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Agricultural mechanization policy options in Rwanda

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CONTENTS

The International Food Policy Research Institute (IFPRI), a CGIAR Research Center established in 1975, provides research-based policy solutions to sustainably reduce poverty and end hunger and malnutrition. IFPRI's strategic research aims to foster a climate-resilient and sustainable food supply; promote healthy diets and nutrition for all; build inclusive and efficient markets, trade systems, and food industries; transform agricultural and rural economies; and strengthen institutions and governance. Gender is integrated in all the Institute's work. Partnerships, communications, capacity strengthening, and data and knowledge management are essential components to translate IFPRI's research from action to impact. The Institute's regional and country programs play a critical role in responding to demand for food policy research and in delivering holistic support for country-led development. IFPRI collaborates with partners around the world

1.ABSTRACT

This paper summarizes general demand- and supply-side issues for agricultural mechanization based on recent studies that focus on experiences and evidence from both Africa and Asia. The paper provides typologies of agricultural mechanization in Rwanda along with policy options within the context of its current mechanization support strategies.

Provincial variations in agroecology and cropping systems, irrigated/rainfed systems, farm size, and labor use intensity, among other factors, characterize the key types of mechanization use in Rwanda. Support for mechanization in Rwanda can be broadly tailored to (a) irrigated medium-scale farmers in the Eastern province and Kigali; (b) rainfed medium-scale farmers in the Eastern and Southern provinces; (c) rainfed, small-scale highland farmers in the Northern province; and (d) irrigated small-scale farmers in the Western province.

Recent experiences in other countries with rugged terrain and smallholder farming systems similar to Rwanda suggest that significant growth in the use of tractors is possible in the medium term among smallholders cultivating rainfed maize and legumes, in addition to irrigated rice. However, farm wages may still be too low in Rwanda and tractor-hiring fees may still be too high to induce a shift to mechanization in the short term. Therefore, it may be advisable for policy support for mechanization to focus on improving the understanding of mechanization needs among each type of farmers identified, knowledge of suitable machines, and required skills for their operations and maintenance. Such efforts should also balance the need to develop competitive markets and supply networks for promising machines, parts, and repair services at a viable and integrated market scale.

1.1 Background

Agricultural mechanization can raise labor productivity, reduce production costs, and bring economies of scale to agricultural production. Policy interest in mechanization for the purposes of food and nutrition security has been growing across many low- and middle-income countries, including Rwanda. The African Union's Agenda 2063 commits countries to banishment of the hand hoe by 2025 as part of the larger goal of achieving overall productivity and food security improvements through a modern and environmentally sustainable agriculture sector (FAO & AUC 2018).

Demand for agricultural mechanization depends, among other factors, on the overall returns to farm power use (either manual, animal, or machine power) and the rate of substitutability among labor, animal, or machine power. Broadly, from a farming systems perspective, much of Rwanda has reached a point where fallow practices are rare and most farmland is prepared every year, both of which are important preconditions for an increase in demand for more intensive farm power use (Diao et al. 2020).

However, identifying policy options for agricultural mechanization is complicated. Apart from these basic issues of power and substitutability, demand for mechanization is often influenced by the type of production or farming systems. There is also the challenge of machinery design and purpose: machines come in many different designs and specifications and can be used for a range of purposes from very general (e.g., tractors) to highly specific (e.g., mechanical rice transplanters). Many machines and their associated equipment are also skill-intensive, i.e., they require the acquisition of new skills in operation and maintenance by the user (Douthwaite et al. 2001). These skill requirements often affect the returns from their use.

This research paper assesses patterns of agricultural mechanization in Rwanda, identifies key types of mechanized farm households, and discusses possible policy options for each type within the framework of the Government of Rwanda's national strategy for agricultural and economic transformation. Emphasis is placed on the use of tractors for land preparation, primarily because the tractor is historically considered one of the most important mechanical innovations in agriculture (e.g., Hayami & Ruttan 1970), and because experience with tractors may offer helpful lessons for other machines. Emphasis is also placed on developing a typology for mechanization in Rwanda and the policy interventions that address inherent market and information failures that influence the mechanization process.

2. AGRICULTURAL MECHANIZATION IN RWANDA

2.1 Current policy landscape for mechanization In Rwanda

The Strategic Plan for Agriculture Transformation 2018-24 (PSTA4) (MINAGRI 2018) is the current policy and strategy in the agricultural sector in Rwanda. The agricultural mechanization strategies in PSTA4 build on the Agricultural Mechanization Strategy in 2013 (Government of Rwanda 2013), the Strategic Plan for agriculture transformation 2013-2017 (PSTA3) (MINAGRI 2013), and the National Strategy for Transformation 2017 – 2024 (NST1) (NIRDA 2017).

The PSTA3 highlighted the concerns regarding relatively low levels of domestic mechanization and manufacturing of the required tools deficiency of actors engaged in leasing farm machinery to farmers and co-operatives. Based on these concerns, the PSTA3 aimed to promote various interventions, such as assessing and developing mechanization options, facilitating investment and financing for mechanization, incorporating mechanization in irrigation schemes, and facilitating training on mechanization. Under these policy and strategy frameworks, the Rwandan government has provided various support to promote agricultural mechanization, including establishing power tiller centers and village mechanization service centers (Malabo Montpellier Panel 2018) in recent years.

PSTA4 maintained such approaches and established updated policies regarding the improvement and development of farm operations mechanization. Notably, these include (i) improving access to credit on good terms for private investors in machines; (ii) promoting high-tech equipment through temporary subsidies; (iii) setting up more mechanization service centers; (iv) establishing the Productivity Window under the Agricultural Development Fund to promote mechanization and incentivize private sector and stakeholders to invest in mechanization; (v) expanding demonstration centers for dissemination of adapted technologies.

