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Agriculture in Pakistan: The Case for a National Nuclear Agriculture Strategy (NNAS)

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ABSTRACT

Pakistan's agricultural sector continues to underperform despite its central role in food security, employment, and economic stability, resulting in persistent malnutrition, low productivity, inefficient resource use, and increasing vulnerability to climate change. These challenges impose high social and economic costs by weakening human capital formation, labor productivity, and long-term development outcomes. While national and provincial policy frameworks emphasize food affordability, social protection, and climate adaptation, they remain largely focused on demand-side and remedial interventions. Structural, production-side solutions capable of addressing the root causes of agricultural underperformance have received limited policy attention. Through an analysis of policy documents, institutional arrangements, and operational constraints, the paper identifies key barriers to the large-scale adoption of nuclear agriculture and proposes a National Nuclear Agriculture Strategy (NNAS) as a coordinating framework to align scientific capacity with national and provincial agricultural objectives. This paper argues that peaceful nuclear agricultural technologies already indigenously developed and internationally validated in Pakistan constitute a strategically underutilized policy instrument for addressing these systemic challenges. Applications such as mutation breeding, isotope-based soil, water, and nutrient management, nuclear hydrology, food irradiation, biosaline agriculture, and the Sterile Insect Technique offer proven pathways to enhance productivity, nutritional quality, resource-use efficiency, environmental sustainability, and export competitiveness without altering consumption behavior or increasing ecological stress. However, these technologies remain marginal within agricultural, food security, and climate policy frameworks due to institutional fragmentation, governance misalignment following decentralization, and the absence of explicit policy recognition. The study concludes that integrating peaceful nuclear agriculture into Pakistan's policy architecture is essential for strengthening food security, enhancing climate resilience, and achieving sustainable socioeconomic transformation.

Key Words: **Nuclear Agriculture, Sustainable Development, Food Security, Agriculture Policy, Peaceful Nuclear Technologies, Pakistan**

Introduction

Agriculture is an integral part of the economy of Pakistan and its socioeconomic development, so its underperformance has negatively affected human capital and economic stability. Despite occupying a major labor force and area, it failed to address nutritional deficiencies, growth issues, and environmental sustainability. The studies indicated the emergence of food security issues in Pakistan, such as a dangerous rise in malnutrition cases, deficiencies of micronutrients. It shows the direct relation between the performance of the agricultural sector and human capital development. The poor nutritional composition of crops tends to cause reduced workforce productivity, poor educational performance, increased healthcare expenditures, and the intergenerational transmission of poverty, highlighting the macroeconomic aspect of agricultural underdevelopment. On the other hand, national and subnational policy responses focused on the demand side, such as subsidizing food items, controlling their prices, and introducing social protection programs. Those policies could not address the inherent dysfunction and rather played a remedial role. They also overlooked the structural imbalances in the production systems, water and soil management, suboptimal nutrient management, and the impact of climate change on crops. Similarly, all the agricultural investment was centered on capital-intensive infrastructure projects and ignored the heterogeneous agroecological conditions. For instance, extensive focus on irrigation expansion overlooked the dire need for soil diagnostic precision to optimize resource use.

PAEC operates institutions focused on specialized agronomic practices in Faisalabad and Tando jam. The National Institute for Biotechnology, genetic engineering (NIBGE) in Faisalabad concerns the usage of biosciences for the sustained socioeconomic growth. It is one of the main biotechnology institutes of the four biocentre run by PAEC. (National Institute for Biotechnology and Genetic Engineering, n.d.)[1] The National Institute for Agriculture and Biology (NIAB), located in Faisalabad, deals with the creation and sustainment of new genetic material, and create modern solutions for agricultural problems using nuclear and related techniques. (National Institute for Advanced Biotechnology, n.d.) Similarly, the Nuclear Institute of Agriculture (NIA) situated in Tando jam focuses on four disciplines including soil and environmental sciences, plant protection, plant physiology, and plant breeding and genetics in the agrarian belt of Sindh. (National Irrigation Authority, n.d.) However, the lack of their proper integration into the mainstream agricultural policies limit their impact siloed**.**

