability, advisory services (veterinary, nutrition)	Still nascent; digital records improving traceability and access to services (pilot states)	Being rolled out as technology support arm under DAHD / NDDB	Digital infrastructure gaps, farmer digital literacy, connectivity in rural areas
Livestock Insurance Schemes (e.g. “Livestock Shield”)	Livestock owners (cattle, goats, sheep, etc.)	Financial protection / claims for death due to disease, accidents	Some states report uptake; practical protection for farmers against risk	Operates in combination with state animal husbandry schemes; promoted under NLM’s insurance sub-mission	Low awareness, administrative claim processes, under-coverage, premium affordability

Pradhan Mantri Matsya Sampada Yojana (PMMSY)	Fishers, fish farmers, fish workers, SHGs, cooperatives, private entrepreneurs, SC/ST/Women in fisheries sector	• Support for pond/cage/hatchery construction, brood banks, aeration, sensors • Infrastructure: landing centers, cold chains, processing, traceability • Subsidies, credit-linked assistance, regulatory strengthening • Welfare: insurance, livelihood support during fishing ban periods	• Projects worth ~ ₹14,654.67 crore approved from 2020-21 to 2022-23 Reduction in post-harvest losses in pilot areas (target from 20–25% to ~10%) Employment generation in fish farming • Better value chain infrastructure and market linkages in some states	Active since 2020; flagship scheme for fisheries under DOF / NFDB	• Disparity in uptake across states •Infrastructure and maintenance challenges • Matching state contributions and coordination • Insurance claims processing • Technical capacity constraints, especially in remote regions • Ensuring environmental sustainability and biodiversity protection
Pradhan Mantri Matsya Kisan Samridhi Sah-Yojana (PMMKSSY) (sub-scheme under PMMSY)	Micro and small enterprises in fisheries sector, fish farmers, fishers, vendors, processors	• Formalization through digital identity (National Fisheries Digital Platform) • One-time incentive for aquaculture insurance • Performance grants for value-chain improvement, safety/quality systems	Yet to be fully evaluated; expected to improve formal sector coverage and insurance uptake	Approved with budget ~ ₹6,000 crore for FY 2023-24 to FY 2026-27	Implementation complexity, digital infrastructure gaps, capacity building needs, alignment with PMMSY
Rashtriya Gokul Mission	Indigenous bovine breed owners, breeders, state agencies	Conservation and genetic improvement of indigenous cattle, establishing Gokul centers, semen banks, breeding infrastructure	Improved breed conservation, slow but growing adoption of higher-yielding indigenous breeds	Ongoing under DAHD / National programs	Funding and infrastructure constraints, low farmer awareness, state coordination gaps

6. Policy Recommendation Gaps

Lack of integrated policies

Soil, water, crop, and climate policies in India continue to operate in isolation, reducing the effectiveness of resilience initiatives. For instance, there is no unified Soil Health and Land Use Policy to harmonize fertilizer management, soil conservation, and carbon sequestration objectives. Watershed and irrigation programmes function through separate administrative channels, while climate adaptation remains marginally integrated into agricultural planning. As a result, national targets such as restoring 26 Mha of degraded land by 2030 lack a cohesive, cross-sectoral roadmap. The NAAS has therefore recommended establishing a National Land Use Policy to coordinate actions across states and institutional levels, ensuring sustainable land governance and inter-sectoral synergy.

Regulatory shortfalls

Persistent regulatory inertia has resulted in gaps in pesticide and input governance. The widespread off-label use of pesticides indicates weak enforcement and outdated approval mechanisms. NAAS recommends harmonizing India's Maximum Residue Limits (MRLs) with Codex Alimentarius standards and adopting a crop-grouping approach for pesticide approvals to minimize residue risks. Moreover, novel inputs such as exogenous dsRNA biopesticides lack clear regulatory classification, impeding innovation despite NAAS's suggestion to recognize dsRNA as a biochemical pesticide with specific risk-assessment protocols. Similarly, gene-edited crops remain outside a dedicated policy framework, while bio-inputs like biostimulants are under-regulated, creating concerns about product quality, misuse, and farmer trust.

