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Gohar Gulshan Mahmood, Sandro Liberatori, Fabrizio Mazzetto

Department of Agricultural, Environmental and Food Sciences, Free University of Bozen-Bolzano, Italy

Corresponding author: Gohar Gulshan Mahmood, Department of Agricultural, Environmental and Food Sciences, Free university of Bozen-Bolzano, Piazza Università 1, 39100 Bolzano, Italy. E-mail: GoharGulshan.Mahmood@unibz.it

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Gohar Gulshan Mahmood, Sandro Liberatori, Fabrizio Mazzetto

Department of Agricultural, Environmental and Food Sciences, Free University of Bozen-Bolzano, Italy

Corresponding author: Gohar Gulshan Mahmood, Department of Agricultural, Environmental and Food Sciences, Free University of Bozen-Bolzano, Piazza Università 1, 39100 Bolzano, Italy. E-mail: GoharGulshan.Mahmood@unibz.it

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Abstract

Agriculture constitutes a critical sector within the economic landscape of Pakistan, engaging 37.4% of the labour force and contributing 22.9% to the Gross Domestic Product (GDP), thus functioning as an essential element of the country's economic architecture and the sustenance of its citizens. The primary agricultural commodities, which encompass wheat, rice, cotton, maize, and sugarcane, occupy extensive tracts of agricultural land, thereby underscoring their paramount importance regarding food security, impacts on territory management and related landscape, as well as income generation through export activities. Despite its crucial role, the advancement of agricultural mechanization in Pakistan is significantly lacking, with the available agricultural power that is a little less than 1.6 kW ha^{-1}, which is below the minimum required farm power of 1.82 kW ha^{-1}. In this study, we seek to investigate the historical evolution, current scenario, and significant obstacles confronting agricultural mechanization in Pakistan, especially right now when innovative trends worldwide are pushing towards a progressive digitisation of the sector. Continuing with the conventional agricultural practices during the period of independence in 1947, the Green Revolution of the 1960s represented a crucial transformation towards mechanization, propelled by the indigenous manufacturing of tractors. Nevertheless, the pace of mechanization has slowed in recent years, primarily due to the prevalence of small farm sizes, economic constraints, and inadequate access to financial resources. While tasks such as land preparation and pesticide application have achieved notable levels of mechanization, fundamental operations including sowing, transplanting, weeding, and harvesting continue to be insufficiently mechanized. Significant initiatives, such as Laser Land Levelling in Punjab, shows the considerable impact of focused interventions. To address the mechanization deficit, proposed strategies encompass the enhancement of local machinery manufacturing, the establishment of quality standards, the promotion of advanced imported equipment, an increase in farmer education, and the implementation of comprehensive government support through subsidies, tax benefits, and dedicated research and development efforts. A collaborative approach between governmental bodies and the private sector is

imperative for fostering advancements in mechanization, thereby ensuring a more efficient, productive, and sustainable agricultural sector in Pakistan.

Key words: farm digitization challenges; agriculture 4.0; farm mechanization policies

Introduction

Pakistan is a South Asian country with total area of 79.6 Mha out of which around 20 Mha is cropped area. Most of the population of the country is directly or indirectly dependent on agriculture as it contributes 37.4% in employment, while agriculture constitutes about 24% of country's GDP (Ministry of Finance, 2024), which shows the impact of agriculture on the economy of Pakistan. There are five major crops of Pakistan, wheat, rice, cotton, maize and sugarcane and these crops covers 27.89, 12.48, 8.99, 7.21 and 5.53 percent of cropped area respectively (Pakistan Bureau of Statistics, 2010). Wheat is the largest crop of country as it is the subsistence crop of Pakistan and the only crop for which government announce minimum support price to encourage farmers so that they grow more wheat to maintain the balance of food security. Other than wheat, rice is also used as food but is a major export commodity and its export volume reached 3.72 million tons, valuing around 2.15 billion USD in 2022-23 (Rice Exporters Association of Pakistan, 2023). Cotton was once known as the white gold by farmers and had a vast use in textile industry but later in recent years, due to infestation of pink worm and white fly, its yield decreased drastically. Maize is used in cattle feed industry and being exported to other countries, its yield increased proportionally because of the introduction of hybrid seeds in last decade. Sugarcane is used in sugar industry mostly and small portion is used for livestock fodder by farmers. Even being an agriculture-based country, agricultural mechanization is still lagging and have a potential of advancement. To have a basic idea, available farm power per hectare can be discussed, it is the ratio of total available farm power in country to the total cropped area. Pakistan has 1.6 kW ha^{-1} (Ministry of Finance, 2024), opposed to the minimum required farm power of 1.82 kW ha^{-1}. Other neighbouring countries, China, India, and Bangladesh have 5.7, 2.49 (Singh *et al*., 2014; Department of Agriculture and Farmers Welfare, 2019) and 1.83 kW ha^{-1}, which is far more available farm power than that of Pakistan.

This study will focus on the evolution stages of agricultural mechanization in Pakistan, while keeping in sight the historical trend, current status, and future path of mechanized farming in the country. With this review, we will be able to highlight the issues in mechanization, reasons of those problems and the proposed solutions to overcome the hurdles. The methodology will include a review of historical data, analysis of current mechanization trends, and field findings from past experiences.

This study aims to provide a comprehensive analysis of the mechanization status of agriculture in Pakistan to better frame a strategy for its improvement. It will explore the historical evolution of mechanization, assess the current state and challenges, and identify key factors influencing the adoption of mechanized farming practices. Through this study, the research will offer actionable recommendations to enhance mechanization levels, thereby improving agricultural productivity and contributing to food security and economic growth in Pakistan. This study acknowledges limitations such as the availability of recent data and the informal nature of the

local machinery manufacturing sector. Nonetheless, it seeks to provide a detailed understanding of the mechanization landscape and propose strategies to overcome existing barriers, paving the way for a more efficient and productive agricultural sector in Pakistan.

Mechanization status of Pakistan

Mazzetto *et al.* (2020) discussed the agricultural and industrial evolution in Italy with a timeline to illustrate the adoption of technologies in both fields. He mentioned that real Information and Technology revolution is missing in agriculture, while it was present in industrial revolution. In this article, we will add another timeline in his concept, shown in Figure 1, to discuss the evolution of agricultural mechanization in Pakistan, while it is understood that agricultural mechanization started way later than that of Italy, where there is an interesting trend towards the adoption of Agriculture 4.0 (Scuderi *et al*., 2022), the level of maturity regarding Agriculture 4.0 is still average (Maffezzoli *et al*., 2022).

In 1947, Pakistan had a cropped area of 11.64 Mha (Pakistan Bureau of Statistics, 2010), and all of that was cultivated using bullocks and human workforce, so we can call it the tradition and ruralism stage. There were limited number of industries in the country because of the shifting of assets during partition in 1947, so this phase continued for several years until 1960's.

