Scale-Appropriate Farm Machinery for

Rice and Wheat Harvesting:

Updates from South and South East Asia

CSISA

Cereal Systems Initiative for South Asia

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(CSISA) 2021

Edited by Scott Justice, Stephen J. Keeling,
Govinda Basnet and Timothy J. Krupnik

Cereal Systems Initiative for South Asia

The Cereal Systems Initiative for South Asia (CSISA) was established in 2009 to promote durable change at scale in South Asia's cereal-based cropping systems. Operating in rural 'innovation hubs' in Bangladesh, India and Nepal, CSISA works to increase the adoption of various resourceconserving and climate-resilient technologies, and improve farmers' access to market information and enterprise development. CSISA supports women farmers by improving their access and exposure to modern and improved technological innovations, knowledge and entrepreneurial skills. By continuing to work in synergy with regional and national efforts, collaborating with myriad public, civil society and private-sector partners, CSISA aims to benefit more than 8 million farmers by the end of 2020.

The International Maize and Wheat Improvement Center (CIMMYT) is the global leader on publicly funded maize and wheat research and related farming systems. Headquartered near Mexico City, Mexico, CIMMYT works with hundreds of partners throughout the developing world to sustainably increase the productivity of maize and wheat cropping systems, thus improving global food security and reducing poverty. CIMMYT is a member of the CGIAR Consortium and leads the CGIAR Research Programs on MAIZE and WHEAT. The Center receives support from national governments, foundations, development banks and other public and private agencies.

Correct Citation: Justice, S., S.J. Keeling., G. Basnet., T.J. Krupnik (2021). *Scale-Appropriate Farm Machinery for Rice and Wheat Harvesting: Updates from South and South East Asia.* The Cereal Systems Initiative for South Asia (CSISA). Kathmandu, Nepal.

Printed in Bangladesh. Published in 2021

Design: Eliot Sánchez Pineda (CIMMYT).

This work was supported by the Bill and Melinda Gates Foundation and USAID through the Cereal Systems Initiative for South Asia (CSISA). The views and opinions in this document are those of the authors and do not necessarily reflect the Gates Foundation or USAID and shall not be used for advertising purposes.

Foreword

With high rates of poverty, declining but persistent food insecurity, and an increase occurrence of damaging climate extremes, the smallholder-dominated agricultural systems of South Asia are under considerable stress while, at the same time, projections suggest that crop productivity will need to increase dramatically in coming years to ensure regional food security. Underlying these challenges is an aging rural workforce and a lack of interest among young people for making farming their profession. These dynamics contribute to an unprofitable present and an uncertain future. The promise of appropriate mechanization offers a pathway forward. At its best, new types of scale-appropriate machinery can greatly reduce drudgery and the costs of production while ensuring precision management and timely field operations. Moreover, when machinery services are provided by small and medium-scale entrepreneurs, new jobs are created that help anchor younger people in rural communities while labor-limited farms stay viable by purchasing essential services. Despite the promise of mechanized solutions, progress in the past decade has been uneven with success achieved in some geographies with certain technologies while others largely stagnate. There is much to learn from this experience. Facilitating mechanization transitions is a complex process. Adapted technologies must be available at the right price, in the right place, with the right enabling environment. In most cases this implies the need for strong synergies between the public and private sectors along with rigorous priority setting and strategic planning to assess the business case and to build a scaling plan for mechanized solutions that differs by technology and geography.

I am delighted that this compilated draws together the diverse perspectives of researchers, extension officers, entrepreneurs, and private sector representatives from across the region. The conversations that inspired these articles draw upon rich insights that can only be reliably developed by understanding technologies in context, i.e. from the field where they are actually used by farmers and service providers. This compilation provides essential insights for 'what's next' as we collectively learn how to bring mechanized solutions to scale. It reflects the types of critical dialogues that are essential for supporting transitions to a more sustainable and productive future for smallholders in the region.

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Abbreviations

2WT	two-wheeled tractors
4WT	four-wheeled tractors
BADC	Bangladesh Agricultural Development Corporation
BARI	Bangladesh Agricultural Research Institute
BAU	Bangladesh Agricultural University
BRRI	Bangladesh Rice Research Institute
CIMMYT	International Maize and Wheat Improvement Center
CSISA	Cereal Systems Initiative in South Asia
DoA	Department of Agriculture, Nepal
GESI	gender equity and social inclusion
hm	hectometer
hp	horsepower
INR	Indian rupees
IRRI	International Rice Research Institute
kW	kilowatt
LKR	Sri Lankan rupee
Mhp/mhp	million horse power
Mt	metric tonnes
Na	not available
NAMEA	Nepal Agricultural Machinery Entrepreneurs' Association, Nepal
NCFE	National Centre for Agricultural Extension, Vietnam
PMAMP	Prime Minister Agriculture Modernization Project, Nepal
VND	Vietnam Dong

Agricultural Harvesting Mechanization in South Asia in View and Review

Govinda Basnet, Scott Justice and Timothy Krupnik

SUMMARY: This introductory paper explains how the eight other papers in this compendium arose from a traveling seminar on 'Scale-Appropriate Machinery for Cereal Crop Harvesting in South Asia' held from 25 to 29 March 2019 in Nepal. It explains how these papers cover the situation of agricultural mechanization in Nepal, Bangladesh, India and Sri Lanka and lessons learned from the more advanced situation in South China and the Mekong Delta in Vietnam. It also presents a case study of the evolution of mechanization in Nepal and concludes with the main overall challenges faced and recommendations for advancing agricultural mechanization in South Asia.

CHAPTER 1

1.1. Introduction

The mechanization of agriculture is transforming rural and national economies by reducing human drudgery and increasing production. Until recently, and despite its importance, agricultural mechanization was largely omitted from academic and development debates and by public sector research and development funding (Biggs and Justice 2016). While mechanization can have negative impacts on the environment, such as soil compaction and chemical pollution, it can also have positive environmental impacts when appropriately applied. The importance of agricultural mechanization in sustainable agricultural intensification and production is accentuated by the rising global costs of food and the increasing movement of youth from rural areas to find non-farm work, thus depriving the agriculture sector of manpower (and it is mostly man power). The papers presented here seek to fill the gap and add to the debate on the situation of agricultural mechanization in developing countries.

1.2. The Travelling Seminar

This collection of nine papers are based on presentations made at a traveling seminar on 'Scale-Appropriate Machinery for Cereal Crop Harvesting in South Asia'. The seminar was organized by the Cereal Systems Initiative for South Asia (CSISA) and was held from 25–29 March 2019 in the western part of Nepal's southern Terai plains. CSISA is a regional initiative to sustainably increase the productivity of cereal-based cropping systems in Bangladesh, India and Nepal. It is led by the International Maize and Wheat Improvement Center (CIMMYT) and is jointly implemented by the International Food Policy Research Institute (IFPRI) and the International Rice Research Institute (IRRI) with funding from the U.S. Agency for International Development (USAID) and the Bill and Melinda Gates Foundation.

Over 40 participants took part in the seminar, including researchers, extension agents, government officials, service providers and private sector representatives from Bangladesh, China, India, Sri Lanka, the Philippines and Vietnam. Participants visited several CSISA project sites and project partners in Rupandehi, Dang and Kailali districts in central and western Nepal. Following the field visits, the experts from several countries presented their research findings.

Ten papers were presented at the seminar (Table 1). This compendium presents versions of six/seven of these papers plus this introduction, a study on women and agricultural mechanization by Ms. Rai that was commissioned by the seminar, and an additional paper by Professor MA Sattar Mandal of Bangladesh Agricultural University.

Figure 1. **Traveling seminar participants observing harvesting by Chinese reaper binder in Padampur, Kailali, Nepal.** Photo: Govinda Basnet.

The papers presented here focus on the history and situation of the mechanization of the harvesting of cereal crops in South Asia (Nepal, India, Bangladesh and Sri Lanka) and two areas of southeast Asia (South China and Vietnam) where mechanization is more advanced and there are lessons for South Asia.

This introductory chapter presents an overview of the evolution of agricultural mechanization in these areas and the drivers, benefits, challenges and lessons from these experiences, focusing on experiences from South Asia and in particular Nepal including a case study of the evolution of mechanization in Nepal.

1.3. Overview of Agricultural Mechanization in South Asia

There are diverse patterns of agricultural mechanization in South Asia. Agricultural mechanization was introduced in India in the early twentieth century when the British colonial government brought in tractors for clearing brush and shrubs. The government began to import mechanical tillers soon after, although their use spread slowly because of their high cost (Bhattarai *et al.* 2018). By the early 1960s, the Indian government and private factories began to produce tractors aided by import-substitution policies that spurred domestic industry. Manufacturing grew so that by the 1980s India was exporting tractors. Production grew even faster after the government introduced economic liberalization in the 1990s. Since 2010, the international manufacturers John Deere, New Holland, Same, CLAAS and others have established plants in India. Today, India is the number one producer of four-wheeled tractors in the world (Singh 2013).

Agricultural mechanization in Bangladesh, Nepal and Sri Lanka occurred more recently and has depended on imported machinery, mainly from India and China. For example, in Bangladesh imports of Chinese-made single-cylinder diesel engines and 2-wheeled tractors greatly increased after the government removed restrictions on their importation in the early 1990s. Previously, the government had banned their sale because a government vetting agency had deemed them as too low quality. However, the popularity of Chinese machines in the free market has proved that the technology is good enough for most farmers' uses (Biggs *et al.* 2011).

The many machines brought into Nepal from China are generally smaller, lighter, and more versatile than their Indian counterparts. Indian tractors are predominantly four-wheeled (4WTs), while the Chinese-made tractors used in South Asia are mostly two-wheeled (2WTs). Biggs and Justice (2015) have argued that the smaller Chinese machinery is better matched to the needs of small farmers, especially in hilly and fragmented holdings (such as in Nepal's Midhills) and for accommodating multiple uses. They pointed out that Bangladesh and Sri Lanka have achieved around 80 percent mechanized tillage, whereas in India the figure is only around 40–50 percent (Pandey 2009, S Singh 2014). However, G Singh (2013) suggested that Indian farmers prefer 4WTs over 2WTs because of their higher horsepower, and because 2WTs are not permitted on highways or busy roads in India. He also cited another statistic, claiming that 90 percent of India's croplands were mechanically tilled (Singh 2013).

The most popular types of agricultural machinery in South Asia have multiple uses including non-farm uses. For example, in addition to tilling and harvesting,

Figure 2. A combine harvester working in Rupandehi, Nepal. Photo: Govinda Basnet.

2 and 4-wheeled tractors with trailer attachment are frequently hired out for transporting goods (Biggs and Justice 2015). Machinery owners, including non-farmers, also rent out their equipment (Singh 2013). In these ways, the mechanization of agriculture has significant knock-on effects.

While in India there has been strong support by central and state governments providing subsidies and loans to buy machines and equipment, until recently in Nepal and Bangladesh, agricultural mechanization has been largely driven by the private sector. Policy makers there have largely ignored mechanization in favor of other aspects of agricultural development. The Green Revolution of the 1960s–1980s, for example, focused mostly on agricultural inputs like fertilizers, improved seed varieties and irrigation (Singh 2013). The dominance of neoliberal economic policies since the 1990s has also made governments averse to heavy interventions in the market to promote mechanization. Nepal has taken a particularly laissez-faire approach to mechanization, excluding the subject entirely from important policy planning documents such as the Agricultural Perspective Plan (1995), which was developed in the 1990s (Biggs et al. 2011).

It is noteworthy that the mechanization in India, Nepal and Bangladesh has taken place without the large-scale consolidation of landholdings that was once thought necessary to achieve economies of scale (Mandal 2017, Biggs and Justice 2017). This is due mostly to the service providers, who have found scale appropriate machinery that fit their farm size (Baudron *et al.* 2015) and after using their machines on their own land, rent them out to neighboring farmers. There is also evidence of the shared use of equipment and machines by smallholders through the communal ownership of machines. In addition, some farm machinery is becoming more affordable like 2WT reapers and mini-tillers and thus more accessible to smaller farmers (Bhattarai *et al.* 2018).

Box 1 gives an overview case study of agricultural mechanization in the country where the travelling seminar took place, which complements the paper by Basnyat in this volume (see next page).

1.4. Overview of the Papers

A diversity of perspectives on harvesting mechanization

The other eight papers in this collection provide diverse viewpoints on harvesting mechanization and agricultural mechanization in Asia. The authors' different backgrounds enable them to see different patterns, benefits, and challenges in the way mechanization processes are unfolding.

The papers relate to a diversity of settings. Three of the papers focus on areas where most rice harvesting is performed by combines – in South China (Chen *et al.*), the Mekong River Delta in Vietnam (Hien) and Sri Lanka (Samarsinghe). Other papers describe the situation where mechanized harvesting is less widespread – in India (Menon), Bangladesh (Mandal) and Nepal (Rai and Basnyat).

The different cases provide snapshots of a linear journey of agricultural mechanization and development. Singh (2013) suggested that countries embark upon mechanization with

Figure 3. Harvesting wheat with a reaper in Kailali, Nepal. (Photo: Govinda Basnet.

Box 1. The evolution of agricultural mechanization in Nepal

Trend of technology adoption

Prior to the 1970s, there was little agricultural mechanization in Nepal and manual labor and draft animals were the dominant sources of farm power (Biggs et al. 2011). By 1981 only 8 percent of farm power came from mechanical power (Takeshima 2017). The percentage of households using tractors was much lower in the hills than in the Terai plains in the south.

Two-wheeled tractors were promoted in the mid-1970s and early 1980s in South Asia with support from Japanese aid programs leading in Nepal to subsidized private-sector imports of over 2,000 2WTs (Takeshima 2017).

Threshing technology was introduced in Nepal's Terai in the late 1970s, and continued to spread through the 1990s (Justice and Biggs 2013). By 2010, all wheat threshing in the Terai was mechanized, with 4WT power takeoff-driven threshers for rice spreading across most of the Terai. The use of reapers for harvesting began in Nepal in 2014 (Paudel et al. 2018). Since then, there has been a steady increase in their use, with about 2,800 in operation in 2018 (Paudel et al. 2018). Almost all of them (about 95%) are 2WT-attachable riding reapers, while the rest are self-propelled walk-behind types. The first combine harvester was introduced in 1999 in the Western Terai (Paudel et al. 2015). Their use is rapidly increasing due to the scarcity of labor and rising wages. By 2018, 650 combines were in use in Nepal, a half owned by Indians who come to Nepal in the harvest seasons (Paudel et al. 2018).

Nepal's hills began to see increased tractor use in the 2000s. The use of Chinese-made mini-tillers – which are lighter weight and can be more easily transported up and down slopes, has also expanded in the hills. There has been a high level of adoption of 2WTs in the Midhills around the Kathmandu and Pokhara valleys with a growing numbers of small-scale mini-tillers and powered threshers in surrounding areas.

The establishment of several custom hiring centers has facilitated farmers' access to new types of machines, but there are still only a few of these centers. The percentage of farming households renting tractors from informal service providers has increased from 11 percent in the Central Terai and 15 percent in the Western Terai in 1995 to 39 percent and 56 percent respectively in 2003 (Takeshima et al. 2015). Since the 2000s, there have been increasing sales of 2WTs in the Terai and hill regions (Justice and Biggs 2013).

In spite of these developments, Nepal's 2011 agricultural census found that the country's agriculture remained heavily dependent on human and animal power, constituting 35 percent and 44 percent of total farm power respectively, with mechanical sources contributing only 21 percent (CBS 2013). The census also reported that only 22 percent of farmland was tilled by tractors or power tillers, and that 22 percent of farmers used mechanical threshers. The pace of agricultural mechanization has increased considerably since 2011.

Agricultural mechanization in Nepal varies by agro-climatic zone. Many technologies were first adopted in the Terai, heavily influenced by trends in bordering areas of India. For example, areas of the Terai bordering Uttar Pradesh experienced more mechanization than areas bordering the less-mechanized state of Bihar (Justice and Biggs 2013). The Eastern Terai has higher levels of industrialization and higher levels of thresher use for harvesting.

Drivers of farm mechanization in Nepal

The growth of agricultural mechanization in Nepal has been linked to i) the widespread migration of rural youth to foreign countries for employment after 1990, and ii) many youth leaving the countryside during the Maoist insurgency (1996–2006), with this trend continuing since then. The absentee population from households in the 2011 census was over 1.9 million, a 151% increase from 2001, with 23 districts in the eastern and central hills and mountains recording negative population growth in the inter-census period. The majority of migrants are male (87% in 2011), causing a decline in the number of males to every 100 females from 98.8 in 2001 to 94.4 in 2011 (CBS 2011a). This has reduced the availability of farm labor and has led to the feminization of agriculture. This has been a prime driver of the adoption of labor and cost-saving machinery such as tractors, pumps, and harvesters.

The adoption of harvesting machinery in Nepal has also depended on other factors. Smaller land holding size and fragmented plots preclude the use of larger harvesting machines. The majority of small-holding farmers cannot afford to purchase harvesting machinery and thus rely on hiring centers or other owners to rent-in equipment. The composition of farming systems also influences the types of harvesting machinery chosen. For example, households that own livestock often prefer reapers over combine harvesters as the straw produced is more palatable as animal fodder. Farming families' levels of cash holdings also influences their access to harvesting machinery with off-farm employment and remittance incomes enabling the hiring of farm machinery. Thus, out-migration contributes to mechanization by reducing the manpower available for the agricultural sector, and by providing cash to access agricultural machines.

The adoption of farm machines also follows ethnic and class patterns. Wealthier farmers, who usually come from the traditionally dominant caste and ethnic groups, are best positioned to invest in buying machines. For example, in the Kathmandu valley, Newar farmers are often early adopters of machinery. In the Pokhara area, mechanization is greatest among Gurungs and Magars who have returned from service in the British and Indian armies (Justice and Biggs 2013).

Related to the above point, another unexplored social dimension of agricultural mechanization is the social prestige that owning a machine accords owners. Machine ownership also changes the dynamics of social relations of production and enhances the sphere of influence of owners when they rent out their machines. It also works in reverse that the ownership of smaller machinery like 2WTs has less prestige for the traditionally higher status groups, such as Thakuri farmers, but brings prestige for traditionally lower status Tharu farmers.

operations that require high power but low control (such as tillage, milling and threshing), then move to operations that require medium levels of power and control (such as seeding, spraying, and inter-row operations), and then to operations that require low power and high control (such as harvesting and transplanting). This suggests that the experiences of countries with more mechanically advanced agriculture can provide lessons for countries where it is less mechanized.

However, not all lessons learned in one country are applicable to other countries as most countries' geographical, environmental, social and economic situations require different technologies and pathways for spreading their use. There is no fixed ladder of mechanization (Biggs *et al.* 2011). Countries that are less mechanically advanced, such as Nepal, may still offer insights for more advanced countries, such as about how to encourage technology adoption among poorer farmers and lessons on extending improved practices. Furthermore, climate change is a major factor for which no country is fully prepared. Each country has to adapt to its effects by finding technologies that can help farmers deal with increased flooding, droughts and extreme weather events. Again, less mechanically advanced countries may have important experiences for more advanced countries, and viceversa.

What influences technology adoption?

Most of the papers in this volume discuss the adoption of new harvesting technologies in the context of increasing labor migration and urbanization. According to the International Organization for Migration, there are nearly a quarter of a billion international migrants and close to a billion internal migrants across the world (IOM 2018). In many parts of South Asia, migration for work has become routine. For example, since 2008, Nepal, with its population of less than 30 million, has issued more than 3.5 million official labor permits for workers to travel abroad, the majority to Gulf countries and Southeast Asia (MoLE 2018). Many more Nepalis migrate to India and in-country urban areas like Kathmandu for daily-wage jobs in construction, services and other activities. Most migrants are young males. In most cases, modern migration is 'circular' with migrants eventually returning home (Hecht *et al.* 2015).

Rigg (2006) argued that worldwide, urbanization and migration are creating new types of rural households that increasingly depend on non-farm incomes for their livelihoods, especially in Southeast Asia. However, agriculture is still crucially important for livelihoods and economies across South Asia. In Nepal, for example, although agriculture contributes less than a third of gross domestic product, about three-quarters of all households depend on it for at least part of their livelihoods (CBS 2011b).

Rather than shift the focus away from rural households, policy makers need to help agriculture adapt to the ongoing rapid social and economic changes. Agricultural mechanization plays a central role in this regard:

- Labor saving – Rural households, whose members migrate or do off-farm work, increasingly seek labor-saving machines such as mechanical harvesters. The papers from Sri Lanka, Bangladesh, and Nepal all mention migration as a key driver of the spread of mechanized harvesting. Basnyat points out how the acute labor shortage has created an increasing demand for mechanization in Nepal. The papers from Vietnam and China cite shortages of agricultural labor and its rising cost as reasons for the spread of mechanical harvesting.

- Advances in technology – The papers also highlight advances in harvesting technologies as a primary driver of their spread. In other words, demand has increased as the technology has better met farmers' needs. Chen *et al.* highlight several improvements in technology over the past few decades including technologies that more efficiently harvesting grain and better handle crop residues, and smaller size machinery for smaller farms. In South China, mini-combines have become popular as they are light weight and can be easily carried to and from fields even in hilly and mountainous areas without paved roads. Light weight machinery is also better for soils as they cause less compaction thereby maintaining soil porosity. The introduction of rubber tracks on large and smaller combine harvesters spreads out their weight evenly and facilitates maneuvering in muddy areas. Hien points to rubber tracks as a key innovation for the combine harvesting of rice in the humid tropics.

- The policy environment – The third important factor for the spread of mechanized harvesting is the role of governments and donors. Many of the countries featured in this volume have instituted preferential tariff schemes, loan programs and subsidies for buying harvesting machinery. For example, in Sri Lanka, Samarsinghe says how the duty-free importation of agricultural machines has helped spread the new technologies. In other areas, the papers argue that a laissez-faire approach aided the spread of these technologies. For example, in Karnataka in South India, Menon says that combine harvesters have become popular in part because there is no requirement for them to be owned or managed by farmers or cooperative groups – they are mostly run on a commercial basis with market-driven hiring rates.

- More prestigious – Finally, in many parts of Asia, young people see farming as low status work, and part of the attraction of off-farm work is that it carries more prestige. However, the introduction of new machinery could help change this. Basnyat says that Nepali youth are attracted to operating machines like combines while for Bangladesh Mandal says that mechanization can encourage rural youth to take up modern farming as a "prestigious and profitable profession."

Figure 4. Farmers bundling wheat harvested by a reaper in Kailali district.
Photo: Govinda Basnet.

The benefits of mechanical harvesting

Many agricultural economists have traditionally advocated for the consolidation of landholdings to create economies of scale and thereby boost the productivity and profitability of farming (Biggs *et al.* 2011). For many small farmers, however, increasing holding sizes is not an option. Mandal suggests that 'operational consolidation' is more appropriate to encourage integrated crop cultivation by synchronizing the use of varieties and planting and harvesting times.

However, the shared use of machines (either through co-ownership or rental services) as well as the ever-smaller size of machines and more affordable prices are helping small farmers to achieve gains once thought to be possible only through larger landholdings. The papers in this volume highlight the fact that mechanized harvesters can increase the profitability of agriculture by increasing efficiency and reducing losses, even on small farms. Hien says for Vietnam that: "Mechanization is the way" and that increased production cannot be achieved and post-harvest losses cannot be reduced without machinery.

