Adoption of Farm Mechanization for Improved Yield in Pakistan: A Comprehensive Review

Zeeshan Memon[1], Satesh Kumar Devrajani [2,3*], Ahmed Ali Tagar [4], Zheng Yongjun[1]
[1]Department of Agricultural Engineering, College of Engineering, China Agricultural University, Beijing, China
[2]Department of Civil, Environmental, Architectural Engineering and Mathematics, University of Brescia, Via Branze 43, 25123, Brescia, Italy.
[3]Department of Environmental Engineering, U.S. Pakistan Center for Advanced Studies in Water, Mehran University of Engineering and Technology, Jamshoro, 76090, Pakistan.
[4]Department of Farm Power and Machinery, Faculty of Agricultural Engineering, Sindh Agriculture University, Tandojam, 70060, Pakistan
*** Correspondence:**
Citation | Memon. Z., Davrajani. S. K.. Tagar. A. A., Youngjun. Z., "Adoption of Farm Mechanization for Improved Yield in Pakistan: A Comprehensive Review." IJIST, Vol. 06 Issue. 04 pp 238-257, Dec 2024
Received | Nov 20, 2024; Revised | Dec 11, 2024Accepted | Dec 14, 2024; Published | Dec 18, 2024.

Agriculture plays a pivotal role in Pakistan's economy, yet the sector faces significant challenges in productivity and efficiency, contributing to widening income disparities between rural and urban populations. This review explores the current status of the adoption of farm mechanization as a strategy to enhance agricultural yield in Pakistan. Despite the importance of agriculture in the national economy, mechanization levels remain low, constrained by financial barriers, inadequate infrastructure, and limited technical knowledge among farmers. The demand for mechanical sowing and spraying equipment has surged, evidenced by a threefold increase in sales from 2012 to 2022. Nearly all cereal threshing is mechanized, supported by an active market of 20,000–30,000 threshers annually. However, Pakistan's farm power availability remains below the optimal level recommended by the FAO, adversely affecting crop yields, which are two to four times lower than those of developed and emerging nations such as China and Japan. Increasing horsepower per hectare and ensuring efficient machinery operation are imperative to close this gap. By addressing the challenges, Pakistan can enhance yield per unit area, ensuring sustainable growth in its agricultural sector and improving rural livelihoods.

Keywords: Mechanization, Farm Power, Yield, Agriculture, Tractors, Pakistan.

Introduction:

Agricultural mechanization is an important component in the agrarian economic transition and plays a key role in improving agricultural labor productivity, thereby contributing to sustainable food security and alleviating rural poverty. The economic growth of Pakistan and its Agricultural development are inextricably interwoven. About 37.4% of the labor force is employed in the agricultural sector, which produces 22.7% of the country's GDP. About 65% of Pakistanis who live in rural areas work in agriculture, accounting for 45% of all labor force members. Pakistan now ranks fifth in the world in terms of population, fifth in terms of cotton production and ninth in terms of wheat production [1]. Due to numerous significant issues, including a slow rate of technical modernization, participation supply issues, a lack of extension services, inadequate investment, publicizing and trade restrictions, and insufficient credit amounts for agrarian production and processing over the past ten years, Pakistan's agriculture sector is not operating to its full potential [2] The agricultural sector's yield percentage is under pressure due to low productivity. It is evident that the yields of non-basmati rice, sugarcane, wheat, cotton and milk are all below the worldwide benchmark, falling to 50%, 35%, 40% and 95%, respectively [3] as shown in Figure 1. The effectiveness of current agricultural techniques and the right application of mechanized technology are primarily responsible for the efficiency of agricultural inputs in sustainable agricultural production [4].

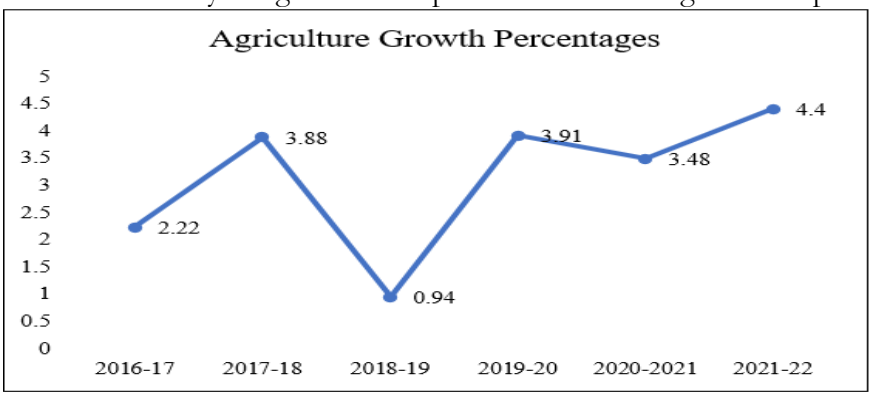

Figure. 1. Agriculture growth percentage of Pakistan

Inputs that are mechanical, biological, hydrological and chemical have an impact on agricultural productivity [5]. Farm mechanization is essential for maximizing the utilization of hydrological, biological and chemical inputs. The commencement of farm mechanization in Pakistan took place during the early 1950s when privately owned tube wells were introduced. These tube wells utilized mechanical power to extract groundwater for irrigation purposes [6]. However, at first, many farmers were unwilling to employ farm equipment because of their illiteracy and inflexibility in using traditional approaches [7]. However, as time went on, it became clear that farm mechanization might increase cultivated production by conserving time, water and other cultivated resources.

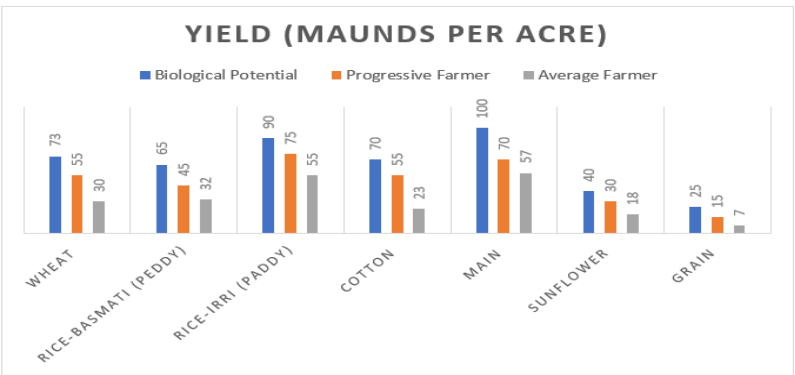

Figure.2. Potential yield of agriculture in contrast to the yield of average and progressive farmers.

In comparison to other nations, Pakistan has a low level of agricultural productivity. This is mostly caused by the farmers' inability to obtain suitable agricultural equipment at the appropriate time, which delays farm activities, especially during the planting and reaping of crops [8] The inadequate productivity of the county's farmlands is also caused by the ineffective selection of agricultural machinery due to the low purchasing power of the farming community, the absence of standardized products and their seasonal utilization [9]. Additionally, the lack of adequate facilities for repair and maintenance across the nation caused agricultural equipment to function poorly and live shorter lives [8]. Improving access to power in Pakistani farms can contribute to more efficient crop production, harvesting, and post-harvesting processes, thereby addressing the issue of significant crop losses. In cereals, where losses range from 20% to 25%, and in fruits and vegetables, where losses can reach 45% to 50%, the availability of adequate power supply can help mitigate these losses. Appropriate mechanization can also reduce the need for 25%-30% of the human labor on farms as well as 25%-35% of working time and 25%-35% of fertilizer. Additionally, it can raise crop output by 15%–20% and cropping intensity by 10%–25% [10] as shown in Figure 2.

In Pakistan, the only agricultural mechanization tools employed are tractors and cultivators. The nation is facing significant production gaps due to reliance on traditional farming practices and limited adoption of new technology. There is a considerable disparity between average yields and the full production potential. Additionally, the rapid population growth seriously jeopardizes the nation's food security policies. In order to basically secure the country's agricultural future, there must be a large increase in agricultural output. The agriculture sector should utilize cutting-edge technologies to boost productivity and close yield discrepancies.