2.2 Typology of agricultural mechanization in Rwanda

We assess current agricultural mechanization patterns in Rwanda using microdata from the latest publicly available datasets. These include the Integrated Household Living Conditions Survey 2016/17 (EICV 5), the Agricultural Household Surveys (AHS) from both 2017 and 2020, and the Seasonal Agricultural Surveys (SAS) from 2019 to 2022. These datasets all originate from the National Institute of Statistics of Rwanda (NISR).

Overall mechanization adoption levels in Rwanda

The adoption of major mechanical equipment such as tractors has yet to take off substantially in Rwanda. 2022 SAS data indicates that about 0.8 percent of plots in Rwanda were plowed by tractors in the 2022 season (Table 1). In terms of area, mechanized plots accounted for 10 percent of all farm areas, indicating that larger plots tend to be more mechanized. Table 1 also suggests that, among plots smaller than 1 ha—which accounts for 93 percent of all plots in the SAS data— just 0.1 percent of plots (0.3 percent of all plot area) were plowed by tractor. While these tractor-plowed plots account for 7.4 percent of farm area, they account for 0.3 percent of the area plowed by tractors. Even among plots 1-10 ha in size, tractors are used for plowing on only 8.0 percent of plots. A majority (90 percent) of the area plowed by tractors are those 10 ha or larger. This suggests that the use of tractors for plowing remains quite rare on plots, particularly on smallholder-operated plots under 1 ha.

Table 1. Farm size distribution and mechanization use in Rwanda in 2022

Plot size	Share among each size range of plots (%)		Share among total farms (%)		
(ha)	Share of plots mechanized	Share of plot areas mechanized	Share of total plots	Share of total farm area	Share of mechanized area
Less than 1ha	0.1	0.3	92.8	7.4	0.3
1ha or greater but smaller than 10ha	8.0	9.9	5.3	10.3	10.3
10ha or above	14.5	10.9	1.9	82.3	89.5
Total	0.8	10.0	100.0	100.0	100.0

Note: Totals may not sum to 100 due to rounding
Source: Authors' estimation based on 2022 Seasonal Agricultural Survey data from NISR (2022).

Cereal crops and legume crops that are viable in medium- to large-scale farming tend to be mechanized first in Rwanda. 2022 SAS data indicates that maize, rice, soybeans, and bush beans account for about 62 percent of mechanized plots and 90 percent of mechanized areas and are primarily mechanized through tractor use (Table 2). Potatoes account for another 4 percent of mechanized plots and 1 percent of mechanized areas, while vegetables account for an additional 7 percent of mechanized plots and 1 percent of mechanized areas. The typical size of mechanized plots varies considerably across crops. Mechanized maize and rice plots are generally larger (averaging about 30 and 150 ha, respectively), while those of vegetables are much smaller (averaging just 3 ha).

Table 2. Crops shares among mechanized plots in Rwanda in 2022

Crops	Percent of plots mechanized	Percent of plot area mechanized	Average size (ha) of mechanized plot
Maize	38.1	58.0	29.0
Maize (excluding maize for fodder)	34.3	56.5	31.4
Rice	3.0	24.3	153.7
Soybean	9.8	4.3	8.3

Bush beans	11.3	3.7	6.3
Total (maize, rice, soy-bean, bush beans)	**62.2**	**90.3**	**27.7**
Vegetables	7.2	1.3	3.4
Potato	3.8	1.0	5.1
Others	18.5	7.4	7.6
Total	**100.0**	**100.0**	**19.1**

Source: Authors' estimation based on SAS (2022).

2.3 Mechanization by farm household in Rwanda

Demand for mechanization can vary considerably depending on the farming system. For example, mechanized land preparation is sometimes adopted first for large field crops (cereals such as rice, maize, and wheat) compared to other field crops (e.g., sorghum or millet), pulses, root crops (cassava, sweet potato, or potato), tree crops (e.g., plantains/bananas) or vegetables (Takeshima et al., 2013). Similarly, mechanization is sometimes adopted first in areas with lower levels of terrain ruggedness. Examples include large wheat-growing zones in Ethiopia, or lowland areas of Ghana and Nepal (Berhane et al. 2020; Takeshima & Liu 2020).

Prior studies suggest that mechanization can play a role in increasing the quality of livestock products (milk and meat) by reducing the level of draft work required by livestock (Lawrence & Pearson 2002). Other studies suggest that apart from substituting for animal traction, mechanization can follow a sequential process, starting from basic land preparation to more control-intensive operations like planting, weeding, or harvesting (Diao et al. 2020).

By drawing on these and other studies, and considering Rwanda's diverse agroecological conditions and farming systems, we conduct a typology analysis of mechanized farm households in Rwanda to better characterize current use. (See the Appendix for details of the methodology and results.) The current use of mechanization—specifically proxied by the use of tractors—can be characterized into one of four categories, as follows.

Type A: Irrigated medium-scale farmers in Eastern province

Type B: Rainfed medium-scale farmers in Eastern province

Type C: Rainfed, highland small-scale farmers in Northern province

Type D: Irrigated small-scale farmers in Western province

Mechanized farms are distributed relatively equally across these four categories, although a somewhat higher share (32 percent) is found in Type A and a lower share (18 percent) in Type C. Mechanization use characteristics vary distinctively across provinces, as well as across irrigation status and farm size.

In Type A, mechanization is likely to be used in labor-intensive irrigated rice and other production systems as a substitute for manual labor. This pattern is also found in other African countries such as Nigeria (Takeshima et al. 2013).