In Nepal, Rai notes that mechanization can have gendered social benefits. Traditionally, men were responsible for ploughing and seeding, while most crops were harvested manually by women. When labor was hired-in at harvest time, women were tasked with cooking for and feeding laborers. Women's responsibility for harvesting has become more pronounced with the spread of migration as many women are left to take care of their homesteads while husbands do off-farm work. Thus, mechanical harvesting with reapers and combines has had special benefits for women in the areas where it is practiced by decreasing the time they need to spend tending their fields and freeing up their time to spend on remunerative non-farm activities. Rai's findings are supported by studies, such as Theis *et al.* (2018), who found that women who hire mechanical harvesters in Bangladesh have spare time to pursue other income-earning activities.

Samarsinghe points to some other social benefits of new harvesting technology in Sri Lanka, such as public health benefits including less fear of snakebites and rat fever during manual harvesting. However, an assessment of the overall public health implications of mechanical harvesting must also consider the risk of injury while using mechanical equipment and crop residue management practices, such as stubble burning, which are discussed below.

Problems associated with mechanical harvesting

These papers identify a number of problems associated with the spread of mechanical harvesting. Governments, extension agents, donors, and the private sector should be aware of and address the following problems:

Lost incomes – The spread of mechanized harvesting changes rural economies hurting some actors in the process. While the new technology enables households that lack the personnel to increase farm productivity, it has displaced other workers who would otherwise earn daily wages manually harvesting crops. Samarsinghe notes that in Sri Lanka this has knock-on effects as local restaurants that used to feed harvest workers have lost much of this business.

Skewed benefits – Another problem has to do with access to the technology. As mechanical harvesters are expensive, they are often rented-in; but even this can be out of the reach of poor farmers. Government subsidies to purchase equipment can help spread the technology, but as Mandal notes, processes for subsidy distribution are often inefficient and leave out deserving individuals. Furthermore, when subsidies are given to machine owners who rent out their equipment, it is unclear how much of the benefits are passed on to their clients. Subsidies can also reduce market efficiency. Menon notes that in India, there have been cases where equipment was procured just because a subsidy was available, without paying regard to whether the equipment could be profitably deployed. Other studies have raised concerns that long-term subsidy programs can raise prices for farmers who are not included in subsidy schemes (Biggs and Justice 2015).

Women can benefit less – Although it benefits some women, in Nepal Rai notes that men are much more likely than women to operate mechanical harvesters, limiting the benefits that women derive. This is despite the fact that women were traditionally responsible for manual harvesting, and also despite the fact that funding options are available for women's cooperatives to purchase mechanical harvesters. In one cooperative, she notes, equipment purchased in the women's names was operated by their husbands. Rai suggests that the main problem is that the machinery is engineered for use by men as operating them requires more strength than most women possess. She also notes a kind of stigma against women operating machinery.

Crop residue management – Most of the papers note problems associated with managing crop residues. In traditional South Asian farming systems, straw from wheat, rice, and other crops has multiple uses, ranging from animal fodder to thatching material, mushroom substrate, mulching material and soil amendment. While mechanical harvesting technology is improving, some machines do not efficiently manage crop residue, with important implications for sustainability.

Chen et al. point out that smaller combine harvesters are worse at managing residue than larger combines due to their limited engine power and simplified designs. Hien acknowledges the trade-offs between combine harvesters more efficiently processing crops when they cut it higher on the stalk, whereas balers perform better when the crop is cut lower on the stalk. Initially, combine harvesters in the Mekong delta spread straw haphazardly around the field, causing a decline in mushroom cultivation, which depends on the easy collection of hay for use as a substrate. In Sri Lanka, Samarsinghe says that cattle reject consuming straw that is processed by combine harvester. Thus, mechanical harvesting can negatively impact animal husbandry.

It is also important to note that when residue is left in the fields, it is often burnt off before the next planting, causing air pollution and thus damaging human health.

Limited skilled personnel – Systems and skilled labor for managing, maintaining and repairing harvesters are sometimes lacking. In Nepal, Basnyat notes that although the government's Agricultural Engineering Division has been mandated to develop appropriate technologies, there is a lack of skilled personnel and education programs for mid-level technicians. The recent establishment of the Agricultural Machinery Testing and Research Centre in Sarlahi, Nepal should contribute to promoting the use of quality equipment and the better use of subsidies for buying such equipment.

Reliance on fossil fuels – It is noteworthy that none of the authors point to agricultural mechanization's reliance on the availability of fossil fuels as a potential challenge. All of the countries featured in these papers have, at the most, limited indigenous supplies of oil and thus rely on purchasing petrol and diesel from abroad. One of the featured countries, Nepal, suffered serious fuel shortages between September 2015 and February 2016 as it was unable to import petroleum products due to an economic blockade. And in the medium to long term fossil fuels are likely to be in short supply and become much more expensive. This and the contribution of the use of fossil fuels to climate change should be kept in mind in long term policy making.

Lessons from the papers

The papers in this volume provide a number of lessons for actors involved in technology design, extension, and policy-making on agricultural mechanization:

Locally appropriate designs – Proponents of appropriate technology have long stressed the need for labor and cost-saving devices to be adapted to local circumstances. These papers remind us that countries' differing terrains, climates and soils require different designs of mechanical harvesters. In addition, design features need to vary by agro-ecological region within each country, as Mandal and Chen *et al.* point out for Bangladesh and China.

Need iterative improvements – Hien emphasizes that designs must be constantly improved through an iterative process in which designers incorporate feedback and user modifications. He demonstrates that in Vietnam, the problem of residue management created by inefficient combines was partly solved as straw balers came into more widespread use. The use of laser land levelers has also improved the efficiency of combines. This suggests that problems created by new technologies can be solved through careful refinement and the adoption of other technologies. However, it should also be kept in mind that this can escalate monetary costs and thus restrict access to wealthier users.

More female-friendly machines – In Nepal, where most agricultural machinery is operated by men, Rai suggests that more efforts are needed to spread the use of harvesters that can be used by women. She acknowledges that smaller, female-friendly machines are available on the market, including self-propelled walk behind reapers, mini-tillers, small threshes and shellers, although most women farmers lack awareness about them. She suggests that extension agents address this problem by providing more information about female-friendly technologies. She also suggests that extension agents work to make women's use of machinery more socially acceptable.

More policy support – The papers also provide lessons for policy makers on how best to promote mechanized harvesting technology. Mandal argues that in Bangladesh, budgets and human resources for agricultural extension must be expanded to popularize appropriate machinery. He also calls for subsidies and the provision of bank loans that better target suitable farmers. In Nepal, Rai proposes expanding loan and subsidy programs that target poor farmers and women farmers, like the Prime Minister Agricultural Modernization Project (PMAMP), which has set up women-managed cooperatives to run agri-machinery custom hiring centers. Theis *et al.* (2018) call for smart subsidies that benefit women, especially women household heads. Of course, subsidies need properly designing to avoid unintended consequences.

Training programs – Greater investment is needed in technical and vocational education in order to service the growing number of machines. Such training programs and repair work create more employment opportunities bolstering the knock-on benefits of the new technologies.

Sustainability – Finally, several of the papers highlight the need to pay greater attention to sustainability. Hongwen *et al.* argue that mechanized harvesting holds great potential when it is combined with conservation agriculture such as no-till farming. When properly returned to fields, straw can reduce wind and water erosion and improve water retention by soils. This suggests that efforts to promote mechanized harvesting should be combined with extension programs that educate farmers about the use of crop residues and how to improve soil fertility. Similarly, Mandal argues that agricultural mechanization technologies will have to adapt to climate change-induced natural disasters like floods and cyclones as they become more common. In particular, machines that can quickly plant a crop immediately after flood waters recede, or that can expeditiously harvest a crop once rains and storms are forecasted, will be in high demand.

In conclusion, these papers show that farm mechanization is contributing greatly to, and can further contribute to, increased food security and rural incomes amidst the ongoing and widespread demographic changes, especially the migration from rural areas. These papers also show that farm mechanization is embedded in the socio-economic and policy context of a particular nation thus exhibiting diverse trajectory. Effective farm mechanization should be able to seize upon the emerging opportunities and address challenges.

Annex 1.1. Papers presented at the Travelling Seminar

SN	Presenter	Institution	Title
1	Dr. Tim Krupnick, Scott Justice*	CIMMYT/CSISA	The Cereal System Initiatives for South Asia: Transforming Livelihoods and Bringing Science into Impact
2	Dr. Allen David Jack McHugh	CIMMYT, China and CIMMYT, Bangladesh	The Spread of Reapers and Combine Harvesters in Bangladesh
3	Gokul Paudel	CIMMYT, Nepal	The Spread of Reapers, Threshers and Combine Harvesters and their Impact on Residue Management in Nepal
4	Madhusudan Basnyat*	Department of Agriculture, Nepal	Agricultural Mechanization in Nepal
5	Melvin Samarsinghe*	Agfour Engineering Services, Sri Lanka	Spread of Small Harvesting Machinery on Small Farms, and Residue Management in Sri Lanka
6	Prof. Ding Qishuo*	Nanjing Agricultural University	Spread of Harvesters and their Impact on Residue Management on Small Farms in South China
7	Prof. Li Hongwen	China Agricultural University, China	The Centre for Sustainable Agricultural Mechanization (CSAM) Project on Straw Management after Harvesting and Conservation Agriculture in China
8	Dr. Phan Hieu Hien*	Nong-Lam University, Vietnam	Mechanization of Paddy Harvesting and Rice Straw Baling in the Mekong Delta of Vietnam
9	Carlito Balingbing	IRRI, the Philippines	Mechanization of Rice Harvesting: Lessons Learned from Southeast Asia and the Philippines
10	Anil Menon*	CLAAS Agricultural Machinery, India	The Mechanization of Harvesting and Residue Management in South and Central India

Note: * denotes papers that were presented at the seminar, versions of which are presented in this compendium.

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CHAPTER 2

Agricultural Mechanization in Nepal

Madhusudan Singh Basnyat

Summary: Agricultural mechanization in Nepal is accelerating due to the chronic shortage of rural labor, the introduction of a facilitating policy environment and support from government organizations and development projects. There is much more mechanization in the southern Terai plains than in the hills and mountains with almost 90 percent of rice and wheat threshed mechanically in the Terai.

2.1. Introduction

The chronic shortage of agriculture labor in Nepal is due to the widespread out migration of youth from rural areas. This has led to agricultural operations often not being carried out on time, and much arable land being left fallow or abandoned. At the same time the traditional practice of exchanging labor to carry out major agricultural operations is declining fast. This labor shortage has created the opportunity and an increasing demand for mechanization and is a means of attracting youth back to agriculture as they like to drive tractors and operate machines. At the same time, agricultural mechanization has a key role to play in boosting agricultural productivity and production in Nepal.

Hence, agricultural mechanization is being prioritized in the plans and policies of national and provincial governments. The promotional activities are mostly capital subsidies for buying agricultural machines, the promotion of custom hiring services for hiring out machinery services, and subsidized bank loans for buying machines. The private sector is importing modern machines, with a few local manufacturers of simple machines like threshers, shellers and milling equipment. The country's dairy, fisheries, meat, honey and other agriculture-based industries are using machines and technologies to process their products.

2.2. Overview

Nepal is located on the southern slopes of the Himalayas with mountain, hill, and Terai (plain land) ecological zones (Figure 5). Hills and mountains regions cover 77 percent of the country and the Terai 23 percent.

Nepal's agriculture sector accounted for 27.6 percent of national gross domestic product in 2017/18 (MoF 2018) and provided more than 60 percent of employment. Agricultural land occupies 21 percent of the country's area, of which 53 percent is irrigated. The average holding size is 0.68 hectares. Many Nepalese industries are based on agricultural products and account for a large share of Nepal's export. However, the average annual growth rate of this sector has been only 3.2 percent over the two decades, which is closely related with about 21.6 percent of the population still living below the absolute poverty line in 2018 (MoF 2018).

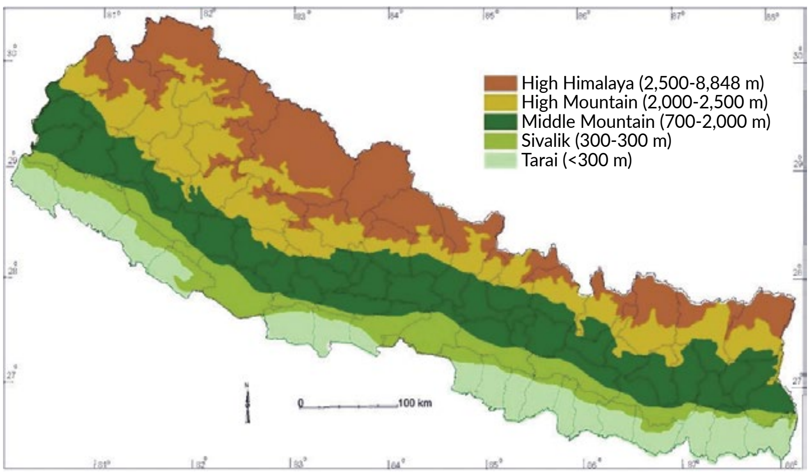

Figure 5. Physiographic regions of Nepal.

2.3. Agricultural Policies and Strategies

Until recently, agricultural mechanization was not recognized as important for enhancing agricultural productivity in Nepal and was not prioritized in national plans and programs. For example, the National Agriculture Policy (MoAD 2004) did not consider agriculture mechanization as important. However, the present chronic shortage of agricultural labor in many rural areas has brought agricultural mechanization on to the policy agenda.

The Constitution of Nepal (2015) has provisions related to food sovereignty, modernizing the agriculture sector, increasing agricultural productivity, and ensuring the access of 'peasants' to farm land. The government has several policies and strategies related to agricultural mechanization:

The Agricultural Development Strategy (MoAD 2015) is Nepal's overarching agricultural development plan for the 2015 to 2035 period. It identifies agricultural mechanization as one of the thirteen priority areas for achieving higher productivity and recognizes the role of the private sector in the mechanization of Nepal's farms. The strategy calls for building awareness, stimulating demand, concessionary financing arrangements and building the capacity of a nationwide network of machinery dealers, particularly for small scale appropriate machinery like 2-wheel power tillers and mini-tillers. It also calls for continuing the low levels of import taxes on agricultural machinery and exemption from value added tax (VAT) for selected machines.

The implementation of the strategy needs coordination between the government, private sector equipment providers and the banking sector. The recommended approaches are (i) promoting power tillers with multifunctional tilling options in the Terai; (ii) increasing the number of 2-wheeled tractors and mini-tillers in hilly areas; and (iii) promoting labor saving low energy implements and mechanized irrigation in the mountains. The strategy also calls for increasing information dissemination, improving access to finance, building the capacity of service and maintenance providers, enabling the business environment for leasing agricultural equipment, revising regulations and taxes to support mechanization, and piloting a voucher scheme for targeting subsidies to needy farmers.

The Agricultural Mechanization Promotion Policy, 2014 (MoAD 2014) calls for modernizing and commercializing agriculture in Nepal by:

- increasing productivity through appropriate agricultural mechanization
- developing agriculture machinery services and businesses
- identifying and promoting women and environment-friendly agriculture machines
- strengthening the organizational structure to develop, quality control, standardize, regulate, monitor and promote agricultural machines.

The Agricultural Mechanization Promotion Operational Strategy (NARMA 2017) is the guiding document for implementing the Agricultural Mechanization Promotion Policy, 2014. Its purpose is to raise the level of mechanization for more productive land and labor through the adoption of appropriate and sustainable agricultural mechanization technologies. The strategy, which is under approval, calls for i) enhancing demand for and the use of appropriate agricultural machinery, ii) improving the supply situation and prioritizing domestic fabrication; iii) strengthening the innovation system and iv) introducing policy, institutional and regulatory measures. The strategy's short, medium and long-term targets are listed in Table 1 aiming for an almost doubling of mechanization and power use between 2017 and 2027.

2.4. Overview of Agricultural Mechanization in Nepal

Timeline

The first tractor was imported into Nepal and an agriculture office was established in the country in the 1920s. The various interventions and efforts to introduce agricultural mechanization since then are summarized in Table 2 (see next page).

Status

An exploratory study carried out for the Agricultural Development Strategy (see NARMA 2017) estimated that close to 40 percent of farm cultivation operations were mechanized including 61 percent in the Terai, only 15 percent in the hills and 2 percent in the mountains. Farm operations were mechanized on 1.03 million of the 2.65 million hectares of Nepal's arable land mostly using 2 and 4 wheeled tractor power.

In the hills and mountains, much cultivation and harvesting is still carried out using wooden ploughs. hoes and sickles. However, in most valley areas, more and more farmers are using power tillers and mini-tillers to prepare their fields with adoption increasing in line with the extension of the road network. Tractor driven threshers are threshing crops in areas with road access. Vegetables cultivation near urban areas is increasing under polythene. Mechanized irrigation, mechanical sprayers, improved water mills, paddy shellers and mechanical grinding mills are being adopted in most valley and hill areas. However, in the mountains, most grain is milled using mortars and pestles, querns and traditional water mills.

In the Terai, manual tools, animal drawn implements (ploughs, harrows and cultivators), and mechanical machinery is in use. Traditional wooden ploughs, iron mold board ploughs, disc harrows and wooden planks are the main animal-drawn implements. Animal power was widely used for threshing through trampling while bullock carts with wooden or rubber wheels are still used for transporting crops. Diesel pump-sets are commonly used for pumping irrigation water although solar power is becoming popular for pumping water. An increasing number of planting and harvesting machines are being used to address the acute shortage of labor. Tractor-driven ploughs, harrows, cultivators and rotavators are now used for primary and secondary tillage operations. These tractors are also used for transport and threshing.

Table 1. Current status and targets of agricultural mechanization

Indicators and unit	Baseline status (2017)	Short-term (2017–2019)	Medium-term (2019–2022)	Long-term (2022–2027)
Percentage agricultural mechanization	40% (Terai 61%, Midhills 15%, mountains 2%)**	50%	60%	70%
Power use in Kw/ha (mechanical)	0.67	0.74	0.85	1.19

Source: NARMA 2017.

Table 2. Timeline of agricultural mechanization in Nepal

Year	Achievement
1921	A government agriculture office was established at Charkhal, Kathmandu
1924	Krishna Bdr Thapa of Biratnagar imported the first tractor into Nepal
1953	An Agricultural Engineering Unit was established under the Ministry of Agricultural Development and the first modern farm equipment was imported for government agriculture and livestock farms
1959	The Agriculture Equipment Research Unit was established at Ranighat, Birgunj for researching and promoting agricultural equipment in the Terai. It developed iron ploughs and rice threshers. It is now under the Nepal Agricultural Research Council (NARC)
1964	The Agriculture Tools Factory was established at Birgunj with support from the Soviet Union (USSR). It manufactured iron ploughs, pedal threshers, corn threshers, wheelbarrows, wheat threshers, pump sets and tractor trailers
1970	The government's Food Technology and Quality Control Department established a fruit processing pilot plant
1971	The Janakpur Agriculture Development Project, which was funded by the Government of Japan, promoted deep tube-well irrigation, power-tillers and modern agriculture equipment in the districts around Janakpur. It is now the Agricultural Mechanization Promotion Center (AMPC)
1973–1983	• The Agriculture Development Bank started to prioritize loans to buy tractors and pump sets • The Livestock Development Farm, Pokhara, was established with support from the German Technical Cooperation Agency (GTZ). It used forage harvesters, incubator hatcheries, and equipment to prepare silage • The Swiss government-supported Jiri agriculture farm used some farm machinery
1990	The Nepalese Society of Agricultural Engineers was registered
1991	The Agriculture Engineering Division of NARC was established for testing and developing agricultural machinery
1996	The Agriculture Tools Factory, Birgunj was privatized, but subsequently went out of business and now closed down
2000	The Institute of Engineering's Eastern Campus at Dharan started a bachelor degree course on agricultural engineering with about 48 students graduating each year
2004	The Directorate of Agricultural Engineering (DoAEngg) under the Department of Agriculture (DoA) was established for agricultural engineering extension and training services. It no longer exists under the new federal system of government
2014	• The first National Agricultural Mechanization Exhibition was held at Narayanghat, Chitwan with more than 500 modern farm tools, equipment and machines displayed from 16 countries • The Agricultural Mechanization Promotion Policy, 2071 (2014) approved • The government started its subsidy program for farmers to buy agricultural machines
2015	The Nepal Agricultural Machinery Entrepreneurs' Association (NAMEA) was established
2016	The Second National Agricultural Mechanization Exhibition was held at Kohalpur, Banke
2017	• The first International Agricultural Mechanization Exhibition was held in Kathmandu • The Fifth Regional Forum on Sustainable Agricultural Mechanization in Asia and the Pacific along with a Regional Workshop on Integrated Straw Management was held in December in Kathmandu, organized by the Centre for Sustainable Agricultural Mechanization (CSAM) of UN/ESCAP and DoAEngg

2018	• The Agricultural Machinery Testing Center was established at Nawalpur, Sarlahi, under NARC
	• The third National Agricultural Mechanization Exhibition was held at Dharan, Sunsari
	• Current government institutions concerned with agricultural mechanization after the restructuring under the new federal system of governance:
	  ○ Agricultural Engineering and Small Irrigation Section in Ministry of Agriculture and Livestock Development (MoALD)
	  ○ Agricultural Engineering and Post-Harvest Section (AEPHS) at the DoA
	  ○ Centre for Agricultural Infrastructure Development and Mechanization Promotion (CAIDMP) under DoA
	  ○ Agricultural Mechanization Promotion Center (AMPC), Janakpur under CAIDMP – to be developed as a training center.
	  ○ Agricultural Mechanization and Small Irrigation Section under the Agricultural Development Directorates of provincial ministries of land management, agriculture and cooperatives (MoLACs)

Almost 90 percent of rice and wheat is threshed mechanically in the Terai. The first combine harvester was introduced in Terai in1999/2000, total of 600 were operated during year 2018, and almost half of them comes from India during crop harvesting season. 2800 reaper for harvesting rice and wheat are been adopted till the year 2018, of which 95 percent is power tiller attached and 5 percent is self-propelled and 80 percent are self-purchased by the farmers (Paudel 2019).

Facts and figures

Data is not available from a single source on the types, models and numbers of agricultural machines in Nepal. The Central Bureau of Statistics has conducted national sample censuses of agriculture every ten years since 1961/62. The sixth census in 2011/12 covered the use of agricultural implements and others machines. There has been an increasing trend in the use of agricultural machinery and equipment in the last 20 years on Nepal's farms with the number of power tillers and tractors increasing by more than six times and other technology too (Figure 6). There is highly likely to have been an accelerated rate of increase since 2012.

The most recent agricultural census (in 2011/12), recorded farmers in Nepal's Terai making far more use of machines and other technology in their farm operations than farmers in the Midhills, with very little use on mountain farms (Figures 7 and 8). The agricultural mechanization policy, subsidies and promotional programs and organizational reform has since greatly increased access to these technologies, which will result in a the next agricultural census (due to be carried out in 2021/22) in all likelihood reporting greatly increased use across all three ecozones.