Institutional and resource gaps

The agricultural support ecosystem faces critical human resource shortages, especially in engineering and veterinary services at the grassroots. NAAS emphasizes the need for deploying agricultural engineers at each Krishi Vigyan Kendra (KVK) and panchayat, alongside creating a National Institute on Agri-AI and Robotics to drive automation-led resilience. Disease surveillance and early warning systems are fragmented; strengthening border quarantine laboratories, field diagnostics, and veterinary training is essential to contain emerging biotic stresses and zoonotic threats.

Incentive misalignment

Existing subsidy frameworks often discourage long-term resilience. Fertilizer subsidies continue to favor excessive nitrogen use, aggravating nutrient imbalance and soil degradation. Similarly, water pricing mechanisms overlook scarcity and regional sustainability, while cropping programmes provide limited incentives for climate-resilient or drought-tolerant varieties. NAAS proposes a paradigm shift toward payments for ecosystem services (such as carbon sequestration and groundwater recharge), alongside repurposing subsidies to support soil health restoration, composting, and conservation agriculture practices.

Data and monitoring gaps

Policy decisions are frequently made without access to reliable, real-time data. NAAS calls for establishing a geo-spatial knowledge infrastructure that integrates soil, erosion, and climate data such as a National Soil Spectral Library and Land Degradation Atlases to enable evidence-based planning and targeted interventions. Without such integrated databases, prioritization of critical areas and impact assessment of restoration programmes remain largely empirical and reactive.

Strategic Framework

To bridge existing gaps, an Integrated Stress-Resilience Framework is proposed that aligns policy, technology, and finance. The framework emphasizes proactive monitoring, data-driven planning, sustainable practices, and institutional convergence for resilience building.

1. Risk Monitoring and Early Warning

- Establish a National Agro-Climatic Observatory integrating remote sensing, IoT, and GIS analytics for continuous monitoring of multiple stress factors.
- Develop high-resolution maps for erosion hotspots, saline and flood-prone zones, and low soil-carbon areas.
- Strengthen district-level drought and flood forecasting systems using enhanced weather codes and localized advisories.
- Expand digital pest and disease surveillance systems to deliver real-time alerts to farmers via mobile platforms.
- Reinforce state meteorological cells for pre-emptive action against local stress events.
- Integrate existing pest and abiotic stress forecasts into a National Agro-Stress Dashboard, with standardized SOPs linking advisories to insurers, extension networks, and state departments.

2. Data-Driven Stress Management Framework

A data-centric policy architecture is essential to predict, mitigate, and adapt to abiotic stresses.

- Establish a National Data-Driven Agro-Stress Management Mission integrating data from IMD, ISRO, CGWB, ICAR, and private networks into a unified platform.
- Link the platform with the Digital Agriculture Mission to provide:

  - Regional and crop-specific analytics on soil moisture, temperature, pest incidence, and climate variability.
  - Real-time decision dashboards for field officers and planners.
- Create a National Agro-Stress Observatory Network equipped with IoT-based field sensors, automated weather stations, and remote-sensing analytics for continuous field intelligence.
- Designate ICAR as the nodal coordination agency, operating an Abiotic Stress Information System (ASIS) aligned with the Agristack ecosystem.
- Integrate Krishi-DSS, Kisan Suvidha, and Pusa Krishi applications within scheme implementation frameworks to link digital data directly with farm-level interventions.
- Utilize the generated data for:
  - Dynamic subsidy targeting and prioritization of vulnerable zones.
  - Risk zoning under PMFBY and geotagging of scheme outcomes.
- Build capacity of KVKs, agricultural engineers, and extension officers in data literacy and analytical interpretation for actionable advisories.
- Institutionalize AI and ML-based multi-stress analytics for joint management of biotic and abiotic risks.
- Launch pilot projects in drought-prone districts to demonstrate economic and operational viability; scale up successful models under PM Dhan-Dhanya Krishi Yojana and NMSA.
- Formulate a National Policy on Data Governance for Agriculture to ensure:
  - Ethical use of data and privacy safeguards.
  - Interoperability across databases.