In Type B, mechanization is likely to be used because economies of scale in mechanization are more significant than manual power.

Type C is characterized by households with heads that are younger than the average, more educated, and implicitly, possibly more willing to experiment with modern technologies and practices. However, this type is of relative minority (accounting for 18 percent of mechanized farm households).

Similarly, in Type D which is mostly found in the Western province, mechanization is likely to be used in an irrigated system that is relatively intensive and, to substitute for manual labor used for land preparation, which has become more expensive than in other types.

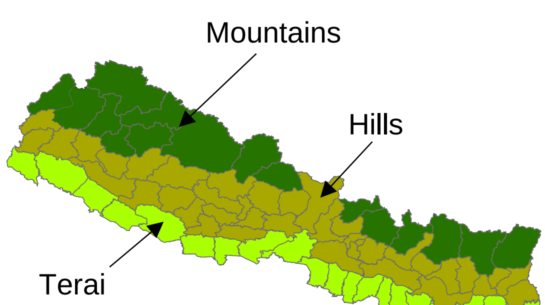
3. ECONOMIC POTENTIAL OF AGRICULTURAL MECHANIZATION AND IRRIGATION FOR SMALL HOLDER FARMERS IN RWANDA

The typology assessment provided in the previous section suggests that while mechanization is clearly growing among medium- to larger-scale farmers, a significant share of mechanization is also found among small-scale farmers in the hilly and mountainous parts of Rwanda. Historically and globally, smallholders in hilly and mountainous regions have experienced a slower rate of agricultural development and transformation when compared to lowland, and especially irrigated, regions. Nonetheless, some smallholders in hilly/mountainous areas of low- and middle-income countries, including those in Asia, have experienced meaningful growth in the use of machinery and equipment such as tractors and irrigation pumps. In this section, we briefly review recent experiences with smallholder mechanization growth in hill/mountain zones of Nepal, which share many similarities with Rwanda.

3.1 The hill/mountain zones of Nepal

The hill/mountain zones Nepal straddle the central and the northern parts of the country (Figure 1). Unlike the Terai zone, which is mainly a lowland region, the hill/mountain zones of Nepal share several instructive characteristics with Rwanda (Table 3). The average landholding size in the hill/mountain zones of Nepal has continued to decline and is likely to drop below 0.5 ha by 2021—a landholding size immediately comparable to Rwanda. The terrain ruggedness index suggests that these zones in Nepal are even more challenging than in Rwanda. More than 60 percent of workers in Nepal are employed primarily in the agricultural sector, with a similar share found in the hill/mountain zones. This too is comparable to Rwanda, where the share is around 55 percent. In 2001 and 2011, 1.1 percent and 3.8 percent of farms under 1 ha in hill/mountain zones were prepared by tractors, respectively (Central Bureau of Statistics Nepal 2011). Recent figures on mechanization in Nepal are likely to be even higher than these figures.

Figure 1. Agroecological belts in Nepal



Source: Takeshima & Justice (2022).

Table 3. Contrasting characteristics of Nepal and Rwanda

Categories	Rwanda	Nepal (Hills / mountains)	Nepal	Sources
Average land holding size (ha)	0.45	0.48	0.54	Rwanda – AHS Survey (2020) Nepal – Agr. Census (2021)
Terrain Ruggedness Index	3.31	6.28	5.04	Riley et al., (1999)
Percent employment share of agricultural sector (2021)	55	62	62	WDI

Source: Various sources as indicated.

3.2 Use of tractors and irrigation pumps in hill/mountain zones of Nepal

During the last two decades (since about 2001), the hill/mountain zones of Nepal have seen significant growth in the number of farm households using tractors (either four-wheel tractors (4wt) or two-wheel tractors (2wt)[1]) and irrigation pumps (Table 4). The number (share) of farm households using 4wt and 2wt has increased from around 10,000 (less than 1 percent) each in 2001 to about 30,000-40,000 (2 percent) each in 2011 and almost 270,000 (13 percent) each by 2021.

Similarly, the number of farm holdings[2] using tractors smaller than 2wt called mini-tillers[3] increased substantially from around 500 in 2011 to 40,000 (4 percent) in 2021, while those using irrigation pumps also grew considerably.[4] The adoption rates of about 2 percent reached by 2011 are still low but meaningfully higher than 0.1 percent (among plots less than 1 ha) in Rwanda in 2022 (Table 1). Most users of 4wts and 2wts use them through custom-hired (i.e., rental) services, consistent with the experiences elsewhere. Custom-hired services are the major source of access to these machines for smallholders

[1] Two-wheeled tractors here refer to power tillers, and distinguished from "mini-tillers" described below.

[2] The term "farm holdings" is used in the Nepal Agricultural Census, which we assume includes both farm households and other types of farming entities including farm enterprises.

[3] Justice et al., (2023) and Paudel et al., (2019) provide concise descriptions of mini-tillers in mid-hills. The common types of mini-tillers spreading in the region are in the 5–9 horsepower (HP) range. Tillage is performed by switching the tires with cultivator blades. The engine can also be used as a stationary source of power. Lately, mini tillers have also been increasingly used by women. The lighter weight of the mini tillers makes them more maneuverable on narrow terraces and dramatically reduces the risks of losing control of the machine in steep terrains. The heavier 2WTs need ramps and two to three people to move them between terraces, whereas the mini tillers can be lifted by two people or driven to the next terrace. Prices ranged from USD 350 for petrol to USD 800 for larger HP diesel models. Given that many originate from China, these prices may be higher when brought into Africa, but with sufficient demand, the adoptions can still grow (for example, the use of motorcycles and tricycles has grown considerably in rural Africa, including Rwanda).