Another source of data on agricultural machines is the registration of tractors and power tillers by the government. All vehicles that ply Nepal's roads, including tractors and power tillers, have to register with the local transport office. Up to 2017/18 the Department of Transport

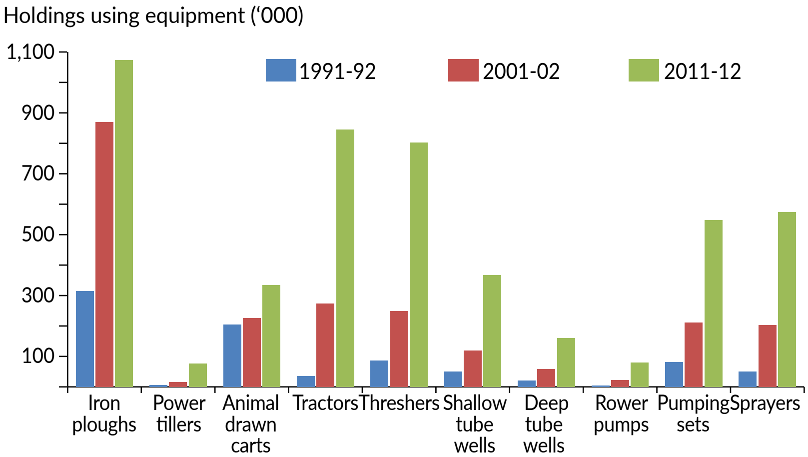

Figure 6. **Trend in number of households using agricultural machines and technology in Nepal, 1991–2012** (Source: CBS 1992, 2002 and 2012).

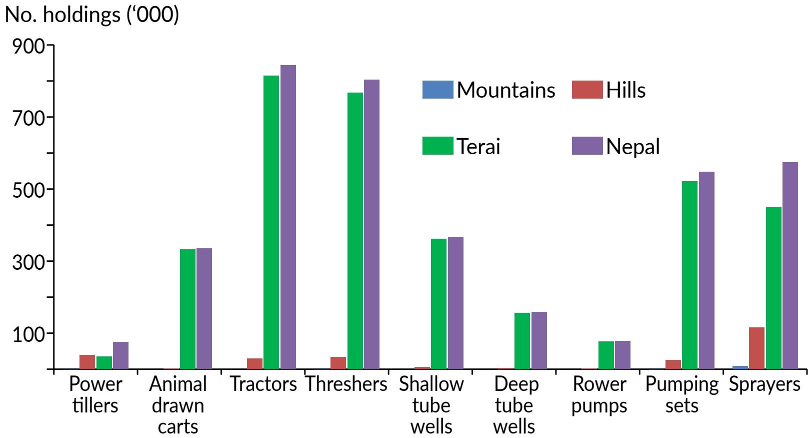

Figure 7. **Number of farm holdings in Nepal using agricultural machines and other technology by ecological belt, 2011/12** (Source: CBS 2014).

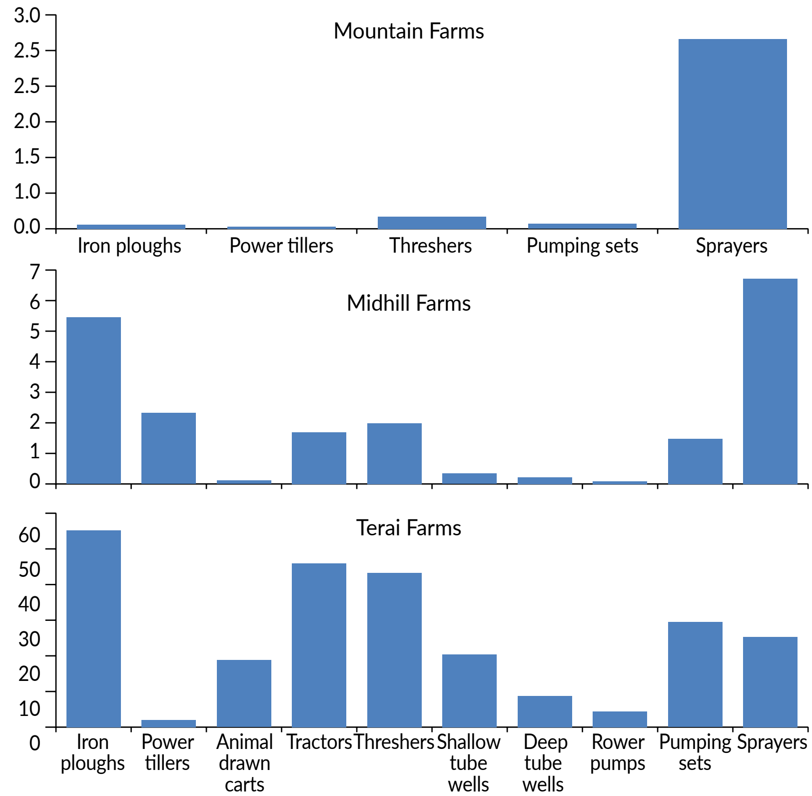

Figure 8. **Percentage of farm holdings using agricultural machines and other technology in Nepal's mountains, Midhills and Terai** (Source: CBS 2014).

Management had registered a cumulative total of 143,962 tractors and power tillers. The number registered annually has increased from less than 2,000 in 1991/92 to more than 13,000 in 2017/18 (Figure 9). But note that the actual number of power tillers is greater as those that do not travel on roads need not register. The sale of tractors declined slightly in 2017/18 after the government imposed 13% VAT on their import in that year.

Some ploughs, tractor and power tiller attachments, threshers and other agricultural equipment are manufactured in Nepal. However, data on these are not available and most of the demand for agricultural machinery is met by imported machines. Imported machines were subject to one percent customs duty and no VAT until 2018/19. These machines include tractors, harrows, seeders, transplanters, threshers, reapers, mowers, balers, combine harvesters, dairy machinery, poultry incubators and meat and tea processing machines. Most of them are imported from India and China. More information on these imports is available at www.customs.gov.np/en/monthlystatstics.html

Nepal is a member of the Centre for Sustainable Agricultural Mechanization (CSAM) of the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP). One of CSAM's activities is to compile data on agricultural mechanization. It initiated a database on agricultural mechanization in Asia and the Pacific on 29 March 2016. Nepal's Directorate of Agricultural Engineering was the focal organization; but this entity ceased to exist during the 2017/18 federal reorganization and the government has yet to appoint a new organization to fulfill this role.

2.5. Organizations Working for Agricultural Mechanization

The government-led projects and the main NGOs, INGOs and other development organizations that support agricultural mechanization in Nepal are listed in Table 3.

Education institutes – Purbanchal Campus, Dharan is the only education institute under the Institute of Engineering (IoE) of Tribhuwan University that graduates agricultural engineers. About 450 agricultural engineers have so far graduated from this institute. However, there are no institutes teaching mid-level agricultural engineering technicians and there is a lack of skilled agricultural mechanization human resources in the country.

Research organizations – After the establishment of the Nepal Agricultural Research Council (NARC) in 1991, the Agricultural Engineering Division (AED) was mandated to develop appropriate agricultural technology for the country. The main technologies tested, developed and recommended by the division are:

- zero tillage and direct seeded rice
- improved iron ploughs, rice weeders, pedal paddy threshers, pedal rice-wheat threshers and millet threshers
- corn shellers, coffee pulpers, low cost solar dryers and cardamom dryers
- low cost poly-houses, ginger washing machines, seed drills and jab planters.

The division has also tested low cost drip irrigation and fertigation systems and equipment to attach to power tiller. It has also successfully introduced mechanical rice transplanting technology, sugarcane planters, potato planters and diggers, milking machines, fish pond aerators. The division also trains local companies to manufacture the machines and equipment it develops.

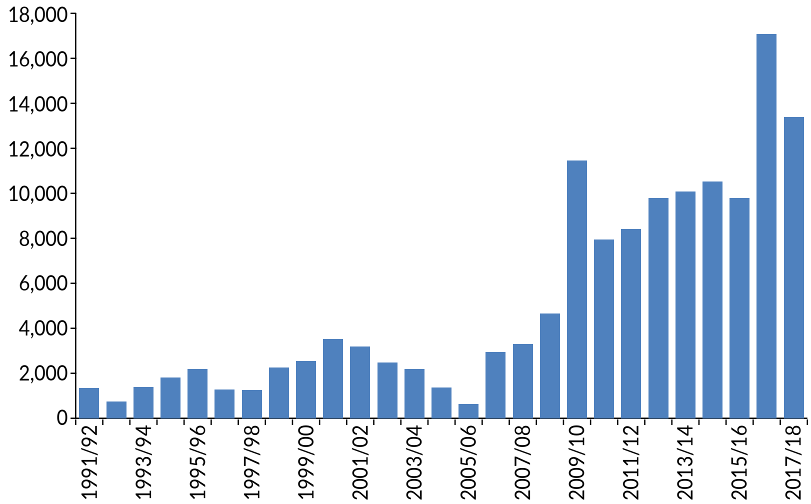

Figure 9. Number of tractors and power tillers registered annually with the Department of Transport Management, 1991/92–2017/18. Source: DoTM 2018.

Table 3. Government projects and NGOs, INGOs and other development organizations that support agricultural mechanization in Nepal.

Government projects	NGOs, INGOs and other development organizations
Project for Agriculture Commercialization and Trade (PACT) (2009-2018)	International Center for Integrated Mountain Development (ICIMOD)
High Value Agriculture Project (HVAP) (2010-2017), now renamed as Agriculture Sector Development Project (ASDP) (2018–2023)	CIMMYT Cereal System Initiative for South Asia in Nepal (CSISA-NP)
Kishankolagi Unnat Biu-Bijan Karyakaram (KUBK-ISFP) (2012-2019)	iDE-Nepal
Agriculture and Food Security Project (AFSP) (2013-2018)	Renewable World
Agricultural Development Project, Janakpur (ADPJ) now Agricultural Mechanization Promotion Center (AMPC) (1971 onwards)	IRRI
Irrigation and Water Resources Management Project (IWRMP) (2008-2018)	Winrock
Raising Incomes of Small and Medium Farmers Project (RISMFP) (2011-2018)	Practical Action
Community Managed Irrigated Agriculture Sector Project (CMIASP) (2006 ongoing)	SNV Nepal
High Mountain Agri-business and Livelihood Improvement (HIMALI) project (2009-2013)	CEAPRED
CSISA's Earthquake Rehabilitation Program (2015-2016)	LI-BIRD
Prime Minister Agricultural Modernization Project (PMAMP) (2017 ongoing)	

AED has the mandate for testing machines but only recently began to develop a testing facility supported by the CSISA Scaling project (CIMMYT-USAID). Work is ongoing to establish the AED's Agricultural Machinery Testing Center (AMTC) at Nawalpur, Sarlahi to test and certify machines that are imported or manufactured in-country.

And AED is the focal institute for CSAM's Asian and Pacific Network for Testing of Agricultural Machinery (ANTAM), which is a regional network of national agricultural machinery testing stations, research institutes, associations and farmer organizations.

Extension organizations – The Department of Agriculture's Directorate of Agricultural Engineering was established in 2004 and was responsible for human resource development, extension services, subsidizing agricultural machines, establishing post-harvest and custom hiring service centers etc. The directorate ceased to exist with federal reorganization in 2018/19. Its activities are now carried out by the department's Agricultural Engineering and Post-Harvest Section (AEPHS) and the Centre for Agricultural Infrastructure Development and Mechanization Promotion (CAIDMP). Agricultural Development Project Janakpur (ADPJ) is renamed as Agricultural Mechanization Promotion Center (AMPC) under CAIDMP as the national training center for agricultural mechanization.

Private sector and professional organizations – Private sector businesses are the key players for bringing the latest agricultural technology into Nepal and some manufacture in country. These organizations formed the Nepal Agricultural Machinery Entrepreneurs Association (NAMEA) in 2015. The association's members conduct demonstrations and on-the-spot training for farmers and mechanics. Demonstrations are done individually or in collaboration with development organizations and government institutions. NAMEA members use their service centers and dealership network to promote agricultural mechanization. They have recently expanded their activities and presence to remote areas of the country. The government requires sellers to train users to use machines purchased under the government's subsidy scheme. Sellers conduct group trainings on machine operation and maintenance. The Nepalese Society of Agricultural Engineers is the professional umbrella organization for agricultural engineering graduate in Nepal.

2.6. Conclusions

The adoption of agricultural machinery and equipment is increasing, and these machines have become one of the major input in Nepalese agriculture due to acute shortage of labor. Most smaller machines are imported from China and larger ones from India, while some are manufactured in country. All levels of government, education institute, NGOs, INGOs, development partners and the private sector need to work together to promote agricultural mechanization to reduce the drudgery of farm work, to make agriculture more attractive for youth and gender friendly to increase production and productivity.

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CHAPTER 3

Engendering Agricultural Mechanization in Nepal Lessons and Observations from Reaper and Harvester use in the Western and Far Western Terai

Megh Ranjani Rai

Summary: This paper reports the findings of a rapid gender study on women and the mechanization of farm operations in Nepal's western and central Terai plains. Women's increasingly important role in Nepalese agriculture has led to them women taking on additional responsibilities for family farms. It is women-heads of households and women farmers who own and lease farmland who have an interest in acquiring and using agricultural machinery as it saves them money and time. However, these women face social and cultural barriers to using machines and hiring in services, while poorer women cannot afford to hire in machinery services. The main challenge that prevents women from operating farm machines is their lack of familiarity with machines and in some cases not having enough strength to use them. However, the overarching problem is that women's needs and interests are often ignored in decision-making in households, communities and projects in Nepal. The study recommends the carrying out of further studies on the issue, introducing measures to improve women farmers' and landowners' access to services and businesses, and building women's skills to operate and hire out machines.

3.1. Background

Nepal's agricultural land occupies approximately 28.7 percent of Nepal's total land area (CIA, 2018; World Bank 2017). In 2007, the country began a slow transition to a federal parliamentary republic composed of seven provinces. The following decade has been marked by political instability, which, when combined with widespread rural out-migration, predominantly of male agricultural laborers and youth, has led to fundamental changes and increased feminization of the farming systems that occupy Nepal's landscapes. This paper reports the findings of a rapid gender study on women and the mechanization of farm operations in areas of Nepal's western and central Terai plains conducted to take stock of women's involvement in farm mechanization in terms of women as machine operators and as hirers of farm machinery services.

3.2. Study details

The study was carried out in May 2019 on:

- the benefits to women from CSISA's initiatives to introduce farm mechanization;
- the factors that constrain women's participation in mechanized agriculture; and
- how to improve women's participation in mechanized agriculture.

The study first compiled reflections from the travelling seminar on women and farm mechanization and carried out a brief literature review of studies and policies related to women in Nepalese agriculture and farm mechanization (see Section 3 below). The subsequent main part of the study held focus group discussions and key informant interviews with men and women farmers, machine users, machine suppliers, project staff and machinery service providers and maintenance staff at the following locations in Nepal's Terai:

- The CSISA project areas of Padampur in Kailali district and Munwa in Kanchanpur district.
- Hirapur, which lies on the outskirts of Bhairahawa town in Kapilvastu district, including the Malkit combine harvester demonstration site (Malkit is an Indian made combine harvester).
- The women's farm machinery service provider cooperative at Satbariya in Dang district.

The study also looked at a case study on a women's farming cooperative in Ransingh, Dang. This site was not visited and the information was collected from CSISA staff.

The main limitation was the limited time available to carry out the study. It was a rapid analysis carried out over three days of the gender dimensions of issues concerning agriculture mechanization for women farmers. The women respondents were female farmers engaged directly or indirectly in farming and were either hill migrants or Tharus (an ethnic group).

3.3. Women and Agricultural Mechanization in Nepal

Women's participation in agriculture mechanization

Women play an increasingly important role in Nepalese agriculture due to the widespread absence of their menfolk working either abroad or in other areas of Nepal. Agriculture contributes a third of Nepal's gross domestic product and about 80 percent of women are employed in agriculture, mostly as subsistence producers.

There have been large recent shifts in the traditional division of labor as women have taken on additional responsibilities, such as ploughing and selling agricultural products, in the absence of their menfolk. Although women's ownership of land is increasing, accounting for about a fifth of agricultural landholders in 2011 (CBS 2013), land-ownership rights remain a major constraint for many Nepalese women farmers (Reliefweb 2019). One implication of this is that most women lack collateral to get loans as land is the major asset used as collateral.

The mechanization of agricultural operations is growing in importance on Nepal's farms. Studies referred to in Kawarazuka et.al. (2018) Acharya et. al. (2017) and Paudel *et al.* (2019) found the following:

- The outmigration of men has increased the time and labor women spend on agricultural activities especially as fewer men are available to plough fields.
- The hiring in of mini-tillers to prepare land increases yields by about 10 percent and increases efficiency by about 12 percent, in terms of labor saved. Some women household heads directly hire in machine services meaning they have to spend less time caring for draft oxen and preparing snacks and meals for ploughmen, thus leaving them more time to spend on other income-generating activities such as milk and vegetable farming.
- Women's limited access to cash affects their ability to hire in mini-tillers for preparing fields for planting and sowing. Women who can't afford to hire them in often share their labor with other women to manually till their fields.
- None of the women interviewed had been trained on operating mini-tillers and pointed to cultural and gender barriers to accessing such training.
- The work of repairing mini-tillers and other machines is all carried out by men.

The policy situation

The mainstreaming of gender concerns in national agriculture and rural development is vital for the development of Nepal's rural areas. The Government of Nepal has the following major strategies and policies to address gender equity and social inclusion in agriculture and rural development. These are being implemented to varying degrees:

- The Agriculture Development Strategy (2015–2035) aims to improve the food and nutrition security of the most disadvantaged rural populations, including pregnant and lactating women (MoAD 2016). Its 10-year plan of action includes developing a GESI strategy for agriculture.
- The National Agriculture Policy (2004) calls for 50 percent participation of women in agricultural development activities. It calls for: i) mobile training programs to encourage women's participation; ii) to provide facilities to farmers who have less resources and land; and iii) to enhance the capacity of women's cooperatives and women farmer groups (MoAD 2004).
- The Agribusiness Promotion Policy (2006) calls for programs to support the poor, women and Dalits to establish agricultural enterprises (MoAD 2006)
- The Agriculture Mechanization Promotion Policy (2014) calls for attracting youth and women farmers to mechanized agriculture and increasing their productivity by identifying and promoting women and environment-friendly technologies (MoAD 2014)
- The Gender Equity and Social Inclusion Strategy Framework (2016) has an overarching strategy to build the capacity of GESI target groups in agriculture (GESI Working Group 2017)
- Country gender assessment of agriculture and the rural sector in Nepal (FAO 2019).

3.4. The Case Study Areas

Padampur and Munwa villages in Tikapur Municipality in Far Western Nepal are populated mostly by Tharus, many of whom were bonded laborers until the Kamaiya System of bonded labor was abolished in 2002. Wheat and rice are the main crops supplemented by pulses and vegetables. Most land holdings are between 2 and 5 kathas in size (677–1,693 m^2).[1] A few areas of 20 bighas[2] (13.5 ha) or more are owned by hill migrants and Tharu Chaudhary landlords. Other locals do not own land and farm under thekka contract leases, bag bandhi mortgaged land and adhiya battiya share cropping, with half their crops going to landlords. The locals said that 2 and 4-wheeled tractor reapers and combine harvesters were used to a limited extent to harvest crops in these areas.

The Hirapur area lies on the outskirts of Butwal in Rupandehi district in the central Terai. Land holdings in this area are mostly between 10 kathas and 2 bighas in size (0.34 ha to 1.3 ha). Rice and wheat are the main crops supplemented by legumes and mustard. The local population is mainly Rana Magars and a few Kunwar-Thakuris. Many local households are headed by women as their menfolk work abroad including in the Indian Army. Most of these women are economically well off and hire in machinery services to carry out operations on their farmland.

Patekhouli, which lies 5 km east of Bhairahawa in Rupandehi District, is populated mostly by Dalits, Thakurs and Tharus. Many of the area's menfolk work away from home or travel for work in nearby Bhairahawa. A number of larger combine harvesters serve this area and are popular with local farmers.

The Satbariya Women's Hiring Center in Dang was founded in 2017/18 and is managed by ex-women bonded laborers[3] as a cooperative. This area is

[1] Kathas are the traditional measure of land in Nepal's Terai. 1 katha = 338.63 m^2

[2] I bigha = 0.67 ha

[3] Kamlharis are Tharu women who served as bonded household in landlords' houses. The system has been abolished.

within the Maize Super Zone of the Prime Minister's Agriculture Modernization Project (PMAMP). In 2018, PMAMP provided a 50 percent subsidy to the cooperative to buy two 4-wheeled tractors and a planter, a 2-wheeled tractor a 2-wheeled tractor reaper and a maize thresher. The group paid NPR 2.7 million to cover the other half of the cost. They advertise their services through personal networks. They charge members NPR 700 and non-members NPR 1,200 an hour for land preparation by their 2-wheeled tractor and NPR 1,600 an hour for members and NPR 1,700 an hour for non-members for land preparation by its 4-wheeled tractor. The women manage the business while their menfolk mostly operate the machines.

In 2018, they received a second-hand diesel-powered mini-tiller from the CSISA Scaling Project. In January 2019, two women operators were trained on operating and maintaining their machines. The group subsequently earned an amount equivalent to the retail price of the mini-tiller from providing tillage services over two seasons. Cooperative members are charged NPR 100 and non-members NPR 400 per hour to hire in the mini tiller. The machine prepared about 20 hectares of land for 60 farmers over the two wheat and spring maize seasons in 2018 and 2019.

3.5. Main Findings

Situation of farm mechanization in the study areas

Traditional division of labor – Across Nepal, women are more involved in crop production and post-harvesting activities than men. Men traditionally perform most heavy physical labor, such as ploughing, while women do more of the weeding (Figure 10), harvesting, threshing and milling (Table 4).

Figure 10. Members of Dhankhola Women's Group's (Dang, Nepal) trying out their mini-tiller. Photo: Lokendra Khadka.

Table 4. The division of pre and post-harvest farm labor, Tikapur, Kailali, Nepal (2019).

Activity	Men's tasks	Women's tasks
Field preparation:	Ploughing	Weeding, clearing brush, breaking sods using spades
Planting rice and wheat:		Mainly done by women
Weeding:		Clearing manually
Harvesting:	Use combines and reapers – either their own or rented in. Men sometimes help if manual harvesting is carried out.	The manual harvesting of crops, including through women's local *perma* networks, when reapers are not available
Baling:	By hand	By hand
Threshing:	By machine, if available	By machine if they can pay hire costs. Otherwise by hand.

Absent menfolk – The traditional roles are changing, however, as many menfolk of the women farmers who were consulted were working outside Nepal leaving the women responsible for running the family farms including hiring in farm machinery services.

The usefulness of farm machinery – The main machines in use in the four study areas were 4-wheeled tractors, 4-wheeled tractor-powered threshers and 2-wheeled tractor reapers, self-propelled reapers and mini-tillers. There were fewer combine harvesters in Kanchanpur and Kailali than in Rupandehi and Kapilvastu. Discussions at the CSISA traveling seminar and the current study revealed how these machines save time and labor for small farmers and are increasingly used to carry out farm operations in Nepal. All the male and female farmers consulted agreed that power tillers, harvesting machines and seed drum rollers save time and labor costs.

High demand for machines – The three combines in the Kapilvastu study area and the two in the Dang study area are heavily booked throughout the harvesting seasons. Local farmers harvest their crops manually if a combine is not available. And there are about 200 self-propelled and 2-wheeled tractor reapers in the study areas, which is insufficient to meet the demand at peak harvesting times.

Men control machines – Despite the forward-looking policies in the country (see Section 3.2), women's needs and interests are often not considered when engine-powered machinery is developed, demonstrated, given market support and brought into use. As a result, these machines are almost all used and controlled by men.

