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REVIEWS **OPEN ACCESS**

Impact of Modern Rice Harvesting Practices over Traditional Ones

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ABSTRACT

Mechanized agriculture plays a key role in the overall socio-economic development in terms of food security, value addition, employment, poverty alleviation and export earnings. Due to the migration of agricultural labor in non-farm sectors and increasing climate vulnerability, it is a great challenge to keep pace of food production for the exponential growth of population, especially in the developing countries. Hence, the main aim of this study was to examine the present status and impact of modern rice harvesting practices over traditional manual harvesting. In order to investigate the interactions between modern rice harvesting technologies and benefits of use, we reviewed overall scenarios of rice harvesting in the world along with identified problems due to present practices and the benefit of using modern technologies including precision agriculture. The major findings of this study were as follows: agriculture in most of the developing countries were characterized by low productivity due to less practice of modern technologies, less management of modern technologies, inadequate control of repeated crop losses due to natural calamities. Identified problems in traditional manual rice harvesting were: labor crisis at peak harvesting period, high harvesting cost as the traditional method was labor intensive and high labor wages, delayed harvesting due to the unavailability of labors, more grain/yield losses owing to the over maturity. Furthermore, identified benefits in modern rice harvesting practices were to save harvesting time, cost and labor involvement with reducing grain/yield loss and human drudgery. The further benefits were enhancing the income through custom hire services and creating a new employment opportunity in technology operation and maintenance. The results indicated that adoption of appropriate rice harvesting technology in the developing countries is urgently needed to increase the cropping intensity, crop productivity and economic emancipation through less inputs of time, labor and cost.

Keywords

benefit of modern harvesting, modern harvesting, problem of manual harvesting, rice, traditional manual harvesting

1. Introduction

Rice is one of the important food crops in the world and ranks second in terms of area and production (Devi *et al.*, 2009). Rice production continues to be greatest in Asia, where 90% of the crop is grown, but it has also been stable or increasing in the Americas, Africa, and Europe (Elphick, 2010). It is grown in at least 114 countries around the world (Maclean *et al.*, 2002) and is a staple food for nearly half of the world's population (Juliano, 1993). However, rice production in Southeast Asia is highly vulnerable to climate change (Redfern *et al.*, 2012). For rice production, harvesting is an important and sensitive part as well as others from seedling to storing. Harvesting is the process of collecting matured rice from field. Timely harvesting operation is known as crucial and influential processes on yield, quality and production cost of rice (Hasan *et al.*, 2019). Bhattacharya and Ali (2015) reported

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that most of the rice in the Asian countries is still harvested by hand sickle while harvesting by combine harvester is mainly practiced in industrialized countries where farm holdings are large and labor is expensive. Manual harvesting of rice is sometimes a troublesome, time-consuming, labor involving and costly operation. Therefore, several rice-producing Asian countries have seriously attempted to introduce compatible technologies for current circumstance (Alizadeh and Allameh, 2013).

Due to the migration of labor in nonagricultural sectors, shortages of labor and cost for rice harvesting are becoming a serious problem in peak harvesting seasons (Noby *et al*., 2018). Due to the industrialization in many of developing countries, labors are shifting towards mills and factories; thus it creates the shortages for agricultural operations. With the continuing urbanization, the loss of agricultural lands, especially for rice production, is predicted to increase rapidly in the next few years (Redfern *et al*., 2012). In addition, as population increases by 2% annually (ADB, 2009), the task of producing the additional rice to meet the expected demands of the year 2025 poses a major challenge. The danger is that stability in rice production is linked to social and political stability of the countries in the Asia-Pacific Region (Hossain, 1996). Coupled with the increase in the urbanization and industrialization, the need to increase food supply is becoming progressively more important. Therefore, policy support to rice research and development to introduce and transfer appropriate and efficient technologies are vital to better understand the role of rice cultivation in drastic changes in socioeconomic status. In addition, it enables farmers to improve their production practices while adapting to the severe challenges to their food security posed by climate change (Redfern *et al*., 2012).

A considerable amount of rice is lost in each stage of production especially in harvesting, processing and storage. Noby *et al*. (2018) reported that significant amount of field losses of rice in every year has been occurred for natural calamities and shortage of time during harvesting period. Bala *et al*. (2010) reported that post-harvest losses of rice at farm level were 9.49%, 10.51% and 10.59% for Aman, Boro and Aus seasons, respectively. Furthermore, Majumder *et al*. (2016) found the similar result that total post-harvest losses of rice at farm level in Bangladesh were 9.16 %, 10.10 % and 10.17 % for Aman, Boro and Aus, respectively. During the peak harvesting period, because of the scarcity of labor, harvesting is normally delayed, which resulted in yield losses of other crops. Mechanized agriculture entails the utilization of farm power and machinery in farming operations to increase productivity and profitability of farming enterprises through minimum inputs. It offers a lot of potential benefits not only to farmers and consumers but also to the whole country's economy. Jones *et al*. (2019) reported that agricultural technologies can improve economic productivity and reduce time spent in agricultural production, processing, and transporting. Decreasing resources (e.g. land, labor, soil health and water) and increasing climate vulnerability (e.g. drought, salinity, flood, heat and cold) appeared as the great challenges to keep pace of food production in the background of increasing population. Sufficient rice production is the key to ensure food security (Brolley, 2015).

