**Pakistan Journal of Social Sciences**

ISSN (E) 2708-4175 ISSN (P) 2074-2061
Volume 46: Issue 1 March 2026
Journal homepage: https://pjss.bzu.edu.pk

# Enhancing Agricultural Productivity through Artificial Intelligence

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**ARTICLE DETAILS**

**History:**
Accepted: 05 March, 2026
Available Online: 18 March, 2026

***Keywords:***
*Artificial Intelligence, Agriculture, Productivity, Sustainability*

**ABSTRACT**

**Purpose:** To explore the potential of Artificial Intelligence (AI) to revolutionize the agricultural industry in Pakistan to overcome major obstacles, which include poor productivity, climate disruptions, poor resource management, and after-harvest losses.

**Methodology:** The paper takes the form of literature review of the current AI usage in agriculture and a qualitative analysis of the case studies in international, regional and national settings. It is based on secondary data sources such as peer review articles, reports, and documented field implementations. It has a tiered estimation model (Conservative, Moderate, Optimistic) that forecasts possible results based on the viewpoints of the policymakers, donors, and implementers.

**Findings:** The research concludes that AI-driven drones, IoT-based monitoring systems, and advisory apps can be highly efficient in enhancing the efficiency and productivity of agriculture. The feasibility and effectiveness of adoption of AI are supported by evidence based on pilot projects, such as the Pakistan-China Joint Lab and the Land Information and Management System. The findings show a huge possibility to improve food security, the income of farmers, and climate resilience.

**Implications/Originality/Value:** The paper identifies the necessity of a national policy on AI in agriculture, enhancing digital connectivity, and specific subsidies that will promote it. It has its contribution by integrating the analysis of policy with the evidence of practical cases and a tiered projection model, providing a systematic perspective on the AI-based agricultural transformation in Pakistan.



**Recommended Citation:**

Salman, A. & Choudhary, S, A. (2026). Enhancing Agricultural Productivity through Artificial Intelligence. *Pakistan Journal of Social Sciences*, 46(1), 29-51. DOI: 10.5281/zenodo.19694459

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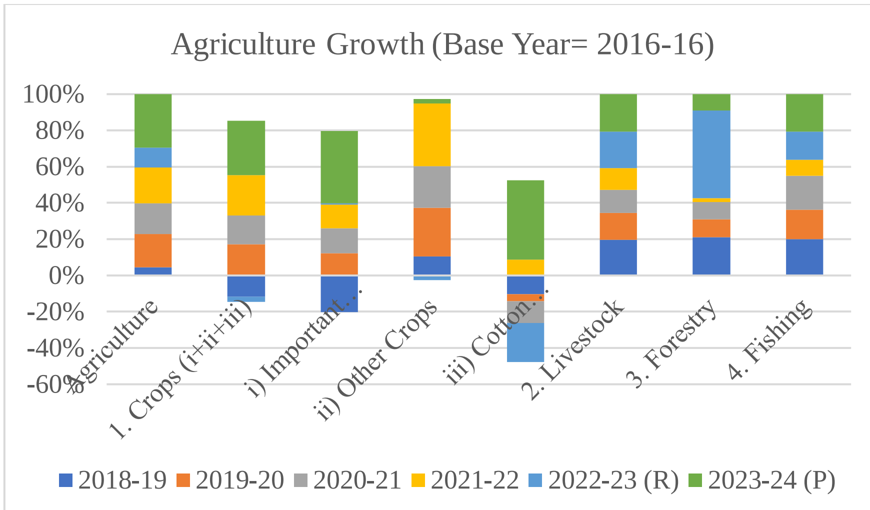
## 1. Introduction

The agriculture sector plays a major role in the economy of Pakistan. It adds approximately 22 percent to the GDP of the country and 37 percent to employment (World Population Review, 2025). The sector of agriculture in Pakistan has increased positively in 2023-2024, by 6.25% (Ministry of Finance, 2024). In this sub-sector, the key crops have shown a great improvement, as they grew by 16.82 percent, which is a good recovery and high production growth. Other crops recorded a small growth rate of 0.90 percent, which was stable but not much towards the overall growth. The primary characteristics of such growth are fruits, vegetables and pulses. Cotton ginning had an amazing 47.23 percent growth, which is an enormous recovery of past falls and a major growth in the overall crop sub-sector. The livestock sub-sector continued to record a stable growth of 3.89 percent, a little higher than the growth rate of the industry last year. It means that there is a stable and long-term livestock production. The growth of forestry is reduced to 3.05 percent compared to a high of 16.63 percent of the last year. While this represents a slowdown, it still contributed significantly to the overall agricultural growth. Fishing also saw a modest increase, growing by 0.81 percent, slightly higher than the previous year's growth (Ministry of Finance, 2024). As such, this steady growth indicates ongoing stability in fishing (Figure 1).

**Figure 1**

*Agriculture Growth*

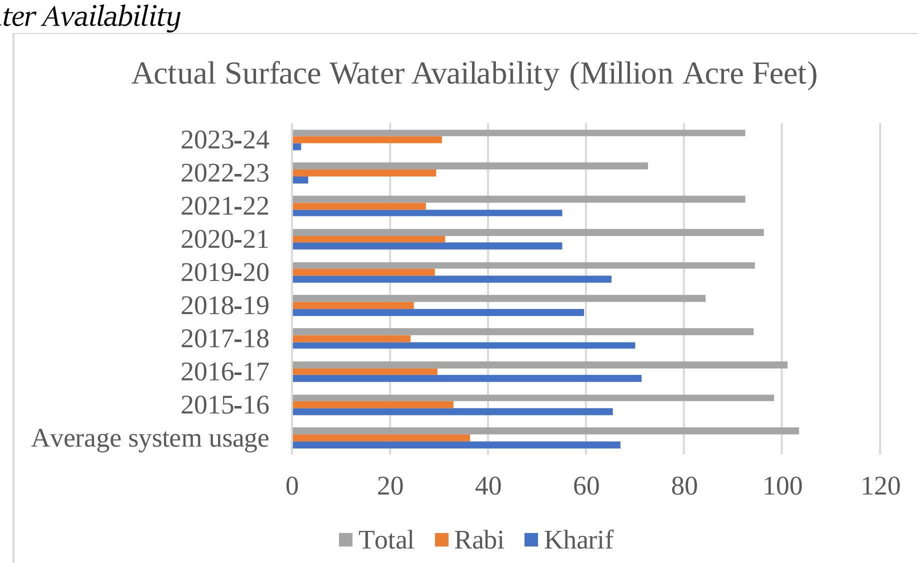



(Pakistan Economic Survey 2023-24)

Water availability during Kharif 2023 increased to 61.9 Million Acre Feet (MAF) from 43.3 MAF during Kharif 2022 (Flood year) and remained at par with the requirements of Kharif crops. While, for Rabi 2023-24, it is recorded at 30.6 MAF, showing an increase of 4.1 percent over the same season last year (Table 2).

**Figure 2**

*Actual Surface Water Availability*

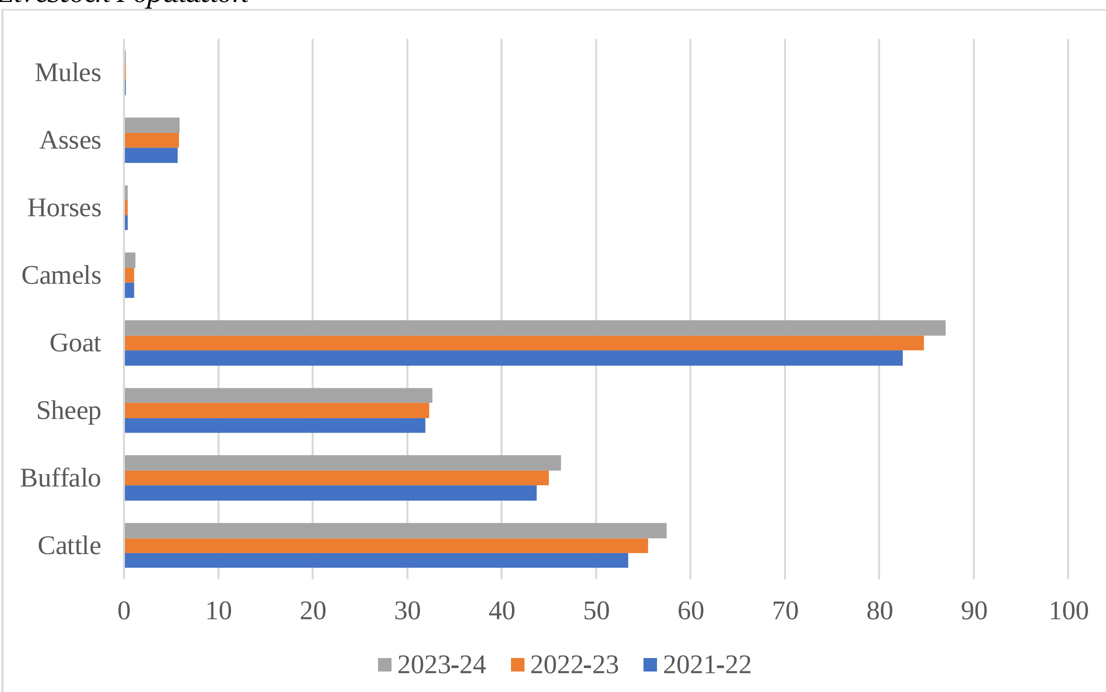



(Pakistan Economic Survey 2023-2024)