Women's interest in acquiring and using agricultural machinery

The study identified the following types of women interested in farm mechanization:

- **Women heads of households** – A major concern of these women is managing the carrying out of farm operations. The shortage of labor means that they have to negotiate and manage the hiring in of machines to prepare land

and harvest crops. A number of women consulted by the study found it difficult to manage this.

- **Women farmers** – Some women consulted in Kanchanpur, Kailali and Dang were women farmers who were beginning to carry out their farm operations with small machinery themselves and even as service providers. A major concern was the need for more women-friendly farm machinery.

- **Women farmers who lease farmland** – These women who lease land are from small and poorer households. Some are ex-bonded laborers who have been allocated small plots by the government covering up to 5 kathas (0.17 ha), which is insufficient to provide their subsistence needs. They therefore lease land from farmers who have large holdings under the bag bandhi (mortgage), adhiya battiya (share cropping) and perma (community contribution of labor to farmers' fields) local systems as well as working part time as daily wage farm laborers.

Women's interest in mechanization – The study found that women are very interested in mechanization as a way of improving their livelihoods. In Hirapur, some remittance money goes to buy farm machinery. Women in this area were interested in learning how to purchase and hire out machines. Younger hill women were confident that once trained they could operate the machines, especially self-propelled reapers and even the large power tillers-2-wheel tractors. The experiences of the mini-tiller group in Dang suggests that women can operate powered machines if supported:

> *"If we can ride scooters, we can drive self-propelled reapers. We just need training!" – Woman respondent, Bhajuli, Rupandehi*

And some women do operate machines. The husband of a member of the Dhankhola Women's Group Cooperative in Dang said:

> *"I would not have been able to service so many farmers if our women had not taken turns to operate the mini-tiller during tilling operations."*

Some hill women, mainly Brahmins and Thakuris in Padampur, Kanchanpur are educated and said they can manage the hiring out of farm machines if they are supported. They said they had seen women organizing into agricultural development groups and being trained on leadership, bookkeeping and enterprise development. They suggested they could form groups and be provided with training and support and be supported to buy machines on a collateral-free basis as women do not own land to put as collateral.

Benefits to women farmers – Local women farmers and landowners spoke of how using or hiring in farm machinery saves them money and time and can make farming easier. In Hirapur, where many menfolk work and live away from home, women are seeing the benefits of mechanization as reapers and combines address the problem of the shortage of farm labor:

> *"We have to pay 500 rupees a day for hired labor and provide them with two meals. It takes 18 to 20 days if we have to use more than two or three persons for the harvest. It's costly; and even then, it's difficult to find labor. Laborers negotiate and don't want to work long hours. It is easier to hire in a reaper at 1,000 rupees an hour." – Women farmer, Hirapur, Rupandehi.*

> *"If I could spend less time worrying about labor, I could spend more time supervising my children's studies. I spend so much time managing the farm work as my husband is in Qatar." – Kunwar woman, Hirapur, Rupandehi*

> *"The harvesting of our crops by machine means my daughters-in-laws have more time to run their businesses. One runs a provision store and the other a beauty parlor," – Tharu woman land owner, Hirapur Rupandehi.*

> *"We saw the reaper-binder machine demonstrated by CSISA. It reaps the crop and ties it into bundles, which are easy to collect and transport. This is great for wheat, but rice needs to dry before it is bundled." – Women respondent, Tikapur, Kailali*

Women carry out subsidiary tasks – When grain is harvested by reaper, it is mostly women who carry out the subsidiary tasks of threshing and storing the grain and collecting the straw. These tasks are often done through collective community labor.

Drawbacks of machines – A number of informants at Hirapur and Kanchanpur said that the main drawbacks of using combine harvesters to harvest their wheat and rice were that they produce less straw (which is used for animal feed) and damage field boundaries:

> *"Combine harvesters waste a lot of straw by cutting crops too high. When we harvest manually, we cut close to the ground. The combine cuts almost a foot high and damages field boundaries, which we have to fix." – Women respondent, Hirapur, Rupandehi*

A woman from Patekhouli, Rupandehi, whose husband owned a combine harvester complained that it had resulted in his behavior taking a turn for the worst:

> *"I was happier before he bought the combine. Now he earns more, drinks more [alcohol] and beats me more!"*

Challenges and some solutions

The study identified a number of challenges for women to hire in and use agricultural machines.

Social and cultural barriers – Social and cultural factors hinder women's involvement in farm mechanization related to poverty, illiteracy, the patriarchal society and caste and ethnic-based marginalization. The traditional outlooks of many rural men do not even consider women using farm machinery. This hinders or prevents women heads of households from searching for and negotiating machinery services as it involves speaking with male service providers from outside their communities.

The hiring in of machinery services – The study found that many women farmers cannot afford to hire in farm machinery. Women from poor households who own less than about 10 kathas of land (0.34 ha) do not have the means to hire in 2-wheeled hand-held reaper harvesters. This was particularly evident in the discussions with women farmers in Tikapur, many of whom are freed bonded laborers. Also, some women landowners find it difficult to manage the process, organize labor and supervise the hiring in of services.

Women unfriendly machines – The main challenge that prevents women from operating farm machines relates to their lack of familiarity with machines and in some cases not having enough strength to use them. Many women struggle to start diesel mini-tillers (Figure 11). It should however be kept in mind that this may be due to lack of familiarity with using machines rather than a strength issue as many rural women are accustomed to carrying out hard physical work.

Figure 11. A woman farmer learning to start a diesel-powered mini tiller, Dhankhola, Dang, Nepal (CSISA).

A number of women said they can run diesel mini-tillers once someone helps them start them. The husband of a member of the Dhankhola Mahila Samuha cooperative in Dang, told how his wife and other women operate the cooperative's mini-tiller with his help:

> *They (the women) find it difficult to start mini-tillers so I start it for them and leave them to till the fields."*

Another issue is that the handlebars of diesel mini-tillers and other machines are set too high for women, who tend to be shorter, although this drawback also applies to shorter stature men.

Scale-appropriate machinery for women

The study also identified scale-appropriate machinery that is suitable for women to own and operate, including petrol powered mini-tillers and drum seeders (Figure 12). Switching from heavy diesel to lighter petrol driven mini-tillers and adjusting handlebar heights makes them easier to operate. Petrol powered mini-tillers are much easier to start than diesel powered tillers.

Also, scientists and engineers at the Regional Agricultural Research Farm at Kajura in Banke district told how the National Agriculture Research Centre (NARC) is adapting drum seeders to make them lighter and more women-friendly. Such machines reduce the time taken to seed fields and so benefit all farmers:

> *"Alternative technologies for rice cultivation like drum seed rollers have been tested in farmers' fields. It can overcome labor shortages and reduce the cost of cultivation. Rice farmers are interested in this technology." – Lokendra Khadka, CSISA Project*

> *"We are working on modifying manual weeders for vegetables and rice after taking feedback from users. Also, we have modified the drum seeder and it is now smaller and easier to pull." – Manoj Joshi. Technical Officer, Nepal Agriculture Research Centre*

3.6. Conclusions and Recommendations

The overarching problem identified by this study is that women's needs and interests are often ignored in decision-making in households, communities and projects in Nepal. It seems that the predominantly male decision-makers have little interest in the issues and needs of women landowners and farmers.

A key objective of most agricultural development projects is to empower women in agriculture. The following questions arise from the findings of this study on enabling the access of women to the benefits of agricultural mechanization:

- Could credit be provided to poorer farmers (including poor women farmers) so that service providers can be paid once harvested crops are sold?
- Could the woman's cooperative in Satbariya be replicated elsewhere in Nepal?
- Could women be trained on service provision and the operation and maintenance of petrol-powered mini tillers for tillage services?

Figure 12. Testing drum seed rollers for preparing rice fields.
Photos: Lokendra Khadka.

The solutions to the above questions and the implementation of the following recommendations would increase women's participation and benefit sharing from the mechanization of agriculture and suggest areas of intervention for future support programs.

Further studies – This paper reports the findings of a brief rapid study. More in-depth studies are needed on gender and the use of agricultural machinery and the disaggregated benefits of agricultural development. There is a particular need to study technologies like reapers to see how scaling trajectories can be modified and benefits spread more widely. There is also a need to better understand who benefits from the mature mainline technologies.

Improve women farmers' and landowners' access to services and businesses:

- Empower women and change communities' attitudes to women operating machinery though training and awareness raising.
- Promote women's ownership and management of harvesting machines through public service announcements, training support and prioritizing women and their groups for loans and subsidy programs.
- Develop materials in local languages to train poor women and women heads of households on negotiating the hiring in of agricultural machine services.
- Support women to access loans and produce simple business plans for buying machines.

Skill building – Build the skills of women to operate and hire out machines:

- Produce extension materials on all types of machines targeting women farmers and landowners.
- Develop women's numeracy and business skills around farm machinery.
- Produce technical training material for women machinery operators and owners.
- Support cross-learning visits and interactions with other women farmers to exchange, learn and adapt methods.
- Promote women-led custom hiring businesses.

Other issues and support

- Consult women farmers on the design of agricultural machines and adapt them accordingly.
- Include well-informed women as decision makers on agricultural development projects.
- Create a database of women farmers and women farmers' groups who are interested in interventions by CSISA and other agricultural mechanization projects.
- Orientate the staff and stakeholders of agricultural development projects on gender analysis and include gender responsive indicators and interventions in their projects.
- Promote the use of household and small farm level machines for processing crops to enhance the livelihoods of rural women.

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CHAPTER 4

Agricultural Mechanization Policy Issues in Bangladesh

M. A. Sattar Mandal

Summary: This paper reviews current policies and issues that need addressing to promote the further mechanization of ploughing, transplanting, seeding and harvesting operations on farms in Bangladesh. The paper presents a series of policy recommendations that address the main challenges to the spread of farm mechanization. The implementation of these recommendations would i) encourage the spread of the use of agricultural machines, ii) improve the system for providing subsidies to buy machines, iii) achieve economies of scale in operating machines on the country's small and fragmented landholdings, iii) foster research and development for farm mechanization and iv) expand the domestic manufacturing of agricultural machinery.

4.1. Introduction

This paper reviews current policies and identifies a number of issues that need addressing related to the rapid pace of agricultural mechanization in Bangladesh.

The increasing mechanization of agriculture in Bangladesh is mainly due to:

- the shortage of male agricultural labor – by about 40 percent during critical farm operations;
- the movement of rural youth from farm to non-farm employment and from rural to urban areas and their widespread migration abroad; and
- rural youth becoming less interested in performing laborious and uncertain seasonal agricultural jobs.

The resulting increases agricultural wages, by about 6 percent a year, has pushed up the cost of rice production to make it unprofitable for some farmers who depend on hired labor.

Farm mechanization has also been prompted by the improved efficiency and productivity it usually brings. Appropriately scaled mechanization can maintain domestic food grain self-sufficiency in spite of the current average 0.5 percent annual loss of arable land. Also, the increasing incidence of floods and cyclones is prompting the more rapid carrying out of critical activities, such as the quick planting of crops after flood waters recede and the speedy harvesting of crops before forecasted flash floods occur.

This paper highlights the urgency of accelerating agricultural mechanization in Bangladesh. It first describes past policy initiatives and emerging issues. It then discusses the current status of agricultural mechanization, the spread of machines, economies of scale, subsidy management, research and development, the growth of the in-country manufacturing of machines, areas of special focus and institutional capacity building.

4.2. Current Status of Mechanization

There are more than 700,000 two-wheeled tractors, 35,000 four-wheeled tractors, 400 rice transplanters, 500 reapers and 200 mini combine harvesters in Bangladesh (Alam 2016; Mandal *et al.* 2017). An employee of the farm machinery supplier ACI Motors Ltd (Figure 13). recently reported that the number of reapers in the country had surpassed 5,000 and there were more than 2,000mini combine harvesters. Another leading farm machinery supplier (The Metal Pvt Ltd) reported that 8,000–9,000 tractors and 50,000–60,000 power tillers are imported into Bangladesh each year (Zamil 2019). In addition, much locally-made small equipment is in use on Bangladesh's farms including centrifugal pumps, maize shellers, sprayers, driers, threshers, weeders and potato graders.

Irrigation, tillage, land preparation, threshing and pesticide spraying are now almost entirely mechanized with transplanting, seeding and harvesting yet to be fully mechanized. The latter are critical farm operations and this 'missing link' needs urgently addressing (Mandal 2016). In 2019, the government responded to the severe labor shortages for harvesting and the falling price of boro paddy (irrigated paddy grown between December/January and May/June) by increasing the budget for subsidizing the purchase of harvesting and planting machines.

Figure 13. A transplanter planting rice in Gazipur, Bangladesh. (ACI Motors Ltd.).

4.3. Policy Review, Needs and Constraints

Agricultural mechanization in Bangladesh was initiated by the public sector introduction of heavily subsidized low-lift pumps and deep tube wells for irrigation in the 1950s, and four-wheeled tractors for addressing the draught power shortages that resulted from natural calamities in the 1970s. The first concerted efforts towards farm mechanization came from the government's mechanized cultivation and power pump irrigation scheme in the early 1950s. Mechanized irrigation picked up mostly with shallow tube wells imported by the private sector following the liberalization of the equipment market in the late 1980s. Import restrictions were withdrawn, import duties reduced and pump spacing regulations scrapped. The market was flooded with affordable Chinese engines and two-wheel power tillers (see Mandal *et al.* 2017: 83-87 for a detailed illustration of the policy pathways to mechanization). The resulting rapid adoption of mechanized tillage and irrigation was a key driver to increasing rice acreage and yield and attaining self-sufficiency in food grains. As various types and makes of machines were increasingly used by farmers, in 2015 the government prepared an agricultural mechanization roadmap to the years 2021, 2031 and 2041 as the basis of its agricultural mechanization policy. The government's high-level commitment and the parliamentary standing committee on agriculture for promoting sustainable mechanization have been other notable initiatives (BARC 2016).

The government's agricultural mechanization policy encourages efficient, profitable, and sustainable commercial agriculture and encourages rural youth to take up modern farming as a prestigious and profitable profession (Figure 14). The policy promotes farmer-friendly cost-effective agricultural machinery that is appropriate to the scale of operations across the country's diverse small and fragmented landholdings and diverse soil types and moisture conditions.

Amidst the diversification of Bangladesh agriculture from growing staple crops to growing other crops, the scope of agricultural mechanization needs to be broadened to encompass machines for pond fish production; dairy, cattle and poultry rearing; floriculture and orchards. For example, fruit production needs drip irrigation systems, milk production needs milking machines and fish farming need auto-sensor aerators for maintaining oxygen levels in ponds.

A major challenge to farm mechanization is to gain economies of scale in the use of machines in a situation where most farms are fragmented in scattered small plots. This is more complicated as farmers choose different varieties of crops at different times resulting in different planting and harvesting times by different farmers. The challenge is to get the farmers of tiny plots to synchronize their operations to facilitate machine use. Machine service providers are working for 'operational consolidation' through the custom hiring of their machines (Mandal *et al.* 2017: 78). Other constraints confronting agricultural mechanization are i) farmers' limited access to bank loans and subsidies for buying machines; ii) inadequate after-sales services and iii) the shortage of skilled machine operators. Also, local machinery manufacturers need more capital machines for making machines and more skilled workers to produce quality machines and spare parts.

Figure 14. **A combine harvester harvesting rice in Manikganj, Bangladesh.** (ACI Motors Ltd.).

4.4. Policy Issues

The spread of agricultural machines

A key policy issue is how to popularize and disseminate appropriate machines to farmers and service providers. The first requirement is the availability of appropriate, affordable and user-friendly machines. For this, the Department of Agricultural Extension needs to demonstrate locally manufactured and imported machines to farmers on farmers' plots. Hands-on training for operators is also essential.

The Bangladesh Bank circular on advancing equipment loans is hardly implemented or monitored (Das 2019) and there is also an urgent need to provide more bank loans for buying expensive agricultural machines. The existing provision of allowing duty free import and levying modest taxes on imported and local equipment should continue. Agricultural extension services, including those related to livestock and fish production, need strengthening through increased human resources and budgetary provisions so that they can popularize appropriate farm machines.

The creation of machinery service providers is a leading policy issue. One option is for the government to establish local machinery service centers and later transfer them to the private sector. This requires setting up training facilities, providing credit support and raising awareness among rural youth who are the prospective service providers. The custom hiring of machines can be popularized by strengthening technical capacity and business development services. ACI Motors Ltd. and The Metal Pvt Ltd, who are the main suppliers of farm machines, have developed comprehensive after-sales services through networks of trained mechanics. Training facilities for researchers, extension workers and private entrepreneurs need expanding within universities and agricultural research centers.

Box 2. Recommendations to improve the subsidy system for purchasing farm machinery in Bangladesh

- Introduce the online submission and processing of farmers' applications to reduce processing time and to bring more transparency to the subsidy scheme.
- Attach barcodes to all imported machines to verify the delivery of machines.
- All importers enlisted for the subsidy scheme should be required to submit data to the Department of Agricultural Extension on the number and types of machines they import.
- Suppliers should be required to prove they can provide after-sales and machine rental services to be enlisted in the subsidy scheme.
- Subsidies should only be provided to purchase certified quality machines.

Subsidies for purchasing machines

The government's present subsidy system covers the purchase of imported mini-combine harvesters, reapers and transplanters, and locally made equipment such as threshers, seeder and foot pumps. The subsidy amounts to at least 50 percent of cost, with disadvantaged areas such as haor areas (vast perennial waterbodies), charland (sand bars), the coastal region and hill areas entitled to 70 percent subsidies. The distribution of these subsidies is implemented by the Department of Agriculture Extension. However, the selection of farmers and service providers for receiving subsidies is a long and cumbersome process resulting in many deserving farmers not being selected. Box 2 provides suggestions for improving the subsidy distribution system now that the government has committed to increasing the number of harvesters and transplanters in the country.

Besides, since providing subsidies is expensive and difficult, the level of subsidy should be reduced or even withdrawn later as the machines become part of farming systems. For example, in the past the purchase of power tillers was subsidized, but the subsidy was withdrawn as they became popular and farmers could afford to buy them at the full market price.

Achieving economies of scale in operating machines

The under-use of machines due to the seasonality of operations and the small fragmented holdings discourages service providers from investing in machines. It is inefficient to use larger machines on small widely scattered holdings. To overcome this challenge, service providers try and develop contractual arrangements with farmers to synchronize ploughing, land preparation, planting and harvesting operations for adjacent farmers at the same time. In some cases, service providers offer special rates or extra services (e.g. free threshing with reaper services) as incentives for the 'operational consolidation' of areas. The provision of low interest credit and subsidizing the cost of diesel for providers are policy options to enlarge operational areas. Other options include promoting the synchronized cultivation of crop varieties and their planting, fertilizing and harvest times. Bank loans for facilitating land leasing and contract farming should also be provided to promote economies of scale in operating larger machines such as rice transplanters, combine harvester and drip irrigation sets.

Research and development for mechanization

A range of measures need taking to foster research and development for farm mechanization in Bangladesh (see Box 3):

Box 3. Recommendations to foster research and development for farm mechanization in Bangladesh

- Provide higher level training, improved laboratory facilities and increased budget support for farm mechanization-related research.
- Encourage coordinated research by research institutes and universities involving private sector manufacturers. Note that there are about 20,000 large metal workshops in Bangladesh of which about 800 are formally registered.
- Increase the capacity of the metal workshops through skill training, apprenticeships, support to acquire machines to manufacture machines and equipment and business development with cooperation from development partners such as CIMMYT's Cereal System Initiatives for South Asia Mechanization and Irrigation (CSISA-MI) project.
- Strengthen the policy environment to facilitate and protect intellectual property rights for machinery innovations.
- Encourage entrepreneurs to invest in research in coordination with quality standardization and training on machine use.
- Build partnerships between developing and developed countries for technology transfer.
- Polytechnics, vocational institutes and technical schools should run more diploma courses in agricultural mechanization to train mechanics and improve after-sales services.
- Build and maintain an agricultural mechanization database to inform the improved planning of agricultural mechanization.

Expansion of the agricultural machinery industry

The foremost policy need to expand the country's agricultural machinery industry is to treat agricultural machinery manufacturing as an agro-based industry so that the sector can access the fiscal benefits the government gives to the agro-industry. The recommendations in Box 4 lead on from this:

Box 4. Recommendations to expand the domestic production of agricultural machines in Bangladesh

- Reduce import duties on machinery setup to increase the capacity of foundries and thus improve the quality of machines and spare parts.
- Encourage the local assembly of agricultural machinery alongside continuing to rebate duty on spare parts.
- Rationalize the list of value added tax and duty rebates on agricultural machinery and spare parts in consultation with stakeholders.
- Rationalize the duty structure on imported machinery considering the cost of locally produced machines and the prospect of the local manufacturing of high-quality machines; wherever possible encouraging joint ventures.
- The government should extend technical and financial support to establish agricultural machinery manufacturing zones and strengthen existing machinery hubs in places like Bogra, Jessore and Sylhet.

However, Bangladesh's capacity to manufacture agricultural machinery remains a point of discussion. There is a sizable in-country capacity to manufacture simple adequate-quality machinery including threshers, shellers and centrifugal pumps. But the Department of Agricultural Extension and farmers complain about the poor quality of locally produced more complicated machines such as Bangladesh Agricultural Research Institute (BARI)power takeoff seeders, reapers and also about some imported combine harvesters.

Rangpur is famous for manufacturing centrifugal pumps, Bogra is renowned for its manufacturing of spares for single cylinder diesel engines and small transmissions for power tillers. It is estimated that 40–50 percent of power tiller parts are made in Bangladesh. But there is little or no manufacturing of sub-assemblies or whole engine transmissions.

The government needs to encourage the country's agricultural machinery industry by providing loans, training and study tours to encourage larger companies to adopt modern manufacturing methods whilst smaller companies supply parts and sub-components. Thailand's agricultural machinery industry is a good example to follow as its policies and programs jump-started the manufacturing of two-wheel tractors and combine harvesters there. The Ministry of Agriculture should partner with the Ministry of Industry to encourage these developments.

One simple illustrative experiment would be for a research institute or university to purchase spare parts made in Bogra, Bangladesh for engines and transmissions and assemble them to illustrate just how many local components is already produced in country. Then import the remaining components to produce the first Bangladesh made machine such as a 2-wheeled tractor power tiller.

Areas of special focus

The following areas of rural mechanization also need policy attention and encouragement to address the growing impacts of climate change and the increasing cost of fossil fuels:

- The use of renewable energy to power irrigation pumps, driers and lighting systems in agro-processing.
- Conservation agriculture, which encompasses zero or minimum tillage for better plant growth and minimum top soil disturbance.
- Smart or precision agriculture, which use remote sensor-based machines such as drones, fish feeders and re-circulatory aquaculture systems.

And the following agro-ecologically unfavorable locations need specific mechanization efforts and tailor-made machinery:

- The Haor regions, which frequently suffer from flash floods and hail and thunder storms.
- The coastal belt, which is affected by tidal surges, salinity, and submergence.
- The sandy soils of the Char lands.
- The hill areas with their uneven topography.
- The drought prone Barind tract.

As the private sector is reluctant to invest in the mechanization needs of these areas due to uncertain returns, the government should implement special policy thrusts for the provision, delivery, and marketing of agricultural equipment for these areas. A 70 percent subsidy is already provided for buying agricultural machinery in these areas.