Jones *et al*. (2019) mentioned that technologies/mechanization can improve the timing of tasks, reduce drudgery, make labor more efficient; and improve the quality and quantity of food. Timely harvesting is a crucial and important process to ensure yield, quality and production cost of rice (Noby *et al*., 2018). Adoption of modern mechanical harvesting practices (e.g. combine harvester, mini-combine harvester, reaper) are urgently needed to save time, labor and money through reducing the human drudgery, harvesting losses and increase the cropping intensity, crop productivity, economic emancipation. The time required for completing the operation of harvesting and threshing with traditional practice (manual harvesting and threshing with mechanical thresher by manual labor) was about 20 h whereas with combine harvester and straw reaper was 3.5 h (Anonymous, 2014). Zhang *et al*. (2012) reported that the working efficiency of combined harvester was 50 times higher than that of manual harvesting in rapeseed crop. Bora and Hansen (2007) examined field performance of a portable reaper for rice harvesting and the result showed that harvest duration was 7.8 times less than manual harvesting. The cost could be saved 52% and 37% for using a mini-combine harvester and reaper, respectively over manual harvesting system (Hasan *et al*., 2019). Hassena *et al*. (2000) reported that the cost per quintal of manual harvesting and threshing was 21 % and 25% higher than the cost of combiner harvesting, respectively. The net benefit of combiner harvesting was about 38% and 16% higher in Asasa and Etheya regions of Ethiopia, respectively, compared to manual harvesting and threshing. Jones *et al*. (2019) mentioned that mini-combine harvester on an average can save 97.50% of time, 61.5% of costs and 4.9% of grain losses over manual harvesting. Strengthening the linkage between research and extension is important to disseminate the available technologies to farmers and also to understand the farmers' demands for technologies. Kashem (2013) reported that the agricultural knowledge and information system integrates agricultural education, farmers, researchers, and extension workers to harness knowledge and information from various sources for better farming and improved livelihood.

Due to precision agriculture (PA), agricultural production systems have benefited from incorporation of technological advances primarily developed for other industries. Precision Agriculture is a farm management approach that uses information technology, satellite positioning data, remote sensing and proximal data collection to optimize returns on inputs while potentially reducing environmental impacts (Zarco *et al*., 2014). The industrial era brought mechanization and synthesized fertilizers to agriculture. The technology era offered genetic engineering and automation. The information era brings the potential for integrating the technological advances into PA (Whelan *et al*., 1997). While the technological tools associated with PA may be most obvious, the fundamental concept will stand or fall on the basis of scientific experimentation and assessment (Whelan and McBratney, 2000). The PA technologies and their application reveal many possibilities for mapping of machinery performance attributes very precisely during mechanical harvesting. Most people associate precision farming or site-specific management with the global positioning system (GPS) (Adamchuk, 2001). Precision agriculture is conceptualized by a system approach to re-organize the total system of agriculture towards a low-input, high-efficiency, sustainable agriculture (Shibusawa, 1998). This new approach mainly benefits from the emergence and convergence of several technologies, including the GPS and geographic information system (GIS).

This review aimed to provide some informative knowledge on the impact of modern rice harvesting practices over traditional manual harvesting practices. The present review would be the first overview on the rice harvesting in the world. In the second part, the existing rice harvesting practices in the world were discussed. Problems and benefits of present harvesting practices were discussed in the third part. Overall impacts of modern harvesting technologies were discussed in the fourth part. Finally, for the future agriculture, our final goals have been suggested as guideline on the solutions from present situations with some extensive information on the mechanization and PA.

2. Present status of rice harvesting practices

In agricultural operations, harvesting plays an important role on production cost of rice (Alam *et al*., 2017). In most of the developing countries, rice is manually harvested with hand tools like sickles, and is manually threshed by hand beating on a hard matter or some cases using a power thresher but in few areas. Arihara (2013) reported that Asian countries are occupying 89% of the world total rice area, and producing 90% of the total rice production; however, in the South East and South Asian countries, farmers are usually reluctant to adopt new technologies such as transplanter, tractor, and combine harvester because they are afraid of higher risk in rice production. Ali *et al*. (2018) reported that developed countries are using automatic combine harvester for harvesting cereal grains, and some developing countries of South and Southeast Asia are also using combine harvesters and as a medium grade technology, and many developing countries are using a reaper for harvesting rice to minimizing production cost.

Amponsah *et al*. (2017) reported that unavailability of appropriate harvesting machinery and technologies is a great disincentive to most rice farmers, especially in the countries of Sub-Saharan Africa. The following harvesting practices are available as shown in Fig.1. Based on the above discussion and flow diagram, mainly two rice harvesting methods are identified, and these are: a) traditional rice harvesting method b) modern rice harvesting method (semi mechanical and mechanical).