Policymakers, organizations, and extension personnel must cooperate to educate and teach local farmers before introducing new mechanical techniques and thereafter modifying, expanding and adapting these techniques in order for farm mechanization to be successfully implemented. This will be achievable once the level of farm mechanization in the nation is critically examined in light of previous government policies and strategies. In-depth information regarding the condition of various agricultural machines utilized in Pakistan is the main goal of this paper. The policymakers will be assisted by this knowledge in determining the advantages of promoting farming machinery to secure food security for the nation's future generations.

Pakistan is a nation that produces little income. Because of its primary responsibility to supply the rapidly expanding population with wholesome food, agriculture is its most significant sector. A proper mechanization strategy should be designed and adjusted with the historical trends of farm mechanization in the nation in mind in order to increase land productivity.

In order to address the problems affecting the agriculture industry, farm mechanization is necessary. Using agricultural machinery for planting, cultivating and harvesting crops increases crop productivity. It is essential to implement farm mechanization practices that suit the specific conditions of the local environment. In situations where extensive land leveling is necessary, such as large-scale projects, the use of bulldozers and laser land levelers is recommended. However, in different areas, traditional methods like thorough seedbed preparation and the cultivation of high-yielding seed varieties can effectively enhance productivity. In regions where canal water is not readily available, it is important to prioritize the development of cost-effective tube wells, with solar tube wells being a highly favorable option. It's crucial to fertilize and irrigate properly [11]. Cooperative farming is a way to improve farm mechanization while maintaining private ownership. The government is responsible for a larger portion of the debt because it is only able to buy and rent farm

equipment from farmers at heavily discounted prices. According to data, the country has a limited supply of agricultural gear, such as multipurpose thrashers, potato diggers, soil levelers, pit diggers, tiller drills, water sprinklers and others [12]. [13] highlight that Pakistan's agricultural sub-sectors exhibit lower productivity levels compared to industrialized nations and similar emerging economies. They also argue that if Pakistan fails to achieve significant and sustainable growth in agricultural production, its economy will become increasingly interconnected with the global economy, posing challenges for the country's agricultural industry to compete on a global scale.

Objectives:

This review aims to assess the current status, challenges, and opportunities and provide recommendations to achieve sustainable agricultural mechanization in Pakistan. It specifically aims to:

1. Discuss the existing agricultural mechanization practices and their impact on productivity in Pakistan.
2. Identify the key challenges and barriers hindering the widespread adoption of mechanization in agricultural sectors.
3. Explore emerging trends and opportunities in agricultural technologies that can enhance mechanization efficiency.
4. Provide strategic approach recommendations that support long-term mechanization goals and improve the sustainability of the agricultural sector

Novelty:

This paper is focused on providing the firsthand information about the status of different agricultural machines existing in Pakistan. This information will help the policy makers to identify the benefits of promoting agricultural machines to ensure food security for the future generations of the country.

Methodology:

This study uses an approach to present the overview of the development process of agricultural mechanization in Pakistan and provides a sense of direction for policymaking and future studies for developing countries in the early stages of agricultural mechanization. A comprehensive literature review was conducted by analyzing studies from the Pakistan to identify mechanization trends, challenges, and policy impacts. Quantitative data, including national statistics on mechanization, crop yields, and regional disparities were collected. Identify the best practices that could be adapted locally. Recommendations for sustainable strategies, including policy reforms, technological innovations, and private sector partnerships were developed based on the analysis. The final report provided actionable recommendations to enhance agricultural mechanization and productivity in Pakistan.

Availability of farmland and farm power:

Availability of farmland:

Pakistan has a land area of 79.61 million hectares, but only 24.16 million hectares are used for cultivation, making up 30.3% of the total land area. The country's forest area is 3.92 million hectares, accounting for 4.92% of the land, whereas the recommended minimum forest area for a country is 25%. Table 1 eloborates that the agricultural land is decreasing which shows that the agriculture land cultivation is being converted in urbanization or due to lack of water and climatic issues, the agricultural land is getting affected. In comparison to other provinces, Punjab province has a highly cultivated area because of the availability of water. The province vise land utilization statistical data from 2010 to 2020 is mentioned in table 1.

Table 1. Land Utilization Statistics of Pakistan

Year/ Province	Geographical area	Total area reported col. (4+5+6+7)	Forest area	Not available for cultivation	Culturable waste	Cultivated area col. (8+9)	Current falloff	Net area sown	Area sown more than once	Total cropped area col. (9+10)	Agriculture land (13+4)	Arable land (6+7)	Uncultivatable area (4+5+6)
1	2	3	4	5	6	7	8	9	10	11	12	13	14
2010-11	79.61	57.76	4.26	23.4	8	22.1	6.38	15.72	7.03	22.75	34.36	30.1	35.66
2011-12	79.61	57.76	4.27	23.25	8.2	22.04	7.05	14.99	7.52	22.51	34.51	30.24	35.72
2012-13	79.61	57.78	4.26	23.05	8.21	22.26	7.04	15.22	7.34	22.56	34.73	30.47	35.52
2013-14	79.61	57.92	4.55	22.93	8.29	22.15	6.52	15.63	7.73	23.36	34.99	30.44	35.77
2014-15	79.61	57.96	4.55	23.01	8.3	22.1	6.39	15.71	7.88	23.59	34.95	30.4	35.86
2015-16	79.61	57.99	4	23	8.25	22.74	7.1	15.64	7.91	23.55	34.99	30.99	35.25
2016-17	79.61	58.01	3.91	22.89	8.36	22.85	7.2	15.65	7.48	23.13	35.12	31.21	35.16
2017-18	79.61	58.02	3.91	22.95	8.25	22.91	7.15	15.76	7.77	23.53	35.07	31.16	35.11
2018-19	79.61	58.03	3.91	23.59	8.27	22.26	7.13	15.13	7.52	22.65	34.44	30.53	35.77
2019-20	79.61	58.03	3.92	23.18	8.19	22.74	6.97	15.77	8.39	24.16	34.85	30.93	35.29

Source: - Provincial Agriculture Departments

3. TOTAL AREA REPORTED is the total physical area of the villages/deh, tehsils or districts etc.

4. FOREST AREA is the area of any land administered as forest under any legal enactment dealing with forests. Any cultivated area which may exist within such forest is shown under heading "cultivated area".

5. AREA NOT AVAILABLE FOR CULTIVATION is an uncultivated area of the farm that is under farm homesteads, farm roads and other connected purposes and not available for cultivation

6. CULTURABLE WASTE is that uncultivated farm area that is fit for cultivation but was not cropped during the year under reference nor in the year before that.

7. CULTIVATED AREA is that area which was sown at least during the year under reference or during the previous year. Cultivated Area = Net Area sown + Current Fallow.

8. CURRENT FALLOW (plowed but uncropped) is that area which is vacant during the year under reference but was sown at least once

9. NET AREA SOWN is that area which is sown at least once during (Kharif & Rabi) the year under reference.

10. AREA SOWN MORE THAN ONCE is the difference between the total cropped area and the net area sown.

11. TOTAL CROPPED AREA means the aggregate area of crops raised in a farm during the year under reference including the area under fruit trees.

The country experiences an annual population growth rate of approximately 1.69 percent, and its current population stands at around 220 million, making it the fifth most populous country globally. The rapid urbanization resulting from this population increase has led to a reduction in cultivable land. The limited availability of land, coupled with a growing population, high crop production costs, and increasing food demand, presents significant challenges for Pakistan's agriculture sector. As a result, the government has prioritized modern agriculture based on mechanized farming.

Availability of farmland:

Seedbed preparation, wheat, and paddy harvesting, and pesticide application have achieved a reasonable level of mechanization in Pakistan. However, the use of machines for other field operations is relatively limited. Manual labor is still prevalent in mechanized nursery transplanting, despite the potential for mechanization in this area. Cattle farming, fishpond farming, and postharvest processing of fruits and vegetables are emerging businesses that hold promise for mechanization. Currently, farm power availability stands at 0.52 horsepower per acre (1.29 horsepower per hectare). Although there are over five hundred small and medium-sized manufacturers operating in Pakistan, issues such as low quality and lack of standardization persist.

This situation presents an opportunity for joint ventures between Pakistani manufacturers and high-tech international manufacturers. Such collaborations can lead to the production of high-quality farm machinery within Pakistan, catering to both domestic and international markets at competitive prices. Given the challenges posed by limited land, a growing population, and the rising demand for food, the government recognizes the need to address these issues through modernization and mechanization in the agricultural sector.