The intensification of climate change-induced problems of water scarcity, pest infestation, and uncertain weather has posed challenges to traditional agricultural practices. Now, the relevance of governmental strategies to aid the struggling

agricultural sector is evident. This paper argues that peaceful nuclear technology can improve the core challenges of Pakistan's agricultural sector. Pakistan Atomic Energy Commission (PAEC) successfully operates a robust civilian nuclear infrastructure that includes a proven agronomic technology. From mutation breeding, isotope-based resource management diagnostic techniques to food irradiation and sterile insect techniques, these technologies are both domestically and internationally proven to increase efficiency, adapt to climate, and yield competitive exports while being environmentally friendly. However, their proper utilization faces bottlenecks of policy integration, so they are limited to research and pilot programs only. Lack of a clear policy for their wide utility, coupled with institutional fragmentation and decentralization, has made these useful technologies absent from the national policy documents. To bridge the gap, this paper proposes a National Nuclear Agricultural Strategy (NNAS) that positions peaceful nuclear technologies as a part of sustainable agricultural growth as outlined by Pakistan's commitment to the sustainable development goal (SDG) 2 on eliminating hunger. (Ministry of Foreign Affairs, Government of Pakistan, n.d.) This study adopts a qualitative and policy-centered approach to understand the rationale behind marginalization of technologies despite their proven capabilities.

Theoretical Framework

This research is carried out from the philosophical standpoint of post-structuralism-driven, post-positivism. In theoretical terms, agricultural underperformance involves policy relevance and technological capabilities is a material reality that exists beyond observation. As a material reality is shaped by the discourse, power relations, and governance practices, the critical realist stance explains the ontological roots of institutional structures being socially constructed. (Hammond n.d.) This study adopts the interpretivism mode of epistemology, where knowledge is contextual, and hypotheses or causal linkages interpret it. With a qualitative, exploratory research design, this research employs policy and discourse as core research methodology. Among the reviewed data are national and subnational policy documents related to agriculture, seed governance polices, and climate change. (Pretorius, 2024) The predominant approach was inductive reasoning through which thematic coding and critical interpretation were utilized, and to understand the dominant narratives, policy silences, and the phenomenon related to nuclear technologies for peaceful purposes. Triangulation and analytical reasoning were used in the process of interpretation, and reliability was examined through the analysis of methodological documents. As a post-structuralist framework of theory, it regards policy as a policy instrument as a body of power and knowledge, and presents a reconstruction of the existing agricultural regime through the introduction of the National Nuclear Agricultural Strategy (NNAS).

Structural Deficiencies of Agricultural Underperformance in Pakistan

Quantified Cost of Agricultural Underperformance in Pakistan

Different malnutrition indicators have been highlighting the bleak scenario in Pakistan. Those trends manifest the direct link between human development and agricultural productivity. The National Nutrition Survey (NNS) 2018 presents an even glimmering picture at the provincial levels, particularly in the rural areas. Indicators from Sindh show that 45.5 percent of the children under five are stunted, 29.8 percent are underweight, while their wasting levels are 17.7 percent. Similar stunting situation prevails in Balochistan (46.6%), Punjab (36.4), Khyber Pakhtunkhwa (KPK) (48.3%), and Gilgit Baltistan (GB) (46.6%). (Government of Pakistan & UNICEF, 2019) The 2024 Children's Malnutrition data released by the United Nations International Children's Emergency Fund (UNICEF) show that of 2 million children screened for malnutrition, 92,000 were screened for severe acute malnutrition. A recent survey on nutrition values in Pakistan shows that the share of those considering themselves 'very healthy' has been halved since 2018. (Gallup Pakistan, 2025) Deficiencies of the micronutrients such as Vitamin A, Zinc, and Iron are prevalent among women and children, impairing cognitive abilities and overall productivity levels of human capital. Trends reflect that only 27% use vitamins, which is quite lower than the average of 34%. (Gallup Pakistan, 2025) According to the Global Nutrition Report 2025, among 15-49 of women in Pakistan suffer from anemia. (Global Nutrition Report, n.d.) These studies prove that the agricultural productivity is neither indirect nor abstract to the human capital in Pakistan.

The economic dimension of these indicators is also substantial. Evidences show that this malnutrition is costing approximately 3 percent of Gross Domestic Product (GDP) annually, which is equal to about PKR 2.5-3 trillion. These low indicators result in reduced labor productivity, low educational outcomes, inflated health expenditures, and intergenerational transmission of poverty. Poor nutrition indicators among the women of childbearing age further risk the development of future generations. Food security in Pakistan is a matter of nutritional quality, dietary diversity, and caloric availability as well, which are currently unaddressed by the agricultural policies. And this failure to align agricultural output with national needs results in a low contribution of human capital investment.