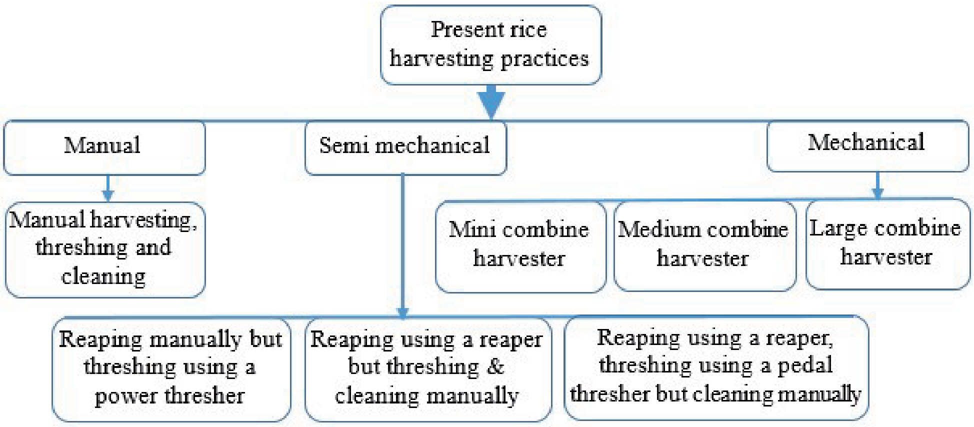

Figure 1: Flow diagram on present rice harvesting scenario

2.1 Traditional method

Traditional method means that all operational activities from rice harvesting to cleaning are done manually using hand tools. Manual harvesting of rice is a laborious, time-consuming and costly operation which requires about 100–150 person-hours labor to harvest 1 ha of rice field (Alizadeh and Allameh, 2013). Hasan *et al*. (2019b) reported that many developing countries are using manual harvesting system widely due to the unavailability of modern technologies. In Pakistan, economic growth is firmly linked with the agriculture but agricultural production is low as compared to the other countries of the world due to the unavailability of appropriate agricultural machines to the farmers at the right time (Rahman *et al*., 2016). Danbaba *et al*. (2019) also indicated that like in most countries of sub Saharan African, majority of Nigerian rice farmers harvest rice using sickle, a semi-circle metal tool with a wooden handle and only few farmers representing about 10% use mechanical harvester and reapers. In Sri Lanka, rice is harvested by manual labor using a sickle, and rice harvesting is delayed due to labor scarcity in traditional method resulting in loss of grain owing to over maturity (Chandrajitha *et al*., 2016). In Nepal, rice-producing technologies that minimize production loss are inadequate and not easily available to farmers (Tripathi *et al*., 2019). Manual harvesting, carrying, threshing and cleaning are shown in Fig.2 (i-iv). Currently, laborers are scarce during harvesting time, which often affects the timely harvesting of rice and timely planting of next crops in the same land.

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(i) (ii) (iii) (iv)

Figure 2: Manual harvesting to cleaning operations: (i) reaping, (ii) carrying, (iii) threshing and (iv) cleaning. (Adopted from Danbaba *et al.,* 2019)

2.2 Modern method

Modern method means mechanical harvesting using latest harvesting technologies during harvesting to cleaning operations. For instance, reaper with power thresher, combine harvester (mini, medium and large size) and incorporation of PA technologies including Global Navigation Satellite System (GNSS) and GIS to evaluate machine performances precisely. Modern harvesting technologies are capable of doing the work of many people within a short time. The application of machines in agricultural production minimizes the burdens and drudgery of manual farm labor, and increases farmers' income (Kepner *et al*., 2003). Ali *et al*. (2017) reported that farmers found the combine harvester attractive as it performs several tasks like harvesting, threshing, cleaning and bagging in a single operation. The most international and national research efforts in rice production have been focused on developing and releasing improved varieties for enhanced yields, but the similar cases have not been applied for rice mechanization. AfricaRice (2012) reported that when production was doubled in The Gambia between 2007 and 2010 for Nerica rice variety, farmers found it difficult to harvest and thresh the extra rice, which resulted in reduced quality because of the delays. It is therefore highly doubtful that modern harvester machines can be widely accepted in the developing areas of the world to minimize the physical grain loss and serious deterioration in quality (AfricaRice, 2011; Ndindeng *et al*., 2015b). At present, there are 4 different types of mechanical harvesting technologies are available as shown in Fig.3-6. Reaper with power thresher and mini-combine harvester are used by small to medium farmers in the developing countries limitedly. Somewhere medium combine harvester is also using by medium to large farmers in the both developing and developed countries. However, large combine harvester is used in the developed countries which price is more expensive and not affordable for small to medium farmers.

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(i) (ii)

Figure 3: Rice harvesting and threshing: (i) harvesting using a reaper and (ii) threshing using a power thresher (Adopted from Ali *et al.*, 2018)

(i) (ii)

Figure 4: Rice harvesting using a mini-combine: (i) harvesting operation and (ii) bagging with harvesting (Adopted from Ali *et al.*, 2017)

(i) (ii)

Figure 5: Rice harvesting using a medium-combine: (i) harvesting operation and (ii) bagging after harvesting (Adopted from Hasan *et al.*, 2019)

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(i) (ii)

Figure 6: Rice harvesting using a large-combine: (i) harvesting operation and (ii) grain unloading after harvesting (Photos captured by M. K. Hasan)

3. Problems and benefits of present harvesting practices

3.1 Problems of traditional practices

Rice harvesting using simple hand tools is a time, labor and cost involving task in comparison to the others farm activities. Currently, most of the developing countries are involving with industrial development. Rural labors are migrated to cities for more earning tasks in the industry for an entire year. Over the last century, agriculture transformed from a labor-intensive industry towards mechanization and power-intensive production systems, while over the last 15 years agricultural industry has started to digitize (Marinoudi, 2019). Through this transformation, there was a continuous labor outflow from agriculture, mainly from standardized tasks within production process. However, increasing unstable climate events are probably caused by climate change, because of more difficulty maintaining rice production levels (Redfern *et al.*, 2012). Climate change presents an additional burden on the world's agricultural and natural resources, which are already coping with the growing food demand driven by population growth and higher income in developing countries (Wassmann *et al.*, 2011). Due to the migration of agricultural labors to non-farm sectors and increasing climate vulnerability, it is a great challenge to keep pace of food production for the exponential growth of population in the developing countries. Some essential findings related to the traditional rice harvesting in the previous researches are presented in Table 1.