In light of the existing conflicting economic conditions in the country, including the energy crisis and numerous internal and external challenges, Pakistan's reliance on the agricultural sector will increase to foster national development. Consequently, it is imperative to prioritize immediate measures to improve productivity and profitability in both expanding and diversifying the agricultural industry. Furthermore, the process of urbanization is diminishing the amount of cultivable land that is accessible, while the scarcity of water hinders the cultivation of additional areas, including the existing cultivable wasteland of 8.31 million hectares. As per the 2012-13 economic survey, the present cultivated area stands at 22.04 million hectares, which is marginally less than the recorded 22.27 million hectares in 2002-03. To address these obstacles, Pakistan needs to adopt cutting-edge technologies and improve the accessibility and effective use of biological, chemical, and hydrological resources. The incorporation of mechanization will be crucial across all agricultural tasks, ranging from preparing the fields to harvesting and storing crops. Therefore, it is imperative for all parties involved, especially the government, to reassess the significance of the domestic tractor industry and enhance its impact. Until now, the agricultural sector has been performing well, standing out as the only area in Pakistan's agricultural inputs where the country is not just self-reliant but also generates foreign currency by exporting tractors and spare parts. This success is attributed to its international competitiveness in terms of both quality and pricing.

Modern farm mechanization programs need to consider farm power as an essential component. While tractors are a primary source of power in agriculture, other power sources used in Pakistan's farming sector include draught animals, human labor, small-scale diesel engines, and electric vehicles [12]. The number of tractors in the country reached around 300,000 by the year 2000, and from 2012 to 2020, this number increased by approximately 100%. Tractor production rose from about 948,000 in 2012 to 1,463,000 in 2022, with most tractors falling within the 60-horsepower category [3] as depicted in figure 3. Punjab province accounts for over 80% of the total tractor production in the country. According to the GOP's projection for 2022, considering Pakistan's tractor population and a total farming area of 22.68

million hectares, there are 25 hectares of cultivated land per tractor. Taking a 60-horsepower tractor as an example, the available power in the country is only 0.84 horsepower per acre, which falls significantly short of the recommended power of 1.21 horsepower per acre [3] Currently, the country's production facilities operate during one shift only, and they are currently sufficient to meet the demand for tractors.

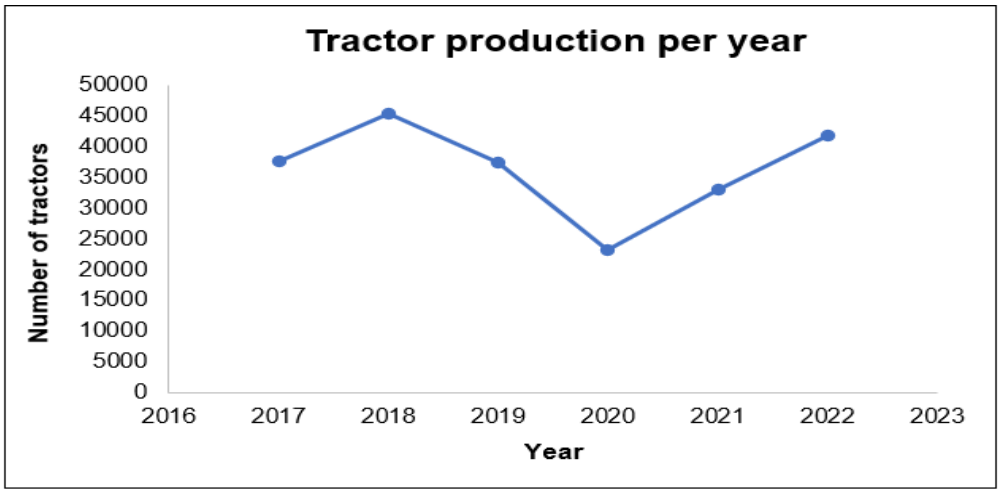

Figure.3. Production of tractors per year [3]

Table 2 Different sources of farm power available in Pakistan

Power Source	Average HP capacity	Population	Available HP
Tractors	60	1463000	87780000
Work animals	0.5	260000	130000
Human laborit	0.2	$38.6*10^6$	$3.86*10^6$
Tubewells	18.37	1305084	23974393

Agricultural Machinery in Pakistan:

Mechanization for the Development of the Land

Ensuring optimal plant population, correct seed and seedling depth, suitable spacing between rows and plants, and successful early crop establishment in the field are crucial for achieving the best results in agriculture. To achieve this, it is important to utilize appropriate farming machinery for drilling and planting [14]. Wheat is a significant crop in Pakistan; however, the adoption of modern mechanization techniques for sowing has not been fully realized yet. Seed drills that are locally available in the country include seed cum fertilizer drills, coulters drills, and disc tiller drills [15]. Traditional sowing techniques like broadcasting are still used in some areas because of a lack of agricultural equipment [16]. Another significant factor contributing to Punjab province's low agricultural yield is the use of broadcasting, which is unable to manage and count the number of plants in the field [12]. Different multi-crop transplanters are used to maintain plant-to-plant distances while planting many rows of crops. However, hand planting of maize and cotton, particularly in Punjab, is still practiced. Due to harsh weather conditions that make drilling cotton unfavorable, cotton growers are switching from semi-mechanized drilling to totally instruction manual planting practices.

In Pakistan, manual transplanting of rice seedlings is the norm; prior to ten years ago, there were no self-propelled rice transplanters. Nonetheless, certain businesses from Korea and China are currently attempting to promote their goods in Pakistan's rice grower regions [17]. China has more cereal crop yield and horsepower as compared to India and Pakistan as shown in Figure 4.

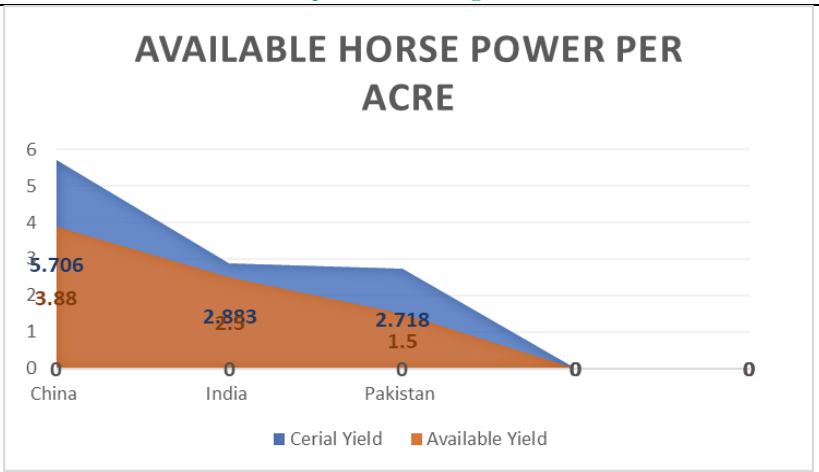

Figure. 4. Comparison of available horsepower per acre with the yield of cereal crops

Given that efficiency is directly related to the availability of mechanized sources of spray, Pakistan's stated agro-chemical application efficiency was just 60% until [18][19]. Low-income and small farmers are very accustomed to using knapsack sprayers (both human-driven and engine-driven) to apply pest and weed control chemicals, while only high-income progressive farmers can use locally manufactured tractor-mounted sprayers due to high capital costs, despite their inconsistent application patterns [20] Both small and large farmers view mechanical weed removal from a variety of row crops as a reliable source [12], and weeds are removed both manually and by using suitable intracultural tools like a bar harrow and a small cultivator [21].