[4] The common type of irrigation in the hill/mountain zones in Nepal is gravity-fed irrigation drawn from surface sources (rivers/lakes/ponds). These irrigation systems were used by about 35 percent of farm households in 2021, while irrigation pumps were used by 20 percent of these households (Nepal Agricultural Census 2021).

(for each owner of 2wts, there are about 6-7 farmers using 2wts via custom-hiring, while for each owner of 4wts, there are about 100 farmers using 4wts via custom-hiring).

Table 4. Growth of tractors and irrigation pumps in hill/mountain zones of Nepal (2001-2021, excluding Terai zone)

Categories	Types of machines	2001	2011	2021
Share (%) of farm holdings using machines	4WT (%)	0	2	13
	2WT (%)	0	2	13
	Mini-tillers (%)	0	1	4
	Water pumps (%)	0	2	7
Number of farm holdings using machines	4WT	11,000	29,811	269,133
	2WT	10,000	40,533	267,648
	Mini-tillers	0	500	40,000
	Water pumps	12,000	25,000	157,363
Number of machines	4WT	1,000	1,163	4,005
	2WT	600	10,000	78,278
	Mini-tillers	0	500	40,000
	Water pumps	12,000	25,000	72,813

Source: Authors' compilations from Nepal Agricultural Census 2001, 2011 and 2021, and Justice et al., (2023). Water pumps include electric diesel-petrol pumps. 4WT = Four-wheel tractors; 2WT = two-wheel tractors.

A majority of tractors, both 4wts as well as irrigation pumps found in the hill/mountain zone of Nepal in recent decades originated from the neighboring lowland (Terai) zone as well as northern India, while a majority of 2wts originated mostly from China. The use of these machines had grown substantially in both the Terai and northern India starting in the mid-1990s (Takeshima 2017; Takeshima & Justice 2020). Their introduction into the hill/mountain zone of Nepal has been supplemented by Government programs, research projects, and the NGO sectors, all of which invested in the demonstration and training of machine uses among smallholders. In contrast to this experience, 2wts in the hill/mountain zones of Nepal originated mainly from the mountainous regions of neighboring China, where their use expanded significantly during recent decades (Takeshima & Justice 2020). Many of these 2wts were initially brought into Nepal in the 2000s by private sector actors on their own initiatives to assess 2wts' market potential (Justice et al., 2023).

For Rwanda, neighboring Tanzania may offer a viable source of tractors (both 4wts and 2wts), given the recent growth in their use and supply networks (Mrema et al. 2020). Studies suggest considerable growth in Tanzania's mechanization market: the number of power tillers in Tanzania had grown to 6,000 by 2014 (Baudron et al. 2015), while the number of motor pumps had grown to 70,000 by 2012 (Giordano et al. 2012), and subsequent studies and statistics suggest continued growth.

The experiences in Nepal also indicate that smallholders have been among the major adopters of tractors and pumps. In the hill/mountain zones in Nepal, medium size of cultivated areas among 4wt-, 2wt- and irrigation pump-using farmers were 0.34, 0.24, and 0.39 ha, respectively, in 2010 (Table 5). Notably, close to 50 percent of farmers using 4wts or 2wts also grow maize under rainfed conditions, and 35 percent of farmers using 4wts also grow pulses/legumes under rainfed conditions (Table 5). Unfortunately, the available data do not allow us to identify whether the tractors were actually used for these specific crops. Nonetheless, given that 4wts are often used for both lowland and upland crops (Pingali 2007), the patterns in the hill/mountain zones of Nepal suggest the transferability to Rwandan contexts dominated by the production of rainfed maize and rainfed beans. For other major crops like rice and potato, irrigation is more widely applied among farmers using 4wts- and 2wts in Nepal, and thus may not be widely applicable to Rwanda.

Table 5. Farm size and main crops grown by mechanized farmers in hill/mountain zones in Nepal

Types of farmers using:	Total cultivated area (ha)	Growing rice (%)		Growing maize (%)		Growing pulses / legumes (%)		Growing potato (%)	
		irrigated	rainfed	irrigated	rainfed	irrigated	rainfed	irrigated	rainfed
4-wheel tractors	0.34	67	9	42	46	23	35	35	11
2-wheel tractors	0.24	68	23	24	44	17	20	48	11
Irrigation pumps	0.39	69	15	32	47	25	25	48	18

Source: Authors' compilations based on Nepal Agricultural Census 2011.

Despite the medium-term growth potential for mechanization among smallholders in Rwanda, economic conditions may still be less conducive to mechanization adoption because of relative costs and wages. In general, we expect the marginal cost of hiring a tractor to be less than or equal to the marginal cost of wages for the same quantity of performance (e.g., hectares tilled) before a farmer shifts from manual labor to tractor use. At present, the cost of hiring a tractor relative to the cost of wages in Rwanda is not yet at that point, whereas Nepal had probably reached that point in the hill/mountain zone by about 2010 (Table). At that point in time, farm wages in Nepal had reached USD 2.86/day (equivalent to about 11.6 kg of maize/day), while tractor hiring fees had declined to 41 USD/ha (about 178 kg of maize/ha).[5] In Rwanda as of 2020-2022, real farm wages were still considerably lower at USD 0.83/day (equivalent to 3.5kg of maize/day), while tractor hiring fees were higher at USD 66/ha (about 300kg of maize/ha).