Green revolution

During 1960's, agriculture in Pakistan took a jump start in the form of Green Revolution, in which Pakistan adopted the technique of using dwarf varieties of grain. These new types of grain were more responsive to fertilizer and thus would be able to grow in harsh environments if there was a source of fertilizer (Child and Kaneda, 1975). This increased the crops yield, especially wheat, which in turn created more profit, jobs and so more land came under cultivation. At this stage, it was felt that there is a need of farm power and implements to overcome the labour requirement and to do more work efficiently and timely.

Introduction of tractor industry in Pakistan

To address this need, tractor manufacturing industry in Pakistan started in 1964 and an assembly plant was set up in 1967 to assemble tractors imported in semi-knocked down condition. This can be marked as the start of second phase of evolution, which is motorization. Later local manufacturing of the tractors under government approved program started in 1981 and five firms were licensed for the purpose. The manufacturers of Belarus, Ford and IMT tractors went out of business and only two manufacturers were left involved in local manufacturing of tractors. Millat Tractors having franchise of Massey Ferguson and Al-Ghazi Tractors having franchise of New Holland tractors continued with producing different models of tractors in the range of 38 to 64 kW (University of Agriculture Faisalabad, 2015). Both companies succeeded in establishing well organized manufacturing/assembling plants, network of distribution and after sale service throughout Pakistan. Figure 2 shows the data of available tractors from 1975, which gives an idea of the trend with which tractor numbers increased in Pakistan.

It is shown in Figure 2 that in 1975 there were only 35.7 thousand tractors available in Pakistan, but these numbers increased gradually with time and by 2014, available tractors were 948 thousand and reached 1.27 million in 2024. Percentage increase was very high in initial years but decreased with time. Even with these numbers, available farm power is far less than required farm power, as on average, one tractor serves about 30 hectares (University of Agriculture Faisalabad, 2015) of cultivable area in Pakistan. Government has been launching tractor subsidy schemes time to time and recently they have announced new initiative named Punjab Green Tractor Scheme, in which 50-70% subsidy will be provided by government to the farmers. In the recent years, other manufacturers, Orient, YTO and ATS are also launching their tractors in the market, while FECTO Belarus has also been in the market.

A noticeable point in the Figure 2 is the percentage of increase in tractor numbers, if we take 1975 as base data, then there was a massive jump in the tractor numbers with 350% of rise from 1975 to 1984 but later it became constant. It might be because of the starting phase of green revolution, which took a great start and then slowed down with the passage of time. We can also say that motorization started in 1960's and progressed at good pace for around 20 years but then slowed down without achieving the required results, which is minimum required farm power.

There may be other reasons for the slowing down of the tractor adoption, one of which can be the small farm size. With the passage of time, farms kept divided in parts due to the transfer of inheritance, which affected the buying power of farmer. Figure 3 shows the data of farm sizes from 1972 and 2010, where small farms (0-5 ha) increased in numbers from 67% to 89%, whereas medium (5-10 ha) and large (>10 ha) farms decreased in numbers from 21% to 7% and 12% to 4% respectively (Pakistan Bureau of Statistics, 2010).

Hyder and Shahid (2019) stated that due to the variation in sales taxes and filer conditions, annual production of tractors has been reduced to 37,300 units in 2019. This is an alarming situation as it widens the farm power gap in the country. Along with the reduction in production numbers, prices of tractors have also been increased due to inflation. This change in price has reduced the purchasing power of farmers, so keeping in view these numbers, the government in the budget of FY22-23 has withdrawn sales tax on tractors (Federal Board of Revenue, Government of Pakistan, 2022), with the hope of expecting an increase in tractor sale and use.

Introduction of agricultural implements industry in Pakistan

With the introduction of tractor and new varieties of seeds to the farmers during green revolution, need for the tractor operated implements were also observed. But manufacturing of agricultural machinery in the country began back in 1954 with the establishment of Eshakhel Estate Farm in Rahim Yar Khan district of Punjab. By 1959, there were only 15 farm machinery manufacturers in the country, but the number increased to 514 in 1984 (Iqbal *et al*., 2022). This increase was due to the liberal government policies such as rebate in import duty for raw materials and exemption of income tax. However, a setback was observed in this industry by closing/reducing production by medium sized manufacturers due to withdrawal of above government incentives. Local farm machinery industry is producing a wide range of farm machinery except for the complex ones like transplanter and harvesters. Agricultural machinery manufacturing business in Pakistan is entirely informal sector, and last agricultural machinery census was conducted in 2004, so without an updated census, it is difficult to estimate the exact

number of implements being manufactured in the country annually, but we also have general data of agricultural machinery from agriculture census 2010 (Pakistan Bureau of Statistics, 2004; Pakistan Bureau of Statistics, 2010).
Now we can understand that both motorization and mechanization was done is single stage in Pakistan as the technology was already available and it was easier to adopt both at the same time.

Operation-wise mechanization extent

Data from agriculture statistics of the Pakistan of Bureau of Statistics (2012) shows the operation wise extent of mechanization in Pakistan (Figure 4). It is divided into five parts as per the mechanization operation during whole crop season. We will discuss the status of mechanization by covering all these five stages.

Land preparation

First stage is the land preparation, which according to the data in Figure 4, is the second highest mechanized operation with 85% mechanization level. There are many reasons for its high percentage of mechanization, one of them is that the implements used for land preparation operation are not much expensive and easy to use with the tractor. Farmers can afford these implements easily, so those farmers who owns a tractor, mostly buys their own implements, while those who does not own a tractor can avail the services from contractors, who are easily available in villages (Figure 5).
Most part of the available farm power is being utilized in the land preparation operation. In recent years, multipurpose machines have been introduced to the farmers with the support from government. Pak-Seeder has been developed by Agricultural Mechanization Research Institute to address the smog issue in Punjab province, which arises after the harvesting of rice crop, this is a multipurpose machine which prepares the land and sow wheat seed without the need of separate tillage operations. This lowers the need of farm power and reduces the sowing time.

Sowing and planting

After land preparation, second operation is the sowing and planting, which as shown in Figure 4 is only 25% mechanized in the country. For the five major crops, sugarcane sowing is entirely manual, while maize and cotton are being sown with drills and planters at a limited extent. Wheat is sown with seed drills and by manual broadcasting, while rice is transplanted manually. In recent years, imported rice nursery raising machines and transplanters are being introduced in the country with success but most part is still being done manually. These transplanters are not being manufactured locally because of their complex mechanism, moreover, use of these nursery raising machines and transplanters is not simple as of other drills, so these are mostly being operated by the contractors and farmers are not using them by themselves (Figure 6).

Weeding and interculture

Weeding and interculture stands at 40%, which also varies according to the crops. Crops being sown on ridges or beds have higher percentage of mechanical weeding as it is easy to operate machines between the rows, while cereal crops like wheat and rice have less extent of mechanization in this category.