Table 3. Prices and production of locally manufactured tractors 2021-22

Tractors Model – Horse Power (HP)	Total Price Including GST@ 5% (Rs)	Actual Production (in Nos.)	Actual Sale (in Nos.)
M/s Al-Ghazi Tractors Limited			
NH-480-S (55 HP)	1,228,500	3,720	3,725
NH-480 Power Plus (55 HP)	1,282,575	2,160	2,164
Ghazi (65 HP)	1,4,19,600	6,495	6,303
640 (75 HP)	1,819,650	3,208	3,078
Dabung (85 HP)	1,879,500	486	432
NH-70-56 4WD (85 HP)	2,472,750	36	35
Total		**16,105**	**15,737**
M/s Millat Tractors Limited			
MF-240 (50 HP)	1,251,600	5,318	5,346
MF-350 P.S (50 HP)	1,449,000	08	0
MF-260 (60 HP)	1,446,900	4,389	4,387
MF-360 P.S (60 HP)	1,527,750	307	329
MF-375 (85 HP)	1,876,350	1,259	1,279
MF-385 (85 HP)	1,953,000	13,692	13,739
MF-375 4WD (75	2,436,000	153	142

HP)			
MF-385 4WD (85 HP)	2,530,000	625	644
Total		**25,766**	**25,866**
Grand Total		**41,871**	**41,603**

Farm mechanization is a crucial component in boosting agricultural productivity. The main obstacle to boosting agricultural output is the demand for more high-quality tractors and other agricultural equipment available when needed at reasonable rates. In order to promote mechanized farming in the nation, the federal government maintained the aid package that permitted lower supplies of imported farm machinery and equipment. The domestic tractor industry has been instrumental in providing for the needs of tractors. With just about 670,000 active tractors nationwide, the available Horsepower (HP) per acre is only about half of what is needed at 1.54 HP per acre. Total tractor output increased by 14.6 percent from last year, from 36,900 to 41,871 from 2021–22 (July–March). Table 2 provides information on local tractor costs and production.

Indigenous tractors produced in the United States, Belarus, Turkey, and China are licensed for use in foreign markets. Pakistan imports agricultural machinery, including tractors and harvesters, from the United States and the European Union. However, the local sector in Pakistan can only meet 15% of the country's total demand for agricultural machinery. In the next 4 to 5 years, production is expected to increase by 8 to 10 percent annually as local companies respond to growing demand by expanding production and diversifying their product offerings. Unfortunately, most of the locally manufactured equipment relies on outdated technology and is not very efficient. Farmers in Pakistan show a preference for locally produced replacement machinery and spare parts due to their affordability compared to imported advanced equipment. In response, the Pakistani government has implemented various initiatives and incentives at both the federal and provincial levels to enhance and expand the agricultural sector. These projects involve educational programs for farmers, subsidized inputs, and the provision of equipment through simple and long-term loans. Additionally, the government offers budgetary support programs that include low taxation on agricultural machinery, aiming to promote agricultural modernization.

The development of cultivable waste land can be achieved by utilizing various earth-moving equipment such as tractor front-mounted blades, dozers, excavators, and land levelers. Private sector providers offer tractor-mounted front blades and bulldozers for land development purposes. The economical conversion of this land for cultivation primarily relies on the use of crawler tractors or bulldozers [22]. However, the current number of operational bulldozers, which is 647 in Punjab and 106 in Sindh, is insufficient to effectively develop the 4.62 million hectares of cultivable waste land. Based on the available bulldozer fleet, it is estimated that it would take approximately 100 years to fully develop the entire cultivable waste land in Punjab province [3]

Mechanization for the Preparation of Seedbed and Tillage:

Tillage tools are necessary to aerate the soil and remove weeds, including crop residues, fertilizers, feed and pre-emergence weedicides, as well as to destroy pests' hiding places and break up their life cycles [23]. Primary and secondary tillage operations make up Pakistan's tillage equation [24]. Primary tillage involves breaking up the hard pan formed by compacted soils by opening up the dense soil with the use of various diggers. Additionally, primary tillage causes soil inversion, weed uprooting and stubble removal [23]. The fields are left over with huge chunks after primary tillage, along with some weeds and partially evacuated stubbles. Further, secondary tillage is done after primary tillage for lighter or finer operations [25].

The digger has become the most popular tool for both primary and secondary soil tillage over the past forty years. The number of cultivators in the nation has increased from 900,000 in 2012 to 1,602,000 in 2022 [3] , while the proportion of moldboard ploughs, disc ploughs, disc harrows, chisel ploughs, and rotavators has increased over the same period from 189,784 to 1,293,421, 142,338 to 829,537, 94,892 to 187,550, 47,446 to 125,893, and 113,870 to 234058 (Table 3). The cultivator's steady growth is a result of its minimal draught need and significantly lower cost compared to other tillage equipment. Repetitive cultivator usage not only results in hardpan, which hinders root progress/penetration but also defeats the goal of tillage as stated above [25]. Most modern farmers utilize disc ploughs and mould board ploughs for main tillage, disc harrows for secondary tillage, and rotary tillers (rotavators) for sowing wheat in Punjab following paddy and cotton. On a small scale, conservation tillage techniques are also used to reduce the cost of tillage and seedbed preparation as well as greenhouse gas emissions. Examples include no tillage [16] for planting wheat in fields with rice stubbles, permanent beds tillage for planting cotton on beds of previous crops, and mulch or stubble tillage [16] for leaving crop residue in fields.

Table 4 Growth of different tillage implements during the last four decades [3]

Years	Cultivator	MB Plough	Disc Plough	Disc Harrow	Chiesel Plough	Rotavator
1992	236272	28413	20372	12233	6535	**5594**
2002	369866	40050	29218	23764	8514	**47919**
2012	901473	189784	142338	94892	47446	**113870**
2022	**1602000**	**1293421**	**829537**	**187550**	**125893**	**234058**

Planting and Sowing Mechanization:

By ensuring the proper sowing depth, the choice of correct sowing equipment might be crucial for successful crop production [14]. Only by using the proper sowing equipment can one attain the ideal plant population and row-to-row distance. Punjab's low crop production is primarily caused by a small plant population [26]. Most ranchers use broadcasting to scatter seeds because of time constraints or the high expense of tillage and seedbed preparation [12]. In the other regions of the nation, this trend of lesser or partial mechanization in sowing is still present, and it neither produces the desired crop growth nor yields as intended.

Around the region, seed drills with fertilizer inputs are typically used to automate the sowing of the wheat crop [15]. To lessen the issues that paddy, sugarcane, and cotton stubbles provide, coulter drills, zone-disc tiller drills, and disc-type furrow openers are utilized [27]. In rice fields that are manually harvested, wheat drills are used in addition to traditional tillage and seedbed preparation techniques. Nevertheless, traditional soil preparation techniques add three to four weeks to the planting process, which results in a poor crop yield [28].

Multi-crop planters are frequently utilized for seed row crops, including maize, cotton, sunflower, peanut and others, while maintaining the intended plant-to-plant space [29]. To tackle this concern, [30] suggests that the use of certain types of planters may require a greater quantity of seeds than initially stated. In Punjab, farmers have adopted limited-scale practices of employing pneumatic planters and inclined/vertical seed bowl planters as potential solutions for this challenge. Over the past ten years, a substantial increase in the sowing machinery market share has been seen, with an average yearly sale of about 34000 implements [3]. Because of the farming community's preference for mechanical sowing, the number of drills and planters increased from 295,000 in 2012 to 826,000 in 2022. The increase in sowing machine purchases was over 200%, and this sharp upward trend over the past decade shows that the agricultural community has finally grasped the necessity of adapting suitable sowing equipment is essential for appropriate crop stand, which is the key to success.

Approximately 6-7 years ago, there was virtually no market for self-driven rice

transplanters (both walking and riding types) in Pakistan, as the entire rice transplanting process was done manually. However, the situation has changed significantly, as numerous businesses in Pakistan are now importing rice transplanters from China and Korea and distributing them in the country's rice-wheat cultivation areas.

Plant-Protection Mechanization:

The main factor that limits crop productivity is weed growth since it consumes nutrients from the plants, competes with the crop, harbors pests and illnesses, and interferes during harvesting [31]. The spray shape, fluid velocity, droplet size, and entrained air features are significant in how pesticides are effectively applied [32]. Because of the use of subpar spray equipment, the efficiency of chemical application in Pakistan was only 55% [33]. Nowadays, chemical and mechanical methods are used to control weeds across the nation. Crops seeded in flatbeds are often cultivated using intercultural instruments like bar ploughs and rigid-type tine cultivators [21].

The most popular tools in the country for applying pre- and post-emergence weedicides are tractor-mounted boom sprayers and knapsack sprayers (both manually and electrically powered) [34] Punjab uses predominantly boom-type tractor-operated sprayers for field crops and canon-type mist blowers for orchards [33]. The booms of locally made tractor-mounted sprayers are often inflexible in design and have a tendency to sag, which results in misapplication [26]. Locally produced sprayers typically lack a pressure control mechanism (control flow valve) that generates the pressure at the nozzle tip to fluctuate, which results in uneven spray [20].