[5] We use value per day for wage, and value per hectare for tractor hiring fees, because these are common units used in both Nepal and Rwanda. We keep these units since our focus here is more on comparison between Nepal and Rwanda, rather than the direct comparison of labor costs and machine hiring costs.

Table 6. Farm wages and tractor hiring fees

Variables	Unit	Rwanda	Nepal hill/mountain zones
		2020-2022	2010
Maize farmgate price	USD/kg	0.24	0.25
Farm wages (adult male)	USD/day	0.83	2.86
	kg of maize/day	3.5	11.6
Tractor hiring fees for land preparation	USD / ha	66	41 (Assuming 5 hours / ha)
	kg of maize / ha	300	178

Source: Authors' compilation from various sources.
For Rwanda, wages are from Labor Force Survey 2020-2022, while other data are from SAS 2020-2022.
For Nepal, data are from Nepal Living Standard Survey 2010.
Exchange rates: 1USD = 1,000 Rwanda Francs for 2022; 1USD = 70 Nepal Rupee for 2011.

4. POLICY OPTIONS TO PROMOTE AGRICULTURAL MECHANIZATION IN RWANDA

In this section, we explore policy options to promote agricultural mechanization in Rwanda based on insights into the typology of farm households and mechanization in Rwanda and based on cross-country experiences such as that of Nepal, Nigeria, Ethiopia, and Ghana. The low adoption levels of mechanization in Rwanda, discussed in earlier sections, suggest that government can play an important role in addressing failures in the market for machinery sales and custom-hiring. These market failures are an unsurprising result of the fact that the Rwandan market for agricultural machinery and equipment is thin—quite simply, there are too few buyers or users to make for a viable business in either the manufacturing or importation of machines, or for mechanized service provision to farmers, or the distribution of equipment attachments and spare parts, machinery repair, or other maintenance services. This sets the stage for government policy to play a facilitative role in mitigating market failures (Diao et al. 2017).

Design mechanization support programs tailored to different types of farm households, rather than a one-size-fits-all approach. As implied in the typology analysis discussed earlier, there is considerable variation across provinces in terms of farm household types and thus in terms of household types that pursue on-farm mechanization. This means that public policies and programs to support mechanization will likely need to vary across provinces, in addition to varying by agroecology (soil types, elevation, climate), cropping patterns, and irrigation systems. This variation also suggests that on-farm mechanization solutions will have to be tailored to a wide range of conditions. This will likely require programs that do more than simply supply machinery and equipment; rather, mechanization will need to be part of a well-adapted set of packages that include a range of inputs, technologies, practices, and services that combine to benefit farm households.

***Explore heterogeneity in machinery and equipment**.* The productivity effects of agricultural machines vary considerably depending on the designs. The performance of a tractor, for example, depends on horsepower and brands for which specific designs are associated. These range from weights that affect traction, rolling resistance determined by the width of front tires and types of gears to the location of the engine or the center of gravity, among others (e.g., Rackham & Blight 1985). The performance of machines also varies depending on the agroecological conditions, ranging from soil workability, topography, and climate conditions, among others. Given the heterogeneity of production environments (even among areas where mechanization is more feasible), focusing support on a narrow range of brands/types of machines can be ineffective.

Thus, it is essential to study the type of tractors and other large machines currently used in the country and better understand why those brands are used. In so doing, understanding tractors used in the informal sector is particularly important. Some types of tractors may be used because they are suitable for the Rwandan environment, or simply because spare parts are widely available locally, or for various other reasons. Understanding these is critical for knowing what types of tractors or machines may be more likely to be successful and for promoting the market growth of these machines, including second-hand tractor markets. Such efforts can supplement a more common approach of simply bringing in tractors that other countries are offering through concessional loans (as has been done by numerous other African countries in recent decades), which tend to lack diversity in brands or types and often questionable suitability for the recipient countries in Africa. Relatedly, without a good understanding of the existing custom-hiring service market, an over-supply of tractors with excessive discounts can also crowd out the private sector.

***Sensitize farmers to the use of small tractors and machines equally**.* The public sector can play a role in gathering and disseminating information regarding smaller machines, including small tractors (e.g., two-wheel tractors and mini-tillers). Smaller tractors are more affordable and can be more mobile. While they tend to be used in irrigated areas, their use in rainfed areas has also been growing in Asia. Two-wheel tractors have also been increasingly used in some SSA countries, including Tanzania (Diao et al. 2020), potentially providing affordable access to two-wheel tractor markets for Rwanda. The growing adoption of other small machines, such as motorized irrigation pumps in Ethiopia or Tanzania (Giordano et al. 2012), can also be potentially worth exploring in areas in Rwanda with shallow groundwater.

***Develop spare parts and repair service supply networks**.* Ensuring the development of the supply network of spare parts is equally important as the development of the market for machines. For example, a tractor consists of spare parts including, but not limited to, dynamo, engine, motor, hydraulic system/pump, steel plate, steel rod, bearing, cast iron/aluminum, chains, wheels, engine housing, chassis, and handle. Past and recent interventions by various governments to bring in machines failed partly due to insufficient focus on spare parts. In 1980s Asia, governments financing the cost of importing machines often ignored the fact that an additional 75 percent of these costs would also be needed to finance replacing parts so that machines could be utilized to their full extent (Rijk 1986). Recently, the Ghanaian government acknowledged this issue and reformed its Agricultural Mechanization Service Enterprise Centers (AMSEC) by negotiating with Brazil, which was providing tractors to Ghana through concessional loans, to also support the development of spare parts supply networks for at least 2 years (Diao et al., 2018).