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Table 1: Findings on time, labor and grain loss during traditional harvesting rice

Findings	References
Timely harvesting of rice is a big challenge due to the shortage of labor and high cost of labor during peak harvesting period in Bangladesh, which is developing country and most of the crops are generally harvested manually.	Ali *et al*. (2019)
Maximum labor is required during traditional rice harvesting practices as compared to other activities of rice production, and it is reported as 381.4 person-hours ha-1.	Stout (1966)
Post-harvest losses of rice between farmer and retailer were estimated at 10–12% due to traditional manual practices during harvesting to selling	Majumder *et al*. (2016)
In the traditional rice harvesting methods, significant amount of field losses has been occurred in every year.	Hasan *et al*. (2019b)
Labor scarcity, harvesting loss, timely harvesting and harvesting cost are crucial in rice and wheat harvesting.	Hossain *et al*. (2015)
5, 7 and, 10 days' delay in harvest resulted in 3, 6, and 11% decrease in rice yield, respectively.	Samson and Duff (1973)
A progressive shrinking of rural labor availability has been occurred, as workers migrated to cities or abroad to be engaged in more remunerative employments.	Zhang *et al*. (2014)
The shortage of labor during the peak harvesting season was forcing the farmers delay harvesting, which caused high post-harvest losses and sometimes loss of the crop by natural calamities.	Hossain *et al*. (2015)

3.2 Benefits of modern rice harvesting practices

Rice harvesting with the latest invented technologies have some remarkable benefits in comparison to traditional manual harvesting rice. Two types of benefit are available from modern harvesting practices. One is a benefit from harvesting technologies (using a reaper, reaper with power thresher, combine harvester) and another is a benefit from PA (incorporation of GPS, GNSS, and GIS with machine to evaluate machine performances precisely).

3.2.1 Benefit from harvesting technologies

Previous researches identified several types of benefit in relation to mechanical harvesting. The major benefits are listed as follows: i) to save rice harvesting time, ii) to save labor involvement, iii) to save harvesting cost, iv) to save grain and yield losses, v) to reduce human drudgery, vi) to enhance income through custom hire services (CHS), and vii) to create new employment opportunities. Several essential findings about the benefit of mechanical rice harvesting are described in the following sections.

3.2.1.1 Save harvesting time

Hossain *et al*. (2015) reported that timely harvesting is extremely important, as delayed harvesting leads to delays in seed bed preparation and sowing operations for the next crops. Currently, timely harvesting of rice is a big challenge due to the shortage of labor and high cost of labor as large number of labors are migrated from rural to city due to the rapid industrialization and urbanization. To overcome these problems, mechanical harvesting is urgently needed (Keerti and Raghuveer, 2018). Using technologies/mechanization can improve the timing of tasks (Jones *et al*., 2019). The modern combine harvester is a versatile machine designed to efficiently harvest a variety of grain crops. The name derives from its combining three separate harvesting operations such as reaping, threshing, and winnowing into a single process. Thus, combine harvester is a time saving technology. Use of efficient machines saved 20–30% of operation time than ordinary machine (Tiwari *et al*., 2017). There is a positive trend of mechanization across the world in rice production, which contributes reducing the time consumption. Average time saving by using combine harvester over manual methods was found to be 97.50% (Hossain *et al*., 2015). Mohammad *et al*. (2007) revealed that the maximum and minimum effective field capacities (operating area per hour) were 0.361 and 0.009 ha h^{-1} for combined harvesting and manual harvesting for rice at Amol, Iran, respectively. The time for harvesting was 111.10 h ha^{-1} for manual harvesting but it was 3.64 h ha^{-1} for mechanized treatments, and the latter was 96.70% less. Padmanathan *et al*. (2006) reported that the operation of combiner harvester resulted in saving time that was 96% as compared to conventional method in Tamil Nadu Agricultural University, Coimbatore. The mechanical harvester saved the time of above 90% over traditional practices while it saved 2–3 weeks of harvesting time, which were also dependent on the cropping intensity (Mohapatra, 2016). Time savings might vary depending on machine types, size, quality and condition of crop field.