Spraying

Spraying tops the mechanization chart in Figure 4 with 95%, but a major portion of this percentage is of knapsack/ backpack sprayers, which is not totally mechanized. According to a study, 50% of the spray is lost during the operation in Pakistan while only 50% is utilized effectively (University of Agriculture Faisalabad, 2015) (Figure 7).

Reasons behind the low efficiency is the major use of knapsack sprayers, as they are operated by human labour, their efficiency depends on the operator's expertise, pressure in the vessel and other factors. Tractor mounted power sprayers are also in use for orchards and tractor operated boom sprayers are used for row crops like cotton and potato. Advanced boom sprayers are being imported by some companies for rice crop also, but their use is limited at this stage.

Harvesting

Harvesting stands at 40%, but the percentage does not represent all five major crops. Most of the harvesting is accomplished in the country with New Holland and Laverda harvesters, which are imported as scrap from Europe and reassembled by local mechanics. These harvesters are being imported since 1990's and a particularly good local market has been established for their spare parts and maintenance facilities. These harvesters are used mostly for the harvesting of wheat and rice, while other crops like maize, cereals and some oilseed crops are also harvested with them. As these harvesters are 40-50 years old and imported in the country after completing their useful life in Europe, high maintenance is required for their operation (Figure 8).

Management of these harvesters require an expert operator, who also acts as a mechanic, but still 10-15% of grain losses occur during operation (University of Agriculture Faisalabad, 2015). There can be many reasons for these losses, which include expertise of operator, condition of harvester and the quality of spare parts. Cotton and sugarcane are harvested manually as there are no harvesters available for them. A small portion of maize crop is harvested with the help of wheat combine harvesters using customized kits, but major portion is still harvested manually. Post harvesting of maize is done mechanically using maize sheller. In recent years, imported rice specific harvesters and maize cob pickers are being used in the country and they are getting famous among farmers for their field performance as well and paddy straw utilization. Adoption of rice harvesters is high, but maize cob pickers are facing issues due to the sowing geometry.

Issues in operation wise mechanization extent

Table 1 gives the highlights of the issues in each stage of mechanization for five major crops of Pakistan.

Table 1. Operation wise mechanization issues in major crops of Pakistan

Crop / operation	Land preparation	Sowing and planting	Weeding and interculture	Harvesting
Wheat	Mostly mechanized	Substandard quality of available seed drills Limited use of seed drills because of high cost Limited availability Pak seeders	Unavailability of precision sprayers Low efficiency due to the use of knapsack sprayers Limited use of boom sprayers because of small land holding and unaligned sowing	Antiquated combine harvesters Unskilled machine operators
Rice	Mostly mechanized Positive trend of laser levelling before each rice season	Limited availability of advanced sowing & transplanting machinery Unskilled operators for advanced transplanting machines	Unavailability of precision sprayers Low efficiency due to the use of knapsack sprayers	Limited availability of rice specific harvesters Unskilled operators for advanced machines
Cotton	Mostly mechanized	Lack of precision planters (pneumatic planters)	Less efficiency due to the use of low quality locally manufactured boom sprayers Limited availability of interculture machinery	Unavailability of harvesting machinery
Maize	Mostly mechanized	Lack of precision planters (pneumatic planters)	Low efficiency due to the use of knapsack sprayers	Limited availability of cob pickers Available cob-pickers are not designed for ridge or bed sowing – planting geometry needs to be aligned with cob-picker's header
Sugarcane	Mostly mechanized	Unavailability of sugarcane planters	Less efficiency due to the use of low quality locally manufactured boom sprayers After certain crop stage, boom sprayers cannot be used	Unavailability of harvesting machinery

Adoption success story

If we focus on mechanization part of the evolution, there is an interesting scenario to look at in the form of a success story for the introduction and adoption of technology by the farmers of

Pakistan. Laser land levelling (LLL) initiative was taken by On Farm Water Management (OFWM) Department, government of Punjab in 1984 when one unit of laser land leveller was imported from USA for testing purposes.

Early efforts and government support

From 1992, department started to provide rental services to introduce and promote the technology amongst farming community by operating 193 units. Later, OFWM directorates of all four provinces started providing subsidized rental LLL services to the farmers under different World Bank and Asian Development Bank funded projects as well as various schemes financed by provincial and district governments.

Upscaling and private sector involvement

In 2006, the Punjab government decided to upscale the Laser land levelling operation by involving private sector service providers and launched the project titled “Strengthening of Laser Land Levelling Services in the Punjab”. Under this scheme, service providers/ farmers were incentivized to purchase 2,500 Laser units by providing 50 percent matching grants during 2006-2009 for provision of LLL services to the neighbouring farmers at market rates. This intervention was the major development in shifting this service delivery from government to the private sector. Resultantly, annual Laser land levelling capacity in the province enhanced from 14,164 ha (35,000 acres) to 300,000 ha (750,000 acres) (Figure 9).

It was, however, still observed that the Laser land levelling services were still inadequate to fulfil farmer’s ever-growing requirements cultivating over 12.6 million ha (31 million acres) of farmland in the province. The breakthrough ensued when 50 percent matching grants were provided to the service providers for procuring 5,000 Laser land levellers during 2012-16 under the World Bank funded "Punjab Irrigated-Agriculture Productivity Improvement Project (PIPIP)" that triplicated the private sector’s capacity for providing LLL rental services across the province. Private sector’s capacity was further augmented through implementing another locally funded scheme implemented in the Punjab for providing 4,000 more Laser units during 2015-16 to 2017-18. In total, presently there are over 15,000 Laser land levellers providing LLL services to the farmers across the province.

Current status and impact

This overwhelming success of Laser land levelling technology promoted its promotion in other provinces of the country i.e., Sindh and Khyber Pakhtunkhwa under the World Bank assisted projects. Figure 10 shows the adoption of LLL in Punjab province of Pakistan (On Farm Water Management, 2024). So, with the help of government, this advanced technology got adopted by farmers on a large scale and units escalated from 193 to 15000, which helped in achieving the goal of levelling the farmers’ fields.

Bridging the technology gap through digitalization

Pakistan’s agricultural sector has the potential to leapfrog traditional stages of mechanization by embracing digitalization. While tractors in Pakistan are primarily used for transport, digital technologies can transform them into unmanned power sources for field operations, bypassing

outdated concepts that characterized agricultural machinery in the 1980s and 1990s in other countries.

For example, autonomous tractors equipped with GPS and IoT sensors can perform precision farming tasks such as ploughing, seeding, and harvesting without human intervention. This not only increases efficiency but also reduces labour costs and minimizes human error. Pakistan can accomplish this with the right policies and investments.