Figure 5 shows the market share of this equipment increased from 1,438,000 to 1,902,000 over the past ten years, which caused a significant change in the sprayer manufacturing business [3]. Due to farmers' resistance to adopting agrochemicals for the elimination of weeds and their steadfast commitment to using mechanical means for weed control, the usage of sprayers increased between 1992 and 2002. [12]. This sharply rising trend indicated that the dramatic rise in pesticide use over the past ten years was caused by a labor scarcity that restricted the application of traditional farming techniques.

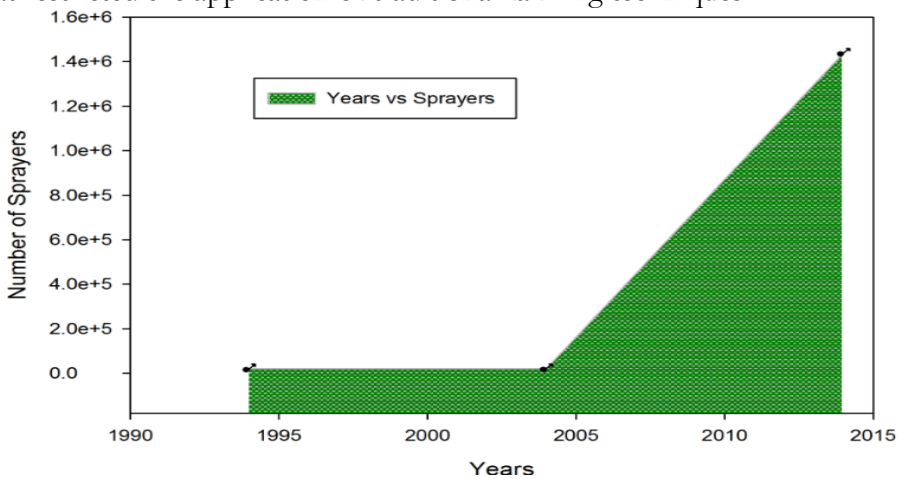

Figure. 7. The sprayers growth [35]

Threshing and Harvesting Mechanization:

In Pakistan, harvesting cereal grains is a significant issue as long as it remains primarily carried out by hand [34]. Moreover, combined harvesters and reaper windrowers mounted on tractors are employed more frequently. For rice, wheat, and other oilseed crops, harvesting losses owing to delayed harvesting and the use of improper reaping technology have been reported to be between 15% and 20%. [36]. When rice is gathered using wheat combines, there is a substantial loss of grain and a low rate of rice recuperation. Additionally, this causes more grain to disintegrate throughout milling operations [37]

Meanwhile, Pakistan's wheat threshing is virtually entirely mechanized [8]. The majority of wheat threshing is done using stationary threshers that are operated by tractor PTO, engines or electric motors. Despite having a high throughput capacity, commercially available wheat threshers are expensive, inefficient in energy use, and risky in ergonomics [38]. Basmati rice is typically threshed manually, though head-feeding style threshers are occasionally employed. There are also entire crop threshers available for threshing coarse grain rice [37]. In the country, chickpeas are typically threshed using a wheat thresher with just minor modifications and by inserting a suitable size sieve. Nevertheless, the threshing process lessens the produce's total marketability [39].

In 2012, the reaper windrower's market share was only 66,000 [35], whereas today is 116,000. The main drivers of recent expansion have been concept emphasized and the advent of self-propelled type reapers and windrowers because of their affordability. Sales of thrashers in Pakistan are thought to be between 20,000 and 30,000 units each year, with practically all cereal crop threshing operations being mechanized [38]. By 2022, there will be 653,000 tractor-mounted stationary threshers, up from 353,000 in 2012. [3]. Over the past ten years, the number of combined harvesters increased slowly, from 29000 to 62000. Because of the expensive equipment cost and comparatively small farm size, which renders it costly for local small landowners, this delayed expansion is the result [40].

Wheat Straw Chopper:

Wheat is an essential food source for the people of Pakistan, serving as their primary staple food. In 2013, wheat cultivation covered an area of approximately 8.7 million hectares. The production of wheat contributes significantly to the overall value generated in the agricultural sector, accounting for 10.1 percent of the value added. Moreover, it contributes 2.2 percent to the Gross Domestic Product (GDP) of the country [35]. Different crop schemes, including cotton wheat, rice wheat, sugarcane wheat, maize wheat, and fallow wheat cotton wheat, are utilized for cultivating wheat. Rice-wheat and cotton-wheat systems make up around 60 percent of the overall wheat production in the country [41]. In Pakistan, the process of harvesting wheat starts in the southern regions as early as March and extends to the northern parts of the country until July concludes. Wheat crops are typically harvested when they have reached full maturity, and the moisture level of the grains ranges from 14 to 20 percent, according to [42]

The increasing acknowledgment of combine harvesters in Pakistan is primarily due to their ability to harvest wheat in a timely manner and replace traditional methods of harvesting and threshing. This recognition stems from the fact that early monsoon rains can lead to significant grain and chaff wastage, resulting in overall low crop yields and delaying the seeding of subsequent crops [43].

Limitations and Development Trends of Agricultural Machinery in Pakistan:

Limitations:

Farmland Limitations:

Soil Quality: The quality and fertility of soil play a crucial role in agricultural productivity. Some limitations include poor soil structure, low organic matter content, soil erosion, salinity, alkalinity, acidity, and nutrient deficiencies. These limitations can reduce crop yields and require management practices such as soil conservation, irrigation, and nutrient supplementation.

Water Availability: Adequate water supply is essential for agricultural activities, but water scarcity or limited access can severely constrain farming operations. Drought, water pollution, over-extraction, and inefficient irrigation practices can limit the availability of water for irrigation, impacting crop growth and yield potential.

Land Degradation: Unsustainable farming practices, deforestation, overgrazing, and improper land management can lead to land degradation. This includes soil erosion,

desertification, loss of topsoil, and salinization, reducing the productivity and viability of farmland.

Salinity And Waterlogging: Salinity and waterlogging directly impact crop growth and productivity. Excessive salts in the soil hinder nutrient uptake by plants, leading to stunted growth, reduced yields, and poor crop quality. Waterlogged conditions deprive plant roots of oxygen, causing root damage and impairing overall plant health. As a result, farmers face decreased agricultural productivity and economic losses.

Land Distribution: The distribution of farmland in Pakistan is uneven, with small fragmented holdings being prevalent. This fragmentation makes mechanization challenging, as small landholdings are not suitable for large-scale machinery.

Small Landholdings: Pakistan has a high percentage of small landholdings, which can limit the use of large-scale machinery. The size and layout of many farms may not be suitable for big tractors or advanced equipment, resulting in reduced efficiency and productivity. Irrigation Infrastructure: Despite having an extensive canal irrigation system, Pakistan still faces water scarcity issues, which affects agricultural productivity. Limited access to water resources restricts the cultivation of additional land.

Irrigation Efficiency: The efficiency of irrigation systems in Pakistan is relatively low, resulting in wastage of water and uneven distribution. The use of outdated irrigation techniques, such as flood irrigation, contributes to waterlogging, salinity, and inefficient water use. Improving irrigation efficiency through measures like drip irrigation and modernizing irrigation infrastructure can help address this limitation.

Urbanization: The process of rapid urbanization has led to the transformation of agricultural land into residential and commercial areas, causing a decrease in the amount of available farmland.

Farm power Limitations:

Electricity Shortages: Pakistan faces electricity shortages, which impact agricultural operations. Frequent power outages disrupt irrigation systems, affecting crop yields and hindering the use of electrical agricultural machinery.

Extended periods of power outages pose a major obstacle to agriculture, with the problem worsening over time. The Government of Pakistan (2011) reported that over 1,075,073 tubewells are utilized for irrigation purposes; unfortunately, their efficiency is severely hampered due to the acute electricity shortage. Although diesel can be employed as an alternative to power these tubewells, the elevated cost of diesel presents an additional challenge for farmers in the country. Furthermore, unanticipated power cuts can disrupt the timely planting of different crops.