Worsening the situation, national documentation also mentions the food insecurity among the poorest. The National food Security Policy (NFSP) has held high prices since 2007, being the primary driver of food insecurity in the vulnerable population. Integrated Food Security Phase Classification (IPC) called 11 million of the 22% analyzed population to be facing the highest levels of acute food insecurity, where 9.3 million are in the crisis phase, remaining 16.6 million are vulnerable to slipping into crisis. The situation remained the same from April

to July 2025, as about 10 million people remained the same shown by the stats released by the Food and Agriculture Organization (FAO). (Food and Agriculture Organization of the United Nations [FAO], 2025) Despite a low-income household distributing a major share of its income for food consumption, the nutritional requirements remain unmet. In response, the Government crafted NFSP to emphasize affordability and social protection, but it failed to tackle the issue. The policy largely focuses on the demand side and comparatively neglects the supply side, which could otherwise improve nutritional production through agriculture.

Regardless of the scenario, the National policy frameworks contain a wide structural disconnect. Different measures do not uplift the determinants of malnutrition despite targeted food distribution and the creation of social safety nets, and only play a remedial role. Whereas, the Nuclear agricultural technologies offer a sustainable solution to the prevailing issues in agriculture by addressing the production side. Through Mutation breeding, the micronutrient density of crops can be enhanced by making crop yield stable and not inducing any changes in consumption behavior. Isotope diagnostic mechanism enables farmers to optimize fertilizer patterns and increase both quality and yield. Their limited incorporation into the national food policies shows a weak commitment to the solution, as they tend to downstream solutions only. The agricultural sector, on the other hand, requires structural interventions to align with the national food security objectives. For that, agriculture should be placed at the core of human development and sustainable economy, and beyond a calorie resource. Such results reflect that the shortfall in food access is not the only determinant of agricultural underperformance but also the inefficiency of production-side of agricultural policies.

Structural Inefficiencies in the Resource Mobilization

Pakistan's agricultural regime is mired in environmental stressors. Many parts of the country are grappling with the issues of water shortage, waterlogging, groundwater depletion, and salinity. Studies reflect heavy water losses during the irrigation processes, where about 60% is lost during field application, 30% during watercourses, and 29% at field levels. (Pakistan Institute for Parliamentary Services, 2024) the irrigation inefficiencies exhibit water losses of about 40-50 percent due to the inefficient practices and poor knowledge. Joined by the unfriendly climate patterns, the fields face increased temperatures, high evapotranspiration, and irregular weather projections that translate into shorter temporal cycles of the climatic catastrophes like droughts and floods in different parts of the country. Pakistan recorded extreme heat, with temperatures exceeding 52 degrees Celsius at Jacobabad, which places great stress on evapotranspiration in crops across the region. (Riasat, 2025)

Skewed public expenditure and policy bias are resulting in ineffective agricultural solutions. Despite the capital-intensive engineering solutions,

environmental problems are critical. To demonstrate, in the financial year 2025, Rs 142.59 billion which accounts for 12.96 percent of the total agricultural developmental budget was dedicated to dam construction projects. (Government of Pakistan, 2025) But their marginal returns do not include reducing the water loss and planting crops smartly by soil testing. Such inefficiencies resulted in the national crop output decline of up to 13.5% where cotton fell 30.7%, maize 14.7% and wheat 8.9%. (Nazar, 2025) There are numerous problems with the flood plain of the Indus, also known as 'Katcha'. It also overlooks the groundwater overuse and uncontrolled installation of aquifers. World Bank report ranks Pakistan at the fourth position in the underground water depletion ranking, with the depletion rate of 1-1.5 meters annually in Punjab and Sindh, as a result of over 60 billion cubic meters of water abstraction.

Ignoring the diagnostics, policy response in Pakistan is largely capital-intensive. Nuclear Hydrological Techniques provide a cost-effective option and can aid in heavy-capital development. The nuclear-enabled isotopic signatures provide precise measurements and projections of water by tracing hydrological movements. Through this technology, evapotranspiration and irrigation estimates can be precisely generated. 'Atoms for Water' (2025) platform of the IAEA has proven that isotope hydrology can contribute to sustainable agriculture. Countries across the globe present a significant international experience in managing irrigation through nuclear technologies. Jordan saved around 30-40 percent of water just by employing the nuclear-enabled isotope diagnostics Morrocco also utilized the isotope hydrology and managed groundwater and optimized irrigation.