Institutional interventions

The sustainable implementation of agricultural mechanization needs strong institutions to foster, monitor, encourage and impose standardization and certification for appropriate machines and to foster coordination and cooperation between different agencies.
The following public sector institutions have played a lead role in agricultural mechanization in Bangladesh:

- The Bangladesh Agricultural Development Corporation (BADC) and the Bangladesh Water Development Board (BWDB) are the mainstream organizations for introducing mechanized irrigation using tube wells and low-lift pumps.

- The Bangladesh Agricultural Research Institute (BARI) has been involved in developing and testing farm machinery, although their dissemination has not been as widespread as expected.
- The Bangladesh Rice Research Institute (BRRI) develops rice transplanters and reapers.
- The Bangladesh Sugarcane Research Institute (BSRI) has developed small machines such as sugarcane crushers.
- The Bangladesh Agricultural University (BAU) has developed and improvised drier, urea super granule (USG) injectors, seeders, threshers and other machines.

As the large-scale privatization of minor irrigation and tillage operations took place in the 1980s, many privately run workshops started manufacturing small equipment, such as threshers, using designs from BARI, BRRI and BAU. Pumps and spare parts and accessories made locally by private companies helped foster the expansion of mechanized irrigation and tillage services.

4.5. Conclusions

The Government of the People's Republic of Bangladeshis proactive and positive about promoting agricultural mechanization. The Ministry of Agriculture emphasized the urgency of agricultural mechanization through its parliamentary standing committee in 2012 and its roadmap for agricultural mechanization in 2015. It is now finalizing its agricultural mechanization policy. At the same time, it has increased the budget to subsidize the purchase of agricultural machinery and is willing to provide more resources for well-implemented mechanization programs.

Private sector importers, distributors and local manufacturers are also contributing to agricultural mechanization. They popularize their planters, mini combine harvesters, threshers and other products at machinery fairs and in other ways. A better-calibrated subsidy program will make machines more affordable including the larger machines that are often more reliable and give greater returns on investment.

Overall, appropriate scale farm mechanization should be promoted by providing farmers and service providers with easy access to low interest finance to buy handy and durable machines. And users need easy access to quality mechanics and machine operator services to support the smooth functioning of their machines. There is a particular need to improve the provision of mechanic training at the local level and to make available appropriate tools and equipment.

Other overarching policy recommendations are to:

- facilitate women's use of farm machinery;
- provide easy access to credit for educated rural youth and women to develop their farms; and
- provide bank loans to machinery manufacturers, farmers and service providers to buy machines.

Finally, it needs to be stressed that the increased use of machines for farm operations, although it will reduce the marginal costs of production, will not alone ensure profitable farming. Rice farming remains the core of Bangladeshi agriculture and needs an improved policy environment with respect to rice procurement, the import and export of food grains, technology adoption and an improved energy policy.

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Mechanization of Crop Harvesting and Residue Management in India

Anil Menon

Summary: The use of combine harvesters to harvest rice and wheat has spread across India with wheeled harvesters used in the north, west and center, and tracked and tractor-mounted harvesters in the south and east. Farm operations are least mechanized in central and east India. Almost all India's combine harvesters are owned by contractors who move between states following the rice and wheat harvests. The government promotes this service provision model to make mechanized farm operations available to farmers. And mechanization is extending to the harvesting of other crops using multi-crop harvesters. The paper also discusses how an increasing number of straw balers are coming into operation, especially to bale rice straw in north India where the burning off of straw is a major cause of air pollution. The central and state governments are addressing the remaining challenges to farm mechanization by promoting custom hiring centers, providing subsidies to promote mechanization, promoting testing and certification centers, and encouraging corporate farming.

CHAPTER 5

5.1. Farm Mechanization in India

The use of combine harvesters to harvest rice, wheat and to some extent soya beans has spread across India in recent decades. The other farming operations of sowing, planting, weeding, inter-cultivation and plant protection have seen a much lower level of mechanization. This paper presents a broad overview of the mechanization of harvesting and residue management in India.

The two main kinds of harvesters in use in India are self-propelled harvesters, which are powered by their own engines, and tractor-mounted harvesters, which are powered by tractors. There are in turn two types of self-propelled harvesters – wheeled harvesters, which are mostly used in the northern, western and central states, and tracked (track) harvesters, which are mostly used in the southern and eastern states. This division is indicated by the oblique line on Figure 15.

About 2,500 wheeled harvesters and 900–1,200 tracked harvesters are sold each year across India. Tractor mounted harvesters are mainly used in south and east India with about 2,000 units sold each year. Note that these are estimated sales figures as there is no formal source of information on combine harvester sales in India. The various types of combine harvesters cost between INR 1.6 and INR 2.8 million ($22,000–$39,000).[4]

Among the various manufacturers, CLAAS, with its range of self-propelled tracked and wheeled harvesters, has been a pioneer of mechanized harvesting in India since 1991.[5] Its wheeled harvesters have multi-crop capabilities and can harvest rice, wheat, maize, soya beans and pulses. Other leading brands of combine harvesters in India are the made-in-India Preet, Kartar, Vishal, Swaraj and New Holland machines and the imported John Deere, Kubota and Yanmar machines. Note that the rest of this paper only mentions machines made by CLAAS in line with the author's experiences.

As to the level of harvesting mechanization, there is a good penetration of harvesters in the region around Punjab in the north (mainly for harvesting wheat and rice) and in the southern states of Andhra Pradesh, Telangana,

4 At October 2019 exchange rate of $1:INR 71.

5 See company website at: https://www.claas.co.in/

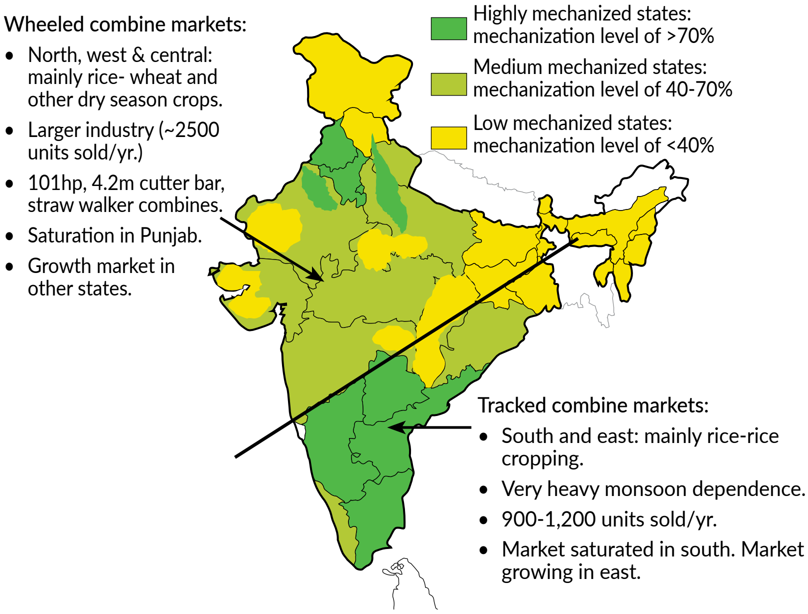

Figure 15. Level of crop harvesting mechanization across India.

Karnataka and Tamil Nadu (mainly for harvesting rice). The penetration of combines into Madhya Pradesh in central India is increasing rapidly for harvesting rice, wheat and soya beans. Much of central and east India has low to medium levels of harvesting mechanization. The areas shaded in green on Figure 1 have the highest level of mechanization and the areas in yellow the least.

5.2. Combine Ownership and the Migrations of Contractors

Almost all of India's combine harvesters are owned by contractors who harvest farmers' fields on a per acre basis in the north and a per hour basis in south and east India. These contractors move between states following the harvests to make full use of their expensive machines seeking a better return on their investments. This has increased the availability of harvesters to farmers, almost all of whom are unable to buy their own machines.

Figure 16 shows the current pattern of the migration of combine harvester contractors across India mainly following the rice and wheat harvests.

A major migration pattern since the combine harvesting of crops took off in the 1990s has been of self-propelled wheeled combine contractors from the Punjab to harvest rice, wheat, and soya beans across west, central, and north India. This is changing however as the local ownership of combines in Gujarat in the west, Madhya Pradesh in central India and Uttar Pradesh in the north is increasing with government support, reducing the extent of migration of Punjab contractors. Contractors who own tracked harvesters in the south migrate to other states in the south and east of India. The increasing ownership of harvesters in Odisha in eastern India has reduced the in-migration of contractors from the South. And the combine harvesting of crops is increasing in West Bengal alongside increased local ownership of machines.

Combine harvesting is yet to take root in the major rice growing area of Assam in the northeast although a few tracked harvester contractors have started moving the very long distance there from the south during rice harvests attracted by the high hiring rates.

Alongside these developments, in central India, innovative startups like EM3 Agri Services,[6] function as aggregators of equipment, with a field team on the ground to tap farm equipment demand from farmers. They offer end-to-end farming solutions on a pay per use model.

5.3. Custom Hiring Centers

The Sub-Mission on Agricultural Mechanization (SMAM) is a government scheme that started in 2014/15 under the Ministry of Agriculture and Farmers' Welfare. It promotes farm mechanization by:

- offsetting the adverse economies of scale that arise from the small landholdings and the high costs of individual ownership of machines;
- providing small and marginal farmers access to farm mechanization through custom hiring centers;
- creating hubs for hi-tech and high value farm equipment; and
- increasing awareness among stakeholders through demonstrations and capacity building.

While the central government provides a broad policy framework for custom hiring centers, the scheme is implemented by state governments in line with local conditions and requirements.

One example of the spread and successful emergence of custom hiring centers is in Karnataka in south India. This has happened as i) there is no requirement for centers to be owned and managed by cooperatives or farmer groups, ii) private companies that can provide rental services and maintain their equipment are allowed to start centers directly or through their dealers, and iii) centers can run on a commercial basis with market-driven hiring rates.

In Karnataka, custom hiring centers that mainly provide harvesters are profitable with good hiring rates. However, it is difficult for centers to be profitable that mainly hire out tractors and implements on account of their low hiring rates (about INR 500 to INR 800 per hour – $7 to $11/hr, depending on type of operation) as the many tractors in the state drive these rates down.

A few manufacturers have set up custom hiring centers. For example, CLAAS has 35 such centers in Karnataka, which are owned and managed by CLAAS dealers with CLAAS being responsible for the quality of service delivery. In addition, CLAAS has sold harvesters to non-CLAAS dealer-managed custom hiring centers in Karnataka, which are also successful. Note that under the Sub-Mission on Agricultural

[6] See: http://www.em3agri.com/

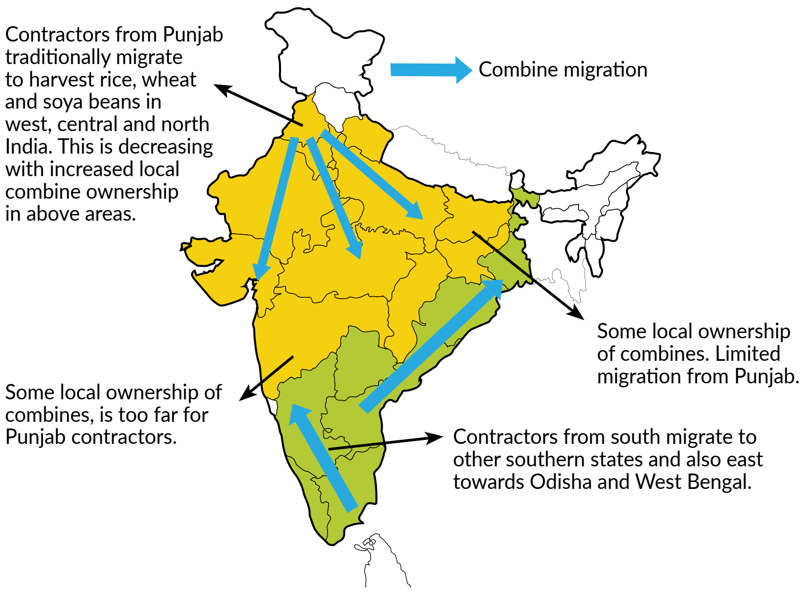

Figure 16. Traditional combine harvester migration across India.

Mechanization, custom hiring centers receive 40 percent subsidy support to buy farm equipment.

Madhya Pradesh and Rajasthan are also implementing custom hiring centers. And Odisha has its own initiative based on the custom hiring center model. However, not all programs are equally successful. There have been instances where equipment has been procured just because a subsidy was available without regard to whether the equipment could be profitably deployed.

Custom hiring centers need to be commercially viable with the right package of equipment and freedom to charge market rates for their services. A suitable enabling environment and effective monitoring by state departments of agriculture are essential for successful custom hiring center programs.

5.4. The Mechanized Harvesting of Other Crops in India

Mechanization is extending to the harvesting of other crops. Maize is the third most important cereal crop in India after rice and wheat. The lack of high quality appropriately-sized harvesters means that about 90 percent of India's maize crop is still harvested manually and then threshed using stationary threshers. To address this gap, in 2019 CLAAS introduced the CROP TIGER 40 Multicrop harvester (Figure 17). It has interchangeable maize and grain headers and can harvest a range of crops including maize, pulses, soya beans, wheat and rice. This makes it a profitable investment for contractors and a very suitable machine for custom hiring centers. This machine costs about INR 2.7 million ($37,000) including the 4-row maize and 2.6m grain headers.

Figure 17. CROP TIGER 40 Multicrop Harvester. (CLAAS India).

5.5. Crop Residue Management

Crop residue management is an important issue in India. In north India, wheat straw is mostly collected by straw reapers and used as cattle feed while rice straw is traditionally burned causing air pollution, which affects far away cities including Delhi. The burning off of rice straw was banned in 2018 in the Punjab and neighboring states, but enforcement is a challenge in the absence of cost effective and comprehensive crop residue management solutions. Wheat is not grown in the south and so rice straw is mainly used as cattle feed there meaning that straw burning is not a serious issue in the south.

The baling of straw is increasing in the Punjab as the state government is encouraging investments in biomass power plants for which rice straw is an important source of fuel. In addition to the standard square balers, larger round balers are growing in popularity in the Punjab.

Nationwide, the central government has advised the country's largest power producer, the National Thermal Power Corporation, to use rice straw pellets and other agricultural residue to generate electricity. This has increased the demand for balers to collect straw.

The baling of rice straw is being rapidly adopted in the south, particularly in Tamil Nadu where small round balers are popular. The bales are mainly used for cattle feed. However, the adoption of mechanized baling lags behind in central India.

Several makes of imported and locally produced balers are available. CLAAS produces the MARKANT range of square balers, which cost about INR 1.1 million ($15,000).

Other straw management solutions promoted by central and state governments are:

- combines fitted with straw choppers;
- happy seeders, which are tractor-mounted machines that cut and lift rice straw, sow wheat seeds and deposit the straw over the sown area as mulch, all at one pass; and
- the incorporation of rice straw into the soil by moldboard ploughs.

The large volume of crop residues generated after harvests mean that a combination of solutions need deploying to effectively manage harvesting residues.

5.6. Conclusions

While there has been a large increase in farm mechanization in India, several challenges remain. Small and scattered land holdings, poor quality farm equipment, inadequate after-sales services, the lack of knowledge among farmers about government schemes to promote mechanization and inadequate financing options are the most pressing obstacles. However, measures are being undertaken by the central and state governments to address these challenges by promoting custom hiring centers, providing subsidies to promote mechanization at all levels of the value chain, better equipped testing and certification centers, and policies that encourage corporate farming.

In coming years, the benefits of farm mechanization will reach more and more farms of all sizes without them having to own or operate machinery. Modern, high quality equipment like laser land levelers, reversible ploughs, forage harvesters, balers, harvesters with GPS and performance tracking devices, and the use of drones, call-centers and app-based rental services are some modern means by which farm mechanization will extend across the country.

CHAPTER 6

Spread of Small Harvesting Machinery on Small Farms and Residue Management in Sri Lanka

Melvin Samarsinghe

Summary: The proportion of Sri Lanka's rice growing land that is mechanically harvested has grown from 5 percent in 2000 to 92 percent in 2015 with combine harvesters harvesting 72 percent of this area. The main type of machine in use has evolved from threshers to reaper heads on walking tractors and self-propelled reapers via tractor-coupled combine threshers, wheeled and ride-on combine harvesters to tracked combine harvesters. In 2018 tracked combines harvested 72 percent of Sri Lanka's rice fields. Their popularity is due to their ability to thresh and reap rice on both wet and dry fields and the cleanliness of the harvested grain. The paper compares the performance of the different types of machines and discusses the issues facing the further mechanization of rice harvesting in Sri Lanka including the need for more training of machine operators, the benefits of levelling fields, the benefits of having a straw chopping mechanism on combines.

6.1. Introduction

Rice is grown on 650,000 ha or 14 percent of Sri Lanka's arable land across diverse conditions. Since the year 2000 the government has encouraged the mechanization of agriculture and has supported the increased production of rice by improving irrigation systems and providing free fertilizer and high yielding varieties of rice to farmers.

Figure 18. Combine harvesting lodged rice in Kudawewa, Sri Lanka in 2018. Photo: Melvin Samarsinghe.

Up to 2002 most mechanization was for preparing land using machines with an average horse power (hp) of 2.2 hp/ha (FMRC 2000). There has since been rapid mechanization of rice harvesting. The proportion of rice growing land harvested mechanically increased from only 5 percent in 2000 to 92 percent in 2015. As of 2018, combine harvesters harvested 72 percent of this area with the remaining areas harvested by combine threshers (11% of the area), buffaloes (6.8%), small threshers (4.8%) and tractors (3.7%) (DoCS 2018) (Figure 18). The level of mechanization in the rice sector in 2015 was 3.9 horsepower per hectare harvested (Samarasinghe, unpublished).

In a normal year with good rainfall, the country produces all its rice needs across its Yala (May to end of August) and Maha (September to March) monsoon seasons. The mechanization of harvesting has greatly reduced the amount of labor needed to harvest these crops. Prior to 2000, the harvesting of a hectare of rice took about 120 person-hours while the current mechanized harvesting takes only 2.5 to 3.5 person-hours per hectare (Epasinghe *et al.* no date).

The average size of Sri Lankan land holdings has changed little in recent times. In 1982, the 4.8 million ha of agricultural land was divided into 1.8 million holdings with an average size of 0.78 ha with 42 percent of holdings less than 0.4 ha, 22 percent less than 0.4–0.8 ha, 14 percent between 0.8–1.2 ha and 22 percent between 1.2–8 ha in size (Guntze 1986). The 2002 agricultural census reported that 81.7 percent of rice land holdings were less than one hectare, 15.7 percent were 1–3 ha and only 2.7 percent were 2–8 ha (DoCS 2002).

6.2. Evolution of Mechanized Harvesting in Sri Lanka

Between 2000 and 2015 the harvesting of rice transformed from predominantly manual to predominantly machine harvesting triggered largely by labor shortages in the agriculture sector. Machine harvesting started on large rice fields (5–8 ha) in the Eastern Province and then spread to the North Central and North Western Provinces. In the initial phase tractors and combine threshers were used followed by 2-meter wheel-driven harvesters. Farmers selected harvesters based on their size, speed, and cost. In the same period, small Chinese harvesters, reapers and threshers were used on the smaller fields that were difficult for large machines to access. In 2002, a 1.2m reaper took 10 hours to harvest one hectare while the small 1.2m width 15 hp Chinese combine harvester could harvest one hectare in 6 hours. Wheel-driven John Deere harvesters harvested one hectare of larger fields in only two hours.

The spread of this machinery was at first mostly influenced by the ability of farmers and service providers to buy machines. By 2009 the main criteria had become the cleanliness of the harvested rice and the ability to thresh and reap rice on both wet and dry fields. Around this time, some farmers used large combine threshers coupled to 45 hp tractors to thresh lodged rice while tracked harvesters were also tried out.

The spread of harvesting machines accelerated from 2007 with the introduction of tracked machines. The limitations of the small harvesters and wheel-driven harvesters (bulkers) led farmers to seek more durable machine that could work on both wet and dry fields with minimal grain losses. These features were not prominent in wheel driven harvesters (bulkers) and other machines. Farmers were thus attracted to Chinese tracked harvesters, which were only a little more expensive than the wheel driven harvesters. The Kubota, Yanmar, CLAAS, and New Holland machines made in China and India also had these features and entered the market. The machines were mostly sold under hire purchase through private finance companies.

Machines designed to harvest large fields were not adopted because of their too large turning circles and low ground clearance. Other machines were unsuitable for local soil conditions. As of 2018, the Chinese tracked harvesters, which cost about $20,000, held the major share of the market. The Japanese and European brands, which are made in China and India, sell for about $40,000 and are becoming more popular as the Chinese machines are less efficient and less durable.

6.3. The Spread of Harvesters in Sri Lanka

The main external factors that led to the mechanization of rice cultivation in Sri Lanka are the increasing cost of rice, the increasing area of rice grown (from 521,000 ha in 2004 to 651,000 ha in 2009 (DoCS 2009) and the movement of many agricultural laborers to urban areas and foreign employment. The main internal factors have been the increased wages of agriculture laborers – from 500 Sri Lankan rupees (LKR) to LKR 1,500 per day ($2.8–$8.4/day),[7] the outsourcing of field operations and the shortage of male labor following the 2004 tsunami.

The growth in demand for machinery has led to 14 importers now offering a variety of brands of harvesting machines. It is important to note that some dealers have sold inappropriate machines without test certificates to farmers, which led to farmers losing their investments and harvests.

The most popular harvesters are the Japanese Kubota and Yanmar machines and the Chinese Agrotech, Mubota, Singer; and Edgro machines due to their good after-sales service. These brands are popular as they are certified and meet farmers' needs. The Japanese combines and the European CLAAS and American John Deere harvesters are more durable than the Chinese combines, which last only about five years. Nevertheless, the Chinese machines have the biggest market share due to their lower cost.

The engine capacities of combines used in Sri Lanka range from 70 to 100 hp with 2–2.2 m cutting widths. Farmers are attracted to buy machines with offers such as trips to China and free spare parts and gift vouchers.

6.4. Types of Rice Harvesting and Threshing Machines

Different types of machines have been used for harvesting and threshing rice. The following describes the evolution of the main types of machines that have come in and out of use in Sri Lanka.

Threshers

Previously, tractors and animals were used to thresh rice crops by pounding and separating the grain from the straw. In 1974, a portable axial flow thresher developed by the International Rice Research Institute (IRRI) was introduced in Sri Lanka, followed soon after by tangential flow threshers. In 1970 to 1980 period these threshers were preferred to tractor threshing as they caused less grain breakage. Three main sizes of axial flow thresher are offered by the Jinasena Company (Table 5). These are carried to threshing fields on bamboo poles where it takes an average of 22 hours to thresh a hectare of rice. The carrying of the bundles to the threshing field takes 20–25 hours per hectare. Nowadays these machines only thresh about 5 percent of rice cropping land, mostly in the wet hill areas.

[7] Exchange rate on 2 September 2019: $1:LKR 179

Table 5. Different sizes of axial flow threshers.

Capacity kg/hr	Drum size di. x length	Horse power	Weight
500	496 mm x 500 mm	3 hp	112 kg
600	500 mm x 700 mm	5 hp	135 kg
800	500 mm x 975 mm	7 hp	150 kg

Source: Jinasena agriculture machines product catalogue (year not available)

The Jinasena threshers use rubber pads for threshing, which are easily replaced when worn out often by pads made from old tires. Local industries manufactured 1,200-2,000 of these machines per year in the 1980s and 1990s, which sold for about LKR 35,000 ($195).