    - Open-access standards for all public-funded systems.

3. Soil–Water Management

- Promote climate-smart agriculture with focus on:
    - Conservation tillage, mulching, and integrated nutrient management to enhance soil organic carbon.
    - Rainwater harvesting and micro-irrigation (drip/sprinkler) in water-scarce regions under PMKSY.
- In flood-prone areas (NE region and Gangetic plains):
    - Implement drainage networks, biodrainage plantations, and raised-bed cropping systems.
- Encourage agroforestry and cover cropping on marginal lands for ecosystem stabilization.
- Adopt site-specific erosion control measures such as bunds, vegetative barriers, and check dams in reservoir catchments to extend dam life.

4. Resilient Cropping Systems

- Promote crop diversification from monocropping to resilient systems.
- Scale up millets, pulses, and legumes in suitable agro-ecological zones:
    - Millets: Rajasthan, Gujarat, Maharashtra, Haryana, and tribal areas of Chhattisgarh and Madhya Pradesh.
    - Pigeon pea and sorghum: Central plateau regions.
    - Nutrient-dense pulses: Rainfed plains.
- Support genomics, molecular breeding, and gene editing for developing stress-tolerant and nutrient-rich varieties.
- Strengthen seed systems through:
    - Seed hubs for pulses and millets.

- Quality planting material for horticultural crops.

5. Integrated Pest and Disease Management (IPDM)

- Promote biological and ecological pest control to minimize chemical dependency.
- Expand biopesticides and biostimulants, particularly dsRNA-based biopesticides as targeted GM-free solutions (as endorsed by NAAS).
- Harmonize MRLs with Codex standards and use crop-grouping for expanded pesticide approval coverage.
- Strengthen livestock disease surveillance through:
  - A National Veterinary Diagnostic Network with regional labs.
  - Standardized outbreak response protocols and vaccination campaigns.

6. Agri-Engineering and Mechanization

- Promote farm mechanization for stress adaptation and labor efficiency.
- Strengthen Custom Hiring Centers (CHCs) and FPO/SHG-based machinery co-operatives to improve equipment access for smallholders.
- Establish Agri-Engineering Departments at the state level and post agricultural engineers at block/KVK levels.
- Transition from purchase subsidies to service-based subsidies to incentivize shared machinery use.
- Encourage local manufacture through a PLI scheme for farm equipment under *Make in India*.
- Develop low-cost processing equipment for millets and pulses via PPP models.
- Establish repair and maintenance hubs (one per Panchayat)

through public–private partnerships.

7. Financial and Market Instruments

- Expand weather-index insurance (PMFBY) coverage to additional crops (including pulses).
- Link insurance premiums to ecosystem service credits such as carbon sequestration or soil conservation.
- Create dedicated stress-relief funds for climate or biosecurity emergencies (e.g., livestock diseases).
- Strengthen Price Stabilization Funds to cushion volatility, especially in pulses markets.
- Gradually restructure fertilizer and gas subsidies, diverting part toward:
    - Soil health inputs (compost, biofertilizers).
    - On-farm water management.
- Introduce Payment for Ecosystem Services (PES) and carbon-credit frameworks to reward farmers for conservation agriculture.
- Expand adaptation credit lines (solar pumps, drip systems, shade nets) linked to FPO-based financing.
- Integrate technical advisories and IPM adoption within crop insurance design using actuarial inputs from field trials.