Despite having signed a five-year cooperation plan with the IAEA, Pakistan has yet to optimally utilize isotope hydrology. These techniques are largely confined to the research environments, causing their absence from the declared national food security policies. This disconnect eventually results in a void between the policy application and the diagnostic capacity. The IAEA's Atoms4Food mission also acknowledged Pakistan's demonstrated effective nuclear agricultural practices. It now recommends scaling and mainstreaming these capabilities citing their relevance in food security and climate adaptation. (Lytton et al., 2021)

Policy Blind Spots: Absence of Nuclear Technologies in the Climate Change Strategies

Despite acknowledging the significance of scientific innovation, climate policy documents stop short on specifying its operational mechanism. The National Climate Change Policy (NCCP) warns that the agriculture sector is one of the most vulnerable sectors. To respond to the extreme and shifting weather patterns, the policy outlined certain research-intensive ways to grow climate-resistant crop varieties and livestock breeds, and adopt advanced climate simulation models. The policy brought biotechnology with a data-driven tool at the center to ensure a

smooth transition to evidence-based agricultural decision-making. The National Adaptation Plan (NAP) of Pakistan, which was promulgated in July 2023, also warns of the climatic threats to the agriculture sector and proposes a plan for sustainable agriculture. (Rehman, 2025) Although the general reliance on scientific methods could not specify the operationalization of this intervention across the agroecological zones.

The case studies of the subnational policies highlight a similar trajectory of latent opportunities. The Agriculture, Fisheries and Livestock Department of GB also necessitated the substance-oriented and ecological zoning to adapt to the difficult terrain of the region. (Rehman, 2025) The agriculture policy of GB outlines that variability in agronomic practice is required as the region require subsistence-oriented planting. Gilgit contains favorable land farming ecological traits that include long days, less humid soil, and cool nights with reduced pest control strains. However, the region's high altitude and scattered patches of farmland are indirectly complemented by the limited access to the markets. This necessitates the significance of technological sophistication for the resilient food supply chains.

Although connectivity sophistication brought by the China Pakistan Economic Corridor (CPEC) and the Karakoram Highway yielded premium prices to the region just by speeding up of transportation of staple fruits and vegetables in the offseason in particular. (Iftikhar, 2025) Yet, the introduction of nuclear technology can increase the gains by increasing the shelf life of the goods. The agriculture policy advocates for further improvement in the agronomical infrastructure to enhance market integration and consolidate these benefits.

To translate technological actions into fruitful agricultural outcomes, policy must contain practical ways. The emerging climatic problems prompted the Ministry of Climate Change which then laid out 300-day national climate preparedness plan to enhance coordination among federation and provinces. ("Pakistan Steps Up Climate Resilience," 2026) The emerging novel climatic problems necessitate climate-resistant crops through the introduction of improved germplasm while conserving the indigenous Deoxyribonucleic Acid (DNA). To incorporate technological tools in the agriculture of this diverse microclimatic region will require the imparting of knowledge and research-based solutions. The need for a strong collaboration between the national and international research institutes to introduce modern research methodologies is also undeniable.

The policy documents on climate remain subsumed by generic research and technological innovation methods. This invisibility dampens a clear policy line on harnessing the immense potential of the peaceful nuclear applications. Despite containing practical ways to aid the climate policy mechanisms, peaceful nuclear solutions are not part of the climate financing and provincial adaptation plans. Resultantly, there is a persistent gap between the theory and practice of both the national and subnational policies. This marginalization emanates not from some strategic resistance or legal prohibition, but lack of explicit policy articulation.

Hence, the explicit recognition would enable the alignment of nuclear technology tools with the agricultural and climatic policies. This integration would help to mobilize innovation for the core objectives of betterment in the agricultural sector without altering the broader strategic posture of Pakistan.