3.2.1.2 Save labor involvement during harvesting

Mechanical rice harvesting contributes more labor saving than manual harvesting. Labor involvement is expressed as the number of labor employed per area from harvesting to cleaning operations. Ali *et al.* (2018) reported that labor could be saved 65% and 52% for using mini-combine harvester and reaper, respectively over manual harvesting system. Saved labors can be engaged non-farm activities in urban areas, which may mitigate the industrial labor crisis and assist the GDP growth. Hasan *et al*. (2019) showed a similar result that labor savings for using combine harvester was 70% over manual harvesting. Combine harvesters are economically important labor saving inventions, significantly reducing the fraction of the population engaged in agriculture (Constable *et al*., 2003). Metwalli *et al*. (2006) reported that walking type vertical conveyer reaper, power tiller and tractor front mounted reaper saved 50–60% labor as compared with manual harvesting. Farmers were feeling the necessity of timely and efficient harvesting operations which can be conducted by modern machines like combine harvesters and mini-combine harvesters (Datt and Prasad, 2000). Ahmmed (2014) showed that labor scarcity was very high during the harvesting period of rice and wheat due to many agricultural labors have been migrating to other off-farm activities like garments and other industries, transportation, small business, road and building construction, etc. Rahman (2004) conducted modification of power transmission system of a Chinese reaper and its performance evaluation. Mechanical harvesting saved 95% labor requirement of manual harvesting. Hossain and Faruque (2003) conducted performance evaluation and improvement of cereal reaper made by Janata Machine Tools Limited. Mechanical harvesting saved 89% labor requirement of manual harvesting. Mondol (1997) tested a power tiller operated reaper at different gear positions for harvesting, and labor reductions were found to be 63 % over manual method. These findings showed that using a mechanical harvester is a labor saving technology, and the saved labors ranged from 60–80%. Labor savings might vary depending on machine types and field capacity as well.

3.2.1.3 Save harvesting cost

The mechanized harvesting can be priced to be lower than the cost of manual harvesting. To facilitate mechanized harvesting, modern harvesting technologies are becoming introduced in the developing countries of the world. The machines reduce harvesting cost and are calculated to save 52% of the costs (Hasan *et al*., 2019). Veerangouda *et al*. (2010) mentioned that the cost saving of operation by a tractor mounted combine harvester as compared to manual method was 57.65–65.55%. Combine harvesting saved 40–50% cost as compared to manual harvesting and threshing by power thresher (Morad *et al*., 1995). Moussa (2008) reported that combiner harvester reduced the cost of harvesting by 32 and 36% as compared to semi mechanical system (mower + transportation + thresher) and traditional system (manual + transportation + thresher), respectively. Not only combine but also mini-combine harvester and reaper are cost-saving technologies. Ali *et al*. (2018) showed that 58% and 46% costs were saved using a mini-combine harvester and a reaper (including harvesting, threshing and cleaning), respectively.

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Meisner *et al*. (1997) showed that a reaper is 14 times more efficient than a daily laborer in cutting and placing cereals in a field. Praweenwongwuthi *et al*. (2010) focused on mini-type harvesters, and the majority (92%) was hiring the harvesters. They stated that the net benefit of combine harvesting was about 30.3% higher than manual harvesting and threshing. They also showed that it was more profitable to use combine harvesters other than manual harvesting for farmers in Sri Lanka with respect to the production cost. There was a significant difference in the average production costs between manual and combine harvesting. Walking type vertical conveyer reaper, power tiller and tractor front mounted reaper saved harvesting cost by 60–70% as compared to manual harvesting (Metwalli *et al*., 2006). Hossain and Faruque (2003) conducted performance evaluation and improvement of cereal reaper, and they found that harvesting cost of rice with reaper was 70% of manual harvesting. Kurhekar and Patil (2011) reported that a vertical conveyor reaper saved up to 44% cost of harvesting. Aung *et al*. (2014) further reported that harvesting cost of power reaper was 67% less than that of manual harvesting. Mondol (1997) tested a power tiller operated reaper at different gear positions, and the cost reductions were found to be 53% over manual harvesting. The machine purchase cost was included in the analyses for all literatures mentioned above. Thus, mechanical harvester can be regarded as a cost saving technology, which is consistent with a previous finding from Manjunatha *et al*. (2009). Furthermore, the saved cost by combine harvester can be summarized to vary from 40% to 60%. Cost saving depends on machine purchase price and machine condition as field capacity, fuel consumption, repair and maintenance cost, etc.

3.2.1.4 Save grain losses/yield losses

Mechanized harvesting could eliminate grain loss during the processes of manual cutting crops, tying the crops for carrying, transporting the harvest, and incomplete threshing. A significant increased yield has been demonstrated through mechanical harvesting. Veerangouda *et al*. (2010) showed the grain losses using a tractor mounted combine harvester, the harvesting losses were in the range of 2.88 to 3.60%; on the other hand, manual harvesting losses were found 6.36% (Hasan *et al*. 2019b). Ali *et al*. (2018) reported that harvesting loss of rice can be reduced 5.12% and 2.14% using mini-combine and reaper, respectively in comparison to manual harvesting system. Hence, the mechanical harvesting would be more feasible and economical than traditional method. Muhammad *et al*. (2015) investigated grain losses of wheat as affected by three different harvesting and threshing techniques -i.e. i) manual plus thresher ii) reaper plus thresher and iii) combiner harvester were used in the study. They revealed that total grain losses during harvesting and threshing processes with manual plus thresher, reaper plus thresher and combiner harvester were 222.63 kg ha^{-1}, 199.41 kg ha^{-1} and 149.87 kg ha^{-1}, respectively, which were 4.28 %, 3.85 % and 2.92 % of the total yield, respectively. Hasan *et al*. (2019b) reported that losses of rice could be reduced by 4.47% using combine harvester over manual harvesting. Amponsah *et al.* (2017) reported that a Sifang mini-combine harvester produced low mechanical grain damage, and the total grain loss ranged from 1.43% to 4.43% and 1.85% to 5.6% for the IR841 and Nerica L20 rice varieties, respectively. Aung *et al*. (2014) reported that power reaper achieved less than 0.5% grain losses over manual harvesting rice. The findings revealed that grain loss/yield loss reduced by approximately 5% using the mechanical harvesting over traditional manual harvesting. Moreover, saved grain losses by mechanical harvesting enhanced more return from the same field. Harvesting loss might vary depending on soil and weather conditions, and the extent of grain maturity. Generally early harvesting reduces the losses; on the other hand, delay harvesting is the cause of more grain losses due to the low moisture content, crops lodging to the ground for over maturity, facing natural calamities like early flood, storm, and cyclone, etc.