During 2023-24, the critical crops contributed 20.67 percent to value addition in agriculture and 4.97 percent to GDP. Other crops contributed 13.51 percent in value addition to agriculture and 3.25 percent in GDP. Cotton production in 2023-24 was 10,223 Bales, sugarcane production was 87,638 tonnes. Similarly, rice production was 9,869 tonnes, whereas maize productivity decreased over the year and reached 9,847 tonnes from 10,985 tonnes. While wheat production increased from approximately 28000 tonnes to 31,438 tonnes (2023-24). Animal farming is a cornerstone of Pakistan's rural economy, with more than 8 million rural families deeply engaged in livestock production. This sector is a vital lifeline for these families, contributing significantly to their livelihoods by accounting for around 35-40 percent of their total income. In the broader economic landscape, the livestock sector has solidified its position as the primary driver of agricultural growth, comprising approximately 60.84 percent of the agricultural value added and 14.63 percent of the national GDP during FY2024. The gross value addition of the livestock sector has shown an increase, rising to Rs 5,804 billion in 2023-24 from Rs 5,587 billion in 2022-23, marking a growth rate of 3.9 percent. The sector's net foreign exchange earnings make a meaningful contribution, accounting for approximately 1.6 percent of the total exports in the country.

**Figure 3**

*Estimated Livestock Population*




(Agriculture statistics of Pakistan 2023-2024)

The focus of the present government is on breed improvement for enhanced productivity, establishing a nucleus herd, identifying breeds well adapted to various agro-ecological zones of Pakistan, and importing high-yielding exotic dairy, beef, mutton breeds, and genetic materials (semen, ova, embryos). By implementing these measures, the government aims to stimulate growth in the livestock sector, generate employment opportunities, and contribute to the country's overall economic growth and food security. The national herd population of livestock for the last three years is given in figure 3.

### 1.1 Global Developments in AI for Agriculture

AI is driving a smart agriculture revolution. Farms now employ satellite imagery, drones, sensors, and internet-of-things (IoT) devices to gather detailed data on soil, weather, and crop health. For example, high-resolution drones and remote sensors feed machine-learning models that generate real-time crop health maps, optimise irrigation and fertilisation, and detect pests and diseases early.

The adoption of digital technologies in the agricultural sector has been a popular topic of study in the larger body of literature on agricultural innovation systems. Research indicates that the persuasion to use the technologies of precision agriculture is not only facilitated by the presence of technology; it should be supported at the institutional level, teach farmers about it, and get their market incentives (Klerkx et al., 2019). On the same note, the studies on the topic of smart farming emphasize the role of data-driven technologies in enhancing the efficiency of decision-making in crop management: sensors, machine learning models, and satellite monitoring can be used to a large effect (Wolfert et al., 2017). Nevertheless, adoption is still uneven in regions because of the infrastructure limitations and the economic barriers especially to the small holder farmers (Lowenberg-DeBoer and Erickson, 2019).

AI systems combine satellite and field sensor data with weather forecasts to guide irrigation, fertiliser and pesticide use. This ensures water and nutrients are applied only where needed, reducing waste and costs while protecting the environment. Farmers receive planting and harvesting alerts tailored to their plots, boosting efficiency (Farmonaut, 2023).

Autonomous tractors, drones, and robots are increasingly used for planting, weeding, spraying, and harvesting. Companies in Asia and North America deploy AI-driven drones for precision spraying of agrochemicals, cutting chemical usage by ~30%. Robotic harvesters and automated greenhouses adjust conditions in real time to maximise yield. These reduce labour bottlenecks and lower production costs (Maraveas, 2023).

Machine learning models process historical and real-time data to forecast yields, prices, and climate risks. AI-powered advisory apps and early-warning systems help farmers anticipate droughts, floods or pest outbreaks (PIDE, 2024). Predictive analytics can suggest optimal crop varieties or planting schedules under changing climate conditions. Pilot studies show AI-assisted weather stations and forecasting can improve timely planting and reduce losses from extreme weather.

These global trends yield economic gains and sustainability benefits. Yield increases of 15–30% and input cost reductions on farms using AI tools. For example, precision fertilisation systems have cut chemical use by up to 25–30% while maintaining or improving yields (World Bank, 2025). AI-driven pest management can reduce pesticide use substantially,field trials in Pakistan's north showed AI-based pest scouting cut pesticide application by ~40% while improving crop health (Pakistan Institute of South Punjab, Department of Agriculture, 2024). AI promotes environmental sustainability, conserving water and reducing runoff of chemicals into soils and water bodies. Efficient farms translate to higher incomes. Farmers using AI-enabled advisory services and market analytics can align harvests with demand, minimising post-harvest waste and securing better prices.

Globally, AI and digital technologies are revolutionising farming. They support data-driven decision-making at every stage, from soil preparation to market. While the potential is clear, adoption still faces hurdles of infrastructure, cost, and skills. The global AI-agriculture market is projected to grow from about $1.7 billion in 2023 to $4.7 billion by 2028 (Markets & Markets, 2023).

### 1.2 AI in Agriculture in South Asia

South Asian countries have begun harnessing AI to boost crop yields and resilience. In India, the emphasis is on smallholder applications. The government's Digital Agriculture Mission is integrating AI for supply-chain optimisation and market access (Press Information Bureau, Government of India, 2024). Public-private initiatives have produced farmer advisory apps that use ML to give personalised weather, pest, and fertiliser guidance. Startups like CropIn and Fasal employ remote sensing and IoT to optimise irrigation and predict soil health. AI-assisted breeding programs at research institutes (e.g. India's IARI) use drone imagery and genomic data to develop climate-resilient wheat and millets (IARI, 2024). Companies such as Stellapps (Stellapps, n.d.) and DeHaat (DeHaat, n.d) offer AI-based animal health monitoring to improve dairy productivity. These efforts have reportedly helped Indian farmers conserve water and enhance productivity in drought-prone regions.

In Bangladesh, agriculture remains a GDP backstop and employs nearly half the workforce. Recent reporting highlights AI pilots addressing longstanding challenges. For example, image-recognition apps allow farmers to photograph diseased plants; the AI diagnoses the affliction and recommends treatments within seconds (GSMA, 2025). This innovation helps overcome the lack of agronomy experts and prevents yield loss. Voice-based AI advisors have also emerged, given many Bangladeshi farmers are illiterate, natural-language AI platforms provide crop and weather advice via phone in local languages (IWMI, 2025). The startups in Agritech are already starting to incorporate such AI tools and the university is amending the curriculum to educate students about smart agriculture. These programs are designed to bridge the technology divide within a short period and avail high-tech knowledge of farming in the rural Bangladesh.

Sri Lanka has also spent on smart agriculture infrastructure. Namely, a remarkable example is the GeoGoviya platform (launched in 2022 by the Department of Agrarian Development in collaboration with CGIAR/IWMI). GeoGoviya ( GeoGoviya, n.d.) offers localised and real-time weather, land use and soil conditions, crop health and water availability data to smallholder farmers. It incorporates geospatial analytics and climate-advised advice, e.g. farmers can receive customized irrigation, pest warnings and fertilizer advices with the help of straightforward dashboard. More importantly, GeoGoviya has also got a farmer and land registry so as to enhance planning and outreach. This system is a good example of how AI tools based on data can enable the system to be more resilient to droughts and floods and facilitate the efficient use of resources and a sustainable future.

The areas that AI in agriculture is working on include system efficiency and farmers services. The initiatives of India focus on scale and small farms, and are based on apps and genomic tools. Bangladesh is testing AI image- and voice-based disease diagnosis and advisory. Sri Lanka is developing country data centers to inform farm smart climate. Such local developments have shown that AI can help increase yields and climate resilience and be customized to meet local demands but this is frequently hampered by infrastructural and literacy constraints.

