Mechanizing the Agriculture Sector for Higher Yield, Crop Diversification, and Precision Agriculture

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Abstract:

The agriculture sector in Pakistan is a cornerstone of the economy, yet its productivity and sustainability are undermined by traditional farming practices, limited mechanization, and environmental challenges. This study highlights the sector's current state, emphasizing the need for mechanization to boost yields, promote crop diversification, and adopt precision agriculture. Key challenges include limited access to modern technology, policy barriers, and socio-economic constraints. The paper explores strategies such as increasing access to machinery, farmer training, and supportive policies to drive mechanization. Emerging technologies like precision agriculture hold transformative potential for farming practices in Pakistan. The study stresses the importance of public-private collaboration, infrastructure investment, and research for sustainable agricultural development. Mechanization is presented as a critical pathway to enhancing productivity, improving livelihoods, and ensuring food security for Pakistan's growing population.

Key words:

Agriculture, mechanization, precision agriculture, food security, Pakistan

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Introduction

Agriculture is the backbone of Pakistan's economy, employing a significant portion of the population and contributing substantially to the country's GDP. However, traditional farming practices and limited access to modern technology have constrained the sector's productivity and resilience. In an era of rapidly advancing agricultural innovations and increasing challenges such as climate change and food security, there is an urgent need to transform Pakistan's agriculture sector.

Mechanizing the agriculture sector offers a pathway to higher yields, greater crop diversification, and the adoption of precision agriculture. By integrating modern machinery, equipment, and cutting-edge technologies into farming practices (Andreoni et al., 2021), Pakistan can enhance the efficiency, sustainability, and profitability of its agriculture. This transformation promises not only to boost crop yields and reduce labor costs but also to facilitate innovative farming practices adaptable to diverse agro-climatic conditions.

By fostering public-private collaboration, implementing supportive policies, and investing in research and development, Pakistan can create an enabling environment for agricultural mechanization. This holistic approach will empower farmers, improve livelihoods, and ensure national food security. As Pakistan embarks on this transformative journey, it stands to gain from increased agricultural output as well as a more sustainable and resilient agricultural system (Uitto et al., 2017).

Problem Statement

Despite being a vital component of Pakistan's economy, the agriculture sector faces numerous challenges that hinder its productivity, sustainability, and competitiveness. Traditional farming practices, limited access to modern technology, and inadequate infrastructure contribute to low crop yields, restricted crop diversification, and inefficiencies in resource management. Therefore, there is a dire need to address these challenges through concerted efforts to promote mechanization, crop diversification, and precision agriculture in Pakistan. By overcoming these barriers, the agriculture sector can unlock its full potential, increase productivity, enhance resilience to climate change, and ensure food security for the nation's growing population.

Scope of Study:

- To assess the current state of agricultural mechanization in Pakistan policies and initiatives.
- To Analyse the existing legal and institutional frame work for federal and provincial government develop over time.
- To analyze Pakistan agriculture sector initiatives and comparison with best practices in the world.
- To analyse challenges and recommend policy measures and strategies for promoting mechanization and precision agriculture at federal, provincial, and district levels through log matrix frame work.

Research methodology

The study adopts a mixed-methods design, combining qualitative and quantitative approaches to gather a holistic understanding of the current state and potential of agricultural mechanization and precision agriculture in Pakistan. The research has applied following analysis:

1. Literature Review & Situational Analysis
2. SWOT Analysis
3. GAP Analysis
4. PESTEL Analysis & Policy Analysis and Recommendation

Situational Analysis of Mechanizing the Agriculture Sector for Higher Yield, Crop Diversification, And Precision Agriculture:

Current State of Agriculture:

Traditional Farming Practices:
Pakistan's agriculture sector predominantly relies on traditional farming methods, characterized by manual labor, rudimentary tools, and limited mechanization. The use of modern machinery and equipment remains low, particularly among small landholding farmers.

Crop Yield Challenges:
Despite favorable agro-climatic conditions, crop yields in Pakistan often fall below their potential due to inefficient farming practices, limited access to quality inputs, and inadequate crop management techniques. Monocropping of staple crops like wheat and rice further limits agricultural diversity and resilience (Shah et al., n.d.).

