CHAPTER 1

Mechanisation of Agricultural Production in Developing Countries

Daniel I. Onwudea, Guangnan Chen, Norhashila Hashim, Jeff R, Esdaile, Chandima Gomes, Alfadhl Y. Khaled, Akindele F. Alonge, Elijah Ikrang

1.1 Introduction

Agricultural production involves almost all aspects of cultivation, harvesting, processing, storage and transportation practices of crops, animals, and other life forms of foods and fibre. Agricultural production depends heavily on the availability of agricultural inputs such as labour, water, arable land and other resources (energy, fertilizer, etc) and it is significantly affected by the type, and scale of farm practices.

In many developing countries, agricultural production offers significant employment opportunities, food security, and economic development to local people. However, for sustainable agricultural production, efforts must be made to introduce changes in agricultural production, in order to increase crop yields, efficiency and sustainability. According to Akinyemi (2007), this can only be effectively achieved by the applications of adequate mechanised agricultural practices.

The advancement in the mechanisation of agricultural production in developing countries of Asia, Africa and Latin-America has been discussed and reported in the past few years (Diao et al., 2014; Deininger and Byerless, 2012). Sims, Helmi and Keinzle (2016) also gave an excellent summary of the context of agricultural mechanisation in Sub-Saharan Africa. They analysed the current challenges being faced including affordability, availability, lack of farmer skills, constraints within the private sector, and gender issues. Opportunities for improvement by sustainable crop production systems, agricultural mechanisation development and further investment were studied. The way forward through more sustainable systems, business models, economic and social advantages, gender, and institutional involvement, (both in the public and private sector) and co-operation by and knowledge sharing was also examined. However, overall, most of the information, especially on the level of mechanisation, present day technologies and their limitations in mechanised agricultural production is relatively patchy and inadequate, as many studies only focused narrowly in a limited aspect of the subject. Hence, a more in-depth review on this subject becomes indispensable.

In this chapter, an evaluation of relevant technology in the mechanisation of agricultural production in developing countries, with a view to bridging the gap in information, is presented. The levels of agricultural mechanisation technology are first discussed. Then, mechanisation in both large scale and small agricultural fields are examined. The opportunities of adoption of specific advanced technology are also evaluated. Finally, case studies of agricultural mechanisation are presented and challenges of mechanisation are discussed. Overall, the main emphasis of this chapter is to focus on key factors affecting mechanisation and future outlook with a view to improving agricultural productivity and reducing cost.

1.2 Agricultural Mechanisation

Agricultural mechanisation is the application of equipment, machinery and implementation of farm tools to improve the productivity of farm labour and land, in order to maximize outputs and increase agricultural and food production. Ulusoy (2013) defined agricultural mechanisation as the use of machines for agricultural production. In similar manner, Ulger et al. (2011) viewed mechanisation as the use of modern agricultural machines in place of traditional tools, equipment, machinery and facilities.

In practice, agricultural mechanisation involves the provision and use of all forms of power sources (manual, animal and motorized) and engineering technologies to enhance agriculture production (Viegas, 2003; Clarke and Bishop, 2002). These engineering technologies deal with production and post-harvest handling, storage system, farm structures, erosion control, water management (water resources development as well as irrigation and drainage), meteorological system, and the techniques for optimally utilizing the above and their proper and economic use and management (Chisango and Ajuruchukwu, 2010; Asoegwu and Asoegwu, 2007). Furthermore, it also encompasses the design, manufacture, distribution, maintenance, repair and general utilization of farm tools and machines (FAO, 2013). According to Akdemir (2013), the most commonly used indicators of the level of agricultural mechanisation are instrument/machine weight per tractor (kg/tractor), tool/machine number per tractor, tractor power per cultivated area (kW/ha), number of tractors per cultivated 1000 hectares field (tractor/1000 ha), and cultivated area per tractor (ha/tractor).