A National Nuclear Agriculture Strategy (NNAS): Rationale and Design

Strategic Rationale

The agricultural sector of Pakistan remains underperforming, regardless of the commendable strides Pakistan has taken in the peaceful application of nuclear technologies. The policy fragmentation, chronic structural inefficiencies, and underutilization the sophisticated scientific technology have hindered socioeconomic development. Pakistan has a robust and peaceful nuclear applications regime that is both internationally acclaimed and domestically proven. Under the auspices of the Pakistan Atomic Energy Commission (PAEC), Pakistan has adopted nuclear-derived agricultural technologies, including isotope diagnostics, mutation breeding, food sterilization, and sterile insect technique. Besides isotope diagnostics and Sterile Insect Techniques (SIT), PAEC has grown 150 types of resilient mutation-bred crops. (Pakistan Atomic Energy Commission , n.d.) But these technologies are weakly integrated into the national and subnational food security policies. The disconnect results from the absence of a coordinated policy framework. A National Nuclear Agriculture Strategy (NNAS) can serve the purpose and provide a platform for integration and attainment of the core national food security objectives. It will not only connect subnational or provincial agricultural policies but also become a pragmatic approach towards sustainable socioeconomic development.

Role of Federation in Institutional Coordination

Keeping provincial autonomy intact, this document can effectively contribute towards market competitiveness, enhanced productivity, increased nutrient density, and soil efficiency. (Human Online, n.d.) The core idea of the policy is to play a role as a capacity-mobilization tool. All the sectors of agriculture, such as crops, livestock, water and soil management, and food safety, necessitate an indivisible agronomic ecosystem. As an incident, the widely recognized nuclear technology for the agricultural sector, isotope diagnostics, can function as a federal nucleus to mobilize an irrigation system comprising basins, mass-rearing facilities across the country, and national-level regulatory frameworks in compliance with the international protocols. In the absence of a federal-level coordinated approach, the provincial setups risk underutilization and fragmented strategies, notwithstanding the funding issues. Whereas the national level NNAS can flexibly

aid the provincial efforts in the adoption of the advanced nuclear application. Not only this, the federation can formalize the multilateral engagement by engaging the private sector, and plan export promotion besides the modification of the existing overarching agriculture regime of Pakistan. The NNAS would transform the standalone scientific progress into s systemic driver of productivity, which will address the core agriculture problem of the supply chain that causes human development such as malnutrition and intergenerational poverty.

Apart from the national integration, this strategy can increase developmental payoffs without undermining the strategic sensitivities. Pakistan enjoys a pivotal position in the Global South for having an advanced set of indigenous nuclear agriculture infrastructure. By utilizing these technologies, can Pakistan achieve fiscal efficiency by cutting off the heavy agricultural expenditures, and ecological resilience through the smart water and soil management, and imparting knowledge and practices by broadening the base of agricultural universities with the integration of nuclear science institutions. Such a strategy also ensures the continuity of strategic ambiguities at the international level while coexisting with domestic functional clarities. The IAEA has also urged Pakistan to integrate nuclear technologies pertaining to agriculture into its agricultural architecture and to ease the institutional rigidities. (Human Online, n.d.) Through this embedding of nuclear technologies into the national policy architecture, the institutional rigidities will be addressed. In this way, peaceful nuclear agriculture can become a setting stage for detailed discussion on expenditure patterns, institutional constraints, convergence gaps, techno-governance, infrastructure requirements, and the adoption pathways.

Institutional and Operational Barriers to Adoption

Governance Constraints in Post-18th Amendment Scenario

The prevailing provincial and systemic hurdles require a sound deliberation to establish a technologically grounded and unified strategy for the integration of nuclear technologies into agricultural practices. After the passage of the 18th Amendment, the constitutional reconfiguration empowered provinces to control all sectors of agriculture through the rise in their sectoral budget allocations. Despite this increase in authority, the structural and administrative bottlenecks do not allow for the complete utilization of the allocated fiscal budget. Evidence from Sindh exhibits that only Rs 133 billion was allocated to agriculture, but only a fraction is being utilized in the province. (Hanif, 2025) The preapproved development schemes consume a lion's share of the spending scheme, leaving very little margin for the adaptive interventions in the experimental cross-sectoral programming. On the other hand, nuclear techniques require cross-sectoral integrated planning that includes regulatory frameworks as well. The silo mandates of provinces do not provide favorable conditions, i.e., monitoring tools,

institutional incentives, and flexible funding for an adaptive scientific intervention. Such operational realities are consequential for the implementation of a coherent strategy, as NNAS and its absence risk the underutilization of the nuclear science potential for a measurable systemic impact.