Resource Management Issues:
Inefficient use of water, fertilizers, and pesticides leads to environmental degradation and diminishes the sustainability of agricultural production. Poor

irrigation practices, soil erosion, and water scarcity exacerbate these challenges, particularly in arid and semi-arid regions (Horrigan et al., 2002).

Limited Crop Diversification:
The agriculture sector is characterized by a lack of crop diversification, with a few staple crops dominating cultivation. This monocropping pattern increases the sector's vulnerability to pests, diseases, and climate variability, posing risks to food security and farmer livelihoods.

Technological Landscape

Low Mechanization Levels:
The adoption of modern agricultural machinery and equipment is limited, particularly among small landholding farmers who lack access to affordable and appropriate technologies. Tractors, harvesters, and irrigation systems are underutilized, leading to labor inefficiencies and low productivity (Sims & Kienzle, 2017).

Emerging Precision Agriculture Technologies:
While precision agriculture technologies such as GPS-guided systems, drones, and sensor-based monitoring are available, their adoption remains limited due to high initial costs, lack of awareness, and technical capacity constraints.

Policy and Regulatory Environment

Policy Fragmentation:
The agriculture sector is governed by a complex regulatory framework characterized by overlapping jurisdictions and fragmented policies. Inconsistent land tenure arrangements, import tariffs on agricultural machinery, and limited financial incentives for mechanization impede progress toward agricultural modernization.

Supportive Initiatives:
Despite challenges, the government has initiated several programs and policies to promote mechanization, crop diversification, and precision agriculture. However, the implementation of these initiatives often faces challenges related to funding constraints, capacity limitations, and coordination issues.

Socio-Economic Factors

Rural Livelihoods:
Agriculture remains the primary source of livelihood for a significant portion of Pakistan's rural population, particularly small farmers. Enhancing agricultural productivity and income opportunities is crucial for poverty reduction and rural development (Sharma et al., 2019).

Gender Dynamics:
Women play a significant role in agricultural production and post-harvest activities in Pakistan. However, they often face gender-specific constraints such as

limited access to land, financial resources, and agricultural extension services, which impact their participation in mechanization and technology adoption (Asian Development Bank, 2021).

Environmental Considerations

Climate Vulnerability:
Pakistan's agriculture sector is highly vulnerable to climate change impacts, including erratic weather patterns, droughts, floods, and temperature extremes. Climate-smart agriculture practices, including mechanization and precision agriculture, are essential for building resilience and mitigating risks.

Natural Resource Degradation:
Unsustainable agricultural practices contribute to soil erosion, water pollution, and biodiversity loss. Adopting mechanized and precision agriculture techniques can help minimize environmental degradation and promote sustainable resource management (Rana, 2023).

Legal and Institutional Framework Analysis

The development of the agriculture sector involves collaboration between the Federal and provincial governments. Key aspects include:

1. **Constitutional Distribution of Powers:**
   Agriculture falls under both Federal and provincial jurisdictions. While the Federal government focuses on national policies, provinces handle implementation and regulation (Government of Pakistan, n.d.).
2. **Federal Laws and Policies:**
   The Federal government has enacted laws and policies such as the Pakistan Agriculture Research Council Act, Seed Act, and National Agriculture Policy to regulate and promote agriculture.
3. **Institutions:**
   Federal institutions like the Ministry of National Food Security and Research (MNFSR) and the Pakistan Agricultural Research Council (PARC) play pivotal roles in policy-making and research (PASSCO, n.d.).
4. **Provincial Departments and Policies:**
   Provinces have tailored laws and institutions, such as the Punjab, KP, and Sindh Agriculture Departments, focusing on their unique agricultural needs.
5. **Coordination Mechanisms:**
   Mechanisms like the Council of Common Interests (CCI) facilitate Federal-provincial collaboration on cross-cutting agricultural issues.
6. **Challenges and Reforms:**
   Efforts to address challenges such as water scarcity and low productivity include reforms like the Kissan Cards scheme and the Prime Minister's Agriculture Emergency Program.

Comparing Pakistan's Agricultural Practices to Global Best Practices

1. **Technology Adoption:**
   Countries like the U.S. and Israel excel in integrating precision agriculture, while Pakistan still lags in widespread adoption (Jat et al., 2011).