8. Governance and Institutional Coordination

- Align major schemes like PM-Kisan, MGNREGA, RKVY, NFSM/NMSA, Atmanirbhar FPO, and Agri-Innovation Fund towards common resilience objectives.
- Ensure:
    - NMSA watersheds prioritize degraded/flood-prone areas.
    - PMKSY projects focus on aquifer recharge and drought proofing.

- Implement a National Land Use Policy to regulate land conversion and ensure sustainable land allocation.
- Strengthen the Soil Health Card Scheme with crop-specific fertilizer dosage guidance.
- Establish a National Soil Carbon Mission aligned with India's NDC commitments.
- Set up a National Bio-Agriculture and One Health Authority, supported by a central Monitoring & Evaluation Coordination Centre (ICAR-led).
- Define TRL-mapped policy streams with clear agency mandates and funding windows.

9. Capacity Building and Extension

- Transform extension into a two-way knowledge and feedback system.
- Train field staff and farmers in:
    - Conservation agriculture and stress diagnostics.
    - Digital tools and advisory systems.
- Establish Farmer Field Schools on Land Management for participatory training in regenerative practices.
- Leverage ICT platforms (IDEA, mobile advisories, chatbots) for real-time decision support.
- Facilitate inter-zonal farmer exchanges to promote peer learning.
- Create specialized training modules for engineers, watershed officers, and veterinarians.
- Mandate non-financial extension deliverables for private input suppliers.
- Strengthen women-led SHG and FPO channels for community-based dissemination.

10. Emerging Technologies

- Deploy AI, IoT, and drone-based systems for real-time stress detection and management.
- Use satellite surveillance and precision spraying for early pest control and efficient input use.
- Promote AI-enabled irrigation scheduling through soil moisture and evapotranspiration monitoring.
- Support gene-editing research to accelerate breeding of stress-tolerant crops (e.g., millets and pulses).
- Strengthen public–private R&D through biotech parks, startup incubators, and IDEA-linked innovation platforms.
- Modernize regulatory frameworks:
    - Revise the Insecticides Act for streamlined TRL-based approvals.
    - Establish gene-editing governance mechanisms ensuring biosafety and innovation agility.

7. Recommended Policy Evaluation Framework for India

Drawing from international best practices and adapting methodologies used by the International Food Policy Research Institute (IFPRI) and other leading research institutions, we propose a comprehensive policy evaluation framework tailored to India's abiotic stress management context.

1. Integrated Policy Evaluation Framework

A. Ex-Ante Evaluation Approaches

Crop Simulation Models: Deploy DSSAT (Decision Support System for Agrotechnology Transfer) and AquaCrop models for scenario-based impact assessment (Bowden et al., 2025, Costa et al., 2023). Run multi-GCM (General Circulation Model) ensembles across RCP scenarios to estimate future yields, irrigation needs, and adaptation performance. Conduct district-level simulations to identify high-vulnerability zones requiring priority interventions.

Computable General Equilibrium (CGE) Modeling: Translate biophysical yield shocks into economy-wide impacts using CGE/GTAP frameworks (FAO, 2023). Assess macroeconomic consequences, price effects, and distributional outcomes of climate impacts and adaptation policies. Estimate cost-benefit ratios for large-scale interventions (irrigation expansion, variety development, soil reclamation).

Climate Risk Mapping: Develop district-level Climate Risk Atlases combining climate projections, soil data, crop calendars, and socio-economic vulnerability (Bowden et al., 2025). Use machine learning models to predict production failure probabilities under alternative irrigation and management scenarios. Prioritize resource allocation to districts with highest projected losses.

B. Ex-Post Evaluation Approaches

Household and Community Surveys: Conduct structured household surveys to capture actual crop losses, coping strategies, employment impacts, and welfare changes following drought/flood events (Birthal et al., 2021). Validate modeled estimates with ground-truth data. Assess equity and inclusion dimensions (gender, landholding size, caste).