In a nut-shell, agricultural mechanisation minimizes drudgery which hitherto makes it difficult or rather impossible to achieve or practice effective food and agricultural production. Effective agricultural mechanisation can help in maintaining improved competitiveness and low consumer price. This can go beyond the application of tools and power machinery, to the application of automation, control, and robotics (Reid, 2011). In fact, agricultural mechanization was identified as one of the top ten engineering achievements of the 20th century: “This revolution has released the rest of the population to pursue the intellectual, cultural, and social development that has resulted in our modern society. Agricultural mechanization, like manufacturing, can be viewed as an enabling technology that made possible the other advances of the 20th century” (Schueller, 2000).

Figure 1.1 shows that the demand for new and improved agricultural technology for mechanisation has continued to increase as the world’s population demand for food and fibre increases, particularly in view of the rural–urban migration amongst the younger generation that reduces the available labour in many developing countries of Asia, Africa, and Latin-America (Cohen, 2006).

1.2.1 Levels of Agricultural Mechanisation Technology

Agricultural mechanisation has been in progress for around 100 years. Farmers have previously principally farmed with high manual labour input on small areas using hand hoe technology, and/or animal traction systems.

In the 1950's, as a result of government policy and various aid programs, schemes were devised by various agencies to introduce Western mechanised agriculture to many areas, particularly in Africa. This involved the import of four wheel diesel tractors (often with government assistance) and associated tillage implements (mainly inversion plows). These units were then loaned or hired to farmers.

However in practically all cases, these schemes failed, often due to the poor technical knowledge and educational skills of local farming community. Tractors and implements were often not maintained correctly and predictable breakdowns occurred. There were also insufficient resources, and mechanical skills available as well as insufficient spare parts to keep these machines operational. These schemes have now been largely abandoned (Sims 2006).

Overall, mechanisation in agriculture may be broadly grouped into three levels, i.e low (manual), medium or fair (animal), and high (mechanical power), with various degrees of sophistication based on the capacity, cost, precision and effectiveness (Henríquez et al., 2014; Rijk, 1997).

Table 1.1 shows the achievements of three levels of mechanisation in selected African, Asian, and Latin-American countries in the year of 2005. Overall, the number of human and animal power usage in Asian countries was mechanical 65.46%, animal 13.65% and human 14.11%, while the case was different for countries in Africa, with a percentage average value of 21.38%, 33.79% and 39.81% for mechanical, animal and human mechanisation levels respectively. In Sub-Saharan Africa, 65% of agriculture is currently carried out by manual labour, 25% by animal traction and only 10% is mechanised (Esdaile, 2016). Also, the data illustrates a 41.5% for mechanical, 14.55% for animal, and 19.95% for human power in Latin-America.

Figure 1.2 further depicts the variations in the use of mechanical power for different regions in Asia, Africa, and South America in the year 2003 (FAO, 2015). From the plot, it can be seen that all Asia regions, and South America have a significant amount of tractors in use for agricultural production as compared to Africa, where due to the abundance of manual labour, the use of human power (the first level of mechanisation) is still dominating, thus limiting the application of present day technology in agricultural production. For post-harvest, most countries in Africa also still rely largely on sun drying. The commodities are either spread on suitable surfaces or by hanging on farm buildings (Alonge and Onwude, 2013). Significant losses may thus result from this practice.

Alternatively, within the historical and economic context, some authors have proposed that agricultural mechanisation has six stages of evolution (Viegas, 2003; Clarke and Bishop, 2002), while others reported as seven stages of evolution (Speedman, 1992; Rijk, 1989). The seven stages of agricultural mechanisation are:

I. Stationary power replacement, where human power is substituted by mechanical power.

II. Motive power replacement, where mechanical power replaces operation systems previously based on human power.

III. Human control replacement, where operations previously controlled by human decision making are replaced by mechanised operations.
IV. Adjusting cropping systems to the mechanisation requirements.
V. Adjusting farming systems to the mechanisation requirements.
VI. Adjusting plant physics to the requirements of mechanisation (plant adaptation).
VII. Automation, where automation, control and robotics are applied to agricultural production operations.