**Table 1**

*AI Based Agriculture in South Asian Region*

| Country | AI Innovations & Focus Areas | Delivery Mechanisms | Challenges Noted |
|---|---|---|---|
| **India** | Digital Agriculture Mission | Mobile advisory apps | Infrastructure gaps |
| | AI for supply chain, weather, and pest advisory | Remote sensing & IoT | Need for localised solutions |
| | AI-assisted breeding (e.g. climate-resilient wheat) | Startups (e.g. CropIn, Fasal) | |
| | | Public-private partnerships | |
| **Bangladesh** | Image recognition apps for crop disease | Mobile phones | Low literacy rates |
| | Voice-based AI assistants in local languages | Natural language processing platforms | Limited AI capacity in rural areas |
| | Integration into agritech startups and university programs | AI-enhanced agri services | |
| **Sri Lanka** | GeoGoviya platform: real-time weather, soil, and water data | National AI data platform | Flood/drought risk |
| | Localised dashboards for pest alerts and irrigation schedules | Government and CGIAR partnership | Need for national coverage |

| | | | |
|---|---|---|---|
| **Pakistan** | Farmer and land registry integration | Geospatial analytics | |
| | LIMS for policy-level crop monitoring | Public–private labs (e.g. Pakistan–China AI Lab) | Infrastructure & coordination gaps |
| | BaKhabar Kissan and Kisan Portal for mobile advisory | Startups (e.g. Farmdar) | Limited adoption by smallholders |
| | Farm-level AI: drones, pest detection, precision inputs | *DIGITAL DERA* for rural connectivity | |

**1.3 Pakistan's Agricultural Productivity**

The agriculture in Pakistan has structural and environmental challenges. The productivity has declined since the size of farms remains small, and irrigation systems are ineffective. Water scarcity is severe. Different reservoirs notably reduced to 18.5 MAF (million acre-feet) in 2020, as compared to 20 MAF in 1990s and over-exploited ground water depletes aquifers (Remote Sensing, 2023). Climate change has increased crop failures; recent research has attributed major decrease in yield and livestock losses to excessive heat and drought to Punjab. In the meantime, rural household constitutes approximately 61 percent of the population of Pakistan and nearly 20-25 percent of the population of Pakistan is residing in rural farming households and, therefore, agricultural growth is also a major poverty-reduction objective (Pakistan Bureau of Statistics, 2023). Farm production per hectare is, however, far below international standards, which is attributable, in part, to archaic practices and lack of efficiency in production factors. These issues suggest that there is need to use modern technology to boost production without necessarily expanding cultivated land.

The latest figures indicate the extent of farming in Pakistan with wheat, rice, and cotton being the major crops and Pakistan is the largest producer of wheat and rice in the world. However, agri growth in Pakistan is not steady; during the period of 2020-24, Pakistan experienced sluggish growth because of climatic shocks as well as retrogressive reforms. Climate-smart farming has become one of the policy objectives in Punjab, the source of about 76 percent of the grain in Pakistan. A World Bank project (Punjab Resilient and Inclusive Agri Transformation, 2022, 200 m) specifically refers to innovation in relation to productivity, financing climate-smart technologies, and increased water use efficiency (World Bank, 2024). The Punjab Agriculture Policy 2018 also stressed the theme of irrigational reform and investment in the hands of the private to enhance production (Punjab Agriculture Department, n.d.). Such efforts represent increased understanding that technology-based intensification has to drive future growth as opposed to expansion of the area.

Estimates suggest up to 30% losses in grain and perishable produce due to inadequate cold chains and forecasting (Ahmad 23et al., 2025). AI and digital tools that provide market price signals or supply forecasts could reduce these losses. Pakistan's agri sector has immense untapped productivity potential, but realising it depends on adopting modern technologies and improving policies.

Pakistan has a high number of smallholder farmers who are the majority of agricultural producers but they are limited by structural issues that hinder their use of advanced technologies. Lack of access to credit inhibits investment in digital technology, e.g. sensors or drones. Moreover, lack of digital literacy and poor internet connectivity limits the farmers with access to the AI-based advisory services. Due to this, the use of AI presents a risk to favor the bigger commercial farms unless inclusive delivery systems, like cooperative drone, shared digital, and voice advisory systems are introduced. In regard to agricultural transformation in Pakistan, Artificial Intelligence (AI) will be used in two different levels but equally important and complementary to each other, namely policy management and farm-level operations.

### 1.4 Artificial Intelligence in Policy Management

This is the merger of AI powered systems and platforms with government organizations, research organizations, and planning agencies to facilitate strategic decision-making. A study case is the Land Information and Management System (LIMS) which collects satellite images, geospatial datasets and agronomy inputs that can be used to enhance macro-level operations including; land classification, crop observation, irrigation programming and climate risk management. Such AI tools can help policymakers to allocate funds, plan the interventions, and improve governance because they supply a real-time and data-rich perspective of the national or provincial agricultural systems.

### 1.5 Farm level AI

Farm-level AI-technologies have been used either by farmers or service providers at the field levels to solve real-time decisions. These have been in the form of artificial intelligence powered spraying drones, surveillance drones, mobile advisory applications (e.g. BaKhabar Kissan), smart irrigation software, image-recognition applications used to identify diseases. The solutions ensure both precision and timeliness at an operational level; they allow farmers to enhance their yields, save on inputs costs, and deal with climate variability at a field level.

### 1.6 Purpose and Contribution of the Study

Although the development of artificial intelligence in agriculture as a global literature indicates, there is little analytical literature on the role of the technologies in bridging the productivity gap in the Pakistani agricultural industry. The available research is mainly descriptive policy debate or pilot project testing. This research is relevant to the literature in the following three ways. Firstly, it offers a systematic literature review of AI applications globally and regionally in the field of agriculture. Second, it approximates the difference between production and marketing output of major cereal crops in Pakistan by using official data. Third, it creates an empirical framework of scenarios in which AI adoption can be used to enhance the agricultural productivity, decrease post-harvest losses, and enhance climate resilience.

## 2. Methodology

The values available in the market sold by farmers, which are shown in this analysis, are the additions of the sale estimates and recorded exports of each crop. Data is gathered from Pakistan Economic survey and Ministry of Finance for the overall production. The annual trade statistics of the Pakistan Bureau of Statistics (PBS) were used to compile figures of export. Since not all crops report high enough detail to cover the domestic sales part of their production, the marketed volumes were estimated under the assumption that losses post-harvest-based on literature and expert estimates, usually around 8-15% (FAO, 2011) are subtracted and overall production levels compared with known exports. In the case where the crops had no significant exports, including cotton and sugarcane, it was considered that almost 100 percent of production went into the home market. In high export produce such as the rice, actual export quantities were added to the estimated domestic consumption numbers to calculate the marketed quantity. Although these estimates will focus on presenting real flows in the market, there can be a gap. There can be informal trade, hoarding and storage which are not added in this methodology.

### 2.1 Estimation Model and Assumptions

The estimation model is based on the comparison of total crop production with the marketed volumes (domestic sale and export) in order to estimate the extent of post-harvest losses and supply chain inefficiencies. It is hypothesized in the model that the percentage of crops harvested is not reaching formal markets because of storage losses, transport losses, informal trade, and subsistence consumption. According to the estimates of FAO (2011), losses observed in the developing countries are between 8-15 percent in cereal. In this research, we use this range as a base assumption to estimate the possible loss margin of the cereal value chains in Pakistan.

Besides that, the analysis also applies a tiered scenario approach to assess the potential outcomes of AI usage in agriculture. Three scenarios are created: conservative, moderate, and optimistic, which represent various degrees of adoption of technology and the implementation of the policy. The moderate scenario is the most realistic based on existing pilot projects and regional experience whereas the conservative and optimistic scenarios are the calculated variations of +-30 percent to represent the uncertainty in adoption rates.