Reaper Heads on Walking Tractors and Self-Propelled Reapers

In 1984, the reaper was the first machine used by Sri Lankan rice farmers to harvest their crops. These locally made Agrimec reaper heads were coupled to two-wheeled tractors and had 1.2m head cutter blade sets that could reap 0.35 ha per hour.

Figure 19. **A self-propelled Agrimec reaper.** (Jinasena Pvt Ltd).

Around 2006, self-propelled lightweight Korean reapers and Japanese Kubota reapers were introduced that could harvest 0.2–0.3 ha/hr (Figure 19). These machines cause little grain loss – usually 5 percent and as low as 1–2 percent depending on the grain's moisture content. Their capacity is affected by machine width, forward speed, cutter bar velocity and grain moisture content. They can harvest a hectare of rice in 4–5 hours compared to 35 person days for manual sickle harvesting. Four-wheeled tractor driven 2m reapers didn't become popular as they caused higher grain losses, even though they could harvest 0.54 ha/hr in the large Eastern Province fields.

Tractor Coupled Combine Threshers

By around 2002, the low performances of traditional threshing methods, labor shortages, the longer turn-around time and the introduction of higher yielding varieties of rice forced farmers to look for alternatives to the small threshers mentioned above. In 2004, the CIC Company, which had large areas of farmland in the Central Province, recognized this need and introduced a new type of thresher. These made-in-Thailand combined threshers, which are coupled to the power takeoff of tractors, became popular with farmers and are locally known as Sunamie (Figure 20). These machines have 96.7 percent threshing recovery, 98.8 percent threshing efficiency, 90.7 percent cleaning efficiency and 1,178 kg/hr corrected output capacity against only 1.8 percent damaged grain, 0.2 percent blown grains and 1.6 percent grain losses. It costs only LKR 2,744 ($15) to thresh a tonne of 15 percent moisture content rice using these machines. Although

Figure 20. **A 45 hp tractor-coupled thresher.** (Hayleys Agriculture Holdings).

they suit Sri Lankan conditions, they create much chaff and dust while operating – 2.04 mg/cm^3/hr of dust in inhaled air and 35.9 mg/cm^3/hr of dust in the surrounding environment (Weerasooriya *et al.* 2011). Three companies (CIC Holdings, Hayleys and Browns) imported these threshers and made spare parts available. Their life span was, however, only about five seasons under heavy use. These machines can thresh a hectare of rice in 2.5 hours with seven persons feeding them and are still used on about 11 percent of the country's rice cropping lands, mostly in Uva and the Southern Province for raw rice milling operations.

Wheeled Combine Harvesters

Combine harvesters were first introduced in Sri Lanka in 2002 by the government for harvesting seed rice to overcome labor shortages at peak harvest times. This was followed by the hiring of two harvesters in the 2002 Maha season by government agrarian services for farmers in the Eastern Province where productivity was high and there was a serious labor shortage following the 2002 tsunami (Mahrouf and Rafeek 2003).

Around 2004, John Deere and CLAAS introduced wheeled combine harvesters in eastern Sri Lanka where many rice fields are large and dry. These machines (Figure 21) successfully addressed the labor shortages as they can harvest one hectare per hour and can harvest a range of crops. However, they are unsuitable for using on wet fields. The demand for this machine declined after the introduction of tracked harvesters around 2006 and no further machines have been imported since then.

Figure 21. **A wheel driven combine harvester.** (Dave Tractors).

Ride-on Combine Harvesters

Farmers with smaller farms (less than 0.5 acres) prefer to own harvesters rather than hiring in contractors as waiting for contractors and their machines can delay harvesting. Smaller 15-17 hp combine harvesters (Figure 22) are handy to use in smaller fields where it is difficult to operate 2m wide combines. These machines began to be used in 2005. They operate with belt and chain drives and need stand by spares for trouble-free operation as they frequently breakdown.

Figure 22. **A 15 hp ride-on combine harvester.** (Farm Machinery Research Center).

However, these harvesters are fast disappearing due to their high maintenance costs and the increase in plot sizes as plots are combined to make them accessible to larger harvesters. The price of these ride-on combines is LKR 680,00 ($4,000). Their main disadvantage is their lack of a winnower to clean the grain.

Tracked Combine Harvesters

In 2006, generic 2m rubber-tracked harvesters from China began to gain popularity as they can operate on most types of terrain where rice is grown (Figure 23) and do not sink into wet fields. By 2018 these machines were harvesting 72 percent of Sri Lanka's rice fields.

Figure 23. A 2m tracked combine harvester. (Hayleys Agriculture Holdings).

The initial models were cheaper than wheel-driven harvesters, performed well and were convenient to use. They are, however, being superseded by Chinese-made Kubota and Yanmar machines, and Indian-made CLAAS machines, which are more durable and easier to operate, although some have higher grain losses during threshing as they are designed for shorter crop heights. The Kubota machine can harvest 2–3 hectares per day and 50–100 hectare per season. The tracks wear out in two to three seasons and cost about LKR 120,000 ($80) to replace. The Kubota and Yanmar machines cost LKR 6.4 million ($40,000), which is twice the cost of Chinese machines (LKR 3.2 million, $20,000). And farmers need to spend an average of four person days per hectare to prepare entry areas to fields and to transport the crop to stores after bagging. However, the amount of labor needed is declining as operators become more skilled including to take machines into fields. The training of operators is reducing grain losses and machine damage. These machines can also harvest lodged rice (see Figure 18). Experience shows that harvesting lodged rice perpendicular to the direction of lodging reduces impurities in the harvested grain.

However, these machines have several disadvantages (Epasinghe *et al.* no date)

- They have to harvest rice with a higher moisture level to prevent shattering losses; but higher moisture content rice sells for less.
- The high operating speed causes higher impurity levels and grain losses.
- Farmers say that weed propagation is greater following the use of these combines.

Harvesting Performance

Table 6 summarizes data available on the performance of the different types of machines used to harvest rice in Sri Lanka (see next page). These data show the following:

- The losses of harvesting as a total do not vary significantly by type of machine.
- The moisture level of combine-harvested rice is higher than for threshed rice.
- According to farmers, the hiring cost of combine harvester varies with the availability of machines. The hire charges shown are when 92 percent of rice lands are cultivated.
- Weed propagation in rice fields is significantly higher in fields after combine harvesting.

Figure 24 illustrates the trend of the import of harvesting machines into Sri Lanka between 2000 and 2015. It shows that the import of mini combines ended around 2004, of combine threshers around 2007 and of bulker wheel-type harvesters around 2013. The branded rubber tracked combines are now the most widely used machine even though they are more expensive suggesting that initial cost is not the main criteria for selecting a harvester. The return on capital is apparently more of a determining factor as the tracked machines can work in most conditions.

Combine harvesters have brought an additional 482,532 hp to Sri Lanka's rice fields amounting to an additional 2.02 hp per hectare (assuming there are 10,000 harvesters harvesting the 650,000 ha of rice crops, with an average of 50 ha/machine in 25 days).

It is important to note that the average life of combine harvesters is low in Sri Lanka at only 5 to 10 years compared to 17 years in Europe and North America (Fuchs et al. 2015).

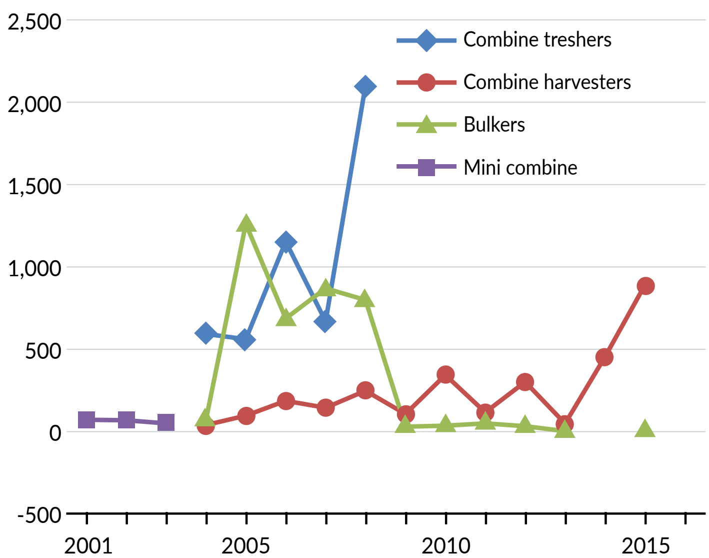

Figure 24. The number of rice harvesting and threshing machines imported into Sri Lanka, 2000–2015. (Samarasinghe unpublished, using customs' data).

Table 6. The performance of rice harvesting machines in Sri Lanka .

Variables	Small threshers	Tractor threshing	Combine threshers	Mini combine harvesters	Rubber tracked combines	Notes
Machine horsepower	5 hp	45/55 hp	45 hp	15 hp	70 hp	
Type of harvesting	Manual or reaper	Manual	Manual or reaper	Machine	Machine	
Grain moisture level needed to harvest	14–22%	13%	16–18%	<18–22%	<20–22%	22% moisture ideal for combine harvesting machine
Hire charges/ha	LKR 6,175	LKR16,300	LKR 13,500–15,750	LKR 36,000–40,000	27,000-31,500	
Variable cost of fuel and other consumables (LKR)	6,520	3,000-4,000	6,356	n/a	2,550	
Machine time to harvest 1 ha	9-14 hrs	64 hrs	5 hrs-	17 hrs	2.5 hrs	Labor involved in all harvesting processes from field to storage
Person-hrs to harvest 1 ha	272	230	77	29	7.5	
Seed germination	Very good	Poor	Poor	Good	Good	Germination varies due to grain damage of raw rice.
Impurities in raw rice	2%	na	2%	4%	1%	
Grain losses	2%	13%	2%	6%	3%	Grain losses are due to grains falling on ground while harvesting or retained in the machine
Grain damage	1%	n/a	1.8%	1.5%	0.5%	
Straw processing	Taken out of fields	Taken out of fields	Remains in fields	Remains in fields and needs to be collected	Remains in field and needs to be collected	
Heavy spread of weeds seen	In threshing areas	In threshing areas	In threshing areas	In fields	In fields	
Total grain losses during harvesting	13%	14-22%	8%-12%	n/a	7%-8%	
Post-harvest losses due to harvesting	0.5%	2 %	1.5%	1%	1%	These losses are due to cracks in milled rice in
Environment friendliness	Good	Good	Poor as creates much dust (35.9 mg/cm²/hr)	Very good	Very good	

Source: Weerasooriya et al. 2011 and scientists from the Hector Kobbekaduwa Agrarian Research and Training Institute (HARTI)

6.5. Other Trends

Usage pattern – Of the 667,191 ha of rice cultivated in 2017 Maha season 476,646 ha (72%) was harvested using combine harvesters. Among Sri Lanka's 25 districts the highest use of combine harvesters to harvest this crop was in Mannar, Polonnarua, Anuradapura, Trincomalee, and Ampara, where over 90 percent of the crop was harvested using combines (Figure 8). The lowest proportion of this crop harvested by combines was mainly in the central part hill country where only between 12 and 30 percent was harvested using combines.

Social implications – The spread of the machine harvesting of rice has several positive social implications:

- It saves time as previously whole families had to participate in manually harvesting the crop or by employing migrant labor.
- It makes farm work more attractive to young people.
- It removes the risk of snakebites and rat fever during harvesting.

However, mechanization has causes loss of employment for the mostly female laborers who used to manually harvest rice and the loss of business providing meals for migrant workers at harvesting time.

Training – One major challenge that faces mechanized rice harvesting is that many machine operators lack certified knowledge and often cause larger than necessary crop losses. Since 2016 the government has subsidized training programs. The National Vocational Education Authority and harvester suppliers have developed a National Vocational qualification level 3 curriculum for harvester operators. The government provides funds to conduct employment link training programs for operators. In 2017, two companies registered for training and trained 30 operators while three companies registered in 2018. The success of this program is yet to be evaluated.

6.6. Crop Residue management in Sri Lanka

In Sri Lanka, rice straw is used mainly for manure, accounting for 90 percent of use in the 2017 Maha season (DoCS 2018) with other uses being animal feed, roofing and burning in the field. Mulching with straw is common before the first puddling in rice fields. In addition, farmers burn unharvested rice and straw in their fields to destroy weeds and pests. In the Eastern Province, straw is collected and used as fuel and to make paper pulp. Note that cattle tend to reject machine harvested straw and that rubber tracked combines do not chop the straw.

6.7. Conclusions

Combine harvester use in Sri Lanka has reached the global benchmark of one machine to every 50–100 ha of rice growing land.

The main overall conclusions of this paper are as follows:

- The outsourcing of harvesting achieves economies of scale and enables farmers to access the latest technology.
- The most effective combine harvesting machine for Sri Lanka's rice fields are 2m rubber tracked combine harvesters.
- Tangential flow threshers are efficient on short crops but inefficient to harvest tall crops and wet rice.
- Harvesting lodged rice perpendicular to the crop reduces impurities in harvested grain.
- Chinese generic harvesters with local and Chinese brand names are less efficient than Kubota and Yanmar Japanese brands, which are made in China.

This review also shows that it is important to use harvesters that match field requirements and to use trained operators to operate machines effectively and efficiently. The efficiency and effectiveness of machines varies with i) the height of harvesting; ii) field levels, soil condition, and the distance between bunds; and iii) the height, moisture content, maturity and density of the crop.

Other conclusions are as follows:

- There is a skill gap in the operation and maintenance of harvesting machines.
- Harvesting losses are minimized when machines are operated by trained operators.
- The levelling of fields can improve the efficiency of machine harvesting by reducing the harvesting crop height and the grain to straw ratio.
- It is beneficial to add a straw chopping mechanism to combine harvesters for pulverizing and mixing straw into the soil for weed control as on new models of John Deere Harvesters.
- Future domestic sales of combine harvesters will depend on the service life of units.

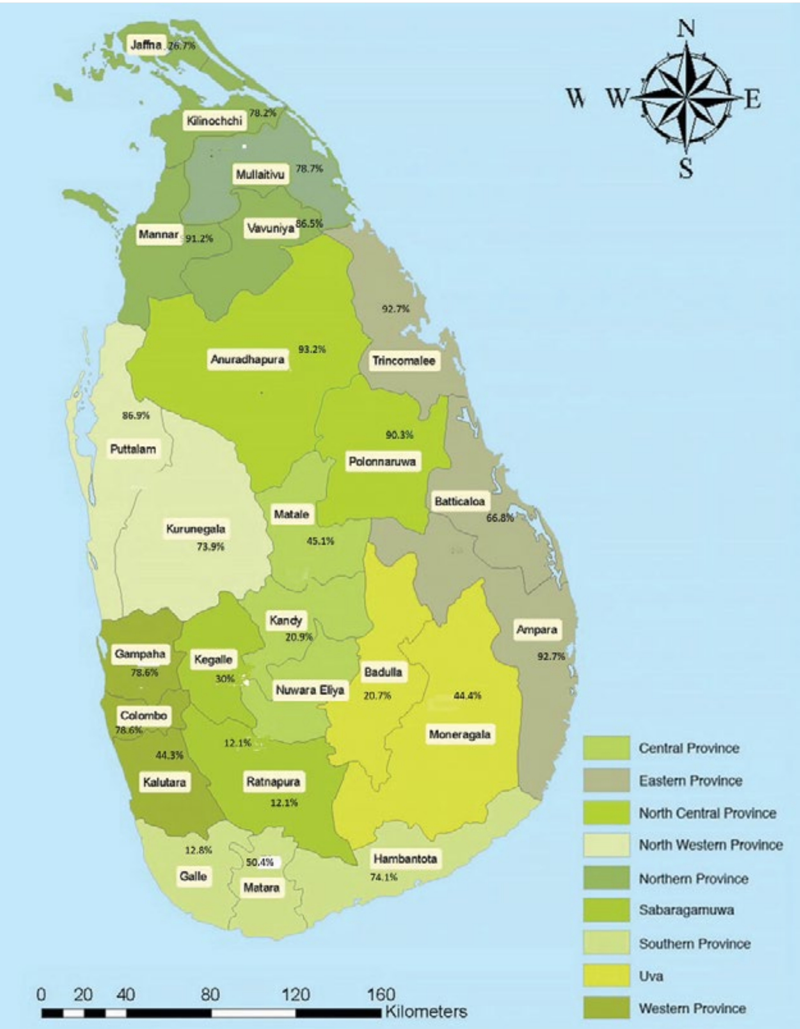

Figure 25. The district-wise proportion of 2017 maha season rice harvested by combine harvester in Sri Lanka. (Department of Agriculture, 2018 paddy statistics).

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CHAPTER 7

Mechanization of Paddy Harvesting and Rice Straw Baling in the Mekong Delta of Vietnam

Phan Hieu Hien

Summary: This paper focuses on the mechanization of rice harvesting in the Mekong River Delta in Vietnam, which is the country's main rice growing area. The main machines used for harvesting rice were initially threshers and reapers, which were replaced by wheeled mini combines from around 2004 which in turn were replaced by rubber tracked combines around 2006. Design improvements were spurred on by annual combine contests. From 2013 Japanese Kubota tracked combines became the most popular machine because of their high reliability. All machines were employed by individual contractors and now more than 95 percent of Mekong Delta rice fields are harvested by combines with a trend towards higher capacity combines that harvest 8–12 hectares a day. The rapid large-scale adoption of mechanized harvesting in the Mekong Delta was facilitated by the existence of thousands of flat-bed dryers, which are gradually being replaced by high capacity column and fluidized-bed dryers. The paper also examines rice straw harvesting in Vietnam. The introduction of straw balers in 2014 facilitated the easy collection of the straw that is left scattered across fields by combine harvesting. Although they are costly to buy, tracked balers with collection platforms are more efficient and produce cleaner bales.

7.1. Introduction

Rice is the major food crop in Vietnam with a 7.7 million hectares planted in 2016 when it accounted for 82 percent of all farm area yielding 43.2 million tonnes of paddy (GSO 2017). The production of rice almost doubled between 1994 and 2016.

The distribution of rice production is highly skewed as the Mekong Delta in southern Vietnam (Figure 26) has only 20 percent of the population but 55 percent of the rice growing area, the same proportion of all rice production and provides 95 percent of the country's rice exports. Each rice farmer-household cultivates an average of 1.2 ha on an average plot size of about 4,000 m^2.

Figure 26. The Mekong Delta (circled) and Vietnam's seven other agricultural regions.

The other seven agricultural regions are home to 80 percent of the population, have 45 percent of their area under rice and produce 45 percent of rice output. Most farms there are only 0.2–0.5 ha in size mostly divided into 4–15 small plots of about 500 m^2 each. The differing farm and field sizes and population densities have determined the mechanization patterns of these two zones.

The Mekong Delta is warm and humid year-round without typhoons and a maximum rainfall of 340 mm in September. Rice is planted in two or three seasons per year. The dry season crop is harvested in January–February and the wet-season crop in the July to September rainy season. In contrast, the weather of the Red River Delta in the north is influenced by tropical monsoons and a cold winter with the first rice crop harvested in June–July and the second in September before the annual typhoons arrive.

The increases in rice production over the past 25 years has been associated with the use of mechanical equipment. This paper explains the mechanization of rice cropping in Vietnam focusing on rice harvesting in the Mekong River Delta.

7.2. Background to Rice Mechanization in Vietnam

Tractor and tillage

Farm mechanization in Vietnam started in the 1960s with the use of tractors for tillage. Between 1975 and 1988 tractors were organized into about 300 state-owned tractor stations. These stations have been discontinued since 1990 when tractor ownership shifted to private owners.

In 2005, there were about 300,000 tractors in Vietnam with a total of 3.5 million horsepower. The four-wheel tractors that are used for rice cultivation are mostly Japanese 20-35 hp machines. In 2012, these were mostly used for tillage in 67 percent of the country's rice fields and 92 percent of Mekong Delta rice fields. The average power usage for rice field operations was 2.2 hp/hectare (ha), and the total power for rice production was 9.0 million hp. The power for carrying out field works accounted for about 20 percent of the 46.0 million hp used for all agriculture-related power, including for cultivating other crops, stationary engines (pumps, processing, etc.), and vehicles and boats for agricultural transport.

Tillage costs account for less than 4 percent of rice production costs in the Mekong Delta. This low cost for the heaviest field work (tillage) is due to a contract system, which started in the delta in the 1980s, and has served as a model for other operations and other areas. Experience suggests that mechanical means of carrying out farm operations in the delta need to cover 3-5 ha per day to be acceptable to farmers.

Seeding, transplanting, spraying

Seeding, transplanting and spraying are much less mechanized than tillage and harvesting (Trinh Hoang Viet 2014). Mechanical seeders and rice transplanters are used on less than 20 percent of Vietnam's rice fields, while mechanical spraying is carried out on less than 40 percent of the area.

Laser land leveling

Laser land leveling is carried out to create level fields (with a less than 3 cm differential) in most cases by merging several smaller fields to facilitate water management for rice cultivation. These larger fields also facilitate mechanization. This technology, which is widely used in developed agriculture, was transferred to Vietnam by the International Rice Research Institute (IRRI) in 2004. Its use has spread across Vietnam with about 1,500 hectares leveled in 2017. The other benefits of levelling land include savings on fertilizer and pesticides and increased yields. Farmers get average increased profits of US$ 260 per hectare per season from laser land leveling (Phan H Hien 2014). The maximum cost of laser leveling is $50/ha/season, which is the contracted fee of $500 for 10 seasons. Thus, farmers who invest in laser leveling can achieve pay-back in only one year across two crops seasons. And the pooling of tiny plots can increase total rice production by 5–8 percent simply by removing unnecessary levees.

Other benefits of laser land leveling are that rice grown on levelled fields is generally more resistant to lodging, which reduces harvesting losses when using combine harvesters. The harvesting of lodged crops often increases shattering losses to as much as 6–10 percent compared to only 1–2 percent for standing crops.

7.3. Mechanization of Rice Harvesting

The mechanization of rice harvesting in Vietnam has happened across two main periods related to the introduction of mechanical threshers and mechanical harvesters.

Threshers and Reapers

The first phase saw manual harvesting continue alongside the new technology of mechanical threshing. The mechanization of paddy threshing in Vietnam began in 1974 with the introduction of the axial-flow thresher (Phan H Hien 1991). This design, originally developed by IRRI, was modified by Vietnamese mechanics to have flatbar threshing teeth instead of the original round teeth, and used an axial rather than centrifugal cleaning fan (Figures 27 and 28). About 100,000 units were in use in Vietnam in 2005, and almost all paddy in the Mekong and Red River deltas was threshed by them. By 2015, the spread of combine harvesters led to them almost disappearing from the Mekong Delta and they are now only used in remote parts of central and northern Vietnam.

The next phase was marked by the spread of mechanical reapers and mechanical threshing. The IRRI designed reaper (Figure 29) was introduced into Vietnam in 1984 by Nong-Lam University (NLU) and then transferred to LongAn Mechanical Factory, which fabricated 150 units up to 1988 (Phan H Hien *et al.* 1990).

Figure 27. The collapsible type axial-flow thresher. (Phan H Hien)[8]

Figure 28. The self-propelled type axial-flow thresher.

[8] All the photos in the paper are by Phan Hieu Hien.

Figure 29. Rice reaper made by Long-An Mechanical Factory in 1985.