To achieve this, the government should:

- **Promote Digitalization**: Introduce policies that incentivize the adoption of digital technologies in agriculture.
- **Invest in Research and Development**: Support R&D initiatives to develop locally suitable digital solutions.
- **Provide Training**: Train farmers and operators on the use of advanced digital tools and machinery.

By leveraging digitalization, Pakistan can modernize its agricultural sector and bridge the technology gap more efficiently than traditional methods would allow.

At the moment, there are many new ICT platforms available in Pakistan, enlisted in Table 2, from which farmers can take advantage.

Table 2. Major ICT platforms working in agriculture sector in Pakistan to support the digitalization of the sector.

ICT Platform	Description of work
Farmdar	Provides precise and actionable crop data using AI and remote sensing technology to help farmers monitor crop health and predict pest attacks.
BaKhabar Kissan	Offers a mobile app that provides farmers with information on soil preparation, crop management, weather updates, and pest control through audio, video, and pictorial presentations.
Ricult Pakistan	Enhances productivity and profitability for small farmers by providing agricultural information, solutions, and access to credit and marketplaces.
Kisan Zar Zameen	Uses multi-spectral imagery from satellites to provide soil condition and crop health analysis, weather updates, and drone spraying services.
Kissan Bazaar	An online marketplace where farmers can buy and sell agricultural items, including fruits, vegetables, poultry, and livestock.
Agri Smart	Launched by the Punjab Public Management Reform Program, this app offers services like farmer training sessions, pest warnings, monitoring agricultural inputs, and soil sampling.

With this discussion, we can conclude that in Pakistan, mechanization stage is still in progress and not completed yet, and there is a need to work on motorization stage also to achieve the minimum required farm power. Since last two decades, different research institutes and universities are doing research and development on the next stage, which is humanism and electronics, which includes operators' safety, automated production using electronics, particularly programmable logic controllers, advanced IT systems, and robotics. This will bring the development of precision agriculture through yield monitoring, guidance systems for

farming, and variable rate application of Agri-inputs on each portion of the farm based on its need. Implementation and adoption of this will take time because of many reasons, some of which include the farmer reluctance towards more advanced technologies, lack of awareness to technology and limited resources of farmers.

Challenges in agricultural mechanization

As seen from the data shown earlier, mechanization in Pakistan got a good start during green revolution but later it slowed down. Presently, there are many issues related to mechanization, one of which is the limited farm power, which in turn restricts the adoption of other advanced agricultural implements. In this section, we will discuss some key issues in the adoption of advanced mechanization.

Low available farm power

Figure 11 shows the available farm power in Asian countries, where Pakistan lies at the bottom of shown countries with only 1.6 kW ha^{-1}, opposed to the minimum required farm power of 1.82 kW ha^{-1} (Hafizov *et al*., 2022; Ministry of Finance, 2024). Another point to be considered here is this available farm power also includes the tubewell along with tractor, so if we must consider farm power available to operate implements, then it will be even less than 1.6 kW ha^{-1}. If we dig for the reasons behind the low available hp, one of them would be the small farm size which limits the purchasing power of farmers and making it difficult for them to invest in mechanization. Maximum tractor power available in country is 64 kW (University of Agriculture Faisalabad, 2015), this is also because of the small farm size and agricultural machines/ implements which require more than 64 kW are not in much demand, so tractor companies are supplying which suites them best for sales.

Small farm sizes

As discussed earlier in Figure 3, 90% of the total farms lies under the category of small farm holdings having area less than 5 hectares. This is one of the major hindrances in the adoption of digital stage in agriculture as Mazzetto *et al*. (2020) discussed the control and decisional levels in a farm where tasks are divided in three hierarchy levels, shown in Figure 12, which are; high strategy, management and knowledge workers, while the base of the hierarchy is process execution. In small farm holdings, distinction between these levels is blurred and owner of the farm is responsible for all decision makings and most of the work. At the top of the hierarchy, where investment and strategic planning should be done, small farmers are mostly focused on short term goals because of the limited resources. Absence of management and knowledge workers also restricts the farmers from adopting digital revolution and small farmers themselves cannot manage all the updated technologies.

Low quality of local machines

Another aspect is the quality of locally available machines/ implements, which is not so good and reliable. In addition, there are no testing laboratories to assess performances and related effects on primary products (Amjad, 2017; Raza *et al*., 2018).

Highlights of FAO policy brief

FAO conducted a multistakeholder policy dialogue in 2024, in which 48 key informant interviews were conducted. These key informants included policy maker, regulators, manufacturers, researchers, academia personals, farmers and think-tanks/ NGOs. Two of the most important take aways from these interviews were the low quality of locally manufactured machines and implements and the non-implementation of quality standards, certification, testing and evaluation. It is reported that low quality of local machines is due to the couple of reasons which include the family-owned business mindset of manufacturers, which prevails in the industry, with very little incentive for innovation. Market competition also plays role in low quality as manufacturers produce substandard machines and sell them to farmers at lowest prices, creating negative impact on farmers.

Other takeaway from the policy brief is the non-implementation of standards. Two ministries are looking after the standards and certification, which are Engineering Development Board (EDB) and Pakistan Standards and Quality Control Authority (PSQCA). They have developed standards and drawings for 70 and 53 implements respectively, but adoption of these is not mandatory but voluntary, which restricts the production of quality implements (FAO, 2024).

Further causes of low quality of local machines

There are two major reasons for the low quality of locally manufactured machines, very limited use of good quality raw material and absence of engineers in most of the industries. Absence of engineers might be due to the limited finances of small industries, but private manufacturers also blame that university graduates are not industry ready (FAO, 2024).

Another issue is the inadequate after sales services, as farmers are not getting follow up and repair and maintenance facilities from the manufacturers or suppliers, which leads to the lack of interest by farmers in new machines for future (Raja, 2023). Prices of agricultural machines/ implements are also remarkably high, which restricts small landholders from buying them. Government have been providing subsidies on different machines to keep them in buying range of small farmers. In Table 3 are the subsidy schemes implemented by Field Wing and On Farm Water Management in last five years.

Table 3. Government subsidy schemes for mechanization & OFWM during last five years

Project	Objectives/ key components	Department/ duration	Status
Mechanized Management of Rice Crop Residue	Provision of 500 rice straw choppers to farmers and service providers Provision of 500 Pak seeders to farmers and service providers	Field Director General Agriculture/ 2020-2022	Completed
Chief Minister green tractor scheme	Provision of 9500 tractors to farmers on subsidised rates	Government of Punjab/ 2024-Ongoing	Ongoing
Promotion of mechanized agriculture for increasing crop productivity	Provision of efficient agricultural machines and implements on cost sharing basis to 7285 agricultural mechanization service providers Capacity building of farmers and service providers for optimum operation and maintenance of agricultural machinery	Field Director General Agriculture/ 2021-2026	Ongoing
Punjab resilient and inclusive agriculture transformation (PRIAT)	Supporting climate-resilient agriculture by promoting reformatory crop production, renewable energy, and on-farm water management technologies (Related with mechanization)	On Farm Water Management Punjab/ 2022-2027	Ongoing
National program for enhancing command area in Barani areas of Pakistan	Provision of 500 Laser land levellers to farmers and service providers	On Farm Water Management Punjab/ 2020-2025	Ongoing
National program for improvement of watercourses in Pakistan (Phase-II)	Provision of 9,500 Laser land levelers to the farmers/ service providers	On Farm Water Management Punjab/ 2019-2024	Completed

Unavailability of skilled machine operators

Another reason for the low adoption rate of advanced machines is the unavailability of skilled machine operators. Current operators have learnt to operate and maintain old combine harvesters, which are in the market for almost three decades now, but the updated machinery is equipped with electronics systems, which is difficult for the operators to understand and maintain if there is any problem.