The sequence of these stages becomes obvious at the farm level (Onwude et al. 2016). However, this sequence could vary according to the type of agricultural production and farming system used. For example, in Asian and African countries, the adoption of labour-intensive rice production increases the demand for labour. This increases the hourly demand for machine which are largely used for land preparation and threshing, particularly in Thailand and Philippines (Viegas, 2003). The mechanisation of agricultural production in the above mentioned countries has often been associated mainly with rice production (Viegas, 2003).

Similarly, countries that have crops other than rice as the main crops may promote a different degree of mechanisation for their production operations, e.g. Malaysia (rubber, cotton, oil palm), Pakistan (wheat), Sri Lanka (tea, spices), Ghana (Cocoa), Nigeria (oil palm, cassava), and Brazil (cotton) (Diao et al., 2014; Clarke and Bishop, 2002). In addition, the different characteristics associated with the geographical locations and terrain of most countries in Africa, Asia and Latin-America may also necessitate different types of machinery and equipment advancement. These factors could also serve as a limitation to the application of present day technologies in the mechanisation of agricultural production.

1.2.2 Large Scale Agricultural Fields

Large scale fields are associated with large scale farming which takes advantage of a proportionate saving in costs gained by an increased level of production, to produce quality and safe food in large quantities at a relatively low cost. A large scale field can also be regarded as a large expanse of agricultural land used for the production of both livestock and plants (Bureau, 2012). According to the World Bank, the total large-scale mechanised farms are up to 20 million all over the world (World Bank, 2002).

Food security is the primary concern for all countries of the world (Ncube and Kang, 2015). This can be more effectively achieved through the applications of modern technology in the mechanisation of its production, storage and distribution process. Consequently, mechanisation of both the large scale and small scale agricultural farming system becomes vital (FFTC, 2005). They are also practiced both in both developed and developing countries, although with different popularities.

According to Deininger and Byerlee (2012), three main factors have recently contributed to the increase in the practice of large scale agricultural farming system in some developing countries, particularly in South East Asia, South America, and Southern Africa. They are:

(a) new mechanised technologies that makes it easier to supervise labour;

(b) the limited availability of labour in some areas, perhaps exacerbated by high wage demands and

(c) more emphasis on integrated supply chains.

Recent development of advanced technology in the mechanisation of plant breeding, tillage, and on-farm production has also made labour supervision easier and can reduce losses in the operations of large scale agricultural production (Viegas, 2003). Nowadays, large scale agricultural fields can be more easily managed and controlled due to improved plant and crop varieties that are pest-resistant and herbicide-tolerant, adoption of conservation farming, reduced number of steps in the planting process (Clarke and Bishop, 2002), reduced labour demand, and the use of automated and mechanised machines for harvesting (Suprem et al., 2013; Viegas, 2003).

Furthermore, the remotely sensed information on climate and field conditions can also reduce the application of local and traditional knowledge (first level of mechanisation). For example, the ability to use Global Navigation Satellite System (GNSS) have assisted machinery operations rather than driver's skills makes labour and its supervision dispensable (Shaw, 1987). However, the application of this type of technology in large scale farms is in general inadequate in most African, Asian, and Latin-American countries.

Figure 1.3 (a-b) shows the available agricultural and arable land in selected African, Asian, and Latin-American countries. From the plot, it can be seen that there are large areas of arable land for large scale production, especially in Africa, with the available agricultural land area is estimated to be above 80% of the total land mass (Nigeria and South Africa). However, less than half of the available agricultural land is currently used for large scale farming. Moreover, Figure 1.3b shows the abundant arable lands in developing countries. From the figure we can see that there is still much land available for large scale farming. Thus, the challenge is the application of mechanisation in these countries. Similar studies have been reported in the literature (Rotimi, 2010; Rasouli et al., 2009).