Since the year 2000, three local manufacturers have produced about 300-400 reapers per year. Between 2007 and 2013, the adoption of these reapers expanded and then leveled out at about 3,500 units across the Mekong Delta (Figure 34), They were used to harvest about 10 percent of rice production in this area. The use of reapers subsequently declined and by 2015 had almost disappeared as they were displaced by combine harvesters.

Combine harvesters

The development of the combine harvesting of rice happened in Vietnam across four periods (Phan H Hien 2010; Gummert and Hien 2013; Vu Anh Tuan 2014).

Before 2000, a few combine harvesters were imported into Vietnam and some were developed by research institutes and provincial factories. But they all had rubber wheels and were too heavy to use on soft soils.

Mini combines, 2000-2008 – From the year 2000, the growing labor shortage motivated researchers and manufacturers to renew efforts to promote combines. About 15 local small-scale combine manufacturers had tried out their machines; but each made only a few units and faced the problems of their machines sinking into soft soils, difficulties in harvesting lodged rice and poor reliability.

A major step forward was the introduction of the mini combine in 2004 as a result of collaboration between the Center for Agricultural Energy and Machinery (CAEM) of Nong-Lam University, the Philippine Rice Research Institute (PhilRice), the U.S gasoline engine manufacturer Briggs & Stratton, and Vinappro, a leading manufacturer of diesel engines in Vietnam. The mini combine (Figure 30) weighed 600 kg and was powered by a 16-hp gasoline engine, and later by a 12-hp diesel engine, and was equipped with a 1.3m cutter bar. It could harvest 0.9-1.3 ha of rice a day. It consumed 15 liters/ha of fuel (Tran Van Khanh *et al.* 2004). Harvesting losses were less than 2 percent and different wheel types could be used for different soil conditions (Figure 31).

The mini combine was released by Vinappro in 2004 and sold 30 units in the first year while all other local manufacturers together sold only about a dozen. In 2009, about 500 mini combines were sold in Vietnam at $4,000 each.[9] About 900 units were produced by two other manufacturers; but the introduction of rubber tracked combines led to reduced demand and the phasing out of mini combines by 2012.

Rubber tracked combines, 2006-2013 – From 2006, the number of combines increased rapidly. This was catalyzed by the annual combine contests held from 2006 to 2011 in five provinces by the Vietnamese Ministry of Agriculture and Rural Development (Figure 32). These contests were judged by experts from research institutes, universities, extension and industrial centers. Competitors were evaluated based on the measured field capacity, total grain loss, paddy cleanliness, reliability, harvesting cost, machine stability and other factors (NECVN 2011).

[9] Exchange rates of $1 to 17,000 Vietnamese Dong (VND) used for 2008-2009 and $1 to 20,000 VND for 2011–2013.

Figure 30. The 600 kg mini combine.

Figure 31. This type of combine is easily lifted for changing its wheels.

Figure 32. The 2009 combine rice harvesting contest at An Giang, Vietnam.

Each contest involved about a dozen combines and directly led to and reflected progress in the design and performance of these machines. By 2009, an increasing number of imported Chinese combines were participating.

The main features and improvements made to the present day to combine harvesters are as follows:

- All models except the mini combine now use rubber tracks for mobility on soft soils. The tracks of 1.7-2.7 tonne combines exert a light ground pressure of only 22-25 kilopascals (kPa). The rubber track is a key innovation for combine harvesting of rice in the humid tropics.
- The decreased weights allow for the easy crossing of canals (Figure 33).
- Cutting widths are mainly 1.5-2.0m, with a harvesting capacity of 3–6 ha/day.
- Grain losses are less than 2 percent when harvesting upright plants in firm conditions; with some combines having less than 1 percent grain losses. Note that between 3 and 5 percent of grain is made up of impurities.
- The problem of harvesting lodged crops has been solved for all commercialized combines by the more logical arrangement of cutting components. Nevertheless, there are losses of up to 10 percent in the combine harvesting of lodged crops.

Rubber tracked combines reduced harvesting costs. In 2008, in An Giang, with diesel consumption of 18-25 liters/ha, the combine harvesting cost was $95-105/ha compared with $130-145/ha for manual harvesting. The rapid payback time of less than two years for owners of these machines explained the rapid increase in their use between 2006 and 2013 (Figure 34).

2013 to date – After 2013, machine reliability became a major concern of combine operators. This is why the Japanese Kubota combine, which entered the market in 2009, became the market leader because of its well-known reliability. In 2014, about 85 percent of combines in Vietnam were Kubota machines. This company did not join any of the combine contests; it just watched and improved its machines, and reaped the benefits from the contests' extension results. The Kubota importer established a network of after-sales service points to supply spare parts.

Problems with locally manufactured combines occurred because of non-standardized engines, gearboxes, rubber tracks and other components. Imported second-hand components were often used, which are sometimes not interchangeable. Local manufacturers realized these problems and some of them began to import new components from China, Korea and Japan, while some installed CNC (computer numerical control) machines to produce the components. By 2014, only three local combine manufacturers remained accounting for less than 15 percent of market share. A dozen other manufacturers, including contest winners, disappeared.

Figure 33. A 2 tonne combine crossing a canal on metal frames.

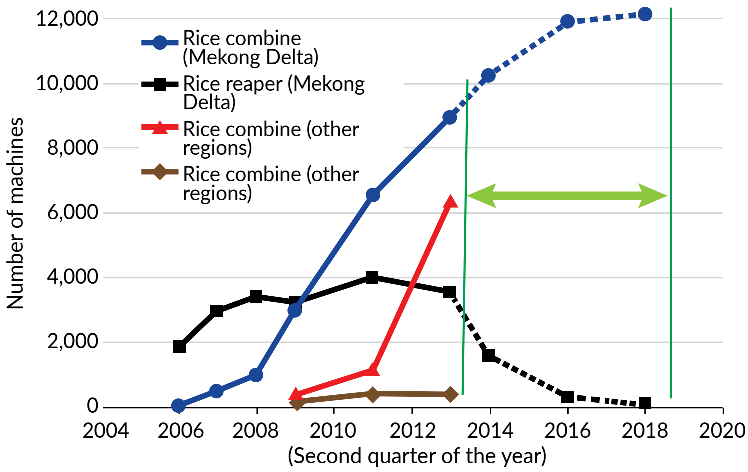

Figure 34. Number of combine harvesters and reapers in use in Vietnam, 2006–2018. (Source: NECVN 2014, compiled from provincial reports).

Vietnamese manufacturers retreated to supplying spare parts such as threshing teeth, augers, reels and concaves for separating grain.

Figure 34 shows the trend in the number of rice harvesting machines in use in Vietnam to 2018. In 2013, rice was being mechanically harvested in 58 percent of Mekong Delta rice fields using about 9,000 combines and 3,500 reapers. There was a wide variation in the mechanical harvesting of rice across this region's provinces. For example, the mechanical harvesting of rice increased from only 10 percent of An-Giang Province's rice growing areas in 2006, mainly with reapers, to 98 percent in 2013 using 2,100 combines and a few reapers (AGDARD 2014). In 2013, the percentages were much lower in the other seven regions, with an average of 6 percent and a range of 1 to 25 percent of rice growing areas. All machines were employed by individual contractors with little cooperative ownership.

The situation changed quickly around 2014. Surveys carried out in three provinces of Central Vietnam in October 2014 (Nguyen Van Xuan *et al.* 2014) found over 80 percent of rice fields being harvested by combines. One Central Province commune had 70 combines, which spent 2–3 weeks harvesting locally, and then moved 200–1,000 km away to harvest for a further 3-5 weeks. Some village areas have 30–50 combines from elsewhere harvesting their rice at peak harvest times.

No statistics are available for 2018 on the number of combines in operation, but we estimate that there are 12,000 units in the Mekong Delta. More than 95 percent of this region's rice fields are harvested by combines, and reapers have almost disappeared. From 2018 the trend in this area is towards using higher-capacity combines that can harvest 8–12 ha of rice a day with 2.2–2.7m cutting widths.

7.4. Mechanical Drying as a Companion to Mechanized Harvesting

The combine harvesting of rice in the Mekong Delta is accompanied by mechanical drying to rapidly dry the rapidly harvested crops. Such driers are only available in this region in Vietnam as the other regions with their less land and more farm workers do not need the support of mechanical dryers.

Flat-bed dryers

Most dryers in the Mekong Delta are flatbed dryers. The first flatbed dryer in Vietnam was installed in Soc-Trang Province (Figure 35) in 1982 by Nong-Lam University (Phan H Hien 1987). Farmers in adjacent areas replicated or modified this dryer using cheap local materials. By 1990, there were about 300 units in the Mekong Delta, half of them in Soc-Trang. Other provinces in the Mekong Delta began to adopt these dryers with the number reaching 1,500 in 1998, 3,000 in 2002 and 6,200 in 2006. Most could dry 4-10 tonnes of rice in 8–14 hours (Phan H Hien 2010). The rate of increase has since slowed with a total of about 7,000 units by 2010 and 9,000 units by 2013. But the batch capacity has increased to 15-40 tonnes, and machines include equipment for loading and unloading the grain (Figure 36). The dryers in the Mekong Delta account for more than 95 percent of all Vietnam's dryers and in 2018 dried about 19 of the 24 million tonnes harvested in the Mekong Delta.

Almost all flatbed dryers use rice husks as fuel (Phan H Hien 2010), which is the main factor in their low running costs. Between

Figure 35. The SHT-10 dryer at the KeSach Seed Station, Vietnam, 1982.

Figure 36. An array of 30-ton flatbed dryers with mechanical handling.

1990 and 2005 the cost of drying paddy was about 5 percent of its value using 4–10 tonne dryers. By 2010–2014, the cost had fallen to 3.5-2.5 percent of the value of the crop with the introduction of higher-capacity dryers.

Column dryers and fluidized-bed dryers

The introduction of 'simultaneous' planting dates from 2010 led to shorter harvesting and drying seasons, which requires high-capacity drying. During harvesting, dozens of combines work in one village area for a week harvesting up to 1,000 tonnes per day. The harvest goes to central drying plants. These plants can operate for 2–3 months per season or five months per year drying the rice from different villages and even provinces with slightly different planting dates and varieties, thus justifying the high investment costs.

Thanks to pre-cleaning by fluidized-bed dryers, arrays of 10–20 units of column dryers, which can each handle 10–30 tonnes per batch, can work smoothly without being jammed by moist paddy (Figure 37). About 10 central drying plants, each with a daily capacity of 1,000 tonnes, were operating in the Mekong Delta in 2013. They are superior to arrays of flatbed dryers in terms of labor saving and grain quality, while the drying cost at mass-production scale is comparable to flatbed dryers due to the higher labor costs of flatbed dryers (Tran Van Tuan *et al.* 2013).

7.5. Rice post-harvest losses

Limited information is available on the post-harvest losses of rice cropping in Vietnam. Even a wide and deep survey over two years (such as the one reported below) may not reveal the true picture, as damaging typhoons and other calamities may only occur once every five years.

A survey by the Ministry of Agriculture and Rural Development and Danida Agricultural Sector Programme Support in 2002 and 2003 in the 12 Mekong Delta provinces (MARD and Danida ASPS 2004) found that harvesting and threshing losses accounted for 4.9 percent of the overall 11.9 percent losses (Figure 38). Although no more recent survey has been conducted, it is likely that the expansion of combine harvesting has significantly reduced harvesting and threshing losses to about 3 percent. With more and better drying, losses due to drying and milling are reducing. We estimate that only around 8–9 percent of the 2015 Mekong Delta

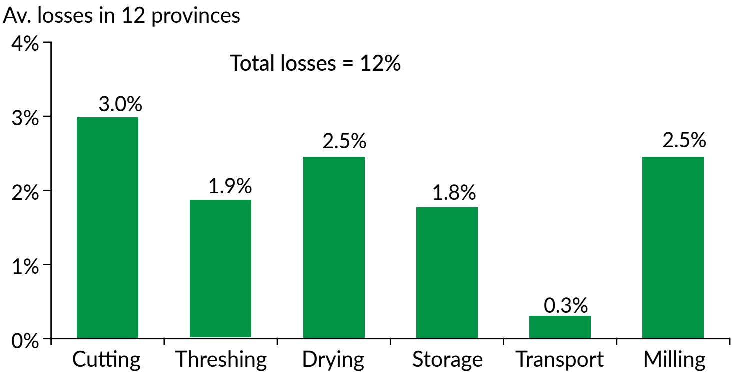

Figure 38. Rice post-harvest losses in the 12 Mekong Delta provinces of Vietnam. (2003 data).

Figure 37. Combination of one fluidized- bed and four column dryers.

rice crop was lost. The aim is to reduce losses to 5 percent keeping in mind that each 1 percent loss forgoes $10 million of income.

7.6. Rice Straw Harvesting

Available straw

The estimation of the amount of harvested straw or available cut straw is based on the ratio of cut straw to grain. As cutting height increases, the proportion of the weight of cut straw to grain decreases. One study found that the average proportion of the weight of cut straw in eight rice varieties in California was 84 percent for straw cut at 0.1m, 55 percent for straw cut at 0.3m, and 32 percent for straw cut at 0.5m (Summers *et al.* 2001). However, no such data is available in Asia. So, assuming a cut height of about 0.27m, corresponding to a cut straw to grain ratio of 0.6 (or 60% of the weight being cut straw) – then with average rice production in Vietnam of 26 million tonnes in 1996 and 43 million tonnes in 2016, the amount of straw available would have been 15 million tonnes and 26 million tonnes in those two years, of which about 55 percent (14 million tonnes) was in the southern Mekong Delta.

The uses of rice straw

In Vietnam, rice straw has traditionally mostly been burned off in situ, especially in the Mekong Delta for clearing fields to prepare for the next crop; with lesser amounts incorporated into the soil and used for cattle feed and mushroom production.

Between 1988 and 2008, with the use of axial-flow threshers, straw was piled up in fields or yards. This straw was easily gathered for cattle feed and mushroom production. In the Northern and Central Provinces, where straw is highly valued, about 70–90 percent of it was used for animal feed and no surplus straw was left for burning off in fields. But in most areas of the Mekong Delta the abundant straw was mostly burned off in fields, with less than 10 percent going for cattle feed, mushroom production and other uses.

Between 2009 and 2013, as the harvesting of rice shifted from threshers to combine harvesters, straw was again scattered in-situ in fields, and gathering it required considerable labor. At this time mushroom growers in An-Giang Province had to pay up to eight times more than previously for the straw, which led to a sharp decline in mushroom production. The gathering of straw became costly and in-field burning increased.

The introduction of straw balers in 2014 facilitated the easy collection of straw from combine harvesting (Figures 39, 40, 41 and 42). These balers produce 13-15 kg 0.5m diameter x 0.7 m height bales (Figure 40) or 0.45m diameter x 0.75m height bales with a bulk density of about 100 kg/m^3 from 15 percent moisture content 'dry' straw. Bales of wet straw with about 70 percent moisture content typically weigh 50 kg and have a density of more than 300 kg/m^3.

In 2016, a seminar and demonstration on technology for gathering and treating rice straw was organized in Can-Tho City by the Vietnamese National Extension Center, Nong-Lam University, and IRRI. Local manufacturers and imported baler dealers participated in the demonstration. Measurements were taken on four balers on a typical field with 4.6 tonnes of straw per hectare. The results are summarized in Table 7. Note the variations of the field capacities in terms of ha/hr and tonne/ha, because of various in-field straw densities, while the machines worked without much changes. The ungathered losses of cut straw left behind was quite high.

Since 2017, two types of straw balers have become popular across southern Vietnam:

- The imported Galan-STAR MRB0855 baler is semi-mounted behind an at least 20 hp tractor (Figure 41). This baler is low-cost (Table 8) as it uses existing tractors; but it ejects bales in-situ,

Figure 40. Ejecting bales from the bale chamber.

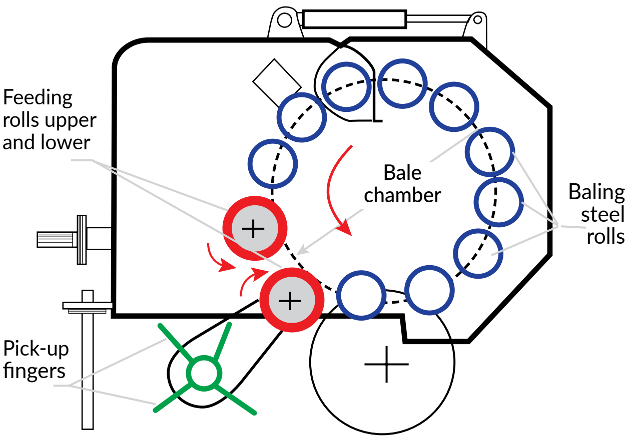

Figure 39. The steel rollers in a baler produce round bales. (Wang et al. 2011).

Figure 41. Galan-IHI STAR MRB0855 baler behind a 30-HP tractor.

thus needing additional labor to collect and transport the bales. Also, as tractor tires lead the way, in muddy fields they spray mud on to the bales making them dirty.

- The Phan Tan PT-CR57 baler, which is fabricated in Dong-Thap Province in Vietnam, is self-propelled on rubber tracks, with a platform that holds about 30 bales (Figures 42 and 43). This machine costs twice as much as the Galan, but it transports bales to field borders thus saving labor; and in muddy fields the bales are kept clean as the baling component is up front.

Problems with the use of combine harvesters and straw balers

Combine harvesters usually operate most efficiently at cutting heights of 0.4–0.45m and produce good grain separation and clean grain. They only need a low cutting height, of 0.2–0.3m, to harvest lodged crops. However, the usual cutting height cuts only 40 percent of the straw with the remainder left behind as stubble. Thus, combine harvesters and straw balers work against each other in terms of economic returns. Research is needed on the trade-off between cutting height, efficiency of operation and economic returns using these two types of machines.

Current status of rice straw baling

The development of straw baling technology is associated with the switch from threshers to combine harvesters. Between 2014 and 2018, the number of straw balers in Vietnam increased from almost none to about 5,000 units, which transformed the rice straw in the Mekong Delta from a residue to a valuable material valued at 25–30 percent of the price of paddy grain.

Costs of baling and transporting rice straw

Research carried out in the USA in 1975 estimated that the cost of baling and transporting straw to storage was $32.06 per tonne[10] (Dobie *et al.* 1977). A third of the cost was for in-field baling and the other two-thirds was for transporting it an average of 16 km to storage. Thus, for any scheme, the price of straw as input material should be based at the utilization site.

However, such data is not available for Vietnam. We thus interviewed baler owners at Tien-Giang and An-Giang Provinces in 2015 on their collection and transport costs (Table 9). It is a coincidence that the collection costs in the USA of $32.06/tonne is between that estimated at Tien Giang and An-Giang of $39.41 and $29.73 per tonne respectively. However, note that the straw was provided free of cost in the USA case while in Vietnam case the collection cost included $4-15 for purchasing the straw from the farmer.

[10] All USD values are converted into 2015 values here.

Table 7. Average performance of four rice straw balers, Can-Tho City, Vietnam, 2016.

Bale mass, kg Ave ± st dev	Bale density kg/m³	Field capacity ha/ hr	Field capacity t/hr	Ungathered losses %	Labor (calculated) man-hr/tonne
12.8 ± 1.2	87 ± 9.1	0.46 ± 0.11	1.60 ± 0.55	26 ± 11	1.82 ± 0.72

Notes: Labor on balers: 2 persons for self-propelled unit; 1 person for pulled-behind tractor unit.
Labor for collecting bales: none for self-propelled units, 3 persons for pulled-behind tractor unit.
Source: Phan H Hien et al. 2016.

Table 8. Specifications and prices of two popular balers in Vietnam.

Model	Dimensions (LxWxH), mm	Mass	Engine power	Bale diameter x length, mm	List price
STAR MRB0855	1,150x1,300x1,300 (without tractor)	340 kg	tractor > 20 hp	500 x 700	$6,200
PT-CR57	4500x2250x2450 (self-propelled)	1,800 kg	45 hp	500 x 700	$13,000

Note: Prices converted at 1 USD = 22,000 VND (March 2016).

Figure 42. Phan Tấn PT CR57 baler.

Figure 43. Bales being delivered from the CR57 platform at a field border.

Table 9. Estimated cost of buying and collecting 1 tonne of straw at two sites in Vietnam's Mekong Delta (2015)

Owner:	In Tien-Giang VND/bale	In An-Giang VND/bale	Notes
Purchase of straw (from farmer)	5,000	1,000	In Tien-Giang straw costs 600,000 VND/ha to buy in fields, yielding 120 bales (so cost = 600,000/120 = 5,000 VND/bale). In AnGiang, straw is much cheaper as baling equipment is uncommon there.
Labor (driver)	1,000	1,000	
Twine for knotting	1,000	1,000	
Diesel fuel	1,000	700	60 hp self-propelled baler, which is pulled behind a 30 hp tractor that consumes 9 liters of diesel/day
Total cost per bale:	8,000	3,500	
b) Labor for transporting to boat	5,000	5,000	
c) Total (a + b):	13,000	8,500	
Bale mass:	15 kg	13 kg	
Cost of collecting 1 tonne of straw:	867,000 VND = $39.41	654,000 VND = $29.73	

7.7. Factors contributing to harvest mechanization

Dynamic characteristics of farmers – Vietnamese farmers work hard to produce 2–3 rice crops per year and are very keen to try technical advances that can increase productivity. Bold and determined, some of them have even redesigned machines at their own cost, although this is not always recommended (Nguyen Le Hung *et al.* 2012). Links between contractors and farmer-users is crucial to exchange the information needed to serve each other.

Research institutes and universities have addressed farmers' needs. The development and application of various machines by IRRI and Nong-Lam University – namely the axial thresher (1974), the flatbed dryer (1982), the mini combine (2004) and the laser leveler (2005), came about in this way. Some of these machines are now widely used while others were only developed to a certain stage, such as mini combines, which did however facilitate the development of track-type combine harvesters.

Manufacturers rapidly produced post-harvest machinery – In Vietnam, both large scale manufacturers of agricultural machinery and small units with limited production have been sensitive to developing new or adaptable technologies. They work with farmers to test new machines and to modify them to suit local conditions.

Effective national extension system – The national agricultural system began in March 1993 to promote agricultural crops, forestry and fisheries. The National Center for Agricultural Extension (NCFE) was established in 2008. There are agricultural extension stations in most of Vietnam's 648 districts. In collaboration with other institutions, the national center runs demonstrations for combine harvesters and training courses for extension officers and farmers. It also produces guidelines for farmers, maintains an extension website and issues extension bulletins. The NCFE's combine harvester competitions boosted the demand for and application of this technology in the Mekong Delta.

Government policies – Since 2004 government policies have promoted the development of mechanized rice production. Farmers have been supported to buy machinery through low interest long-term loans, which led to the purchase of thousands of combine harvesters across the country between 2008 and 2013.

7.8. Conclusions

This review of mechanization of rice harvesting and rice straw baling in Vietnam with a focus on the situation in the Mekong Delta could be useful for planning the mechanization of rice production in other Asian countries. To reduce post-harvest losses, improve grain quality, increase the value of crops and enhance the livelihood of farmers, the mechanization of rice production needs further developing in line with the following three points:

Mechanization is the way! – It is very difficult to carry out large-scale rice production and reduce post-harvest losses without machinery. The mechanization of farming on small landholdings requires particular types and sizes of machines, as well as appropriate research and extension.