2. **Water Management:**
   Innovative practices in Israel and Australia offer lessons for Pakistan, where inefficient irrigation systems prevail.
3. **Research and Development:**
   Global leaders prioritize R&D to enhance yields, whereas Pakistan's research initiatives need more funding and collaboration.
4. **Market Access and Value Chains:**
   Strong value chains in the Netherlands contrast with Pakistan's weak infrastructure and post-harvest losses (University of Agriculture, Faisalabad, n.d.).
5. **Sustainable Agriculture:**
   European nations lead in organic farming and agroforestry. Pakistan requires increased awareness and capacity building to scale such practices.
6. **Farmers' Access to Finance and Insurance:**
   Innovative financial products in India and Kenya provide a model for Pakistan to improve financial inclusion and risk management for farmers.

SWOT - ANALYSIS OF PAKISTAN'S MAJOR AGRICULTURE INSTITUTIONS:

SWOT analysis of Pakistan's major institutions responsible for the development of the agriculture sector is as under:

Pakistan Agricultural Research Council (PARC)

Strengths:

- Extensive network of research institutions and centers across the country.
- Mandate to conduct research, develop technologies, and provide technical assistance to farmers.
- Collaborations with international research organizations and universities.
- Strong focus on crop improvement, pest management, and soil conservation.

Weaknesses:

- Limited financial resources and funding constraints affecting research activities.
- Bureaucratic inefficiencies and delays in technology dissemination.
- Insufficient coordination with provincial agriculture departments.
- Dependency on traditional research approaches, with limited emphasis on emerging technologies.

Opportunities:

- Potential for increased funding and partnerships with the private sector and international donors.
- Adoption of modern research methodologies, biotechnology, and precision agriculture.
- Collaboration with universities and industry for the commercialization of research outputs.
- Addressing emerging challenges such as climate change adaptation and sustainable agriculture.

Threats:

- Competition for limited research funding from other sectors.
- Brain drain of talented researchers due to better opportunities abroad.
- Political interference and instability affecting institutional autonomy.
- Resistance to new technologies or genetically modified organisms (GMOs) from certain interest groups.

Provincial Agriculture Departments (e.g., Punjab, KP, & Sindh Agriculture Departments)

Strengths:

- Proximity to farmers and grassroots-level implementation of agricultural policies.
- Extensive network of extension services for technology dissemination and farmer training.
- Knowledge of local agricultural conditions and challenges.
- Coordination with district-level agriculture offices for effective service delivery.

Weaknesses:

- Lack of capacity and resources in terms of trained staff and infrastructure.
- Inconsistent policy implementation and enforcement across districts.
- Limited access to modern farming practices and inputs in remote rural areas.
- Dependency on federal funding and policies, limiting provincial autonomy.

Opportunities:

- Strengthening extension services through digital platforms and mobile technologies.
- Promoting public-private partnerships for agricultural extension and input supply.
- Tailoring agricultural policies and programs to address province-specific challenges.
- Enhancing collaboration with research institutions and universities for technology transfer.

Threats:

- Political interference and nepotism affecting recruitment and promotion within the department.
- Budgetary constraints impacting the delivery of extension services.
- Resistance to change from traditional farming communities or vested interests.
- Competition with other provincial departments for limited resources and attention from policymakers.

Pestle Analysis of The External Factors Influencing the Agriculture Sector in Pakistan:

The PESTLE analysis focuses on the external factors influencing the agriculture sector in Pakistan:

Political Factors:

- Stability and governance issues can affect policy continuity and implementation.
- Political interference may hinder effective decision-making and resource allocation.
- Government policies on subsidies, tariffs, and land tenure impact agricultural production and profitability.

Economic Factors:

- Fluctuations in global commodity prices affect export earnings and farmer incomes.
- Access to credit and agricultural finance is crucial for investment in inputs and technology.
- Exchange rate volatility influences the competitiveness of agricultural exports.

Social Factors:

- Rapid population growth increases food demand, putting pressure on agricultural production.
- Rural-urban migration affects the availability of labor for farming activities.
- Socio-cultural preferences and dietary patterns influence crop choices and market demand.

Technological Factors:

- Adoption of modern technologies like precision agriculture and biotechnology can enhance productivity.
- Access to agricultural machinery and equipment improves efficiency and reduces labor dependency.
- Digital platforms and mobile applications facilitate access to market information and extension services.