Strategies for agricultural mechanization advancement

Pakistan started late in agricultural mechanization but due to the availability of technology around the world, it was possible to adopt two stages simultaneously. As shown in Figure 1, stage 2 and three progressed simultaneously. Now for the last decade, stage 3 and 4, which are "Humanism and Electronics" and "Precision Farming, Traceability, and Cyber-Physical Systems" (Mazzetto *et al.,* 2020) are also in progress at the same time, which is an advantage for the country as technology is already available, so agriculture sector of Pakistan just needs a policy to adopt the available technology and a need to work towards climate smart agriculture to ensure the food security (FAO, 2015), which includes:

- Sustainable increase in agriculture productivity and income for workers in the sector
- Adaptation to climate change through the acquisition of new forms of resilience

- Reduction of greenhouse gas emissions where possible

The implementation strategies for these varies from country to country, while there is a need to develop strategies for developing countries like Pakistan by following which can help them achieve the above goals.

Proposed solutions and recommendations

In this research, we made a state of the art of agricultural mechanization in Pakistan by describing the current state of mechanization and problems being faced by different stakeholders. These problems can be addressed by taking right steps in right directions by implementing the appropriate policies form government. Here are the key solutions for the above-mentioned problems, explaining what to be done and how to be done.

Establishment of machinery hubs in rural areas

To facilitate access to advanced agricultural machinery, machinery hubs can be established on union council level. This way, farmers of each hub can easily get the facilities of advanced agricultural machinery on contract basis, commonly known as service provision locally. These hubs would provide shared access to precision equipment and advanced tools, making them more affordable for smallholder farmers. The ownership of the available machinery should be private, ensuring accountability and efficient operations, while a government body should oversee and regulate the standard and rental rates of the machinery. Farmers would benefit from the high-end machinery without a need to purchase.

Farm service center in KPK

A similar model was introduced in Khyber Pakhtunkhwa province, where farm service centers were established on Tehsil level, which provides agricultural inputs on subsidized rates and the agricultural machinery on rental basis. This machinery is owned by the government and farmers can rent these out as per their usage. Rana *et al*. (2023) conducted a study on farm service centers and found that machinery sector is not very much successful in operation due to several reason, which are unavailability of latest machines, unavailability of machines on time, huge logistics costs due to the far-off location from farm areas and the non-alignment of machines with the local crops. A major drawback in this model was the selection of the machine operators, as this is the responsibility of the farmer who rents out the machine from the center. This way, operator changes every time machine is rented, resulting in the low maintenance and care of the machine. This will be eliminated in the proposed model as ownership of the machine will be private and the owners will arrange their own operator.

This machinery hub model will work on the base of contracting, as machine owner will provide services to farmers on contractual basis. This will open doors for the adoption of ICT in this sector also. As stated by Mazzetto *et al*. (2019) in Figure 14, contracting have a moderate strength in ICT adoption than that of agriculture sector.

Introduction of advanced imported machinery

As discussed earlier regarding the state of mechanization, even with the maximum mechanization in spraying and harvesting, losses are still extremely high with 10-15% losses in harvesting and 50% during spraying (Pakistan of Bureau of Statistics, 2010; University of

Agriculture Faisalabad, 2015). Variable rate sprayers and telemetry system can be introduced to minimize the use of chemicals and reduce application losses (Sarri *et al*., 2020; Wang *et al*., 2024). Reason behind this is the use of old and low quality locally manufactured machines. There is a need to introduce new and advanced imported agricultural machines to minimize these losses. In this regard, foreign companies should be invited to visit and access the local needs, so that they can recommend suitable available advanced machines in the local market, which will help the agriculture sector to reduce losses.

Trainings and spare parts availability by importers

Companies importing these machines must be required to ensure the availability of spare parts and to organize training workshops for the buyers and operators so that they can use these advanced machines with the highest efficiency. Along with the training on machine use, these trainings should also include agronomic behavior of crops also as along with how to harvest, when to harvest also important. As an example, one of the factors which plays major role in grain losses is moisture content (Looh *et al*., 2025), so operator should know if the crop stage is suitable for harvest or not. Machine manufacturers should be bound to provide these trainings in Pakistan, this way, they will also get a better understanding of the local conditions. This will ensure that farmers are well trained to use and maintain the machinery, leading to better adoption rates of the advanced machinery.

Trainings are important to increase the adoption rate as in the past, some technologies were not adopted because of the improper use of new machines. When rice transplanters were introduced in the late 2000's in Pakistan, there were no proper trainings for the farmers and operators, which resulted in the failure in adoption. Major reasons for its failure as described by Ghafoor *et al.* (2008) was the improper growing of rice nursery as it should have been according to the transplanter requirement. As compared to the last decade, rice transplanters are more in use by the farmers, but the issues persist as mentioned in a latest study by Umar *et al*. (2022) where they highlighted the unskilled operators and difficulties in the maintenance of transplanters.

Government support

Targeted subsidies and tax rebates

As mentioned earlier, most of the available farm power is utilized in land preparation operation, so there is a need to provide awareness to farmers to use it for other operations also. Government can play a vital role in this by subsidizing the machines/ implements which they think should be promoted, but in recent years, subsidies include land preparation implements also, even after their adoption by farmers. Farmers have a limited knowledge about the new and advanced machines developed by government or private sector, so they simply prefer to buy basic implements. Eliminating already adopted machines from the subsidy schemes and providing subsidies on advanced machines, will enhance the impact of mechanization.

Another support from the government can be the tax rebate, which will open the gates for importing new advanced machines in the country, which at this stage cannot be manufactured locally. By doing this, farmers and agricultural machinery contractors will prefer to buy new advanced machines instead of scrap machines, which will surely have better performance and adoption rate will increase.

Awareness campaigns

Along with all the support from the government, awareness campaigns should also be conducted with subsidy schemes so that farmers can have good knowledge about the use and benefits of new advanced machines/ implements. This can be done by establishing "Model Farms/ Demonstration Sites" in different areas, these demonstrations should be equipped with advanced agricultural machinery, so that farmers can observe and see the use and benefits of latest machinery.