The availability of services is the key to the success of mechanization – In Vietnam, the mostly poor farmers hire services from contractors, who own the costly equipment and have good mechanical skills and are business minded. This model works well in the Mekong River Delta and has led to mechanized rice harvesting across this region.

The mechanization process is dynamic – Machines and associated technologies should be constantly improved through feedbacks and modifications to suit users' needs.

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CHAPTER 8

Crop Harvesting Technology in Smallholder Agriculture in South China

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Summary: Recent years have seen a rapid increase in agricultural mechanization across the South China region in the southeast of China with a shift to combine harvesting due to the increasing cost of labor, cost savings and improved machinery. 'Small combines' provide satisfactory crop residue management while 'mini combines' provide timely harvesting and threshing services but the non-ideal handling of crop residues. It remains a technical challenge to develop small powerful and lightweight combine harvesters that can provide both satisfactory grain harvesting and straw management for South Chinese smallholder agriculture. This paper review scale-appropriate farm mechanization in South China to improve understanding of the crop production and the harvesting technologies in use there.

8.1. Introduction

China's three major climatic zones are the Tibetan Highlands, the North-West, and the Eastern Monsoon region, which comprises North and South China (see Figure 44). The Eastern Monsoon region has most of the country's farmlands and is split into South and North China (Li 1997). Agriculture in South China is dominated by rice farming due to sufficient precipitation, while North China has mostly dry land farming systems.

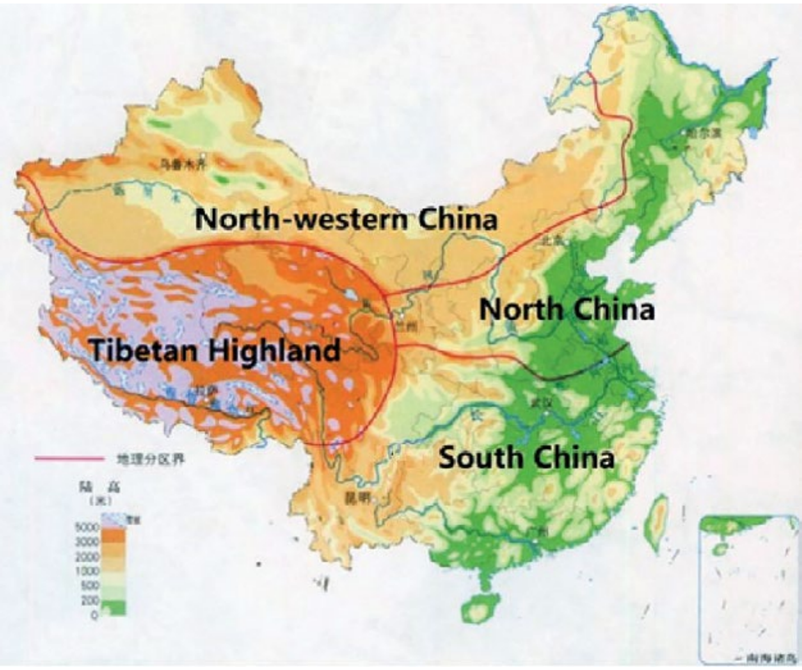


Figure 44. China's agricultural regions.

Recent years have seen a rapid increase in agricultural mechanization across South and North China's agriculture systems. In 2016, the total engine power of agricultural machines in China reached 0.97 billion kW with officially registered machines numbering 6.45 million large and medium sized tractors, 1.9 million combine harvesters and 0.77 million rice transplanters – 6, 5 and 15-fold increase respectively in the number registered in 2004.

The annual gross income of China's agricultural machinery industry reached 451.6 billion Yuan RMB (US$ 677 million)[11] in 2016. While almost all planting and harvesting is mechanized in North China; in 2016 in South China, mechanized planting occurred on only 45% of irrigated rice-growing land and mechanized harvesting on 87% of this area (Luo 2019).

In South China, agriculture is practiced across all provinces, which account for 31.5% of the area of national farmland and contribute 35.5% of the country's food grain (Hu *et al.* 2011). Most of this arable land is in hilly and mountainous regions. Rice has long been grown on the terraced and fragmented farmlands of these areas in ways similar to many areas of South and Southeast Asia.

[11] Exchange rate used: Yuan RMB 6.67: US$ 1 (30 June 2016).

In the last 50 years, crop harvesting in South China has evolved from manual harvesting through the use of reapers and threshers to mini and small combine harvesters. Most rice farmers choose smaller horsepower combines to harvest their rice that are well-adapted to the small plots and fragmented holdings. Most of these machines are manufactured in South China.

Studies by Liu *et al.* (2018) and others suggest that the hilly geography, small plots, terraced landscapes and wet rice fields in South China have precluded the introduction of large harvesters. Note that in 2016, 98.1% of China's more than 207 million farms were managed by smallholders (NBS 2017). Liu *et al.* (2018) reported that the highest rate of crop harvesting by smaller horsepower combine harvesters was 4,300 m^2/hr.

Scale-appropriate agricultural machinery is increasingly recommended for use on small and fragmented landholdings for the conservation of agricultural resources (Krupnik *et al.* 2015 and Baudron *et al.* 2015). Scale-appropriate mechanization is a powerful driver of rural development in South Asia with it being a major reason for the large growth in agricultural productivity (Mandal *et al.* 2017).

This paper reviews scale-appropriate farm mechanization in South China to improve understanding of the crop production and harvesting machine technologies in use there.

8.2. Study Methodology

This review collected information from the internet on the types of combine harvesters used in South China and classified it based on agricultural engineering criteria and specifications. The study also consulted experts, harvester producers, users, sales representatives, and extension agencies about these machines.

This literature review and market investigation classified the harvesters used in South China into reapers, mini combine harvesters and small combine harvesters. The technical specifications of each class and type of machine were then analyzed. Harvesters with similar machine power, weight, cutting and header widths and other factors were grouped and their features analyzed. This allowed us to study the performance and costs of the various harvesting machines.

In addition, the study analyzed the social, economic and agronomical characteristics of crop management and harvesting technologies across South China and the management of crop residues by these machines.

8.3. Results and Discussion

In the last 50 years, South Chinese agriculture has moved from manual to mechanized reaping and threshing and on to combine harvesting (Figure 45). In the latest phase many farmers have purchased or hire in the services of mini and small combine harvesters. Note that combine harvesters carry out cutting, threshing and cleaning in a single pass.

Reaping and reapers

Reaper harvesters and stationary threshers to process rice crops were rapidly adopted by farmers in South China from the mid-1970s (Zhu 1990). Mechanized reaping radically increased the speed of harvesting as an individual operating a reaper can harvest 2 hectares of rice in a day, which is 20 times faster than manual harvesting (Zhu 1990). Reapers have an average capacity of 2,300 m^2/hr.

Many Chinese manufacturers have produced a range of types of reapers, mostly for harvesting rice and wheat. The main types have been the ride-on 1.2–1.4m wide reaper attachment for 2WTs and the later single purpose self-propelled reaper. Since around 2010, the self-propelled models have been modified as reaper binders and to harvest additional crops such as oil seeds and jute. As domestic demand shifted to combine harvesters these manufacturers shifted to selling their machines abroad. Some representative producers and their products are shown in Figure 46.

The large market for reapers prompted engineers and manufacturers to develop industrial standards for their products. Table 10 illustrates the major specifications that have served as general guidelines for reaper

Figure 45. The three stages of crop harvesting technology in South Chinese agriculture.

Xinmingyue Machinery Ltd, Yancheng, Mingyue: 4GL120 2WT attached reaper

Changqing Mine Machinery Ltd, Shangdong: self-propelled reaper

Qufu Hongxin Machinery Ltd: self-propelled reaper binder

Xinda Machinery Ltd, Botou: 4GL-120 self-propelled pepper reaper

Ninglian Machinery Ltd, Shandong: 4SZ-150 self-propelled rice reaper

Ruikuang Machinery Ltd, Shandong: multi-purpose reaper for tall crops

Figure 46. Common reapers used in South China. (Source of photos: manufacturers' websites).

Table 10. The four most common technical specifications for reapers in China.

Model	Weight	Rated power	Header width	Productivity (hm^2/hr)
4HGL80	70 kg	4.41 kW	800 mm	0.133-0.167
4HGL100	90 kg	4.41 kW	1,000 mm	0.167-0.233
4HGL120A	110 kg	4.41 kW	1,200 mm	0.2-0.3
4HGL150	140 kg	4.41 kW	1,500 mm	0.233-0.3

producers. Note that technical information is not available on stationary threshers as they were not industrially standardized.

Mini combine harvesters

Between 2004 and 2009, the reaping and threshing of crops was replaced by harvesting with mini combine harvesters (Wei 2014). Mini combines were mostly developed by the private sector and made combine harvesting available to smallholders whose fragmented holdings and terraced fields precluded the use of large-wheeled combines.

An important issue reviewed by this paper is the lack of any official categorization or standards for the different sizes and classes of combine harvesters in China. This is in contrast to other types of farm machinery such as tractors. Also, regional variations in nomenclature within and between the agricultural and automotive engineering fields challenge the consistent categorization of combine harvesters in China.

The following definitions have been proposed based on engine size and other factors, which, however, reflects the lack of an agreed categorization for harvesters (also see Table 11):

- Liao *et al.* (2007) categorized combine harvesters into large harvesters (engine power >36.8 kW), medium harvesters (29.4 – 36.8 kW) and small harvesters (<29.4 kW).
- Li (2012) defined and proposed the name 'small combine harvester' for machines with engine power of less than 12 kW, gross weight of less than 650 kg and a header width of less than 1,200 mm.

Table 11. Proposed parameters for mini combine harvesters.

Specifications	Threshold parameters	References
Machine weight	<650 kg	Li et al. 2012
Header width:	800–1,200 mm	Yang. 2006
	1,200 mm	Li et al. 2012
	1,000 mm	Xu et al. 2014
Feeding rate:	0.3–1.0 kg/second	Xia et al. 2017
Field capacity:	0.04–0.1 hm^2/hr	Yang. 2006
	0.05–0.1 hm^2/hr	Chai et al. 2012
	0.67 hm^2/hr	Xu et al. 2014
Rated power:	4.5–7.5 kW	Yue et al. 2018
	<29.4 kW	Yang. 2006
	5.5–7.5 kW	Liao et al. 2007
	<12 kW	Chai et al. 2012
	7.5 kW	Li et al. 2012
	5–10 kW	Xu et al. 2014

Note: 1 hm = 1 hectometer = 100m

- Xia *et al.* (2017) used the term 'small harvester' for combines that cut, thresh and clean crops with an engine power of 5–10 kW and a feed rate of 0.3-1.0 kg/second. He added that they should be self-propelled.

- Chai *et al.* (2012) defined mini combine harvesters as machines with a header width of 800–1,200 mm, 5.5–7.5 kW engines and the ability to harvest crops at the rate of 0.04–0.1 ha/hr.

- Yue et al (2018) defined large to medium harvesters as machines that could harvest at 0.13–0.2 ha/hr, which is twice the rate of small harvesters (0.067 ha/hr).

It is, however, generally agreed that mini combines:

- harvest crops in one-pass field operations;

- cut crops, thresh, and clean the grain with the separated grain collected in containers or bags ready for transporting from fields; and

- are light weight to facilitate manual carrying in and out of fields even in hilly and mountainous places without paved roads and in muddy and flooded rice fields.

Local manufacturers have made a number of technical improvements to their combine harvesters. These include i) downsizing rubber track or caterpillar type ground drive systems to use on mini combines, ii) increasing the on-board capacity for storing grain and bagging cleaned grain, iii) introducing true multi-crop combine harvesters, and iv) mounting combines behind tractors (mostly for the Chinese market) and tractors mounted behind combines (mostly for the Indian market).

Other features of mini combine harvesters thus now include:

- tracked or caterpillar ground drive systems for traction in wet rice fields;

- double cutting bars for improved crop residue management and to reduce the power needed for threshing;

- powered engines with electric starters, which facilitate operation by the elderly and women;

- alternative air cleaning mechanisms;

- greatly reduced weights;

- sit on designs that reduce operator strain; and

- integrated handle operation panels for ease of operation and control.

Discussions on what constitutes scale-appropriate machinery for smallholder farmers on fragmented holdings have progressed in recent years, mostly around 2WTs and 4WTs and their attachments (Khondoker *et al.* 2016, Kienzle *et al.* 2013, Mahmud *et al.* 2014, Krupnik *et al.* 2015 and Baudron *et al.* 2015).

The following authors have identified the following features of the evolution of crop harvesting technologies in South China:

- Compact construction, light weight, ease of operation (Xia *et al.*, 2017; Wang 2006; Zhen and Lin 2007).

- Low cost and lower fuel consumption (Xia *et al.* 2017).

- Adaptable to smallholder farming and rice fields (Xia *et al.* 2017; Zheng *et al.* 2007).

- Addressing the time constraint for shifting to the next crop for harvesting, e.g. 5–10 days shift window between two crops (Zhang *et al.* 2018; Zhang *et al.* 2012).

- Operation and maintenance requirements (Wang 2006).

The specifications of mini combine harvesters available in South China are listed in Table 12 while some major features are illustrated in Figure 47.

Although they only have limited power, current models of mini combines meet the needs of agriculture in South China with their tracked chassis for traction in irrigated rice fields, seated designs to reduce operator drudgery and integrated handle operational panels for ease of operation (Figure 48).

Small combine harvesters

There has also been progress on the larger technology of 'small combine harvesters'. As already explained, even in South China's flatlands, most farms are small with fragmented small plots for growing irrigated rice. This pattern is explained by the need to precisely manage irrigation water in level fields as smaller plots enable easier land leveling, irrigation and drainage.

The fields tend to be more regular shaped and plot sizes larger in flat areas than the terraced fields on hill farms. This has allowed the industry and farmers to pursue higher profits by shifting from mini combines to the larger 'small' combine harvesters to harvest their crops. The small combines in use in South China mostly have tracked or caterpillar ground drives and have some similarities with larger combines and are more or less scaled-down versions of 90 kW wheeled combines.

Table 12. Specifications of mini combine harvesters available in South China.

Model	Machine weight (kg)	Size (mm)	Header width (mm)	Feeding rate (kg/sec)	Field capacity hm²/hr	Rated power (kW)
anmi 4LBZ-70	145	2200×930×1100	700	0.3	Na	4.05
Shuntian 4LZ-0.6	268	2700×1380×1300	1100	0.6	0.05-0.1	6.6
Xinyuan 4LZ-0.3LA	320	2500×1100×1500	900	0.5	0.05-0.1	6.8
Xinyuan 4LZ-0.5LB	340	2500×1100×1500	920	0.5	0.05-0.08	6.3
Jinnantian 4LZ-0.6	Na	2840×1200×1470	1050	0.6	0.08	Na
Taishen 4L-90A	360	Na	Na	0.5	0.1	Na
Jinnantian 4LZ-0.9	372	2980×1400×1470	1200	0.9	0.12-0 14	Na
Xinyuan 4LZ-0.5LC	380	2200×1100×1500	920	0.5	0.05-0.08	Na
Tianyuanty 4lz-0.6	Na	2700×1420×1350	1200	0.6	0.07-0.12	Na
Shuntian 4LZ-0.8	470	2700×1420×1350	1200	0.8	0.07-0.12	Na
Gangyi 4L-0.9B	580	2914×1250×1200	1060	0.9	0.05-0.1	Na
Xinyuan 4LZ-0.9LB	630	3100×1450×1500	1000	0.9	0.07-0.1	Na
Nongyou 4LZ-1.0	750	Na	1200	1	0.08-0.2	14.7
Kaiyuan 4LBZ-100	820	2510×1300×1690	995	Na	0.08	8.82

Nongyou Agri. Machinery Ltd, Hunan: model Nongyou 4LZ-1.0

Sanmi General Machinery Ltd, Dongguan: model 4LBZ-70

Shuntian Machinery Ltd, Changsha: model Shuntian 4LZ-0.8

Xinyuan Agri. Machinery Ltd, Chongqing model 4LZ-0.9LB

Xinyuan Agr. Machinery Ltd, Chongqing model 4LZ-0.5LB

Tianyuan Agri. Machinery Ltd, Qufu model Tianyuan ty4lz-0.6

Figure 47. Some mini combine harvesters in use in South China. (Source of photos: manufacturers websites).

Figure 48. Features of mini combine harvesters: 1. rubber and steel racks for improved traction, 2. double cutting bars for improved residue handling, 3. powered engines with electric starters, 4. improved cyclone air cleaning mechanism, 5. seats, 6. integrated handle operation panel. (Source: www.sogou.com)

Small combines are also referred to as 'medium harvesters'. They tend to have 1,600–2,500 mm cutting or header widths, gross weights of 2–3 tonnes, 35 to 70 kW+ engines and a feed rate of 0.13–0.8 ha/hr. Some common models of small combines are listed in Table 13.

The operation of these small combines has been studied on South China smallholder farms (Yang 2016,Ding *et al.* 2013). They are either semi-feeding (head fed) or whole fed. The two types of whole

Table 13. Specifications of small combine harvesters common in South China.

Type	Machine weight (kg)	Size l×w×h (mm)	Header width (mm)	Feeding rate (kg/sec)	Field capacity (hm^2/hr)	Rated power (kW)
Bilang 4LZ-1.0	2,000	4,400×2,300×2,700	2,000	Na	0.13-0.26	36.7
Longzhou 4LZ-2.3	2,300	4,940×2,810×2,550	1,830	2.3	0.27	44.8
Jiubaotian PRO488	2,200	Na	1,450	0.6	0.2-0.4	35
Liulin 4LZ-145 2,550 Na			1,450	1.2-2.0	0.2-0.33	43
Leiwogushen RC12	2,400	Na	1,380	1.2	0.13-0.2	32.4

feeding machine are axial and tangential flow types. See Figure 49 for some representative models.

Figure 49 shows that the design of small combines is similar to the larger horsepower wheeled combine harvesters. However, there is no consensus on where small combines 'end' and large combines 'begin'. We suggest that the divide comes between machines with motors greater than 80 kW and headers wider than 3m.

Economies of scale of crop harvesting technologies on small farms in South China

Debates and definitions of the scales of crop harvesting technologies inform the economic analysis of harvester-induced impacts on farming systems (e.g. crop residue management) and policy-making. The rapid increase in agricultural wages in South China made manual field harvesting uneconomical (Figure 50). The cost of manual harvesting is about $671/ha due to the large number of worker-days needed. This made mechanized, and especially combined harvesting, economical in South China.

A study in Sichuan province, South China found that, within the available annual working days of two seasons (20 days per season), the harvesting of the two crops of rice using a mini combine harvester

Wuxi Comb. Ltd, model Taihu: 4LBZ-145 – semi or head-feeding

Keleshou Agri. Machinery Ltd, Shandong: model Chunyu 4LZ-5

World Agri. Ltd, Jiangsu: model Ruilong 4LZ-5.0E

Aike Dafeng Agri. Machinery: model Dafengwang 4LZ-2.0

Jvming Machinery Ltd, Shandong: model Jvming 4LZ-1.6

Yanmar Agri. Machinery Ltd, China: model Yanmar 1180

Longzhou Agri. Ltd, Hunan: model Longzhou 4LZ-2.3

Liulin Machinery Lt., Zhejiang: model Liulin 4LZ-258

Kubota Agri. Ltd. Jiangsu: model Kubota PRO488

Figure 49. Nine types of 'small' combine harvesters in use in South China. (Source: manufacturers' websites).

Figure 50. Increased wages drove the shift from manual to combine harvesting in South China. (Source: www.sogou.com).

provided an annual profit of $2,600 (Zhan 2017) for farmers compared to only $ 2,230 from manually harvesting the crops.

Outmigration from rural areas has made the carrying out of field operations more expensive using manual labor. A study in Guangdong rural region found that men older than 50 years and women laborers accounted for more than 70% of the active rural labor force (Cheng 2015). The scarcity of labor and the increasing wages best explain the widespread adoption of mini combine harvesters. Their relatively low cost compared to larger combines, and government subsidies make it attractive for smallholder farming households to buy them (Figure 51a).

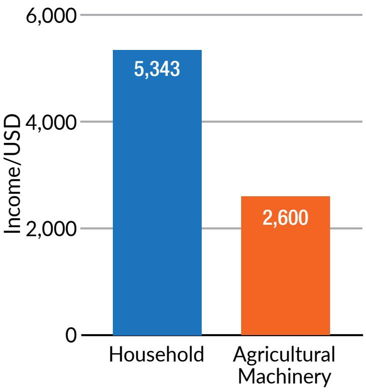
Mechanized harvesting in South China is mostly carried out using small combines. Different crop harvesting times mean that the work of contract harvesters in the main season may start at the end of April in Sichuan province in southwest China and end in mid-June in Henan province to the east. The country's good highway infrastructure and policies mean that a well-managed harvesting schedule for a small combine can provide as much as 50 days harvesting services per season. This contract harvesting has been termed 'cross-regional mechanized harvesting' (Wang 2014).

The high profits from small combine harvesters that provide cross-regional harvesting services, as found in Jiangsu Province in 2014 (Figure 51b), has attracted many farmers to this work. This type of service meets a major need in rural China and other developing countries (Wang 2014).

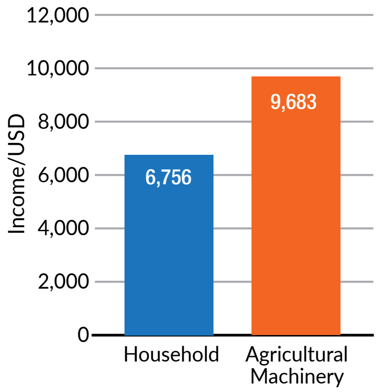
Crop residue management

The post-harvest burning off of rice straw by farmers is a major cause of air pollution in many towns and cities in South China in spite of it being prohibited in 2016 by the central government. What happens to straw usually depends on how it is left in fields.

In conventional rice farming, the straw is either left in windrows for easy collection or is spread evenly over the fields if the next crop is directly seeded. Mini and small combines distribute straw differently. Small combines, with their higher engine power, mature threshing mechanisms, grain separation, straw cutting and spreading enable crop residue management as they windrow straw for later collection (Figures 52 and 53).



a) Mini combine harvesting



b) Small combine harvesting

Figure 51. Attainable profit of mechanized harvesting (red) versus household annual income expectations (blue) from mini and small combine harvesting.

Figure 52. Stacking method of stubble under small combine harvesting with evenly distributed straw (left) and windrowed straw for recycling (right).

Figure 53. Crop residue management under small combine harvesting – preparations for planting next crop.

However, due to their limited engine power and simplified mechanical designs for straw cutting and threshing, mini combines do not satisfactorily cut and process crop residues as they erratically distribute straw in fields (Figure 54). This is one reason why many farmers prefer small combines for harvesting their crops.

8.4. Conclusions

The last 50 years have seen major changes in crop harvesting in South China with the shift from manual harvesting to the use of powered reapers and threshers and on to combine harvesting. Cost savings and the increasing cost of labor have been the main reasons for the shift. Currently mini combines predominate for individual household ownership while small combine harvesters are the main machines used by crop harvesting service providers. Small combines provide satisfactory crop residue management while mini combines provide timely harvesting and threshing services but the non-ideal handling of crop residues. It remains a technical challenge to develop small powerful and lightweight combine harvesters that can provide both satisfactory grain harvesting and straw management for South Chinese smallholder agriculture.

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Figure 54. Crop residue management with mini combines (a) in wheat fields and (b) in rice fields. (Source: Baidu).

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Funded by

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