Legal Factors:

- Land tenure laws, property rights, and tenancy arrangements impact land use patterns and agricultural productivity.
- Regulatory frameworks governing seed quality, pesticide use, and environmental conservation affect farm practices.
- Trade agreements and tariff policies influence market access and competitiveness.

Environmental Factors:

- Climate change poses risks such as erratic rainfall, temperature extremes, and pest outbreaks.
- Soil degradation, water scarcity, and deforestation threaten long-term agricultural sustainability.
- Adoption of climate-smart agricultural practices is crucial for resilience and adaptation.

GAP Analysis of Agriculture Sector of Pakistan:

GAP analysis of current practices and policies in agriculture sector of Pakistan

Aspect	**Current Practices/Policies**	**Desired Practices/Policies**	**Gaps Identified**	**Actions Needed**
Farming Techniques	Traditional farming methods.	Modern, mechanized farming techniques.	Reliance on outdated methods.	Training programs for farmers, subsidies for machinery, model farms projects.
Water Management	Inefficient irrigation practices (e.g., flood irrigation).	Efficient water uses through drip and sprinkler systems.	Water wastage and reduced productivity.	Develop infrastructure for modern irrigation, educate farmers on water conservation.
Quality Inputs	Limited access to certified seeds, fertilizers, pesticides.	Universal access to high-quality agricultural inputs.	Low availability of high-quality inputs.	Strengthen supply chains, financial support for to small farmers to purchasing inputs.
Subsidies and Support	Misallocated or insufficient subsidies/support programs.	Efficient and transparent distribution of subsidies/support.	Bureaucratic hurdles, small-scale farmers not benefiting.	Develop transparent mechanisms for subsidy distribution,

				focus on small-scale farmers.
Research & Development	Limited investment in agricultural R&D, weak extension services.	Robust research and extension systems.	Insufficient research, weak knowledge transfer to farmers.	Increase funding for R&D, improve extension services, disseminate research findings.
Market Access	Poor infrastructure, lack of market information.	Well-developed market infrastructure, easy access for farmers.	Difficulty in accessing markets, unfair prices for produce.	Build/upgrade transportation and storage facilities, establish market information systems.
Post-Harvest Handling	Poor post-harvest handling, storage, and transportation.	Effective post-harvest management and infrastructure.	Significant post-harvest losses.	Improve storage and transportation infrastructure, train farmers in post-harvest handling.
Climate Change Adaptation	Inadequate policies for climate resilience.	Comprehensive climate-smart agricultural practices.	Lack of climate-resilient farming policies and practices.	Develop and implement climate-resilient policies, promote sustainable farming practices.

Issues and Challenges

1. **Limited Access to Machinery:** Small farmers in Pakistan often lack access to modern agricultural machinery due to high costs and limited availability. This hinders their ability to mechanize farming operations and achieve higher yields.
2. **Fragmented Land Holdings:** The prevalence of small and fragmented land holdings in Pakistan makes it challenging to adopt mechanization at scale. Machinery designed for large farms may not be suitable or cost-effective for small plots, limiting the uptake of mechanized farming practices.
3. **Technological Awareness and Education:** There is a lack of awareness and technical knowledge among farmers regarding the benefits of mechanization and precision agriculture techniques. Many farmers hesitate to adopt new technologies due to limited understanding and perceived risks.
4. **Infrastructure and Power Supply:** Inadequate rural infrastructure, including roads, electricity, and irrigation facilities, poses significant challenges for mechanizing the agriculture sector. Power outages and unreliable electricity supply hinder the operation of machinery, especially in remote rural areas.
5. **Financial Constraints:** The upfront investment required for purchasing agricultural machinery and equipment is often beyond the financial means of small farmers. Limited access to agricultural credit and financing options further exacerbates this challenge, hindering the adoption of mechanization.
6. **Crop Diversification and Market Demand:** While mechanization can facilitate crop diversification by enabling the cultivation of high-value crops, market demand and price fluctuations present uncertainties for farmers. A lack of market linkages and market information systems can deter farmers from diversifying their crops.
7. **Precision Agriculture Technologies:** The adoption of precision agriculture technologies, such as GPS-guided tractors and drones for crop monitoring, faces challenges related to affordability, technical expertise, and data management. Integrating these technologies into existing farming practices requires investment in training and infrastructure. (Schimmelpfennig & Ebel, 2016)
8. **Water Management and Conservation:** Efficient water management is critical for sustainable agriculture, yet many mechanized farming practices in Pakistan are water-intensive. Adopting precision irrigation systems and water-saving technologies can help address water scarcity issues but requires investment and technical support.
9. **Environmental Concerns:** Intensive mechanized farming practices can have adverse environmental impacts, including soil degradation, water pollution, and loss of biodiversity. Balancing the benefits of mechanization with environmental sustainability requires careful planning and regulatory oversight.
10. **Policy and Regulatory Frameworks:** Inconsistent policies, outdated regulations, and bureaucratic hurdles impede the adoption of mechanization