Twining arrangements and third mission

Use of advanced technology can be adopted in the country by making twining arrangements with foreign universities especially European as most of the harvesting machinery being used in Pakistan is imported from Europe. With the introduction of twining arrangements, personals from academia and public sector can visit European universities and agriculture departments and learn about the updated technologies. This will open the gates for third mission also, which encourages universities to engage in societal and community development activities. By fostering relationships between European universities and Pakistani agricultural institutions, Third Mission can play a pivotal role in facilitating knowledge exchange, collaborative research, and innovation tailored to local farming conditions.

Establishment of testing and certification centres

Moving towards the next stage of evolution, Pakistan needs to start the digitization of agricultural machinery, government can take initiatives like bringing agricultural machinery manufacturers on a single platform by registering them with government departments, digitization of locally manufactured machines, which will help identifying the number of machines/ implements available in the country. This will help in forecasting future demand and help policy makers to launch projects accordingly. At the moment, testing of farm machines before selling them to farmers is almost non-existent (Sims and Kienzle, 2009). During the implementation of standards and certification procedures, most impacted stakeholders will be manufacturers, it is important to keep them in discussions and decision making. There will be some arguments from manufacturers, being the major stakeholders, which are addressed in Table 4.

Table 4. Arguments and counterarguments for testing and certification.

Argument	Counterargument	Possible responses
Digitization of agricultural machinery: digitizing agricultural machinery and registering manufacturers will help in identifying the number of machines available, forecasting future demand, and aiding policymakers in launching relevant projects.	**Cost and bureaucracy**: establishing a certification body and digitizing machinery may involve significant costs and bureaucratic hurdles.	**Long-term benefits**: while initial costs may be high, the long-term benefits of improved quality, safety, and marketability of agricultural machinery outweigh these costs. Streamlined processes and digital records can reduce bureaucratic inefficiencies over time.
Need for standardization: standardization, testing, and certification are essential for ensuring the quality, safety, and trustworthiness of agricultural machinery, facilitating smoother trade.	**Adaptability of local manufacturers**: local manufacturers may struggle to adapt to new regulations and standards.	**Support measures**: The government can provide support through training programs, subsidies, and phased implementation (voluntary at initial stage) of regulations to help local manufacturers adapt. **Involvement of stake holders** Establishment of standards should not be one party job. All the stake holders, manufacturers, researchers, academia, farmers and service providers should be the part of this process.
Third-party certification: third-party certification is crucial for impartial assessment and avoiding conflicts of interest that may arise with in-house testing and certification.	**Effectiveness and impartiality**: there may be concerns about the effectiveness and impartiality of third-party certification bodies.	**Accreditation and oversight**: accreditation of certification bodies ensures they operate to international standards, providing an extra layer of confidence in their impartiality and effectiveness. Regular audits and oversight can further ensure their reliability.
Ongoing initiatives: the establishment of a testing, evaluation, and certification centre by the agriculture department of Punjab is a positive step towards digitization and quality control.	**Harmonization Challenges**: varying interpretations of methodologies can impact test results and create challenges in harmonizing standards.	**International collaboration**: international organizations like ANTAM and OECD play a vital role in establishing clear and consistent standardization, testing, and certification processes. Collaboration among these organizations can help address and mitigate harmonization challenges.

Need of standardization

Standardization, testing, and certification are crucial for the smooth flow of trade, providing a framework that supports quality, safety, and trust in products and services. In-house testing and certification may work for large companies; however, at a global level, it may create conflicts for other stakeholders, making third-party assessment critical for impartial certification. According to the European Committee for Standardization, standards result from the collaboration of all interested parties, including manufacturers, consumers, and regulators, and benefit all through improved safety, quality, and lower costs. In this process, testing serves as the essential link between standards and certification, ensuring that products meet established

requirements. However, testing is only valuable when solid standardization and certification processes are in place, governed by clear and effective regulations. ISO defines certification as an independent body's assurance that a product, service, or system meets specified requirements. Accreditation, while not mandatory, provides an extra layer of confidence, as it confirms that a certification body operates to international standards. Harmonized standards streamline the conformity assessment for products, services, and personnel, but varying interpretations of methodologies can impact test results. Consequently, international organizations like ISO, CEN, and OECD play a vital role by establishing standardization, testing, and certification processes that uphold quality and conformity. This creates a trustworthy system, especially valuable when companies operate in different regions and economic systems (Liberatori, 2013).

Ongoing initiative

Recently, engineering wing of agriculture department of Punjab is in process of establishing a testing, evaluation and certification centre for agricultural machinery being manufactured locally, this can be a good initiative towards the digitization and a good record can be maintained of all the tested machinery along with the addition of trackers or bar codes on the machines/ implements to keep the check and balance of the quality and maintenance scenario in future. Pakistan should adopt the model quoted by Liberatori (2013), by making standards, initialize the harmonized testing procedures and giving third party certifications. This will pave the way for export of local machinery to different international markets without difficulties in the quality department.

Updated agricultural machinery census

Along with all the measures needed to be taken to make advancement in agricultural mechanization, updated data of available machines and implements should be collected so that government can use this data in planning future projects. Along with this, updated data can also be utilized by private sector, or investors to identify the potential areas for future investments in agricultural mechanization, which will bring more opportunities and growth in this sector. As last agricultural machinery census and agriculture census was conducted in 2004 (Pakistan Bureau of Statistics, 2004) and 2010 (Pakistan Bureau of Statistics, 2010) respectively, so it is difficult to get a clear picture of the status of available machines/ implements in the country.

Stakeholders contributions to mechanization challenges

After discussing challenges and proposed solutions, it is apparent that there is a need for different stakeholders to work collectively to address the present issues. Figure 13 shows the required "Intensity of Support" from major "stakeholders against the challenges being faced in agricultural mechanization sector". Figure 13 shows that government support is required in all sectors, while to ensure the quality of locally manufactured machinery and availability of imported machine, all stake holders, government, private sector, international collaborations and research departments should play their roles. One important consideration here is that the role of research departments in the availability of updated technology knowledge is not shown, reason for this is the updated technology is already available with different countries and Pakistan can take advantage by adopting already developed technologies as per their local

requirements, which will save time and will give a jump in the adoption of latest reliable technology. These major stakeholders are government, private sector, international resources and research and development sector (including academia and research organizations)

Conclusions

There is a varied level of mechanization in different agricultural operations. As land preparation is mostly mechanized, there is a lot to be done in sowing, weeding, spraying and harvesting operations. Government must play a key role to achieve a certain level of mechanization status, as learned from the adoption of laser land leveller success story and it also shows that there is good potential of mechanization adoption if right steps are taken. Key issues hindering the growth of mechanization are low available farm power, lack of local manufacturing of advanced machinery, low quality of locally available agricultural machinery and absence of testing and certification facilities, limited awareness of farmers about the advanced machinery and unavailability of updated agricultural machinery data in the country. Critical measures which should be taken to address the mechanization issues would be the establishment of testing facilities, introduction of advanced imported machines, increase the local manufacturing of agricultural machines, farmer awareness campaigns, targeted subsidies, government support in importing advanced imported machinery and to work on digitization of machinery data.