1.2.3 Small-Scale Agricultural Fields

Globally, 70% of farmers are smallholders (<1 ha). Smallholders also manage over 80% of 500 million farms in the world. Small-scale agricultural farming promotes self-sufficiency in food. Normally, small-scale agricultural fields are traditionally associated with the type of farming that provides for the family's food needs. Sometimes it is a mixed farming system, combining crop production with livestock rearing in a way that promotes interdependency (FAO, 2008).

In the developing countries, almost 2.8 billion people live with less than $2 per day, most of which reside in rural areas (Boutayeb and Boutayeb, 2005). Two and half billion are practicing agriculture and one and half billion are on small-scale farms with average of 2 hectares or less in size (Altieri, 2008). Therefore, small-scale agricultural fields play a very important role in increasing global agricultural production and food availability.

Mechanisation in Small-Scale Agricultural Fields

Although, this farming system can feed the urban people but it is largely considered the essential source of food for rural populations in developing countries (Reijntjes, 2009). In some countries, small-scale farms contribute drastically both to national and export food needs. Rukuni and Eicher (1994) stated that small-scale farming in Zimbabwe contributed almost 60% of national food needs and almost 20% of food exports. Similarly, Altieri (2008) reported that small farms in Latin-America produced 77% of beans, 61% of potatoes, and 51% of maize consumed nationally.

Nonetheless, one of the major problems faced by small farmers is the adoption of present day mechanised technologies to increase their productivity. Rukuni and Eicher (1994) stated that most small-scale farmers in the developing countries are yet to benefit from research and advanced mechanisation in agriculture. Additionally, many of the current education systems do not adequately support the improvement of family farms: they promote industrial agriculture. In other cases, modern technology is not available, either because it is too expensive or because it is not appropriate for the system (Altieri, 2008).

The technological characteristics of small-scale agricultural fields in developing countries could be measured in terms of variables like economies of scale, the technological base, technological disparity, learning, and labour intensity. Currently, the machinery for small-scale farming is becoming more readily available, which include; tractors, tillage and seeding implements, harvesters and efficient human-propelled tools. Besides that, small-scale controlled environmental agriculture is also becoming viable. These can control the environmental factors such as light, heat, atmosphere, nutrients, and much higher production can be obtained per unit of space (Fisseha, 1987).

In areas of the developing world where Western ‘commercial farmers’ have introduced large farming enterprises, mechanisation with advanced farm tractors and implements has achieved many successes. However, there has been little ‘trickle down’ effect to the small subsistence farmers, often due to poor financial resources, limited technical knowledge, and low educational standards.

Development and Applications of Two Wheel Tractors

As a parallel to the development of large scale agriculture by Western farmers, there has been the development of a range of small farm traction units. This was initially developed in the West, and was followed by development in the Far East, principally Japan after World War 2 (WW2). These have taken the form of what is commonly called the two wheel tractor. They have also been variously described as ‘walking tractors, ‘garden tractors’ ‘power tillers’ or ‘iron buffaloes’. These were first introduced in the 1920’s and 1930’s (Figure 1.4 a-c).

These tractors were mainly purchased by small area farmers in Western countries. From the 1930’s until the 1950’s they were widely used in vegetable gardens, and small horticultural enterprises. Often they came equipped with a rotary tiller unit (rotavator) as the standard tillage implement (Figure 1.5).

During the 1950’s and 1960’s, the two wheel tractor focus moved to Japan and various manufacturers (Kubota, Yanmar) moved into production for the local market, with some exports as well.

However by the 1970’s, the Chinese had taken over the technology. The local farm machinery manufacturers (Dong Feng, Sifang) have now become the major manufacturers of two wheel tractors. Other major producers are Thailand (Siam Kubota), India (VST Shakti) and Indonesia (Quick).