3.2.1.5 Reduce human drudgery

Modern rice harvesting technologies affect not only on harvesting cost, labor involvement, grain loss reduction, but also on reducing human drudgery, i.e., labor for harvesting, threshing and cleaning during the in-field and out-field operational activities. World Bank (2007), Kienzle *et al*. (2013) and Mahmud *et al*. (2014) showed that agricultural machinery may be of great interest to smallholder farmers because of the potential production cost savings with reduction in drudgery by substituting manual labor and traditional tools with efficient machineries. Odigboh (2000) and Azogu (2009) reported that agricultural mechanization can more simply be defined as the use of any machines to accomplish a task or an operation involved in agricultural production. Such tasks or operations include reduction in human drudgery, improvement in the timeliness and efficiency of various agricultural operations, bringing more land under cultivation, preserving the quality of agricultural products and providing better rural living conditions. Sayed *et al*. (2015) found that more than 90% of the villagers were agreed that mechanization makes the rice farming easier and reduces human drudgery in Bangladesh. It is often believed that drudgery of manual agricultural labor could make farming unattractive to youth, which might force them to seek off-farm employment that is potentially less productive (Mrema *et al*., 2008). Also, Hasan *et al*. (2019b) reported that appropriate harvesting machinery was an urgent need to develop and introduce for agricultural mechanization to increase production with less drudgery and less labor involvement. Consequently, this study revealed that utilization of appropriate mechanical harvesting technologies could be replaced with a human drudgery along with economic emancipation in the rural people of developing countries like developed countries.

3.2.1.6 Enhance income through custom hire services

The owners of private equipment can consider to provide the custom CHS of various machines to the farmers at appropriate times and at reasonable rates which ultimately reduce the fixed cost of farm operations and reduce the burden of capital investments or credit from the bank for rural farmer. The machinery cost of farm operations could be reduced to almost half by CHS (Shidu, 2012). Due to the high initial investment, it is not suitable for the small and low-income farmers. There is an opportunity to use agricultural machines through CHS to avoid initial investment issue. Even the smallest farm households can usually access relatively affordable machinery services through CHS (Justice and Biggs, 2013; IDE, 2012). The operations of the CHS in agricultural mechanization are economically viable. Hasan *et al*. (2019b) mentioned that there is a great opportunity to use a mini-combine harvester through CHS by a local service provider and custom-hire entrepreneur to avoid initial investment. Instead, increasing numbers of farm machinery, smallholder farmers could access agricultural machinery services through custom hiring arrangements (Biggs and Justice, 2015). Local machinery service providers are making business in the farmers' field as CHS basis (Hossain *et al*., 2014). Thus, it is recommended that mechanical harvester can be used by CHS entrepreneur to avoid initial investment of rural farmer to meet up labor crisis at peak harvesting period with reducing cost and human drudgery.

3.2.1.7 Create new employment opportunities and social dignity for educated farmers

Another important opportunity will be created for the unemployed educated people in the field operation of modern rice harvesting technology and maintenance of harvesting technology in the engineering workshop. Miah *et al*. (2002) showed that farm mechanization has remarkable positive impacts on creating employment opportunities, higher income, increasing household assets, and increasing the overall standard of living of rural laborers. Also, in limited areas, utilization of modern harvesting technologies (i.e. automatic combine harvester for rice harvesting) has been increasing social dignity, and attracted educated people to farm activities without hesitation. Badiane and

Braun (2018) reported that mechanization, if adapted to local contexts and needs, can result in increased farm incomes, improved livelihoods for smallholder farmers, and created new employment opportunities. Agricultural mechanization is an important input to agriculture for performing timely farm operations including improving the productivity of land, and labor and for improving the dignity of labor (Goyal *et al*., 2014). Farmers can invest the financial benefit of mechanical harvesting system to other agricultural sectors like poultry, fishery, and vegetable and fruits production (Ali *et al*., 2018). Consequently, the utilization of modern harvesting technologies would contribute not only to increase total agricultural production but also to create a new employment opportunity in operational maintenances, which in turn will develop socio-economic status of rural people.