While Pakistan has made significant developments in agricultural mechanization evolution, there is still a long journey ahead to achieve the required farm power and mechanization levels. Addressing the identified issues through coordinated efforts from the government, private sector, and farmers can pave the way for a more mechanized, efficient, and productive agricultural sector in Pakistan.

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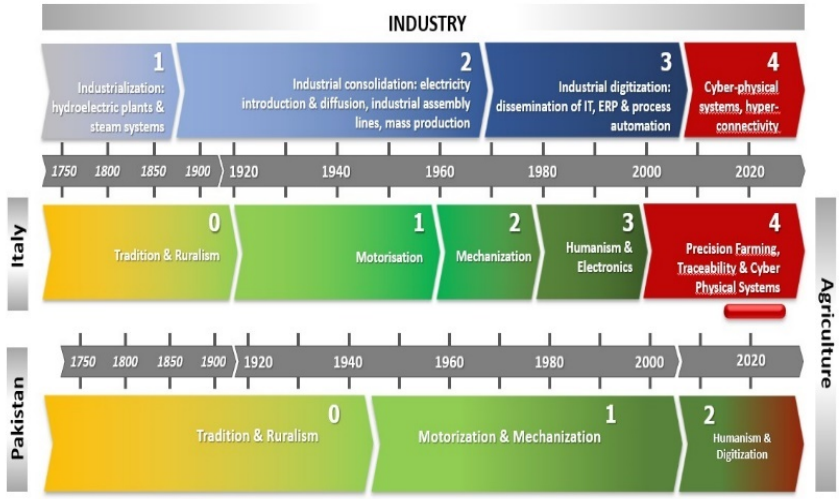

Figure 1. Evolution timeline of industry and agriculture.

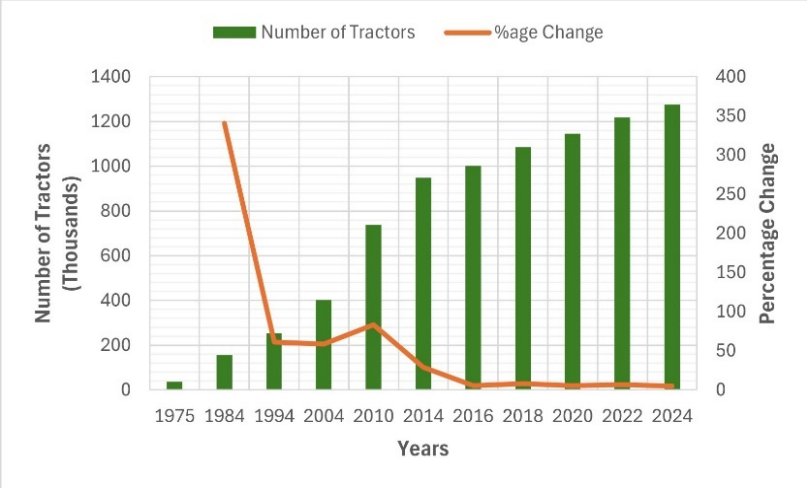

Figure 2. Tractors availability and percentage increase (Pakistan Bureau of Statistics, 2010; Ministry of Finance, 2024). Source is not homogeneous because tractor data until 2010 is taken from Agricultural census by Pakistan Bureau of Statistics, while data from 2011 until 2024 is taken from Ministry of Finance annual reports.

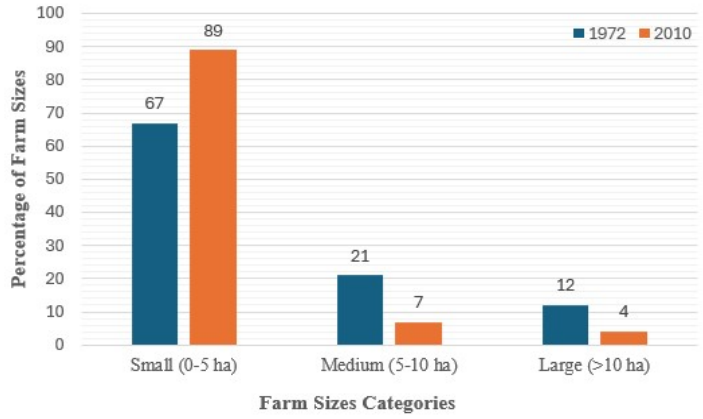

Figure 3. Percentage of farm sizes in Pakistan from 1972 and 2010 (Pakistan Bureau of Statistics, 2010).

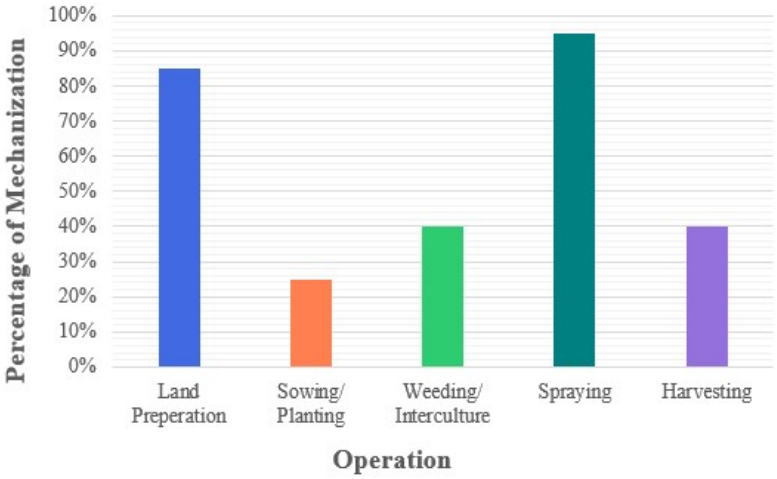

Figure 4. Operation wise level of mechanization. 95% of spraying mechanization also includes major portion of knapsack sprayers, which are operated manually and according to studies, 50% of spraying losses occurs while operation.

Figure 5. Land preparation implements/ machines. a) Pneumatic planter for maize sowing manufactured locally; b) Pak seeder for land preparation and sowing of wheat developed by AMRI and local manufacturing firm Greenland Engineers; c) Land preparation operation (puddling) for rice nursery transplantation using locally manufactured tine cultivator

Figure 6. Sowing and planting implements/ machines a) Ride on rice nursery rice transplanter manufactured by Kubota; b) Locally manufactured tractor mounted potato planter.

Figure 7. Interculture implements/ machines. a) Locally manufactured tractor mounted row interculture implement; b) Locally manufactured tractor mounted boom sprayer; c) Advanced self-propelled boom sprayer manufactured by Kubota.