### 2.2 Crop Production vs Marketed Sales (2018–23)

Using official sources (Pakistan Economic Survey, PBS trade reports, etc.), we compare annual crop output with quantities sold into domestic and export markets. The table below summarises production and estimated marketed quantities (domestic sales + exports) for Pakistan's major crops; the gap is the shortfall between production and marketed volume. (Values in thousand tonnes, cotton in thousand bales*). The data to identify this gap is extracted from the Finance Division and the Pakistan Bureau of Statistics (Government of Pakistan, Finance Division, 2025, PBS, 2025)

**Table 2**

*Production and Estimated Marketed Quantities*

| Year / Crop | Production | *Domestic+ Export* | Exports | Gap (Prod–Sales) |
|---|---|---|---|---|
| **2018–19** | | | | |
| Wheat | 24,349 | 22,158 | 0 | 2,191 |
| Rice | 7,202 | 6,122 | 4,150 | 1,080 |
| Maize | 6,826 | 5,802 | 0 | 1,024 |
| Sugarcane | 67,174 | 67,174 | 0 | 0 |
| Cotton (bales)* | 9,861 | 9,861 | 0 | 0 |
| **2019–20** | | | | |
| Wheat | 25,248 | 22,976 | 0 | 2,272 |
| Rice | 7,414 | 6,302 | 4,149 | 1,112 |
| Maize | 7,883 | 6,701 | 0 | 1,182 |
| Sugarcane | 66,380 | 66,380 | 0 | 0 |
| Cotton (bales) | 9,148 | 9,148 | 0 | 0 |
| **2020–21** | | | | |
| Wheat | 27,464 | 24,992 | 0 | 2,472 |
| Rice | 8,420 | 7,157 | 3,685 | 1,263 |
| Maize | 8,940 | 7,599 | 0 | 1,341 |
| Sugarcane | 81,009 | 81,009 | 0 | 0 |
| Cotton (bales) | 7,064 | 7,064 | 0 | 0 |
| **2021–22** | | | | |
| Wheat | 26,208 | 23,849 | 0 | 2,359 |
| Rice | 9,323 | 7,925 | 4,200 | 1,398 |
| Maize | 9,525 | 8,096 | 0 | 1,429 |
| Sugarcane | 88,651 | 88,651 | 0 | 0 |
| Cotton (bales) | 8,329 | 8,329 | 0 | 0 |
| **2022–23** | | | | |
| Wheat | 27,634 | 25,104 | 0 | 2,530 |
| Rice | 7,322 | 6,222 | 3,717 | 1,100 |
| Maize | 10,183 | 8,656 | 0 | 1,527 |
| Sugarcane | 91,111 | 91,111 | 0 | 0 |
| Cotton (bales) | 4,910 | 4,910 | 0 | 0 |

Source: Own depiction based on PBS and the Ministry of Finance

Cotton production is reported in thousand bales (1 bale ≈170 kg). Export of raw cotton has been negligible, so market sales for cotton are effectively its entire production (all sold to domestic ginners). The Marketed column for cotton thus equals production; the small gap is effectively zero.

**2.3 Year-by-Year Insights**

In 2018–19, Wheat output was 24.3 Mt, but only ~22.2 Mt was marketed; about 2.2 Mt (≈9%) was effectively lost or not sold. Rice production (7.2 Mt) fell to 6.1 Mt marketed because 4.15 Mt were exported and roughly 1.08 Mt (15%) was lost. Maize shows a similar pattern, 6.83 Mt produced, but ~1.02 Mt (15%) loss. Sugarcane was fully crushed (gap ≈0). Only rice was heavily exported (4.15 Mt); wheat had no exports (export bans began only in mid-2020).

In year 2019–20, Wheat output rose to 25.2 Mt but still only ~22.98 Mt was sold (gap ~2.27 Mt, ~9%). Rice production (7.41 Mt) yielded 6.30 Mt marketed (exports 4.15 Mt, plus ~1.11 Mt lost). Maize (7.88 Mt) had ~15% losses (gap ≈1.18 Mt). Again, sugarcane was fully marketed and cotton production (9.15 M bales) was entirely sold domestically (exports negligible).

In 2020–21, Wheat production jumped to 27.46 Mt, with ~2.47 Mt (9%) not reaching market. (No wheat was exported under the continued export ban.) Rice output (8.42 Mt) produced 7.16 Mt marketed (with 3.68 Mt exported and ~1.26 Mt lost). Maize (8.94 Mt) had ~1.34 Mt lost. No significant sugar or cotton gaps.

In year 2021–22, Wheat fell to 26.21 Mt (notwithstanding floods/drought); ~2.36 Mt (9%) was not marketed. Rice hit a record 9.32 Mt, of which ~4.20 Mt was exported and ~1.40 Mt lost. Maize (9.53 Mt) lost about 1.43 Mt. Sugarcane was fully crushed, and cotton (8.33 M bales) again sold out. (The government imported ~3 Mt of wheat in FY2021-22 to meet domestic demand.)

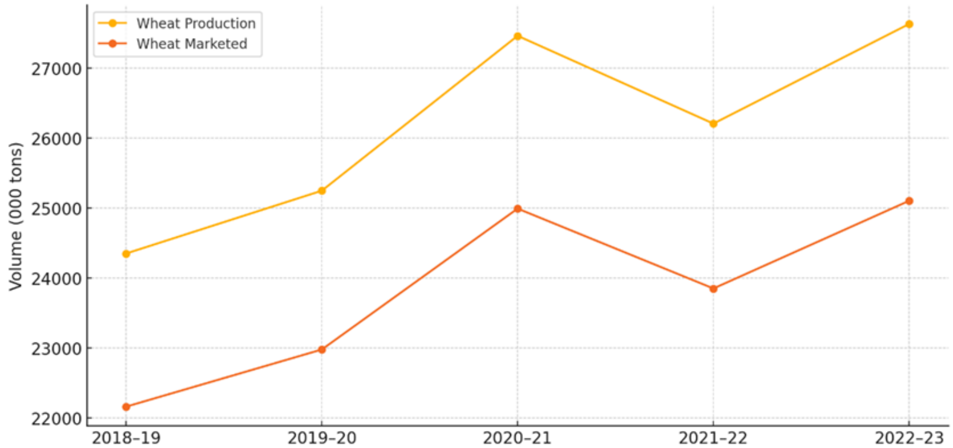
In 2022–23, Wheat rebounded to 27.63 Mt, but floods and heat damaged harvests. About 2.53 Mt (9%) did not enter markets (matching recent loss estimates). No exports occurred. Rice production plunged to 7.32 Mt; ~3.72 Mt was exported, leaving ~6.22 Mt marketed and ~1.10 Mt (15%) lost. Maize (10.18 Mt) again saw ~15% (1.53 Mt) lost, with domestic marketing around 8.66 Mt. Floods sharply cut cotton yields (to 4.91 M bales), but this entire crop was sold to mills; exports remained negligible. Sugarcane output (91.11 Mt) was fully milled for domestic sugar.

The production and sales gaps above translate to large monetary losses. For example, CropLife Pakistan estimates that ~2.53 Mt of wheat lost in 2022–23 cost about Rs 158 billion, and ~1.10 Mt of rice lost cost Rs 79.8 billion. (Maize losses ~1.53 Mt were similarly on the order of Rs 115 billion.) These losses represent value that never reached the market (nor consumers). Conversely, in years when production lagged demand (early 2019–22), Pakistan imported cereals to close the gap. The un-marketed volume arises largely from post-harvest losses and wastage, estimated at ~8–15% in cereals annually. Poor harvesting techniques, inadequate drying and storage facilities, and a lack of modern handling mean large volumes spoil in transit or in godowns. Natural disasters also play a role, the 2022 floods in Sindh/Balochistan wiped out large areas of standing cotton and wheat, boosting the gap.

Other factors include market inefficiencies. Farmers may store (hoard) produce to await higher prices, delaying sales; incomplete market channels (informal trade) mean some production never passes through formal markets. In addition, government policies can affect market flows. Each year, these factors help explain why marketed crops fall noticeably short of total harvest volumes.