3.2.2 Benefit from the precision agricultural technologies

Currently, PA refers to the use of technology that helps farmers to manage their technologies in fields in a more precise and accurate manner. Precision agriculture is one of the top ten revolutions in agriculture (Crookston, 2006), although it has only been practiced commercially since the 1990's. The fundamental technologies of PA are GNSS/GPS and GIS. Rice harvesting using PA technologies are shown in Fig. 7 (adopted from Kurita *et al*., 2017 and Cho *et al*., 2015). These technologies and their application revealed many possibilities for accurate mapping of machinery performance attributes like area coverage, operational time, harvesting speed, machine idle time, effective operational time, field capacity, harvesting location with operational track, turning pattern with losses time, etc. Precision agriculture offers to improve crop productivity and farm profitability through improved management of farm inputs (Larson and Robert, 1991; Zhang and Wang, 2002). Grisso *et al*. (2004) reported that geo-referenced data can play an important role in the management and operation of farm equipment. Proper crop management strategies would enhance rice production (Shelley *et al*., 2016). Adamchuk *et al*. (2004) mentioned that in every case, the efficiency of farm machinery operation can be affected by three factors: i) travel speed, ii) effective swath width, and iii) field traffic pattern. Abo *et al*. (2010) evaluated the performance of local combine for harvesting wheat crops. They found that the highest cutting efficiency 94.81% was obtained at the forward speed of 0.53 km h^{-1}, the highest effective field capacity 0.48 ha h^{-1} was obtained at the forward speed 1.15 km h^{-1}, and the highest efficiency 78.38% was obtained at the forward speed 0.53 km h^{-1}. Amponsah *et al.* (2017) found that with the harvesting speed ranging from 0.8 to 4.5 km h^{-1}, the mini-combine harvester had a field capacity of 0.10 to 0.39 ha h^{-1} and consumed fuel of up to 11 L ha^{-1} while it had a track slip of 6% to 9%. Therefore, speed of the harvester directly affects field capacity and efficiency. Pandey and Devnani (1987) evaluated two harvest patterns, and concluded that field efficiency, expressed as the ratio of effective field capacity (ha hr^{-1}) to theoretical field capacity (ha hr^{-1}), could be improved by optimizing harvest patterns. Note that effective field capacity is a value computed from area coverage and required time, and theoretical field capacity is a value computed from the cutting width and forward speed of combine harvester. Also, field efficiency decreases with increasing turning time. Taylor *et al*., (2002) suggested that given a strong relationship between turning time and harvest efficiency, farm managers should focus more effort on reducing the time spent turning during harvest rather than on-the-go unloading. Farm managers could more quickly improve harvest efficiency by modifying harvest patterns to minimize turning than by on-the-go unloading. Machine idle time is also one of the most important factors to reduce machine efficiency. Machine idling during harvesting can occur for many reasons such as operator's problem, clogging of the machine, any disturbances in the field, etc. Niehaus (2014) revealed that estimated machine idle time was 16.1% of the total harvesting time during corn harvesting using a combine harvester, and idling of machine contributed the ineffective time of field operation; thus it reduces field efficiency. The GNSS/GPS based evaluation of heading changes and harvesting track can be considered one of the methods for utilizing harvesting machines more efficiently. The results revealed that mechanical harvesting is extremely essential to enhance agricultural production with minimum inputs, and the utilization of PA technologies might create opportunities to identify the causes of machine inefficiency and take actions to increase the efficiency.

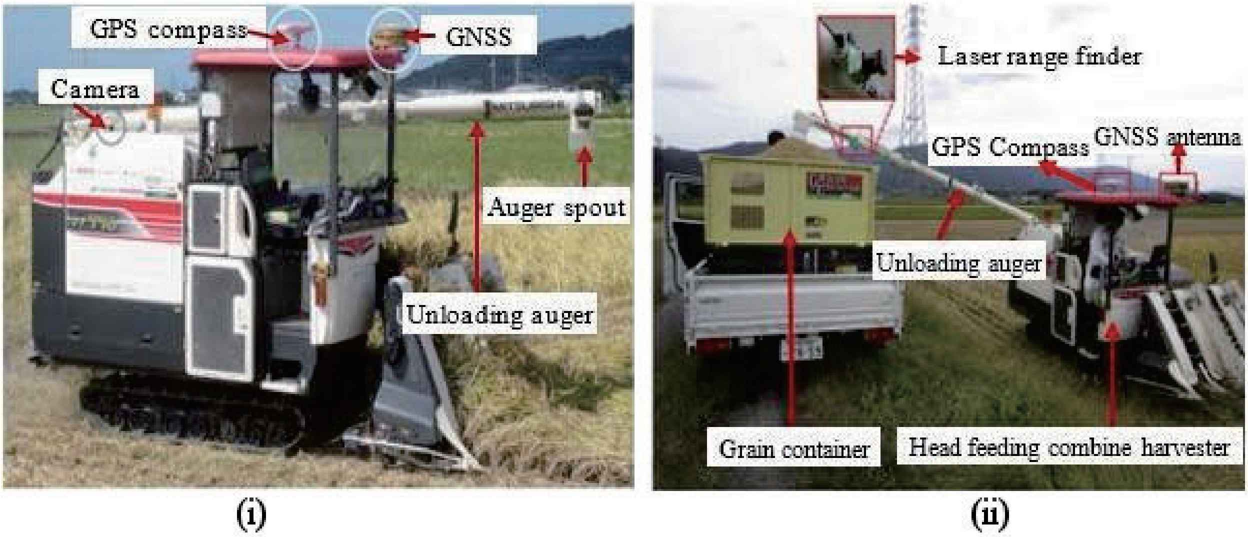

Figure 7: Rice harvesting using a precision agriculture technology: (i) (Adopted from Kurita *et al*., 2017) and (ii) (Adopted from Cho *et al*., 2015)

4. Overall impacts of using modern harvesting technologies

Before twenty first century, many scientists showed that farm mechanization, to some extent, seriously affected the employment and income of small farmers and landless laborers, and contributed little to the overall productivity of farming systems (Jabbar *et al*., 1983; Gill, 1984; Duft, 1986; Campbell, 1990). However, after twenty first century, the perception has been changed as different agro-based and allied industries have emerged to support farm mechanization. It has increased the involvement of small farmers and rural laborers both in cultural operation and post-harvest activities. Zami *et al*. (2014) suggested that introduction of appropriate machinery was one of the major factors for reducing time, labor requirements and production cost, and it also helped fitting another crop between successive two crops. Another study conducted by Singh (2006) suggested that mechanization technologies keep changing with industrial growth of the country, and socio-economic advancement of the farmer. Whereas declining interest in agriculture of the landowners and non-availability of the agricultural labor for field operations may be one of the major socio-economic issues in highly industrialized nations, and increasing land and labor productivity are requiring the mechanization in the developing countries.