Panel Data Analysis: Use longitudinal state/district panels to estimate historical impacts of climatic hazards on agricultural growth (Birthal et al., 2021). Evaluate effectiveness of past policy interventions (irrigation schemes, crop insurance, input subsidies). Identify successful models for scaling.

Participatory Monitoring: Establish 1,000 Climate-Smart Village (CSV) pilots in vulnerable districts (Rao et al., 2016, Roy et al., 2022). Engage farmers in co-design, implementation, and monitoring of adaptation packages. Collect real-time feedback through digital platforms and farmer field schools.

2. Data Systems and Monitoring Infrastructure

Core Data Requirements: Weather and Climate Data: High-resolution daily weather series, computed indices (SPEI, VPD, GDD), and downscaled climate projections [Bowden et al., 2025, Debnath et al., 2021. Soil and Salinity Measures: Spatially explicit soil electrical conductivity (EC), pH, organic carbon, and micronutrient status (MoA&FW (2024b). ICAR-NBSS&LUP (2022), Rao et al., 2022.

Crop Performance Data: District and grid-level yield panels, phenology observations, and trial network results.

Socio-Economic Data: Household income, input use, credit access, and market integration.

Digital Monitoring Tools: Krishi Decision Support System (KDSS): Integrate climate forecasts, soil health data, and crop advisories (PIB (2024). National Pest Surveillance System (NPSS): Adapt for abiotic stress monitoring (drought, heat, waterlogging alerts). Remote Sensing and GIS: Use satellite-based vegetation indices (NDVI, EVI) for early warning and damage assessment (DoA&FW (2024). Blockchain for Traceability: Ensure transparency in input quality (seeds, fertilizers) and subsidy delivery.

3. Specific Recommendations for Improving Policy Evaluation in India

Prioritize District-Level Targeting: Focus evaluation and adaptation investments in districts identified by crop models as highest-loss areas (Bowden et al., 2025, Costa et al., 2023). Develop district-specific adaptation portfolios based on dominant stress types and cropping systems

Assess Irrigation Expansion as Mitigation: Explicitly evaluate irrigation access scenarios in ex-ante analysis (Bowden et al., 2025, Ramachandran et al., 2017). Prioritize micro-irrigation (drip, sprinkler) for water-use efficiency (NAAS Policy Paper 32, MoA&FW (2023). Model groundwater sustainability alongside irrigation expansion.

Monitor Compound Stresses: Incorporate interaction effects (e.g., salinity × vapor pressure deficit, drought × heat) into evaluation metrics (Rao et al., 2022). Recognize that combined stresses have non-linear, often multiplicative impacts.

Integrate Ex-Ante and Ex-Post Evidence: Link multi-model projections to household surveys and panel analyses (Bowden et al., 2025, 34). Create feedback loops for model validation and policy refinement.

Scale Climate-Smart Agriculture Pilots: Expand CSV approach to cover diverse agro-ecologies and stress types (Rao et al., 2022). Document and disseminate successful locally-embedded adaptation practices.

Establish Independent Evaluation Units: Create state-level Policy Evaluation Cells within Agriculture Departments. Partner with ICAR institutes, NITI Aayog, and universities for rigorous third-party evaluation. Mandate periodic impact assessments for all major schemes (PMKSY, PMFBY, soil health missions).

Adopt Results-Based Financing: Shift from input-based to outcome-based budgeting for climate adaptation programs. Link funding to measurable indicators (area under stress-tolerant varieties, soil health improvements, yield stability).

8. Policy Recommendations

1. Institutional and Governance Reforms

Establish National Abiotic Stress Management Mission: Create a unified mission with appropriate fund allocation over five years: Coordinate activities across ICAR, State Agriculture Departments, KVKs, and FPOs Integrate with existing missions (NMSA, PMKSY, NFSM).

Strengthen Inter-Agency Coordination: Establish Abiotic Stress Task Forces at national and state levels. Foster convergence between agriculture, water resources, environment, and rural development departments. Create dedicated budget lines for abiotic stress research and extension.