**Figure 4**

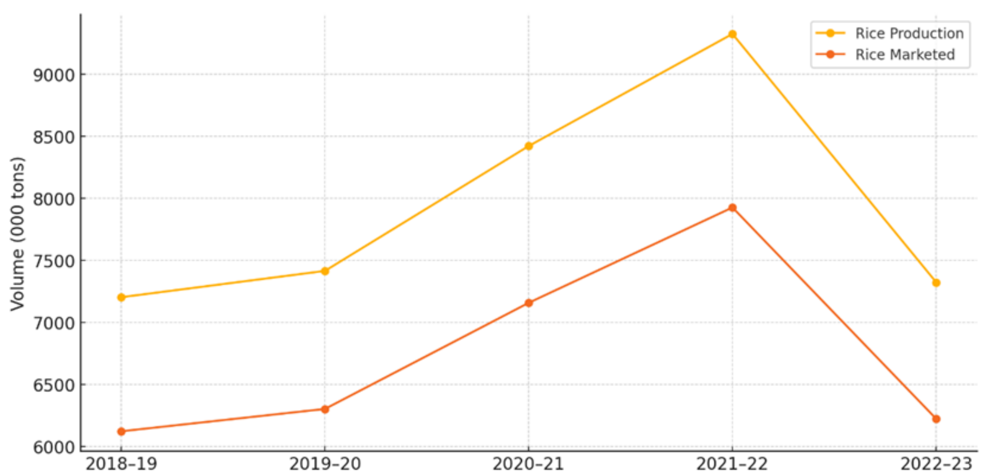
*Wheat Production Vs Marketed*




The graph shows the pattern of the wheat production and marketed volume in Pakistan between 2018-19 and 2022-23. There is an overall positive movement of wheat production (in yellow), with the range being between 24.5 million tons in 201819 and more than 27 million tons in 2022-23, even though it decreased in 202122. Domestic sales and exports (marketed wheat as shown in the orange line) present an upward trend as well, but their extent does not exceed that of the total production, which means that there is a substantial gap. This is the gap which shows post-harvest losses, subsistence or inefficiencies of the supply chain. It is important to note that the margin decreases when the production is more significant, as it indicates a stronger integration in the market or less wastage during those years.

**Figure 5**

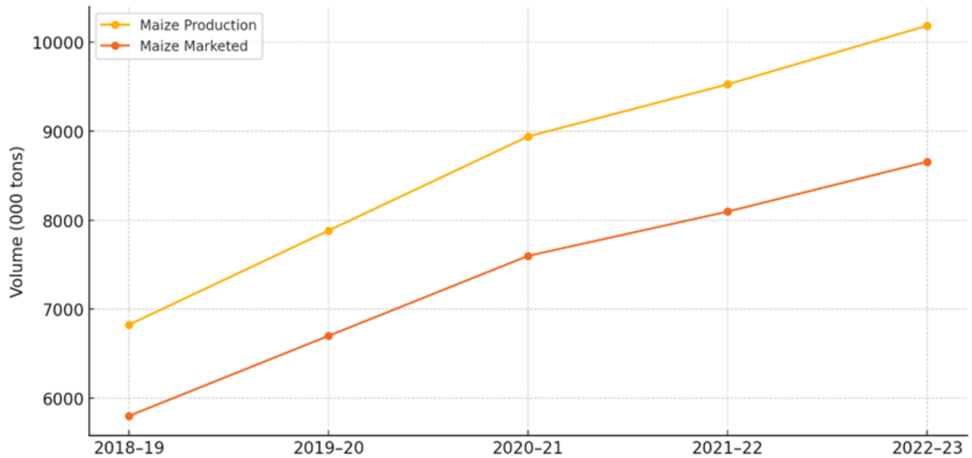
*Rice Production Vs Marketed*




This graph shows the trends in rice output and marketed quantity in Pakistan from 2018-19 to 20222023. Rice production (yellow line) increased over time, reaching approximately 9.3 million tons in 202122. However, the year 2022-23 saw a sharp decline in production, likely due to climatic shocks such as floods. Similarly, rice sold (orange line), which includes both local sales and exports, rose to about 7.9 million tonnes in 2021-22 before dropping sharply from 2022-23. The globally marketed volume was always less than the production, reflecting on-farm consumption, losses, or market access issues. The significant decline in production and marketed volumes in 2022-23 indicates severe disruption in the rice value chain, which could negatively affect farmers and exporters.

**Figure 6**

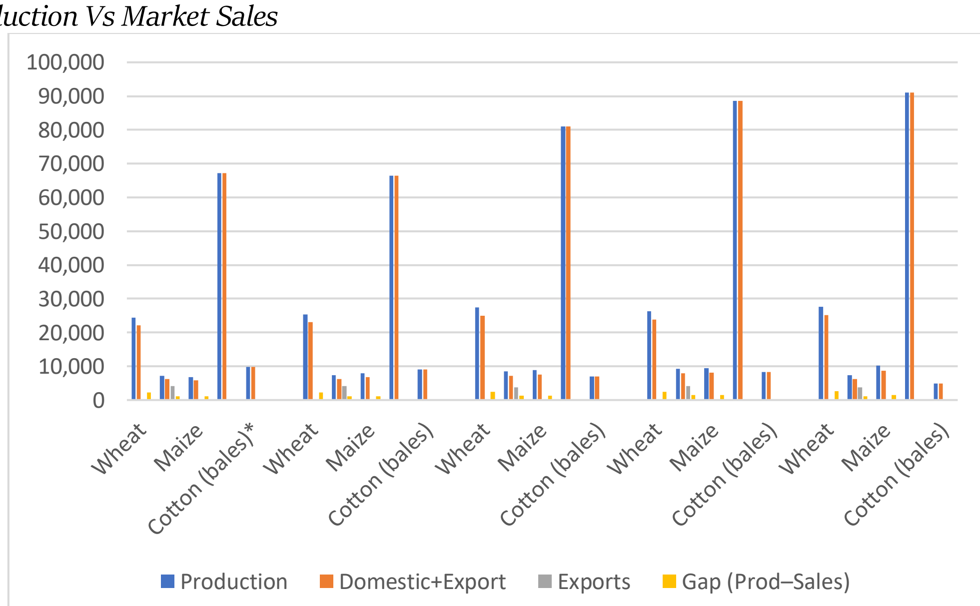
*Maize Production Vs Marketed*




The figure illustrates the pattern of maize production and marketing in Pakistan between 2018-19 and 2022-23. Maize production has shown steady growth since 2018-19, increasing from about 6.8 million tonnes to over 10.2 million tonnes in 2022-23. Similarly, there has been a rising trend in maize trade (orange line) over this period, reflecting growth over the last 30 years. This is indicated by the increasing demand for maize in both local consumption and potential export markets. The narrowing gap between production and the marketed volume suggests improved access to markets and better handling after harvest. Compared to other crops, maize has not faced significant production issues, making the crop seeds more resilient and appealing to farmers.

**Figure 7**

*Total Crop Production Vs Market Sales*



### 3. Digitalisation and AI Initiatives in Pakistan

Pakistan has been undertaking several initiatives of digitisation of agriculture and the introduction of AI. One of them is the Land Information and Management System (LIMS) (Punjab Land Records Authority, 2025), which was introduced as part of the Green Pakistan Initiative (GPI) and Special Investment Facilitation Council (SIFC). LIMS is a GIS based system that integrates data about soil health, crop status and water consumption. LIMS will maximise resource allocation and climate adaptability by providing farmers and the petroleum sector with satellite-based monitoring of crops and irrigation systems performance. Practically, Punjab and KP are testing LIMS in pilot farms where they are testing smart irrigation and fertilisers management. Scaled LIMS may inform the managers about the danger of drought or soil depletion real-time and prescribe interventions at the field-level.

The government in Pakistan has also experimented with other digital applications in addition to LIMS. SMS and mobile advisories on weather and pests are made available on E-Agriculture websites such as BaKhabar Kissan (BaKhabar Kissan, 2025) (Provincial) and the federal Kisan Portal. Crops can be monitored via satellites (which might be a part of LIMS) and allow yield to be predicted nearly in real time. Miniature Ministry of Information Technology has specifically recognized the use of AI; it, for instance, agrees to the use of AI in the national agri strategy that will educate farmers and enhance efficiency. Remote training and extension through video and mobile is also offered by new e-agriculture networks and ICT-for-development projects that are emerging as public-private partnerships. These digital extension initiatives fill the knowledge gap in small farmers in Pakistan, and it is reported that mobile advice can substantially increase yields. In fact, according to one PARC study, farmers who had SMS advisory services on their farms experienced an increase in crop yields of nearly 20 percent compared to those who did not receive the services, which showed how the access to information could be converted into productivity increase (PARC, 2020).

The *digital dera* project (launched in Pakpattan in 2021 by the NGO Agriculture Republic) (Internet Society, 2021) is one such example. It set up a free community Wi-Fi hub ("*Digital Dera*") providing rural farmers with internet access. Farmers there can check market prices online, use e-learning modules, and access digital finance and e-commerce, activities that were previously impossible in the "network desert". Early reports note that this connectivity allows smallholders to bypass middlemen, improving their bargaining power and incomes. However, as experts observe, one village is not enough, scaling broadband access and power infrastructure remains a national priority for enabling all farmers to use online AI tools.