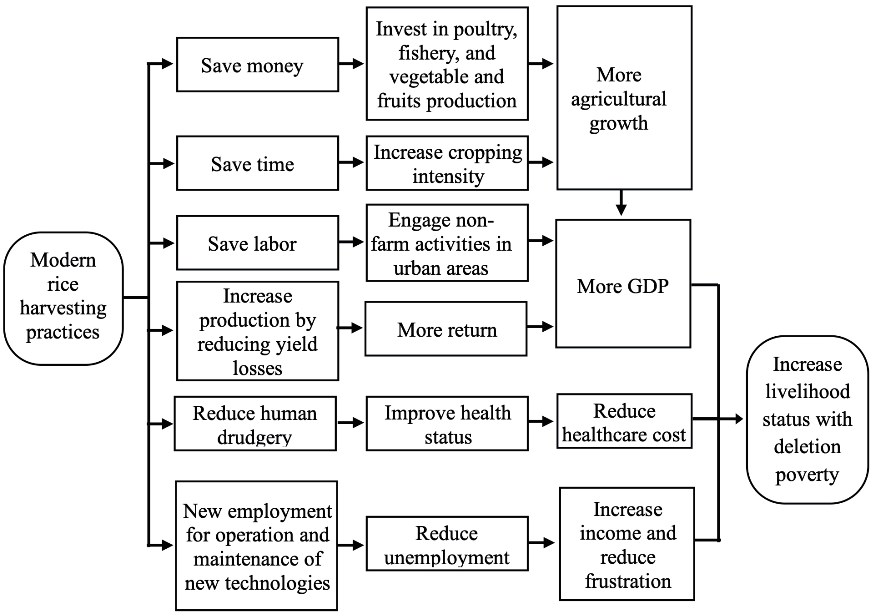

Figure 8: Flow diagram on the linkages among mechanization, agricultural growth, save money, GDP and livelihood status. Rounded rectangles represent the input and output, and rectangles represent intermediate processes.

A flow diagram presenting a close and clear linkages between modern rice harvesting practices and livelihood status of rural people, is shown in Fig.8. In this flow diagram, it is clear that modern harvesting practices contribute saving time, labor, and cost with reducing human drudgery and post-harvest losses. Also, new employment will be created for operation and maintenance of new harvesting technologies. Money and time saving has a great impact on GDP growth through enhancing agricultural growth by investment of saved money in the others agricultural sectors like poultry, fishery, vegetable and fruits production. This could further increase cropping intensity due to the proper utilization of saved time. The saved labor can be engaged in non-farm activities in urban areas, which will mitigate the industrial labor crisis to enhance the GDP growth. Here, the agricultural growth is an important element to enhance the GDP, and GDP is an important indicator to enhance the growth of an economy in many developing countries (Anthony, 2010; Hussain and Khan, 2011; Nazish *et al*., 2013). Appropriate utilization of technologies reduces human drudgery, which may influence human health to save healthcare cost. Furthermore, it also reduces food import cost through increasing production and reducing yield losses. Another important opportunity will be created for unemployed people in operation and maintenance of new technologies. Therefore, there is a need to facilitate the utilization of modern rice harvesting practices to increase yield with minimum input cost and labor, which will similarly have a positive impact on the GDP and country's economic growth. Finally, all factors identified above will affect livelihood status of rural people in the developing countries through enhancing agricultural growth and GDP.

5. Conclusions and Recommendations

In time rice harvesting is extremely important, as delayed harvesting leads to considerable grain losses and delays in seed bed preparation and sowing operations for the subsequent crops. The major findings of this study are as follows: agriculture in most of the developing countries are characterized by low productivity due to less practice of modern technologies, less management of modern technologies, inadequate control of repeated crop losses due to natural calamities and labor crisis. Identified problems in traditional manual rice harvesting are: delayed harvest is attributed to labor crisis due to changes of occupation from agriculture to others, which subsequently resulted in more grain/yield losses due to over maturity of grains, and labor intensive and costly manual harvest should be replaced with combine harvester. Furthermore, identified benefits in modern rice harvesting practices include save harvesting time, labor involvement, and cost, and reduce grain losses/yield losses and human drudgery. Modern rice harvesting practices enhance income through CHS and creating a new employment opportunity in technology operation and maintenance.

The modern harvesting technologies are regarded as advantageous and profitable technologies to do the work of many people within a short time with more precise and accurate manner than traditional manual harvesting. Precision agriculture also helps farmers to manage their fields more accurately. Under these circumstances, adoption of appropriate modern harvesting practices that has been implemented in the developed countries, is urgently needed to increase the crop productivity and economic emancipation in the developing countries. Therefore, we suggest what governments of developing countries should take initiatives for the adoption activities are as follows: i) demonstration on the modern harvesting technologies, ii) training on operation and maintenance of modern technologies, iii) providing a government subsidy on purchasing a new technology, and iv) development of rural infrastructure for easy transportation of technology.

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