and precision agriculture in Pakistan. Streamlining regulatory processes, providing incentives for technology adoption, and fostering public-private partnerships can create an enabling environment for innovation in the agriculture sector. (Hameed & Baig, 2016)

Log Frame Matrix for Addressing the Issues and Problems Identified:

Log Frame Matrix for Addressing Issues in Mechanizing the Agriculture Sector for Higher Yield, Crop Diversification, and Precision Agriculture in Pakistan:

Overall Goal:

- Increase agricultural productivity, promote crop diversification, and enhance sustainability through mechanization and precision agriculture in Pakistan.

Purpose/Objective:

- Facilitate the adoption of mechanized farming practices, promote crop diversification, and implement precision agriculture techniques among small farmers in Pakistan.

Outputs:

- Increased access to modern agricultural machinery and equipment.
- Improved technical knowledge and awareness among farmers about mechanization and precision agriculture.
- Enhanced infrastructure and support services for mechanized farming.
- Strengthened market linkages and value chains for diversified crops.
- Implementation of precision agriculture technologies for efficient resource management.

Activities:

- Conduct training programs and demonstrations on mechanized farming techniques and precision agriculture.
- Provide subsidies or incentives for the purchase of agricultural machinery and equipment.
- Upgrade rural infrastructure, including roads, electricity, and irrigation facilities.
- Establish farmer cooperatives or machinery-sharing arrangements to increase access to machinery.
- Develop market information systems and facilitate access to markets for diversified crops.
- Pilot precision agriculture technologies in collaboration with research institutions and private-sector partners.

Indicators:

- Percentage increase in the adoption of mechanized farming practices among target farmers.

- Number of farmers trained in mechanization and precision agriculture techniques.
- Improved availability and reliability of rural infrastructure.
- Increase in the production and sales of diversified crops.
- Adoption rate of precision agriculture technologies and practices.

Means of Verification:

- Surveys and assessments conducted before and after training programs.
- Monitoring and evaluation reports from extension services and implementing agencies.
- Infrastructure improvement reports from relevant government departments.
- Market data and sales records from agricultural produce markets.
- Field observations and feedback from farmers regarding the adoption of precision agriculture technologies.

Assumptions:

- Adequate funding and resources are available for implementing the plan.
- Political stability and consistent support for agricultural development.
- Farmers are willing to adopt new technologies and practices with proper training and support.
- Effective coordination and collaboration between government agencies, research institutions, and private-sector stakeholders.

By following this Log Frame matrix, the plan provides a structured approach to addressing the identified issues and challenges in this study. It emphasizes capacity building, infrastructure development, market linkages, and technological innovation to achieve sustainable improvements in agricultural productivity and livelihoods.

Conclusion

The Public Policy Simulation Exercise on "Minister of Agriculture's Task Force for Mechanizing the Agriculture Sector for Higher Yield, Crop Diversification, and Precision Agriculture in Pakistan" emphasizes the urgent need for a transformative approach to agriculture. The task force's comprehensive strategy addresses the pressing challenges facing Pakistan's agricultural sector, including low productivity, limited crop variety, and inefficient resource utilization. By integrating mechanization, crop diversification, and precision agriculture, the task force envisions a future where Pakistan's agricultural sector achieves sustainable growth and resilience (Social Policy and Development Centre [SPDC], n.d.). This holistic approach aims not only to enhance yields and diversify crops but also to ensure the efficient use of resources, ultimately contributing to the long-term sustainability and stability of Pakistan's agriculture.