Agritech startups and innovation are driving AI deployment on farms. For example, *farmdar* (a Lahore-based startup) provides an AI-powered platform that integrates satellite imagery with soil and weather data to guide irrigation and pest control. The *FARMDAR* co-founder notes that such tools, once affordable, can offer large-farm insights to smallholders. Other companies (e.g. Tazah, DeHaat Pakistan) are piloting AI in supply-chain forecasting and precision input application. These entrepreneurs help translate research into user-friendly apps. Nonetheless, there are still difficulties on high equipment prices and low digital literacy levels translates to poor farmers having little uptake. In response to this, analysts believe in subsidies and government extension integration, in order to make smart tech as common as better seeds.

The biggest recent event is the Pakistan-China Joint Lab of AI and Smart Agriculture in the University of Agriculture Faisalabad. This project is an experimental high-throughput crop monitoring project in Punjab based on computer vision. The AI-powered cameras mounted on drones scan the field on autopilot to determine its growth, identify pests and diseases, and determine irrigation requirements. Pilot tests involving approximately 600 farmers in the local area automated operations such as accurate spraying Farmers state that the system eliminates instances of overwatering and over-fertilisation, reducing the input expenses and enhancing predictability. According to the director of that lab, assuming that drone spraying is integrated into every village in Punjab with 25,000 villages, it would lead to a significant increase in productivity and a reduction in costs. Such partnerships imply that Pakistan starts to leverage the Chinese experience of using agri-robots and AI.

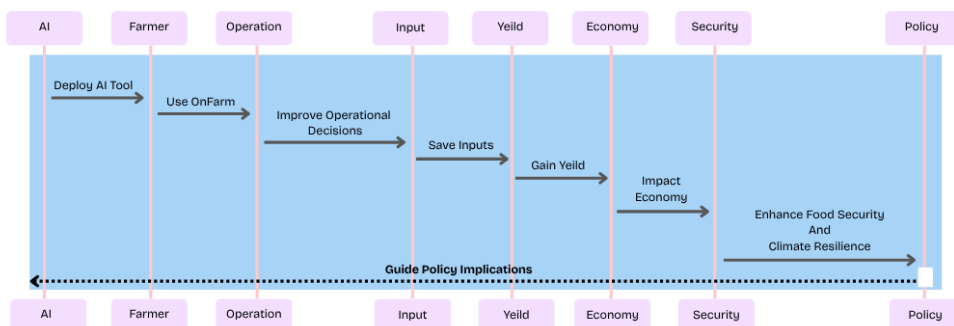
There are other national programs that are coming up. In 2023, the Ministry of National Food Security came up with the Policy Framework of Smart Farming and AI Adoption. Weak coordination of agencies and few smallholder-oriented tools were found in this review. It also suggested prioritizing the low-cost AI solutions, promoting the collaboration between the government and innovators, and enhancing the connections between the policymakers and the innovators. The greater Digital Pakistan and National AI plans of Pakistan focus on the innovation hubs, on digital assistance and AI research and development. These programs, combined with policies in the sector, present a platform on which to scale AI in agriculture.

## 4. Theory of Change: From AI Tools to Policy Impact in Agriculture

The theory of change below describes how the use of AI tools in agriculture can bring a systemic effect, both on-farm practices and the implications of the national policy:

**Figure 8**

*Theory of Change: AI Tools to Policy Impact*




The advent of the AI tools is a place of beginning change of the agricultural practices. When deployed, the tools are embraced by farmers on-farm and they could be used to arrive at better operational decisions such as precise irrigation and proper pest control. Consequently, there is significant reduction of input such as water, fertilizers, and pesticides. Such efficiencies result in yield increases through increased and improved production of crops. The resulting economic effects are that farmer revenue will be raised and there is the risk of post-harvest losses being reduced. And collectively, these developments can help increase food security and climate resiliency. In the end, such results help to generate meaningful policy implications, promote evidence-based strategies, expansion of programs that are effective, and in crafting designs of targeted subsidies.

## 5. Proposed Monitoring Indicators under M&E Framework

### 5.1 Tiered Estimation Model for AI M&E Indicators

The tiered estimation model offers three estimates of projected outcomes based on the projections made by the policymakers, donors, and implementers that offer a sense of range that each indicator can take including Conservative, Moderate, and Optimistic. Such approach is necessary in case of adverse conditions of availability of real-time data or uncertainty of outcomes (with regard to developing technology, such as AI in agriculture). Details of the Indicatoes and estimation are in Annex.

**Table 3**

*Tiered Estimation Model for AI M&E Indicators*

| Category | Indicator | Conservative | Moderate | Optimistic |
|---|---|---|---|---|
| AI Adoption Metrics | % of farms using AI tools | 24.5 | 35 | 45.5 |
| AI Adoption Metrics | AI adoption rate by province | 28 | 40 | 52 |
| AI Adoption Metrics | Farmers registered on advisory platforms | 105000 | 150000 | 195000 |
| AI Adoption Metrics | Area monitored via LIMS | 350000 | 500000 | 650000 |
| Infrastructure Readiness | % rural farms with mobile internet | 38.5 | 55 | 71.5 |
| Infrastructure Readiness | DIGITAL DERA hubs established | 84 | 120 | 156 |
| Infrastructure Readiness | Villages with broadband or IoT | 31.5 | 45 | 58.5 |
| Training and Literacy | Farmers completing AI training | 56000 | 80000 | 104000 |
| Training and Literacy | % trained farmers using AI in 6 months | 49 | 70 | 91 |
| Training and Literacy | % women farmers trained in AI | 21 | 30 | 39 |
| Economic Outcomes | Input savings per hectare | 17.5 | 25 | 32.5 |
| Economic Outcomes | Yield increase per hectare | 14 | 20 | 26 |
| Economic Outcomes | Net farm income increase | 10.5 | 15 | 19.5 |
| Economic Outcomes | Post-harvest loss reduction | 8.4 | 12 | 15.6 |
| Environmental and Climate Resilience | % reduction in pesticide use | 21 | 30 | 39 |
| Environmental and Climate Resilience | Water-use efficiency gains | 24.5 | 35 | 45.5 |
| Environmental and Climate Resilience | AI-based early warnings issued/responded | 210 | 300 | 390 |
| Environmental and Climate Resilience | Crop diversification index | 0.49 | 0.7 | 0.91 |
| Gender and Inclusion | % women-led farms using AI | 15.4 | 22 | 28.6 |
| Gender and Inclusion | AI services in local languages/voice | 35 | 50 | 65 |
| Gender and Inclusion | % subsidies to women/marginalised | 12.6 | 18 | 23.4 |
| Innovation and Ecosystem Health | Agritech startups supported | 35 | 50 | 65 |
| Innovation and Ecosystem Health | Public-private AI partnerships | 8.4 | 12 | 15.6 |
| Innovation and Ecosystem Health | AI-agri research publications | 21 | 30 | 39 |
| Policy and Governance Indicators | National AI strategy implemented | 0.7 | 1 | 1.3 |
| Policy and Governance Indicators | % provinces aligned to national strategy | 52.5 | 75 | 97.5 |
| Policy and Governance Indicators | Data governance framework established | 0.7 | 1 | 1.3 |

The measure of the percentage of trained farmers taking an AI onboard within six months after training will be an indication of how successfully training programs helped farmers to apply knowledge to practice. It demonstrates whether farmers embrace AI tools, after trainings have been administered to them, in their daily farming practices. The latter indicates that approximately 50 percent of the trainees can start using AI because they have some obstacles such as a lack of resources, digital literacy, or poor infrastructure. The moderate estimate has demonstrated that approximately 70 percent of farmers was able to successfully adapt these tools, which points to a high correlation between training and practice. Ideally, the adoption will be over 90 percent, and this would occur when the training, accessibility and system supporting the systems are well harmonized. This indicator is therefore obligatory when it comes to the level of training programs as well as the real impacts that it could have in the farming activities.

### 5.2 Technological, Economic, Policy, and Environmental Implications

On a larger scale, AI-based agriculture has implied the following effects:

#### 5.2.1 Implications of technology

A combination of sensors, IoT, and computing by AI brings new levels of enhanced precision to the work of the farm. Jobs that previously depended on the experience of the farmers are automated and data-intensive. This transition will necessitate the infrastructure, broad band, drones, weather stations and power supply in the rural set ups. It also requires new skills; farmers and agronomists would have to learn how to use AI applications and understand the results of the data. Expert advice is made available to farmers via mobile applications, bypassing the conventional steps, and this is an example of technology jumpstarting. The progressive adoption of AI in Pakistan is one of the indicators that the country is shifting to smart farming environments.