2. Technology Development and Dissemination

Accelerate Climate-Resilient Crop Varieties: Scale stress-tolerant varieties (drought, heat, salinity, waterlogging) to cover 50% of vulnerable areas by 2030. Fast-track varietal release and seed production through public-private partnerships - Establish dedicated seed hubs in stress-prone districts.

Promote Precision Agriculture: Deploy sensor-based irrigation scheduling, variable-rate fertilization, and drone-based monitoring. Subsidize adoption of micro-irrigation systems (target: 10 Mha expansion by 2030). Integrate IoT and AI for real-time stress detection and advisory.

Strengthen Soil Health Management: Expand Soil Health Card scheme with micronutrient testing and site-specific recommendations. Promote organic amendments, green manuring, and conservation agriculture. Target reclamation of 5 Mha degraded land by 2030 through watershed development and agroforestry

3. Water Resource Management

Expand Sustainable Irrigation: Increase irrigation coverage to 60 Mha with emphasis on drip and sprinkler systems. Rehabilitate existing canal infrastructure and improve water-use efficiency. Promote community-based groundwater management and aquifer recharge.

Enhance Water Harvesting: Construct farm ponds, check dams, and percolation tanks in drought-prone regions. Incentivize rainwater harvesting through MGNREGA convergence - Revive traditional water conservation systems.

4. Financial Instruments and Risk Management

Strengthen Crop Insurance: Expand PMFBY coverage with focus on abiotic stress-related losses. Reduce claim settlement time through remote sensing and digital platforms - Introduce parametric insurance products for drought and heat stress

Provide Targeted Subsidies: Offer input subsidies (seeds, fertilizers, micro-irrigation) for farmers in high-stress zones. Establish Stress Adaptation Fund for immediate relief and recovery - Link subsidies to adoption of climate-smart practices.

5. Capacity Building and Extension

Empower Farmers: Train maximum possible farmers annually on relevant stress management practices through KVKs and FPOs. Establish Farmer Field Schools in 5,000 vulnerable villages. Promote women-led farmer groups for inclusive adaptation.

Strengthen Extension Systems: Recruit and train additional extension personnel specializing in abiotic stress management. Deploy mobile apps and SMS-based advisories for timely information dissemination. Create demonstration plots showcasing stress-tolerant technologies

6. Research and Innovation

Prioritize Adaptive Research: Increase funding for abiotic stress research. Establish regional research hubs in high-stress zones (e.g., ICAR-CRIDA, CSSRI, CAZRI and NIASM/NIBSM) - Promote public-private research partnerships and open-source innovation.
Leverage Biotechnology: Accelerate development of gene-edited and biofortified stress-tolerant crops - Ensure biosafety compliance and farmer acceptance through participatory trials - Invest in genomic selection and marker-assisted breeding.

Implementation Roadmap

Short-Term Actions (2026-2027)

- Launch National Abiotic Stress Management Mission with clear targets and timelines
- Develop District Climate Risk Atlases for all 700+ districts
- Scale stress-tolerant crop varieties to 10 Mha
- Expand micro-irrigation to 2 Mha additional area
- Establish 200 Climate-Smart Villages as demonstration sites
- Digitize Soil Health Card system with mobile-based advisories
- Strengthen weather-based agro-advisories with last-mile delivery

Medium-Term Actions (2027-2030)

- Achieve 50% coverage of vulnerable areas with stress-tolerant varieties

- Reclaim 3 Mha degraded land through integrated watershed management
- Expand irrigation to 55 Mha with 70% water-use efficiency
- Establish 1000 additional Climate-Smart Villages in vulnerable districts.
- Implement results-based financing for state adaptation programs
- Create state-level Policy Evaluation Cells for continuous monitoring

Long-Term Vision (2030-2050)