Despite having thematic convergence of policy objectives among the provincial agricultural policies, they lack operational entry points for scientific innovation as nuclear technologies. In Punjab's agriculture strategy, a repetitive mention of science-based innovation, intellectual property protection, and yield gap reduction is found. Punjab is integral to the export competitiveness as it alone comprises 54% of the agricultural GDP. (Hussain, 2025) The strategy also contains a structural support for the establishment of a commodity traceability platform in the form of the Punjab Agricultural Research Board. This strategy has immense value as the province alone contributes to the 60 percent agricultural exports of the country. The agricultural policy of Sindh also discusses the nutrition-sensitive approaches to agriculture that are centered at climate resilience as well. Balochistan stresses the climate-smart practices that also focus on soil and water management to yield high-value crops for the local and international crop markets. In spite of the willingness to adopt modern scientific approaches to enhance agricultural gains, all the policies lack exclusive mention of the scientific technologies, i.e., nuclear. This functional invisibility of nuclear technologies also excludes them from any departmental schemes, budget tagging, performance indicators, and administrative accountability, despite their high scientific-economic relevance.

Systemic misalignment can also be viewed in the National Seed Governance. The declared National Seed Policy 2024 outlines a comprehensive regime comprising the biotechnology development and biosafety compliance through the four-generation seed multiplication system of Pakistan. PAEC has officially estimated 150 mutation-bred crop varieties that are both compatible to this governance regime as well as proven stress-tolerant, climate-smart smart and nutritionally rich. (Ministry of National Food Security & Research, National Seed Policy, 2024) Structural commercialization of those crop varieties can be crucial to the food security and export revenue generation of Pakistan. However, there exists a gap between the varietal release and its large-scale adoption. They are usually considered generic outputs instead of being a strategic technological asset, which leads to their invisibility in the commercialization incentives, public-private partnership ventures, and performance parameters. The institutional frictions and structural impediments are hindering the way of scale mutation-bred varieties, eventually reducing their significant utility and proven agronomic benefits.

The civilian nuclear agriculture system run by the PAEC is distinguished schools in the Global South. These capabilities can address the issues highlighted by the export rejection data. Aflatoxin contamination, pest infestation, traceability deficiencies, and residue exceedance are causing recurring losses in Pakistan's economy by resulting in foreign exchange losses. Pakistan's basmati rice exports

dropped by 43% in 2025 due to the residue compliance challenge. ("Sharp 43 % Fall in Basmati Exports", 2025) Unfortunately, the proper integration of PAEC capabilities into the routine agricultural workflows is limited. Strategic sensitivities, together with the policy silence and absence of any standardized inter-agency mechanism, have caused underutilization instead of overexposure of the critical assets.

Poor performance of the fiscal category also underscores the need to shift towards nuclear technologies. Agronomic studies indicate the inefficiency of the fertilizer regime governance, where, despite subsidizing a major chunk, 30-40 percent of nitrogen gets leeched off due to the chemical reactions in the environment. ("Fertilizer Offtake Increases 11%," 2025) Not only this, but the runoff of fertilizer also becomes an environmental externality by contaminating groundwater and air with nitrate contamination and nitrous oxide emissions. Whereas the modern nuclear technologies, such as the isotope tracer of Nitrogen-15, not only generate the location-specific recommendations but also optimize nutrient use. Where these are widely used internationally, Pakistan has yet to institutionalize them at scale. Examples by nuclear-derived nutrient management from China and Brazil highlight up to 15-20 percent reduction in fertilizer usage. Significant fiscal savings and environmental conservation are possible through the application of this technology, which faces a bottleneck of institutional inertia.

The gap between policy implementation and technical capability is indicated by the marginal lands as well. FAO's assessment in 2024 showed that nearly 30% of the agricultural land in Pakistan is affected by the sodicity and salinity. ("Pakistan Loses 30 % of Agricultural Land to Soil Salinity", 2024) It makes soil reclamation viable for economic growth. Nearly one-quarter of the cultivable land of Pakistan, i.e., southern Punjab and Sindh, is affected by sodicity and salinity. All existing methods of soil reclamation, including the alteration of drainage infrastructure and gypsum application, are economically, financially, and developmentally unviable for smallholders. As a result, those uncultivated saline lands are omitted from the infrastructure and socioeconomic development projects. On the other hand, the nuclear biosaline agronomic technologies and the climate-resistant crops developed by the PAEC have proven capabilities to convert these lands into cultivable farmlands. Again, this would require institutional recognition and inclusion of the nuclear technologies into the land reclamation projects, extension services, and climate adaptation initiatives; otherwise, their under-utility will make food security and climate adaptation a distant dream.