#### 5.2.2 Economic Implications

AI is reported to have gained a lot of economic benefits by empirical research and pilot projects. In the northern districts of Pakistan, AI-based system of pest control and irrigation reduced the inputs consumption at the rate of about 40 percent (Invade Agro Global, 2025) and increased the yield by 20-25 percent (Verbitskaya, 2024). Minimal yield increases cause greater income gains in low-margin agricultural activities. The economy of Pakistan would experience positive growth under the leadership of AI, more productivity would be accomplished in the rural areas and this would stabilise the price and supply, hence lowering inflation on food commodities. Rural tech services and agritech entrepreneurship are other new business opportunities that can be made by AI. The gains may also be concentrated in the hands of large farmers who can afford to invest in machinery without inclusive policies which can make inequality even greater. In this way, economic studies emphasise that the target to smallholders is important, such as, in India, the emphasis on low-cost mobile AI is to disable benefits to large numbers. The way the AI dividend is distributed will be determined by the policies of Pakistan.

#### 5.2.3 Environmental Implications

Environmental sustainability is a significant reason why AI can be used in agriculture. AI helps to lose less water and chemicals, as it allows a more accurate use of the inputs. Each of those, as an example, is computer-vision pest monitoring, which would avoid the blanket application of pesticides to non-infested places to reduce the amount of pesticide needed. Automated irrigation systems will be able to adjust water supply to the existing soil moisture, hence usually decreasing water consumption by 30-40%. This efficiency is very important in climate-stressed Pakistan; AI-fine-tuned weather forecasting and soil scanning will enable farmers to adjust to the droughte or flood cycle and thus appropriately plant. In Sri Lanka, Drought monitoring based on AI gives an early warning that minimizes loss due to extreme events. Furthermore, AI enhances the creation of climate-tolerant crops types via genetic examination which may additionally boost the resilience. AI is a way of attaining sustainable intensification, increasing the yield per hectare with a reduction in the environmental cost. Nevertheless, the environmentalists warn that digital agriculture is to be regulated, as, examples, the consumption of energy is produced by data centres and drones, and algorithms need to be adjusted to local environments to reduce the possibility of unintentional damage.

#### 5.2.4 Policy and institutional implications

Governments should be able to ensure that regulatory, educative and infrastructural systems are in tandem. The policymakers in Pakistan should seek to handle data ownership and data privacy when dealing with farm data, establish standards on the reliability of AI tools. The extension agents also need to be trained to ensure that farmers get a chance to utilize AI platforms effectively. The coordination between sectors is also important, the weaknesses along the connections between ministries, research institutions and the business world can stop the innovation. On the one hand, national strategies offer a conceptualization to mainstream AI. Knowledge and standard transfer can be facilitated through international collaboration such as through TAP-AIS partnership and China-Pakistan lab. Finally, to be successful, the vital aspect will be synchronizing technology activities with social policy so that the rural communities could enjoy equal access and that AI tools those can be incorporated into an expanding rural development agenda.

The future of agriculture is based on AI and digital innovations. The AI applications are already leading to yield and efficiency in the regions globally and internationally. To Pakistan this implies a definite chance through investing in smart agricultural systems, establishing extensive research among the populace and governmental supporting policies, Pakistan could increase farm output and resilience. This will not only strengthen food security, but will also give the rural economies a boost. The advantages of AI will simply be achieved by employing a holistic strategy that compensates on technological ambiguities, economic inclusivity, environmental protection, and good governance. The increasing literature offers a blueprint to such a strategy, noting that technology should be accompanied by policy and expansion to revolutionize the agriculture sector in Pakistan that will benefit the country.

### 5.3 Intersecting Gender, Inclusion, and Digital Equity in AI in Agriculture

Even though AI is capable of transforming the industry, it cannot be applied fairly unless gender concerns and inclusion are well stipulated. In Pakistan, women constitute large share of the work force in agriculture especially in the rural communities where they contribute in cleaning and taking care of livestock, harvesting and subsistence farming. But they usually do not have access to mobile technologies, online connections, and official extension services, which puts them at a systemic disadvantage in getting access to digital innovations. The digital literacy divide is particularly severe among women in the rural area, and it restricts the potential of these groups to access AI-based innovations, such as mobile advisory, automated irrigation systems, or the disease diagnosis apps. Otherwise, without dealing with the issue, there is a threat that the accelerated digitalisation of the agricultural branch can only serve to marginalise women farmers and increase the already entrenched disparities.

Gender-sensitive policies should be integrated in the national AI policy to make them inclusive as opposed to exclusive as it usually happens now with the AI. These are specific training activities that target women farmers, the use of inclusive technology (e.g. voice technology or multilingual interfaces) and fair access to digital infrastructure. Extension services and the public-private partnerships should also focus on reaching out to female farmers. AI empowerment of women will have the following additional outcomes due to social equity being promoted, improved productivity and resilience at the household level and within communities.

## 6. Financing AI for Agriculture

The policy will only be enough to scale the AI in the agriculture in the Pakistan but also will be inclusive and sustained financing processes. Although pilot projects are promising, lack of access to affordable technologies, infrastructure and advisory services limit the extent to which they will be adopted, especially by small holders.

A number of funding channels are coming up. Digitalisation is one of its main pillars and can be used as a long-term investment funding mechanism in the implementation of AI under the Pakistan Agriculture Transformation Plan (PATP). There is also the World Bank-financed PRISM investment (Punjab Resilient and Inclusive Agriculture

Transformation), which sets aside 200 million to push climate-smart technologies, the efficiency of water consumption, and digital extension services, leaving room for AI-powered solutions to grow.

Constrained cash transfer schemes, such as the Benazir Income Support Programme (BISP) may be modified to introduce selective subsidies or incentives applicable to the usage of digital tools by vulnerable farming households, specifically women. These transfers might be associated with attending digital literacy program, adoption of AI-guided advisories, or application of mobile extension software.

In addition, blended finance models that mix the funds of the state with investor income and donation can decouple the risks of innovation and advance agritech entrepreneurship. Technical assistance and seed funding in AI are already being provided by international partners, such as China, as well as the FAO. To achieve greater effect, the government should institutionalise these funds sources into budgeting processes at the national levels and prioritize AI interventions under the agricultural and rural development dockets.

## 7. Legal and Regulatory Gaps in AI for Agriculture

The state of AI in agriculture in Pakistan features a number of legal and regulatory gaps that are likely to adversely affect its deployment in an efficient and fair way. It can be considered one of the significant issues that there are no national standards on agricultural data. Along the way, platforms such as LIMS and mobile advisory systems are producing immense amounts of farm level data, but there are no standardized ways to classify that data, share and assure its quality. Moreover, without strong safeguards against the collection of privacy data of farmers, the collection of personal and operational data is being done without clear protection in terms of consent, access or control. This exposes the smallholders to the possibility of misuse of information.

The other major gap is the lack of regulation of AI startups and the providers of digital tools. Though there are increased agritech enterprises that are proposing AI-based solutions, the formal process of certifying and licensing such occurrences is lacking and this brings doubt about the consistency and responsibility of this kind of technology being presented to farmers. Additionally, the reach of public-private partnerships in AI is growing, though, there is no legislative framework that applies to data exchange, intellectual property, and liability of the concerned parties. The identified gaps highlight the necessity to have a consistent legal framework to promote the use of responsible AI in the agricultural sector in Pakistan.

**Table 4**

*Legal and Regulatory Gaps*

| Legal Gap | Impact | Recommendation |
|---|---|---|
| No agri-data standards | Fragmented systems, low trust | National Agri-Data Governance Framework |
| Weak privacy for farmers | Exploitation, loss of trust | Farmer data protection laws with consent and access rights |
| No AI startup licensing | Quality risk, misinformation | National certification/accreditation for agri-AI tools |
| Unregulated data sharing | Low PPP engagement | Legal templates for public-private AI agreements |

## 8. Conclusion

Pakistan's agriculture still faces low productivity, poor water use, and high post-harvest losses, nearly 30 percent, which hinders food security and livelihoods in the country. Globally, AI technology has been effectively applied in agriculture, leading to crop production increases of up to 30 percent and a significant reduction in input costs. In Pakistan, efforts like the Land Information and Management System (LIMS), BaKhabar Kissan, and the Pakistan-China Joint Lab for AI in Smart Agriculture are working to incorporate AI technology.

This paper is an addition to the growing body of literature on digital agriculture in developing economies because it involves policy analysis and a quantitative study of production-to-market gaps in the Pakistani major cereal crops. The study can offer an analytical model to understand how digital technologies can decrease the inefficiencies in agricultural value chains by connecting these gaps to possible AI-based interventions.