Dependence on Diesel: In areas without reliable electricity supply, farmers often rely on diesel-powered generators to meet their energy needs. However, high fuel costs and limited availability make this an expensive and unreliable option.

Infrastructure Challenges: The agricultural sector in Pakistan faces infrastructural challenges, including inadequate road networks, limited access to electricity, and irregular water supply. These limitations can affect the efficient use and maintenance of machinery, particularly in rural areas.

Technical Limitations:

Lack of Mechanization: One of the major technical limitations in Pakistan's agriculture machinery sector is the low level of mechanization. The majority of farmers still rely on traditional farming methods and manual labor due to various factors such as limited access to machinery, high costs, and lack of awareness about the benefits of mechanization.

Outdated Technology: Another limitation is the use of outdated technology in agricultural machinery. Many farmers still use older models of tractors, harvesters, and other equipment, which may not be as efficient or productive as newer and more advanced models.

The lack of access to modern technology hampers productivity and efficiency in the agriculture sector.

Limited Adaptation to Local Needs: Some agriculture machinery available in the market may not be suitable for the specific needs and conditions of Pakistan's agriculture. The machinery developed for other regions or countries may not be adequately adapted to the local crops, soil types, and terrain, which can limit their effectiveness and performance.

Maintenance and Repair Challenges: Limited availability of skilled technicians and proper maintenance facilities pose a challenge for farmers. When machinery breaks down, farmers may struggle to find qualified repair services or access spare parts, resulting in downtime and reduced productivity.

Development Trends of Agriculture Machinery in Pakistan:

Increased Mechanization: The government of Pakistan, along with agricultural research institutions and private sector stakeholders, is promoting the adoption of mechanization in agriculture. There is a growing recognition of the benefits of mechanized farming, such as increased productivity, reduced labor costs, and improved efficiency. As a result, there is a trend towards increased mechanization in the agriculture sector.

Precision Agriculture Technologies: Precision agriculture technologies, such as GPS-based systems, remote sensing, and data analytics, are gaining traction in Pakistan. These technologies enable farmers to optimize the use of inputs such as fertilizers, pesticides, and water, resulting in improved resource efficiency and better crop yields. The integration of precision agriculture technologies with machinery is expected to enhance the effectiveness and accuracy of farming operations.

Customization for Local Needs: Efforts are being made to develop agriculture machinery specifically tailored to the needs and conditions of Pakistani farmers. This involves adapting machinery to local crops, soil types, and terrains, ensuring optimal performance and efficiency. Local manufacturers and research institutions are working towards developing customized solutions to address the unique requirements of the Pakistani agriculture sector.

Sustainable and Environmentally Friendly Machinery: There is a growing emphasis on sustainability and environmental conservation in the agriculture sector. As a result, the development of agriculture machinery with improved fuel efficiency, reduced emissions, and lower environmental impact is a significant trend. This includes the adoption of alternative fuels, such as biofuels, and the implementation of emission control technologies in machinery.

Integration of Digital Technologies: Digital technologies are being integrated into agriculture machinery to enable data-driven decision-making and enhance overall farm management. These technologies include sensors, Internet of Things (IoT) devices, and farm management software. Integration of digital technologies with machinery allows for real-time monitoring, predictive analytics, and automated control, improving efficiency and productivity.

It is important to note that these trends and developments are ongoing and may vary in their implementation and pace across different regions of Pakistan.The advancement of farm mechanization in Pakistan is contingent upon shifting from manual tools to implements pulled by animals, and eventually embracing mechanical power technologies. This transition has a substantial influence on the ability to mechanize and the duration of time needed for agricultural tasks. Pakistan offers a diverse range of domestically produced farm machinery, such as tractors, front-end loaders, wheat and maize threshers, and potato diggers. It is not uncommon to refurbish old, imported ginning and rice mills. The local production of hundreds of farm machines and implements has increased in recent years, with some even being exported. However, tracking the overall trend is challenging due to the lack of comprehensive data. The manufacturing sector has detailed records of tractor production, but there is limited official information available regarding the production of sugarcane machines, wheat thrashers,

and chaff cutters. Unfortunately, there is a significant lack of statistics concerning the production and sales of various agricultural machines such as multipurpose thrashers, potato diggers, soil levelers, pit diggers, tiller drills, water sprinklers, and others. It is believed that farmers have been making significant investments in mechanizing their farming activities due to the increased support prices for important crops in recent years. However, the absence of comprehensive data on a wide range of agricultural machinery makes it difficult to determine the exact extent of these investments.

The growth pattern of tractor, sugarcane machine, wheat thrasher, and chaff cutter production in Pakistan demonstrates a lack of consistency. In terms of horsepower usage per hectare, Pakistan lags behind countries like India, China, and Japan with a value of 1.50 compared to their respective values of 2.50, 3.88, and 7.0. Moreover, Pakistan experiences lower yields in key crops such as sugarcane (40% lower), wheat and cotton (20% lower), non-basmati rice (40% lower), and significantly lower milk yield per animal compared to global benchmarks (90% lower). In Pakistan, the agricultural sector experiences significant losses after harvest, which are much higher (ranging from 40% to 80%) compared to global standards. The country has around 500 small and medium-scale agricultural machinery units that produce farm implements and machines for various farming activities such as land development, seedbed preparation, planting, inter-cultivation, harvesting, threshing, spraying, and transportation. These units play a crucial role in meeting the demand for agricultural machinery in Pakistan. To support the local manufacturing industry of farm machinery and implements, incentives like zero sales tax have been provided. However, there is a need for standardization and improvement in the quality of locally manufactured farm machinery. Standardization is necessary to ensure the use of appropriate materials, interchangeable components, and facilitate easy repair and maintenance of the products. Unfortunately, the quality of locally produced farm machines is generally poor due to factors such as inadequate workshop layout, lack of managerial, engineering, and technical expertise, suboptimal designs, improper manufacturing techniques, limited availability of quality raw materials and components like gears and sprockets, insufficient finance and marketing skills, and manufacturers' lack of awareness about standards. Furthermore, the absence of standards in the local language (Urdu) and their enforcement poses additional challenges. Currently, advanced farming machinery like seed drills, planters, mechanical rice transplanters, and vertical conveyor reapers are primarily used by large-scale landlords and farmers, while small-scale farmers have limited access to such equipment.Recently, small farmers in Pakistan have shown a positive response to the adoption of modern agricultural machinery such as zero-till drills, raise bed planters, laser land levelers, and turbo happy seeders. This shift towards mechanization has also reached small and medium-scale farmers in the country, with financial support often coming from family members working abroad. The number of cultivators has significantly increased from 146,000 in 1984 to 369,000 in 2004. During the same period, the number of mould board ploughs was 40,000, while there were 29,000 disk ploughs and 70,000 ridgers. Additionally, there were 23,000 disk harrows and 242,000 trolleys in 2004. The number of tube wells also experienced significant growth, reaching 931,000 in 2004 compared to 454,000 in 1994.

Recommendations:

To address the challenges and unlock the full potential of agricultural mechanization in Pakistan, the following actionable recommendations are proposed:

Promotion of Mechanization Cooperatives: Establishing farmer cooperatives that allow smallholders to pool resources and share mechanized equipment. This approach can mitigate the constraints posed by small and fragmented land holdings, enabling economies of scale and reducing individual costs.

Subsidies and Financial Support: Introducng targeted subsidies and low-interest loan schemes to make mechanized equipment affordable for small and marginal farmers. Financial incentives should focus on machinery that aligns with local farming needs and conditions.

Research and Development (R&D): Investing in R&D to design and manufacture low-cost, efficient machinery tailored for small-scale and fragmented farms. Collaboration between local universities, research institutions, and the private sector can accelerate the development of appropriate technologies.

Training and Capacity Building: Organization of a regular training programs for farmers and machine operators to enhance their skills in operating and maintaining agricultural machinery. These programs should emphasize efficiency and proper usage to maximize output.

Strengthening Infrastructure: Improve rural infrastructure, including roads, to facilitate the transportation of machinery and access to markets. Establish service centers in rural areas for timely maintenance and repair of equipment.

Policy and Regulatory Support: Development of comprehensive policies to encourage Public-Private Partnerships (PPPs) in the manufacturing and distribution of farm machinery. Regulatory frameworks should ensure the quality and safety of imported and locally produced equipment.