Among the other operational challenges are pest infestation and export competitiveness. Swat alone documented high indices of Tephritidae in peach orchards. (Murad Ali et al., 2025) Fruit-fly and other pest infestations pose a great risk to the horticulture sector of Pakistan as they hinder its access to the premium international markets. Traditional chemical pesticides involve high costs and clash with the international benchmarks of residues. Nuclear-powered Sterile Insect Technique (SIT) successfully prevents the breeding of pests and has been used

globally. In Pakistan, the large-scale deployment of the system would require a comprehensive framework and sound coordination mechanism among the federation and the provinces to avoid any fragmented implementation and monitoring efforts, and increase the efficacy of this economically viable and technologically demonstrated option.

Finally, knowledge spillover and utilization of human resources are also undiscovered. Agriculture and biotechnology institutes under the aegis of PAEC organize about 40 specialized training programs every year and contribute to the capacity building of the human capital. NIAB has been designated as a collaboration center of the IAEA, which demonstrates the international trust and recognition of the nuclear agronomic applications. (International Atomic Energy Agency [IAEA], 2025) The weak integration of the nuclear technology into the provincial systems constrains the translation of the human resource into productive outcomes by uniting with the vocational training curricula and farmer advisory networks. Institutional silos have isolated the scientific research outputs and limited the adoption potential of the nuclear technologies.

Conclusion

This study demonstrated that the persistent underperformance of the agricultural sector of Pakistan was a result of policy fragmentation, institutional misalignment rather than the lack of scientific expertise and financial limitations. Pakistan has not effectively deployed the existing, mature, indigenous, and internationally recognized agricultural techniques into its national and subnational-level food and climate policy documents. The dispersal of authority across provinces through decentralization became problematic in the absence of a coordinated mechanism to collaborate on sophisticated scientific technologies. This scientific invisibility in the policy documents excluded nuclear technologies from planning documents, budgetary allocations, performance indicators, commercialization incentives, and adaptation financing. The scope of nuclear technologies was constrained, rather than their application to large-scale productivity gains. Consequently, agroecological challenges such as water scarcity, soil degradation, inefficient fertilizer use, pest infestation, post-harvest losses, food safety concerns, and export rejections remained prevalent, even when technological remedies were available. Therefore, given a range of demonstrated solutions, important systemic problems such as water shortages, soil erosion, ineffectual fertilizer usage, insect infestation, post-harvest losses, food safety concerns, and export rejections remain. The current policy gap costs heavily in terms of decreased economic production, reduced human resource generation, wasteful fiscal spending, and increased susceptibility to market along climate shocks.

The conclusions additionally point out the distinct and harmonious ability of peaceful nuclear agricultural applications to solve several agronomic and socioeconomic restrictions at the same time, especially in the face of growing

financial strain and climate stress. Nuclear agriculture can improve yield resilience, micronutrient concentration, land and water productivity, fertilizer optimizations, food safety, and market access through mutation breeding, isotope diagnostics, nuclear hydrology, food irradiation, biosaline agriculture, and the Sterile Insect Technique without demanding consigning shifts in behavior or incurring more ecological costs. The proposed National Nuclear Agriculture Strategy (NNAS) presents an institutionally viable and practical policy as it creates a central coordination mechanism that meets the global benchmarks, and also preserves the provincial autonomy of provincial units.

This strategy will improve the results of government expenditures, stabilize the agricultural supply chains, and convert siloed scientific breakthroughs into a cohesive engine of socioeconomic development. Formal legislative recognition of nuclear agriculture can also facilitate revenue generation, business community involvement, export promotion, and human capital development, allowing Pakistan to leverage its current technological capabilities for broader socioeconomic advantages. The success of Pakistan's agricultural renaissance ultimately depends on political will and organizational will to choose structure-based alternatives over small-scale, corrective initiatives. Therefore, including peaceful nuclear agriculture technology into the foundations of policy development is not only a theoretically viable option but also a crucial factor in achieving sustainable socioeconomic transformation and a sustainable food supply. Without proper utilization, Pakistan's nuclear agricultural capacity will remain a scientific success but a developmental failure.

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