- Achieve climate-resilient agriculture across all agro-ecologies
- Eliminate acute abiotic stress-related crop failures through early warning and rapid response
- Restore 5 Mha degraded land to productive use
- Ensure 60 Mha sustainable irrigation with groundwater balance
- Position India as global leader in abiotic stress management and climate adaptation
- Align with SDGs and Paris Agreement commitments

Convergence with recently launched Central Sectoral Agricultural Schemes

On October 11, 2025, the Government of India announced a landmark ₹42,000 crore investment in agricultural and allied sectors, prominently including the Pradhan Mantri Dhan-Dhanya Krishi Yojana (≈ 24,000 crore) and the Pulses Self-Reliance Mission (≈ 11,440 crore) to strengthen productivity, credit access, value chains, and sustainable practices in 100 under-performing districts. These schemes present strategic opportunities to merge or align stress-resilience measures into their implementation. For instance: the focus on crop diversification, soil health, and improved irrigation infrastructure in PM Dhan-Dhanya dovetails with abiotic stress strategies such as micro-irrigation, soil moisture conservation, and alternate cropping (millet/pulses). The Pulses With convergence across 36 schemes and 11 ministries (as envisaged), these new programmes can act as central anchoring platforms to fold in the institutional, mechanization, and extension reforms proposed in this framework. Therefore, many of the stress-resilience interventions from custom hiring of machinery in drought-prone zones, to financial incentives for ecosystem-based practices, to regional targeting of stress-mitigating varieties can be embedded into the operational guidelines of these flagship schemes, thereby avoiding creation of parallel structures and ensuring integration of resilience with existing investment momentum.

Monitoring and Evaluation Framework

The monitoring and evaluation framework will track progress through key indicators such as the expansion of stress-tolerant crop varieties, improved irrigation and micro-irrigation coverage, restoration of degraded lands, and strengthened farmer capacity to manage climate-related stresses. It will also monitor the growth of Climate-Smart Villages, reductions in abiotic stress losses, and the universal use of Soil Health Cards. By 2030, the framework aims for substantial advancement across all these areas, reflecting widespread adoption of climate-resilient practices and systems. By 2050, these efforts are expected to evolve into a fully climate-resilient agricultural landscape supported by restored ecosystems, skilled farming communities, and robust climate-smart infrastructure. Together, these indicators will guide continuous learning, adaptation, and evidence-based decision-making for long-term agricultural sustainability.

Reporting and Accountability

- Annual Progress Reports submitted to Parliament and State Legislatures
- Third-party impact evaluations every three years by independent research institutions
- Public dashboard displaying real-time progress on key indicators
- Farmer feedback mechanisms through mobile apps and grievance redressal systems
- International peer review of policy effectiveness and innovation

9. Conclusion

Abiotic stresses pose a factual threat to Indian agriculture, with projected exponential losses annually and climate change intensifying vulnerabilities. However, India possesses the scientific knowledge, institutional capacity, and policy instruments to build resilience and transform challenges into opportunities.

This policy framework provides a comprehensive roadmap for action integrating technology, institutions, finance, and farmer participation. By adopting recommended evaluation methodologies, India can ensure evidence-based, adaptive, and inclusive policy-making. The proposed National Abiotic Stress Management Mission, supported by district-level targeting, climate-smart agriculture, and robust monitoring systems, will safeguard food security, enhance farmer incomes, and position India as a global leader in climate adaptation.

The time to act is now. With coordinated efforts across government, research institutions, private sector, and farming communities, India can achieve abiotic stress resilience by 2030 and sustainable, climate-smart agriculture by 2050 securing prosperity for current and future generations.

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ICAR

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ICAR-National Institute of Biotic Stress Management, Raipur, Chhattisgarh
ICAR-National Institute of Abiotic Stress Management, Baramati, Maharashtra
ICAR-National Academy of Agricultural Research Management, Hyderabad, Telangana
Indian Society of Agricultural Economics, Mumbai, Maharashtra