Recommendations

Mechanizing the agriculture sector for higher yield, crop diversification, and precision agriculture in Pakistan requires a coordinated action plan at federal, provincial, and district levels. Below are practical recommendations for each level:

Federal Level Actions

1. **Policy Framework and Legislation**:

- **Develop a Comprehensive Agriculture Mechanization Policy**: Create policies to promote the adoption of modern agricultural machinery and practices.
- **Subsidies and Incentives**: Provide financial incentives, subsidies, and tax exemptions for purchasing and maintaining advanced agricultural machinery.
- **Research and Development (R&D)**: Increase funding for R&D in agriculture technology, focusing on machinery suitable for local conditions.
- **Import Policies**: Simplify import regulations for advanced agricultural equipment and spare parts to ensure availability.

2. **Infrastructure Development**:

- **Establish Agricultural Machinery Manufacturing Hubs**: Promote the establishment of manufacturing units for agricultural machinery to reduce dependency on imports.
- **Enhance Rural Infrastructure**: Improve rural roads, electricity supply, and internet connectivity to facilitate the use of modern machinery and precision agriculture tools.

3. **Education and Training**:

- **National Training Programs**: Launch national-level training programs for farmers on the use and maintenance of agricultural machinery.
- **Collaboration with Universities**: Partner with agricultural universities to include mechanization and precision agriculture in their curricula.

Provincial Level Actions

1. **Implementation of Federal Policies**:

- **Adaptation of Federal Policies**: Tailor federal policies to provincial needs and ensure effective implementation.
- **Monitoring and Evaluation**: Establish mechanisms to monitor the implementation and impact of mechanization policies.

2. **Provincial Agricultural Research Institutions**:

- **Strengthen Research Institutions**: Enhance the capacity of provincial agricultural research institutions to develop and test machinery suited to local agricultural practices.
- **Collaborative Research**: Promote collaboration between provincial research institutions and international organizations. *(National Research Council, 2010)*

3. **Extension Services**:

- **Strengthen Extension Services**: Improve extension services to provide on-ground support and training to farmers in mechanization and precision agriculture.
- **Demonstration Farms**: Set up demonstration farms to showcase the benefits of modern machinery and precision agriculture techniques.

4. **Financial Support Programs**:

- **Credit Facilities**: Establish easy credit facilities for farmers to purchase machinery.
- **Insurance Schemes**: Develop insurance schemes for agricultural machinery to mitigate investment risks.

District Level Actions

1. **Local Implementation of Policies and Programs**:

- **Awareness Campaigns**: Conduct awareness campaigns about the benefits of mechanization and precision agriculture.
- **Local Partnerships**: Partner with local agricultural cooperatives, NGOs, and private sector players to promote mechanization.

2. **Support Services**:

- **Machinery Hiring Services**: Set up machinery hiring services to allow small-scale farmers to access advanced machinery on a rental basis.

- **Maintenance and Repair Centers**: Establish local centers for the maintenance and repair of agricultural machinery.

3. **Farmer Field Schools (FFS)**:

- **Practical Training**: Organize FFS to provide hands-on training to farmers on the use and benefits of agricultural machinery and precision agriculture.
- **Community-Based Models**: Encourage community-based models where farmers can share resources and knowledge.

4. **Local Data Collection and Analysis**:

- **Precision Agriculture Tools**: Implement local data collection initiatives to support precision agriculture, such as soil health monitoring, weather stations, and yield mapping.
- **Customized Solutions**: Use collected data to provide customized recommendations to farmers, improving efficiency and yield.

Cross-Level Coordination

1. **Integrated Information Systems**:

- **Data Sharing Platforms**: Develop integrated information systems for data sharing between federal, provincial, and district levels to ensure coherent and coordinated efforts.
- **Centralized Database**: Create a centralized database for tracking the adoption of mechanization and its impact on agricultural productivity.

2. Regular Stakeholder Meetings:

- **Inter-Level Meetings**: Organize regular meetings between federal, provincial, and district stakeholders to review progress, address challenges, and adapt strategies as needed.
- **Farmer Feedback Mechanism**: Establish mechanisms for farmers to provide feedback on policies and programs, ensuring they meet ground realities. *(Zain, Fatima, Naqvi, Farid, & Nasir, 2024)*

By implementing these recommendations, Pakistan can effectively mechanize its agriculture sector, leading to higher yields, diversified crops, and the adoption of precision agriculture techniques.

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