Explore various custom-hiring service models. Many African countries' recent efforts in promoting the growth of custom-hiring services to mechanize smallholders have focused on promoting those who specialize largely in serving others' farms instead of using machines on their own farms. These models often turned out to be less viable due to the difficulty in achieving sufficient machine utilization rates (Diao et al. 2020). In contrast, custom-hiring services have been more successfully provided by tractor-owning medium-scale farmers who can both achieve sufficient machine utilization rates through intensive use on their own farm and yet have incentives to further enhance utilization rates by serving other farmers (Diao et al. 2020).

Another question is whether there are viable models of mechanization service centers that pool machinery and equipment for use by farmers, or mechanization demonstration centers that disseminate adapted machinery and equipment. There may be opportunities to develop localized service centers that are specifically adapted to the major crops, agroecology, and farming systems in each province, district, or lower administrative levels. These approaches have been pursued in a range of countries and contexts (e.g., Paudel et al. 2019; Diao et al. 2018).

***Resolve bottlenecks that limit machine utilization rates by machine owners**.* Some mechanization service providers achieve sufficient utilization rates by engaging in migratory services. Given the small country size of Rwanda, allowing the movement of service providers to and from neighboring countries through regional coordination (FAO & AUC 2018) may encourage investments in machines by certain agents who would then also start providing service to the local area or encourage the entry of service providers from neighboring countries, both of which can improve accessibility to mechanization services. Exploring through R&D on multi-functional uses of machines can also help machine owners to recoup their investment costs, although this may not always be promising in Rwanda. For example, such multi-functional uses for tractors include the use of tractor engines for running irrigation pumps or other power needs, as in Asia. Off-farm use of machines, including tractors, can be encouraged by, for example, granting exemptions for using tractors for transportation purposes.

***Improve technical skills training on machine uses and related farming practices**.* Machine selections, operations, maintenance, and mechanized agronomic practices have been increasingly considered knowledge-intensive, where the public sector can play significant roles (Diao et al., 2020). For example, experiences across SSA suggest that government-selected custom-hiring service providers often exhibit lower efficiency and lower profitability from hiring business than the informal-sector service providers (e.g., Ghana, Nigeria), likely to be attributable to insufficient knowledge of suitable brands in their production environments, inferior skills in machine operation and maintenance, limited knowledge for avoiding machine breakdown, suggesting significant scope for overall efficiency improvement through training. The Ghanaian government, for example, continuously reforms its AMSEC program by making participation in machine-use training programs mandatory for program applicants (Diao et al. 2018). They followed the lessons from the early phase of the AMSEC program, during which many program applicants faced machine breakdowns due to inappropriate uses.

Since mechanization can complement many improved farming practices, harmonizing it with training and knowledge diffusion on these enhanced practices can be effective. For example, farmers' knowledge of better land preparation methods for rice production can be improved more effectively where mechanization services are accessible (Mano et al. 2020). Similarly, experiences in India show that smart subsidy designs using mechanization can enhance the knowledge and the adoption of improved production practices like Laser-Land-Leveling (e.g., Lybbert et al. 2018).

***Encourage and facilitate value-chain financing**.*

Importantly, mechanization programs will likely need to support access to credit given the high upfront costs of machinery and equipment relative to, say, other inputs such as seed, fertilizer, or even seasonal hired labor.

Several financing options for mechanization have been promoted. Among them, the most promising modality has been what is sometimes called "value-chain financing" (Ströh de Martínez et al., 2016), whereby either machinery dealers or retailers provide references or a guarantee to a financial institution for machine buyers ("external value chain finance") or the former directly provide loans/credit to machine buyers ("internal value chain finance"). These models have been successful in Asia in the early days (e.g., IRRI 1986; Diao et al. 2020) because, among others, these machine dealers have had a good understanding of local production environments in which machines primarily operate, loan repayment timing given the seasonality of machine use, or the likelihood of repayment and risk of default. In many Asian countries, value-chain financing provided by machinery and equipment sellers, state-supported agricultural banks, or cooperative financing institutions has been a major key of credit for smallholders. While many of these financial institutions and services do not exist at the same scale in Rwanda (or do not operate at the right scale), further exploration of diversified credit sourcing is required to advance the PSTA 4 mechanization agenda. Creating an enabling environment for mechanization value chains and avoiding the crowding-out of private-sector actors, is therefore important.

Additionally, credit access from formal financial institutions could be facilitated with greater support to entrepreneurs looking to develop commercial farming operations, custom-hired mechanization services, or other business ideas. These ideas must be accompanied by business plans that provide credible analyses of expected demand patterns and trends, costs and returns, and loan repayment schedules that are convincing to lenders and investors. Efforts to help entrepreneurs build detailed business plans accompanied by business training and business plan competitions are a particular area of interest to private funders, governments, and social entrepreneurs (McKenzie 2017; Fafchamps & Woodruff 2017; Blattman et al. 2016).

Next is the question of subsidies for machinery and equipment, provisions for which are provided in PSTA 4. Subsidies have a role to play, for example, if they are made available without overwhelming other complementary forms of public expenditure such as rural infrastructure development, agricultural R&D, or public extension and advisory services. Subsidies can also be useful if they follow market signals to determine which types of machinery or equipment are preferred or required by farmers and entrepreneurs, rather than choosing specific items to subsidize based on a priori assumptions about what farmers and entrepreneurs *should* need. Subsidies can also be useful if they strike a balance between supporting crop-specific machinery/equipment designs and promoting fungible and flexible machinery/equipment designs that can encourage economies of scale and scope in importation, sales, maintenance, and repairs.