Agritech startups such as *farmdar* and *tazah* are working to alter digital tools for smallholder farmers, a gap that had not been addressed before. To maximise value in the field, increasing the adoption of AI in farming requires stronger public-private partnerships, universal rural internet connectivity and reliable power supply, as well as affordable and easy-to-learn AI toolsets. These tools must be supported by farmer training and digital literacy programmes to ensure they are used effectively. A coherent national AI-agriculture strategy that aligns with broader climate resilience and rural development agendas would be crucial in guiding Pakistani agriculture towards an inclusive and sustainable long-term growth path.

The empirical studies in the future must be directed at the farm level adoption of AI technologies in Pakistan. Survey research would be able to consider the relationship between farm size, education, and the access to digital infrastructure and technology adoption. Also, the causal effect of AI tools on crop yields, input efficiency, and farmers incomes could be estimated with the help of econometric analysis with panel data.

## 9. Policy Recommendations

- Build a coherent national strategy on AI in the agricultural sector, which ensures that provincial efforts are harmonised and that AI is applied through strategies of climate resilience and the rural development plan.
- Enhance broadband and mobile internet connectivity in villages and expand solar-powered IoT, energy to provide a stable supply of energy to adopt AI.
- Facilitate the availability of affordable and user-friendly AI toolkits and mobile advisory apps targeting smallholders and encourage the use of such tools through farmer trainings, digital literacy initiatives and incorporation of such technologies into extension.
- Back agritech startups and SMEs with investment status, incubation, and public-private alliances to roll out AI innovation and bring precision farming technologies to farms of all sizes.
- Lay a national farm data governance scheme guarding farmer data rights, promoting ethical data sharing and performance of open-data precincts with the view to research and advancement of agri-business.
- Support precision subsidies and funding towards the use of AI-based technologies such as drones, automated irrigation, and pest detection systems, with priorities on productivity and resource efficiency and adaptation to climate change.
- Promote partnering with other countries and international regions and create research centres in agricultural universities to instigate local innovations, capacity building, and speeding up the AI to be integrated into farming systems.
- Implement powerful observing and measuring frameworks to gauge the impacts of AI on adoption, and refine policies through the assistance of evidence-based planning and to give sustainable and inclusive reshaping of agriculture.

**Action Matrix**

| Action Area | Pathways to Solution | How to Implement Each Solution | Actor Responsible | | Implementation Timelines |
|---|---|---|---|---|---|
| | | | **Primary Actor** | **Support Actor** | |
| **National AI Strategy for Agriculture** | Harmonise federal and provincial efforts; integrate with climate resilience and rural development | Create an inter-ministerial task force; develop AI strategy; include provincial consultations and stakeholders | Ministry of National Food Security & Research (MoNFS&R), | Planning Commission, Provincial Agriculture Departments | Short-term: 6–9 months Medium-term: 1–2 years |
| **Expand Connectivity & Energy Access** | Improve digital and power infrastructure for rural AI adoption | Expand broadband (via USF); incentivise solar-powered IoT systems; ensure stable electricity supply to farms | Ministry of IT & Telecom, | Provincial Governments, Ministry of Energy, USF, NEPRA | Medium-term:1–3 years |
| **AI Toolkits and Farmer Capacity Building** | Make AI tools affordable and usable by smallholders | Develop and distribute mobile apps/toolkits; launch farmer training & digital literacy campaigns; integrate AI tools into extension services | Pakistan Agricultural Research Council (PARC) | Provincial Extension Services, NGOs, agri-tech startups, MoITT | Short-term: 6–12 months |
| **Agritech Startup Support** | Strengthen AI innovation through public-private ecosystems | Offer tax incentives, startup grants, incubation spaces; build PPPs for scaling solutions | Ministry of Science & Technology (MoST) | SMEDA, Ignite, Private Accelerators, Ministry of Finance | Short to medium-term: 6–18 months |
| **National Farm Data Governance Scheme** | Safeguard farmer rights and promote ethical data use | Draft and enact national agri-data governance law; set up open-data platforms for R&D | Ministry of IT & Telecom (MoITT) | NADRA, MoNFS&R, Pakistan Agricultural Research Council (PARC), Legal Advisory Bodies | Medium-term: 1 year |

| | | | | | |
|---|---|---|---|---|---|
| **Targeted Subsidies for AI Tech** | Boost adoption of AI-based precision agri-tech | Design AI-driven subsidy models; incentivise adoption of drones, sensors, automated irrigation | Ministry of Finance, | MoNFS&R, Provincial Governments | Short-term: 6–12 months Medium-term: 1–3 years |
| **Regional Collaboration & Research Hubs** | Build institutional capacity and stimulate innovation | Establish AI centres at agri-universities; forge regional partnerships and tech transfer agreements | Higher Education Commission (HEC) | Agricultural Universities, Ministry of Foreign Affairs (MoFA), MoST, International Partners | Short to medium-term: 1–2 years |
| **Monitoring & Evaluation Framework** | Ensure accountability and adaptive policy making | Develop M&E indicators, integrate real-time AI impact data into planning | Planning Commission, | MoNFS&R, Academic Institutions, FAO, UNDP | Short-term: 6 months |

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**Annex**

The tiered estimation model involves developing three potential outcome scenarios: moderate, conservative, and optimistic. The middle estimate serves as a benchmark and represents the most probable outcome. It is derived from data in the document above, comparisons with similar cases in South Asia or other countries adopting new technologies, such as India and Bangladesh, and expert reasoning based on standard adoption curves. The conservative estimate reflects an underestimated or pessimistic perspective, incorporating assumptions of delays, ineffective adoption, infrastructure bottlenecks, or smallholder exclusion, and is calculated using the formula.

$$Conservative = 0.7 \times Moderate\ Estimate$$

It represents an underperformance compared to the baseline of 30 percent. Conversely, optimistic estimate gives an upper bound or a possible ambitious estimate. It presupposes favourable circumstances like good implementation of the policy, sufficient funds, positive scaling up of pilot project, and positive farmer behaviour. This is numerically computed

$$Optimistic = 1.3 \times Moderate\ Estimate$$

The Optimistic is a 30 percent overperformance to that of the moderate scenario. Collectively, these levels give a plausible planning, monitoring and decision-making range.

**1. AI Adoption Metrics**

- % of farms using at least one AI-enabled tool (e.g., drones, smart irrigation, advisory apps)
- AI tool adoption rate by province (disaggregated by region and farm size)
- Number of farmers registered on AI advisory platforms (e.g., BaKhabar Kissan, Kisan Portal)
- Annual increase in land area monitored using AI platforms (e.g., LIMS coverage in hectares)

**2. Infrastructure Readiness**

- % of rural farms with access to mobile internet and electricity
- Number of DIGITAL DERA-style hubs established
- % of villages with broadband/solar-powered IoT systems installed

**3. Training and Literacy**

- Number of farmers completing digital literacy or AI training programs
- % of trained farmers actively using AI tools within 6 months of training
- % of women farmers trained in AI applications (to assess digital inclusion)

**4. Economic Outcomes**

- Input savings per hectare (water, fertiliser, pesticide) in AI-adopting farms
- Average yield increase per hectare on AI-enabled farms
- % increase in net farm income among AI adopters vs non-adopters
- Estimated reduction in post-harvest losses (%) due to AI-based forecasting and handling

**5. Environmental and Climate Resilience**

- % reduction in chemical/pesticide use due to AI-based precision agriculture
- % of AI-adopting farms with improved water-use efficiency
- Number of AI-generated early warnings issued and responded to (e.g., pest outbreaks, floods)
- AI-driven crop diversification index (e.g., shift toward climate-resilient varieties)

.

**6. Gender and Inclusion**

- % of women-led farms using AI tools
- % of AI extension messages/services delivered in local languages or voice-based formats
- % of subsidies or grants allocated to female farmers or marginalised groups

**7. Innovation and Ecosystem Health**

- Number of agritech startups supported via grants/incubators

- Number of partnerships established between public sector and AI startups
- Number of research publications or innovations from AI-agriculture centres (e.g., Pakistan-China Joint Lab)

**8. Policy and Governance Indicators**

- Existence of national AI-agriculture strategy and its implementation status
- % of provinces aligning their AI initiatives with national policy goals
- Data governance framework established (Y/N) and % of farmers registered under open-data systems

**Acknowledgments**

The authors are grateful for comments from two anonymous referees.

**Disclosure statement**

No potential conflict of interest was reported by the author(s).

**Disclaimer**

The views and opinions expressed in this paper are those of the authors alone and do not necessarily reflect the views of any institution.

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