Incentivizing Local Manufacturing: Providing incentives for local manufacturing industries to produce affordable and durable machinery. Tax exemptions and subsidies for raw materials and production processes can reduce costs and enhance accessibility.

Adoption of Precision Agriculture: Encouraging the integration of precision agriculture technologies, such as GPS-guided machinery and automated systems, to improve resource efficiency and reduce operational costs.

Improved Data Collection and Monitoring: Establishment of a centralized database to monitor the adoption and impact of mechanization efforts. Data-driven insights can guide future policy decisions and resource allocation.

Collaborative Regional Efforts: Learning from successful mechanization models in other developing countries like India and China. Collaborative efforts through regional forums can provide valuable insights and foster technology transfer.

Implementing these recommendations can significantly enhance the efficiency of Pakistan's agricultural sector, improve yields, and contribute to narrowing the rural-urban income gap while ensuring sustainable economic growth.

Conclusion:

By adopting new farm machinery and using it more frequently, the productivity gap can be filled. Furthermore, as a result of the industrial and housing colony revolution, cultivation waste is also growing, which results in an annual decrease in the amount of harvested farmland. Increasing the usage of equipment, such as drills, planters, tractors, harvesting equipment, and sprayers, is necessary to sustain crop output and meet food demands. There are numerous prospects in Pakistan to profit from this industry, but doing so requires the introduction of efficient government policies and approaches. Better usage of cutting-edge equipment for better manufacturing would ultimately strengthen the country's research institutions and enhance their effectiveness. The analysis of various surveys and research on farm mechanization in Pakistan consistently highlights the predominant focus on tractors. As a result, farm mechanization has been inaccurately equated with tractorization. This misconception has led to the widespread adoption of tractors by farmers, either through ownership or rental. However, the mechanization efforts in Pakistan have largely been limited to specific tasks that were previously performed manually by men or bullocks, prioritizing convenience and efficiency. In order to enhance productivity per unit of land, it is imperative to enforce the mandatory utilization of tractors in conjunction with appropriate farm equipment.

Authors' Contribution:

Research idea was Conceptualized by Z.M, S.K, A.A.T, literature reviewed by Z.M, S.K.D, the relevant information was synthesized by Z.M and A.A.T. The initial draft was prepared by Z.M, S.K.D and A.A.T. The proofread by Z.Y.

Conflict of interest: The authors declare no conflict of interest.

References:

[1] P. G. Hiroyuki Konuma, "FAO statistical year book 2014. Regional office for Asia and the Pacific, Bangkok.," *Food Agric. Organ.*, pp. 1–195, 2014, [Online]. Available: https://openknowledge.fao.org/server/api/core/bitstreams/15d5b8c6-8162-41e4-bd69-54f5124c9868/content

[2] Mumtaz Ali Baloch and G. B. Thapa, "Review of the agricultural extension modes and services with the focus to Balochistan, Pakistan," *J. Saudi Soc. Agric. Sci.*, vol. 18, no. 2, pp. 188–194, 2019, doi: https://doi.org/10.1016/j.jssas.2017.05.001.

[3] G. of P. (GOP), "Economic survey of Pakistan 2021-2022," *Financ. Div. Econ. Advis. Wing, Islam.*, 2022, [Online]. Available: https://www.finance.gov.pk/survey_2022.html

[4] H. C. J. Godfray *et al.*, "Food security: The challenge of feeding 9 billion people," *Science (80-.).*, vol. 327, no. 5967, pp. 812–818, Feb. 2010, doi: 10.1126/SCIENCE.1185383.

[5] M. Y. Yamin Muhammad, Abdul Nasir Awan, "Studying the impact of farm mechanization on wheat production in Punjab-Pakistan," Soil and Environment. Accessed: Dec. 22, 2024. [Online]. Available: https://www.researchgate.net/publication/260083175_Studying_the_impact_of_farm_mechanization_on_wheat_production_in_Punjab-Pakistan

[6] M Ghaffar Chaudhary , "Mechanization and agricultural development in Pakistan," *Pak. Dev. Rev.*, vol. 25, no. 4, pp. 431–449, 1986, [Online]. Available: https://file.pide.org.pk/pdf/PDR/1986/Volume4/431-449.pdf

[7] U. Yamin, A. R. Tahir, A. Nasir, and M. Yaseen, "Short communication: studying the impact of farm mechanization on wheat production in Punjab-Pakistan.," *Soil Environ.*, 2011.

[8] A. Tahir and A. Mohamed, "Probing Agricultural Engineering Education in Pakistan a Changing World," *Educ. Pract. Innov.*, vol. 2, no. 1, pp. 21–28, Mar. 2015, doi: 10.15764/EPI.2015.01003.

[9] M. S. Z., Ahmad I., S. Hussain, and Syed Akhtar Hussain Shah "Why the green revolution was short run phenomena in the development process of Pakistan: A lesson for future," *J. Rural Dev. Adm.*, 2004, [Online]. Available: https://www.researchgate.net/publication/316897179_Why_The_Green_Revolution_Was_Short_Run_Phenomena_In_The_Development_Process_Of_Pakistan_A_Lesson_For_Future

[10] G. Singh, "Estimation of a Mechanisation Index and Its Impact on Production and Economic Factors—a Case Study in India," *Biosyst. Eng.*, vol. 93, no. 1, pp. 99–106, Jan. 2006, doi: 10.1016/J.BIOSYSTEMSENG.2005.08.003.

[11] M. Ali, Y. Geng, D. Robins, D. Cooper, and W. Roberts, "Impact assessment of energy utilization in agriculture for India and Pakistan," *Sci. Total Environ.*, vol. 648, pp. 1520–1526, Jan. 2019, doi: 10.1016/J.SCITOTENV.2018.08.265.

[12] S. A. Iqbal Muhammad Aamir, Asif Iqbal, Nadeem Akbar, "In Pakistan, Agricultural Mechanization Status and Future Prospects." Accessed: Dec. 22, 2024. [Online]. Available: https://www.researchgate.net/publication/278019970_In_Pakistan_Agricultural_Mechanization_Status_and_Future_Prospects

[13] I. Khan *et al.*, "PROBLEMS OF AGRICULTURE IN PAKISTAN: AN INSIGHT INTO THEIR SOLUTION," *Pakistan J. Biotechnol.*, vol. 19, no. 02, pp. 73–83, Dec.

2022, doi: 10.34016/PJBT.2022.19.2.73.

[14] S. K. Tanveer, . I. H., . M. S., . N. S. K., and . S. G. A., "Effects of Different Planting Methods on Yield and Yield Components of Wheat," *Asian J. Plant Sci.*, vol. 2, no. 10, pp. 811–813, May 2003, doi: 10.3923/AJPS.2003.811.813.

[15] I. H. Abbas G., M. Ali, and M. Azam, "Impact of planting methods on wheat grain yield and yield contributing parameters," *Int. Symp. Collab. Technol. Syst. CTS 2009*, vol. 19, no. 1, pp. 30–33, 2009, [Online]. Available: https://www.researchgate.net/publication/286530236_Impact_of_planting_methods_on_wheat_grain_yield_and_yield_contributing_parameters

[16] K. A. H. Muhammad Iqbal, Anjum Munir, Manzoor Ahmad, "Evaluation of Energy Efficient Zone Disk Drill for Sowing Wheat after Harvesting Paddy Crop," International Journal of Agriculture and Biology. Accessed: Dec. 22, 2024. [Online]. Available:https://www.researchgate.net/publication/290569430_Evaluation_of_Energy_Efficient_Zone_Disk_Drill_for_Sowing_Wheat_after_Harvesting_Paddy_Crop

[17] W. A. Nadeem Akmal, Abid Hussain, Muhammad Yousuf, "Exploring potential of mechanical transplanting of rice in Punjab, Pakistan," *Pakistan J. Agric. Res.*, vol. 36, no. 2, pp. 169–182, 2023, doi: 10.17582/journal.pjar/2023/36.2.169.182.

[18] S. A. Mahmood Riaz, Muhammad Khalid, Muhammad Nouman Ashraf, "Study on Sustainable Mechanized Farming of Vegetables in Pakistan," *6th Int. Conf. Energy, Environ. Sustain. Dev. 2022*, 2022.