Maintain and encourage competition in markets for mechanized products and services. When supporting market development for mechanization, it is essential to maintain the competitive functions of the markets. If subsidies are needed, it may be ideal to make them applicable for broader types/brands of machines while reducing subsidy rates applicable to each machine (as was done in India (Diao et al. 2020)) instead of subsidizing a narrow set of machines with significant subsidy rates. Doing so also avoids distorting the market, such as crowding out successful types and brands of machines already popularly used in the country, as mentioned above.

Similarly, governments tend to hand-select mechanization service providers when promoting the growth of custom-hiring services. They are commonly selected through the review of application materials by a committee in the government. While these selection processes reflect some expert knowledge, they have often failed to identify the most efficient service providers. For example, among studied samples in Ghana and Nigeria, service providers identified in the informal market are more efficient than government-selected service providers in providing services to greater farm areas while keeping costs lower and minimizing machine breakdown (e.g., Takeshima et al. 2015). Supporting the growth of mechanization service providers should reduce the risk of crowding out these potentially efficient non-beneficiary service providers already operating in the custom-hiring market.

Expand capacity for research and development on agricultural mechanization. There is also the question of how to adapt mechanization options to the specific and diverse needs of Rwandan farmers. The Rwanda Agriculture and Animal Resources Development Board (RAB) has a mandate to conduct research that identifies promising machinery and equipment, sensitize potential investors and entrepreneurs, and create demand where such demand may not currently exist. In many cases, this means collecting data and information on machinery and equipment used outside of Rwanda for commonly mechanized crops like maize, beans, rice, soybeans, potatoes, and vegetables.

Additional research is also needed on the current labor-use intensity by farming operations (e.g., land preparation, harvesting) and at which rate they can be substituted agronomically by animal traction or tractors/harvesters. Typical substitution rates can be inferred from already mechanized areas in Rwanda or neighboring countries. Relatedly, research is needed to assess the relative cost of farm labor (wages) and the cost of existing mechanization services, as well as research on the structure of markets and supply chains of machines and mechanization services. Based on labor use and work rates equivalent in animal traction and machines for different agronomic operations, it should be assessed whether the cost of using animal traction and mechanization service is significantly lower than using manual labor, which can give us ideas of effective demand for mechanization in Rwanda today.

Research on mechanization technologies suitable for each province and irrigated/rainfed systems can inform the other policy areas of identifying and sensitizing farmers and entrepreneurs to promising machinery and equipment. Research can also help identify successful business models of custom-hiring services suitable for each province (while fully utilizing cross-provincial applicability of particular machines, to raise machine utilization rates and earnings to recover machine investment costs. Increased research is also critical in assessing the returns to tillage frequency (e.g., differences between single-crossing and multiple crossing). Increased yield effects of more frequent tillage raise machine utilization rates even for small farms and can reduce transaction costs for custom-hiring service providers to serve small farms. Increased tillage frequency has been found to increase yield in Ghana (e.g., Takeshima & Liu 2020) and Ethiopia (Abro et al. 2018), particularly in high-rainfall areas (Teklewold & Mekonnen 2017).

***Encourage engagement of women and youth**.* Lastly, mechanization support should be inclusive for women and youth farmers. Empowering women to articulate better their needs for mechanization and improving the understanding of women’s demand for mechanization is critical. Women’s tasks often differ from plowing, which is more commonly done by men and still dominates mechanization dialogue, and yet women often lack the capacity to express their needs (as in Tanzania (Mrema et al. 2020)). For example, women are usually more involved in weeding, harvesting, processing, and transporting farm products, water, and fuel collection, among others (Vemireddy & Choudhary 2021; Takeshima 2024). Promoting female extension agents and female engineers can be critical for reducing gender gaps in access to technical information on machine operations, maintenance, etc., and also stimulating R&D in women-friendly machines. Promoting mechanization for women should also be integrated into broader efforts for rural job growth, including those in the nonfarm sector, given that farm mechanization often encourages women to engage more in the nonfarm sector income-earning activities (Takeshima 2024).

For youth, demonstrating how mechanization can not only save labor use and productivity but also transform farming into commercial businesses and empower youth in rural resource management is critical, as indicated in recent experiences in other African countries (e.g., Amanor et al. 2022; Diao et al. 2020). Improving innovative financing, as mentioned above, and access to it is particularly critical given that youth often lack financial resources or assets compared to some of the older farmers. More youth farmers should be included during the mechanization policy formulation process (Daum et al. 2022). Youth farmers can also be encouraged to pursue off-farm businesses associated with mechanization, such as mechanics, processors, and transporters (Diao et al. 2020).

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6. APPENDIX

TYPOLOGY ANALYSIS OF FARMING AND AGRICULTURAL MECHANIZATION USE IN RWANDA

6.1 Modified cluster Analysis

Cluster analyses have commonly been used to assess the typology of farm households (e.g., Takeshima et al. 2013). Some of the common approaches for cluster analyses include hierarchical method and *K*-mean method. We combine the hierarchical method and *K*-mean method in the following way. First, we conduct hierarchical clustering using Ward's minimum variance method to obtain a first approximation of a solution. Second, we use the mean of *j* from the first step solution as a starting point for the subsequent *K*-mean method. In the *K*-mean method, we use Gower (1971) dissimilarity measure, which is appropriate for our data, in which the variables *j* contain both binary and continuous data.