Figure 8. Harvesting machinery. a) Locally manufactured tractor mounted wheat reaper; b) New Holland conventional wheat combine harvester; c) Chinese self-propelled maize cob picker manufactured by Dafeng; d) Kubota built half feed paddy harvester working in paddy fields

Figure 9. Locally manufactured Laser Land Leveller in a farmer's field. These LLL are equipped with imported transmitters mostly imported from USA and China.

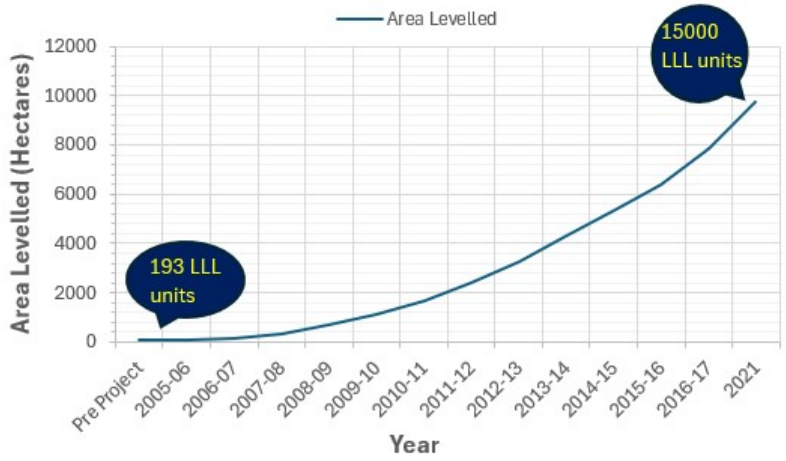

Figure 10. Area levelled over the years using LLL and number of LLL at start and in 2021.

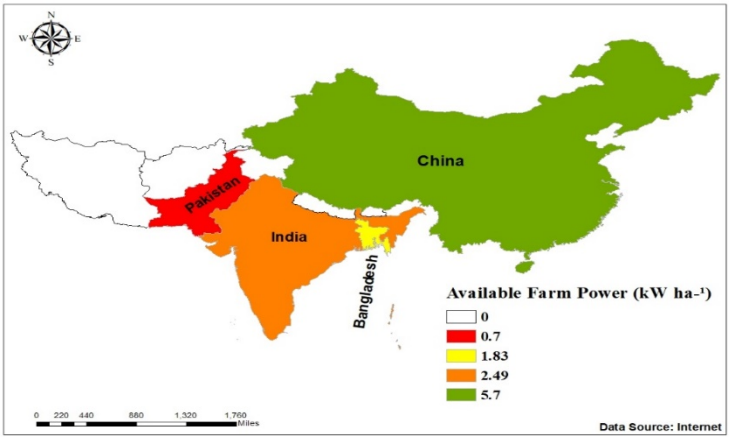

Figure 11. Available farm power in neighbouring countries of Pakistan.

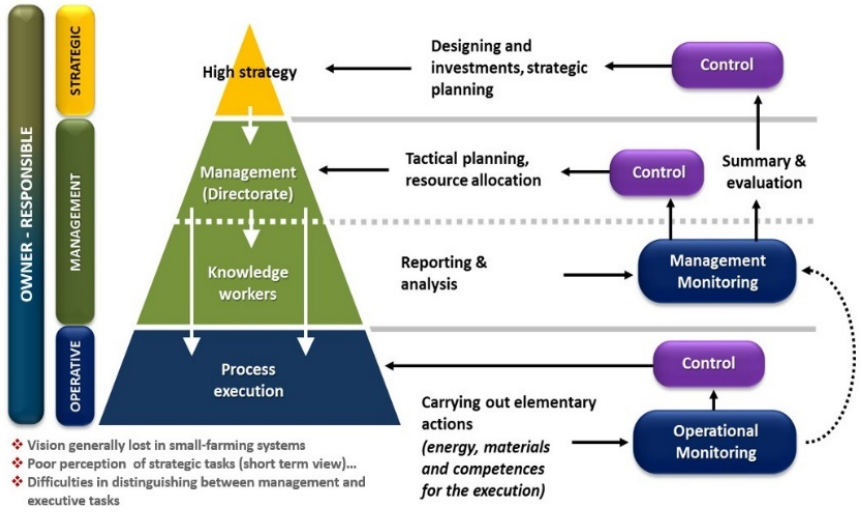

Figure 12. Schematization of the hierarchical levels of an enterprise and indication of the main tasks of the responsible people at each level.

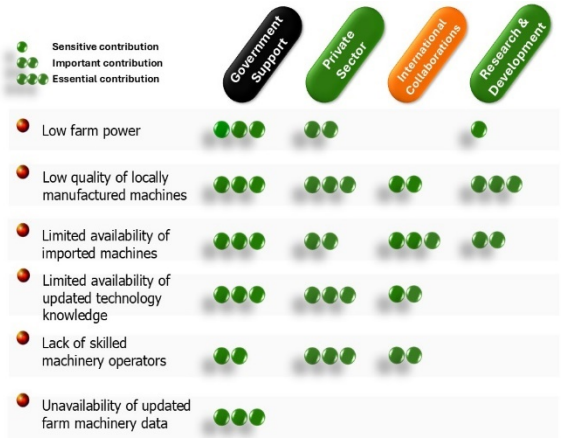

Figure 13. Challenges in agricultural farm mechanization and intensity of support from each stakeholder against the challenges.

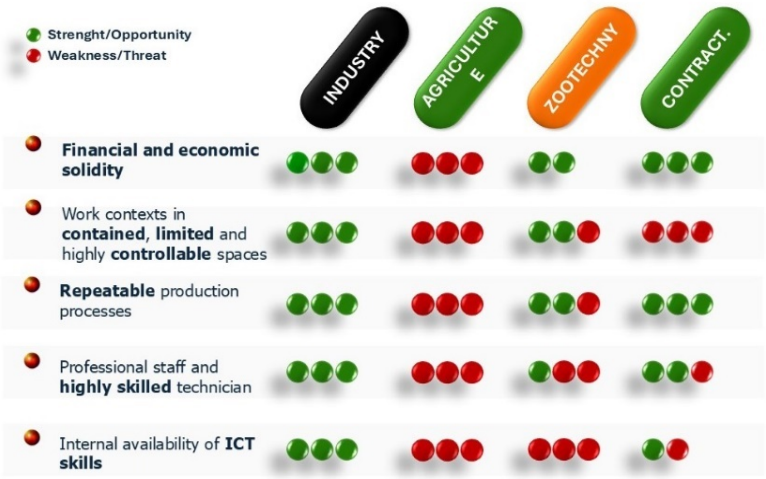

Figure 14. Aspects influencing ICT use in different production contexts.