[19] F. E. Nasir, M. S. Alam, M. Tufail, and M. T. Khan, "A Novel Pressure and Flow Control Technique for Variable-Rate Precision Agricultural Sprayer," *2021 Int. Conf. Robot. Autom. Ind. ICRAI 2021*, 2021, doi: 10.1109/ICRAI54018.2021.9651446.

[20] A. K. Rasyidah Tahir, Faizan-Ul-Haq Khan, "Effect of Constant Flow Valves on Performance of Pesticide Sprayers | Request PDF," International Journal of Agriculture and Biology. Accessed: Dec. 22, 2024. [Online]. Available: https://www.researchgate.net/publication/354676668_Effect_of_Constant_Flow_Valves_on_Performance_of_Pesticide_Sprayers

[21] M. A., Safdar M. E., M. Asif, A. Ali, A. Aziz, and M. Yasin, "Comparative efficacy of different weed management strategies in wheat," *Chil. J. Agric. Res.*, vol. 71, no. 2, 2011, doi: http://dx.doi.org/10.4067/S0718-58392011000200003.

[22] R. Tanzeel, M. U. Khan, M. Tayyab, M. W. Akram, and M. Faheem, "Current status and overview of farm mechanization in Pakistan – A review," *Agric. Eng. Int. CIGR J.*, vol. 18, no. 2, pp. 83–93, 2016.

[23] M. Y., Ashraf M., M.S. Sabir, and M. Ahmed, "Effects of different tillage systems on bulk density and sugarcane yield," *Pakistan J. Life Soc. Sci.*, vol. 1, no. 1, pp. 69–71, 2003, [Online]. Available: https://pjlss.edu.pk/pdf_files/2003_1/69-71.pdf

[24] M. Iqbal, Anwar-ul-Hassan, and M. Ibrahim, "Effects of Tillage Systems and Mulch on Soil Physical Quality Parameters and Maize (Zea mays L.) Yield in Semi-Arid Pakistan," *Biol. Agric. Hortic.*, vol. 25, no. 4, pp. 311–325, 2008, doi: 10.1080/01448765.2008.9755058.

[25] K. J. Fiaz Ahmad,Ding Weimin ,Ding Qishuo,Mubshar Hussain, "Forces and Straw Cutting Performance of Double Disc Furrow Opener in No-Till Paddy Soil," *PLoS One*, 2015, doi: https://doi.org/10.1371/journal.pone.0119648.

[26] A. N. Muhammad Amjed Iqbal, Azhar Abbas, Syed Asif, "Drivers of Farm Households' Perceived Risk Sources and Factors Affecting Uptake of Mitigation Strategies in Punjab Pakistan: Implications for Sustainable Agriculture," *Sustainability*, vol. 12, no. 23, p. 9895, 2020, doi: 10.3390/su12239895.

[27] M. A. Munir, M. Iqbal, and S. Miran, "EVALUATION OF THREE SEED FURROW OPENERS MOUNTED ON A ZONE DISK TILLER DRILL FOR RESIDUE

MANAGEMENT, SOIL PHYSICAL PROPERTIES AND CROP PARAMETERS," *Pakistan J. Agric. Sci.*, 2012.

[28] A. A. Younis, M., M. Sabir, and M. Iqbal, "Comparative performance of zone till sowing, slot planting and conventional sowing technique of wheat in rice-vacated fields," *J. Agric. Res.*, vol. 44, no. 1, pp. 59–70, 2006.

[29] S. I. A. and A. M. Farooq, M., "Developments in mechanical planting of sugarcane," *Agric. Mech. Asia, Africa Lat. Am.*, vol. 23, no. 1, pp. 28–32, 1992.

[30] R. C. Singh, G. Singh, and D. C. Saraswat, "Optimisation of Design and Operational Parameters of a Pneumatic Seed Metering Device for Planting Cottonseeds," *Biosyst. Eng.*, vol. 92, no. 4, pp. 429–438, Dec. 2005, doi: 10.1016/J.BIOSYSTEMSENG.2005.07.002.

[31] G. Kinsman, "The history of the lowbush blueberry industry in Nova Scotia 1950-1990.," *Semant. Sch.*, 1993, [Online]. Available: https://www.semanticscholar.org/paper/The-history-of-the-lowbush-blueberry-industry-in-Kinsman/c6327fad21208b7fb9ab7d2850b052a2b174bad6

[32] P. C. H. Miller and M. C. Butler Ellis, "Effects of formulation on spray nozzle performance for applications from ground-based boom sprayers," *Crop Prot.*, vol. 19, no. 8–10, pp. 609–615, Sep. 2000, doi: 10.1016/S0261-2194(00)00080-6.

[33] "Performance evaluation of modified self-leveling boom sprayer for cotton | Request PDF." Accessed: Dec. 19, 2024. [Online]. Available: https://www.researchgate.net/publication/354676423_Performance_evaluation_of_modified_self-leveling_boom_sprayer_for_cotton

[34] A. R. Tahir, H. Khan, and K. Ejaz, "Techno-Economic Feasibility of Combine Harvester (Class Denominator) - A Case Study," 2003.

[35] G. of Pakistan, "Economic survey of Pakistan 2014-2015," *Financ. Div. Econ. Advis. Wing, Islam.*, 2015, [Online]. Available: https://www.finance.gov.pk/survey/chapters_15/highlights.pdf

[36] L. K. Sattar, Muhammad Mueen-u-Din Ali, Mushtaq Ali, Liaqat Waqar, Masood Qadir Ali, Muhammad Anjum, "Grain Losses of Wheat as Affected by Different Harvesting and Threshing Techniques," *Int. J. Res. Agric. For.*, vol. 2, no. 6, pp. 20–26, 2015, [Online]. Available: https://www.ijraf.org/pdf/v2-i6/4.pdf

[37] A. D. Sheikh, T. Rehman, and C. M. Yates, "Logit models for identifying the factors that influence the uptake of new 'no-tillage' technologies by farmers in the rice–wheat and the cotton–wheat farming systems of Pakistan's Punjab," *Agric. Syst.*, vol. 75, no. 1, pp. 79–95, Jan. 2003, doi: 10.1016/S0308-521X(02)00014-8.

[38] Ahmad S. A., M. Iqbal, M. Ahmad, and A. Tanveer, "Design improvement of indigenous beater wheat thresher in Pakistan," *Pakistan J. Agric. Sci.*, vol. 50, no. 4, pp. 711–721, 2013, [Online]. Available: https://www.researchgate.net/publication/287613731_Design_improvement_of_indigenous_beater_wheat_thresher_in_Pakistan

[39] Peksen E., T. Koyuncu, C. Artık, and A. Sessiz, "Seed Viability and Yield of Chickpea (Cicer arietinum) Cultivars Threshed by Different Types of Beaters and Concaves," International Journal of Agriculture and Biology. Accessed: Dec. 22, 2024. [Online]. Available:https://www.researchgate.net/publication/236742452_Seed_Viability_and_Yield_of_Chickpea_Cicer_arietinum_Cultivars_Threshed_by_Different_Types_of_Beaters_and_Concaves

[40] L. L. Yang L, W. Wang, H. Zhang, "Improved design and bench test based on tangential flow-transverse axial flow maize threshing system," *Nongye Gongcheng Xuebao/Transactions Chinese Soc. Agric. Eng.*, vol. 34, no. 1, pp. 35–43, 2018, doi: 10.11975/j.issn.1002-6819.2018.01.006.

[41] O. E., Farooq Umar, and Muhammad Sharif, "Adoption and impacts of zero-tillage in the rice-wheat zone of irrigated Punjab, Pakistan," 2007, [Online]. Available: https://repository.cimmyt.org/entities/publication/96665518-029c-4967-80e5-3aff749a8588

[42] Pioneer, "Wheat Harvest Tips | Pioneer Seeds," DuPont Pioneer Agronomy Sciences. Accessed: Dec. 22, 2024. [Online]. Available: https://www.pioneer.com/us/agronomy/harvest-tips-wheat.html

[43] R. . Mahajan, A., Gupta, "The Rice–Wheat Cropping System," *Integr. Nutr. Manag. a Sustain. Rice—Wheat Crop. Syst.*, pp. 109–117, 2009, doi: 10.1007/978-1-4020-9875-8_7.