We conduct a statistical test to determine whether the number of clusters we select is better than any small number of clusters. For each *K* cluster identified through the cluster analysis, we calculate the between- and within-cluster variances for each variable *j*. Following Siou et al., (2011), between-cluster variance for *j* is defined as

$$V_{\text{between}-\text{cluster } K,j} = \frac{1}{K-1} \times \sum_{i=1}^{K} \left(\bar{x}_{ij} - \bar{\bar{x}}_j\right)^2,$$

where $\bar{x}_{ij}$ is the sample average of variable *j* within cluster *i*, and $\bar{\bar{x}}_j$ is the average of $\bar{x}_{ij}$. In other words, $V_{\text{between}-\text{cluster } K,j}$ is variance of within-cluster mean of *j*.

$$V_{\text{within}-\text{cluster } K,j} = \frac{\sum_{i=1}^{K}(n_i-1)\times s_{ij}^2}{\sum_{i=1}^{K}(n_i-1)},$$

According to Siou et al., (2011), the greater ratio of $V_{\text{between}-\text{cluster } K,j}$ to $V_{\text{within}-\text{cluster } K,j}$ indicates better clustering with respect to variable *j*. Siou et al., (2011) presented the natural log transformation of the ratio for each *j*. We calculate the statistic

$$\sigma_K = \sum_j \ln\left(\frac{V_{\text{between}-\text{cluster } K,j}}{V_{\text{within}-\text{cluster } K,j}}\right),$$

which proxies clustering performance across all *j*. Greater σ_K indicates that the cluster solution better identifies distinct farm household types across all dimensions of their characteristics. Table A1 summarizes σ_K corresponding to our cluster analysis results. Clustering farm households into six types, and mechanized farm households into four types seem to lead to significantly higher σ_K, and the values of σ_K tend to relatively stabilize for greater number of types.

Table A1. Cluster analysis statistics (σ_K) for different number of clusters

Types	Number of clusters		
	2	3	4

Cluster analysis statistics	–45.4	–33.6	–28.6

Source: Authors.

6.2 Cluster analysis variables

Table A2 lists the set of factors used in cluster analyses. Following earlier studies (Takeshima et al., 2013), principal components were extracted for soils, crops grown, and livestock owned. In addition, crop sales and the cost of hired labor for AHS are imputed using EICV 2016/2017 and SAS 2019/2020.

Table 8: Factors used in cluster analyses

Categories		Note
Elevation		
Rainfall (January – June)		
Rainfall (July – December)		
Soil	Sand (%) Silt (%) Clay (%) Bulk density Organic contents Cation exchange pH	1st principal component [a]
Crops	Maize Rice Sorghum Soybean Groundnuts Potato Sweet potato Cassava Vegetables Bananas Fruits	4 principal components [a]
Farm size (ha)		
Use irrigation (yes = 1)		
Sell crops or not (yes = 1)		Figures for AHS 2020 imputed using AHS 2017, EICV 2016/2017, SAS 2019/2020 [b]
Hired labor cost		Figures for AHS 2017/2020 imputed using EICV 2016/2017, SAS 2019/2020 [b]
Daily wage		

Age of head		
Education of head		
Nonfarm (whether any member work in nonfarm sector)		
Household size		
Livestock ownership	Cattle Goat Sheep Pig Rabbit Poultry	2 principal components [a]

Source: Authors.
[a] The numbers of principal components are determined by selecting those with eigenvalues greater than 1, as suggested by Kaiser (1958).
[b] Multiple imputations methods are used following Rubin (1987; 1996) and Kilic et al., (2017).

6.3 Typology results

Table A3 presents the average values of factors used in cluster analysis, for each type of 4 mechanized farm households (A, B, C, D), respectively.

Table A3. Typology among mechanized farmers

Categories		Statisticss in each type					
Distribution across provinces (%)		East	South	West	North	Kigali	
	A	70	15	3	3	8	
	B	60	27	1	8	3	
	C	0	8	30	62	0	
	D	0	11	89	0	0	
Elevation and rainfall		Elevation (m)	Rainfall (Jan – Jun, mm)	Rainfall (Jul – Dec, mm)			
	A	1486	555	419			
	B	1487	555	449			
	C	2114	625	561			
	D	1488	810	663			
Soil		Sand (%)	Clay (%)	Bulk density	Cation Exchange	Organic contents	pH
	A	47	33	1.26	15	26	5.3
	B	47	33	1.24	15	28	5.3
	C	33	38	1.01	25	55	5.3
	D	27	45	1.04	29	53	5.9
Crop (%)		Maize	Rice	Sorghum	Soybean	Groundnuts	
	A	92	29	30	36	36	
	B	90	6	30	36	25	
	C	81	0	42	3	0	
	D	89	13	16	14	8	
Crop (%)		Potato	Sweet potato	Cassava	Vegetables	Banana (all types)	
	A	48	63	48	85	64	
	B	41	57	50	78	55	
	C	87	59	7	82	46	
	D	38	52	75	91	63	
Production		Farm size (ha)	Irrigated (%)	Market sales (%)	Hired labor cost	Daily wage	
	A	1.7	100	89	22003	737	
	B	2.5	0	81	4203	705	
	C	0.7	4	67	72	805	
	D	1.3	72	91	7006	951	
Household head characteristics		Age	Female (%)	Education (year)	Nonfarm (%)	Household size	
	A	39	7	5.9	75	5.2	
	B	42	14	6.7	63	4.8	
	C	35	12	7.2	71	4.5	
	D	40	9	6.1	78	5.2	
Livestock owned (Number)		Cattle	Goat	Sheep	Pig	Rabbit	Poultry
	A	1.1	1.2	0.2	0.4	0.2	1.7
	B	2.0	1.9	0.2	0.3	0.2	2.3
	C	0.5	0.5	0.5	0.2	0.2	0.7
	D	0.4	0.5	0.1	0.6	0.2	0.6

Source: Authors based cluster analysis applied to AHS 2017/2020 and EICV 2017 data.

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