There are now over 500,000 two wheel tractors manufactured annually world-wide (Hossain et al., 2009). They come in two main classes. The single cylinder diesel motor 12~18HP Asian made units, which have multi-speed gearboxes, and are driven by a Vee belt from the motor. These are normally sold with a standard 60-80 cm wide rotavator. They have a tare weight of 400-500 Kg. There are also many types of 6-10HP units with various drive systems, made both in Asia, USA and Europe. These have either petrol or diesel motors and are essentially lighter in construction, having a tare weight of 80-150 Kg.

Traditionally, two wheel tractors have often been used in paddy rice production. When fitted with steel cage wheels, they can be an ideal lightweight unit for land preparation, including initial ploughing, land levelling, and puddling before planting of a rice crop by the transplant method. In fact, one of the possible alternative strategies for small farm mechanisation in Sub-Saharan Africa is the appropriate use of two wheel tractors, as the first step down the mechanisation path. A number of African countries like Ethopia, Ghana, Kenya and Nigeria are currently studying Bangladesh's experience in agricultural mechanization, which uses two-wheel single-cylinder diesel tractors to power well pumps, river boats, threshers, mills as well as producing crops.

Over the last ten years, the two wheel tractor technology has been further developed for upland crop production, in addition to the traditional paddy rice system. Several types of farm implements mainly seeders and planters are commercially available for these tractors. Farmers with access to appropriate use of such smaller-horsepower tractors can also operate them with planters that deposit seeds directly into the soil with minimal disturbance, in line with zero tillage or conservation agriculture regimes (Esdaile, 2016). Two-wheel tractors are also a popular mode of transport and farm equipment in a number of developing countries like India, Bangladesh, etc.

1.3 Present Day Technology

It has been established that most developing countries currently practice the first and second levels of mechanisation as compared to the developed countries (Clarke and Bishop, 2002). However, in terms of agricultural mechanisation, countries such as Japan, Brazil, Korea, and Egypt could be classified as developed countries because they currently practice at a more advanced level of mechanisation compared to their counterparts (Diao et al., 2014). In spite of this, most countries in Africa, Asia, and Latin-America are still classified as developing countries (Anelich, 2014; Mondal and Basu, 2009).

Overall, some of the most important present day technology for the mechanisation of large and small scale agricultural fields may include: (a) precision agriculture, (b) mobile and web applications for agriculture, (c) digitalizing crop varieties and yield, (d) forecasting farm weather and modelling, (e) Geographical Positioning Systems and Geographic Information System (GNSS/GIS) applications (f) remote sensing, (g) automated tractors and farm equipment (h) robotics; and (i) data mining and warehousing (Suprem et al., 2013, Zhang et al., 2002).

Many countries such as USA, Canada, Netherland, England, and Germany have already applied some of these advanced technologies in agricultural production, and have been able to improve their agricultural technology, and reduce the total cost of agricultural production, and increase farm size successfully (Figure 1.6.). For example, farmers in these countries can now routinely use portable mobile devices like PDAs to collect and share data and information to the interested parties and stakeholders (Suprem et al., 2013). Furthermore, electronic sensors and imaging tools are also used to characterize crop growth and development (Onwude et al. 2016). Remote sensing has now been applied using Unmanned Aerial Vehicles (UAV) (popularly known as ‘drones’) (Everaerts, 2008). Precision agriculture has been around since the '90s, but it really took off when GPS technology became cheap and ubiquitous in the mid-2000s.

Wireless remote sensing is also being increasingly applied to various equipment (Wang et al., 2006). In the future, robotics and automation can play a significant role in meeting the future agricultural production needs and will revolutionize the way food is grown, tended, and harvested. Research development in this area, although still largely experimental, has received enormous amount of attention from both the government and private sectors due to the following reasons (1) robots improve productivity, (2) scarcity of labour, and (3) practicable to design and easier to handle (Suprem et al., 2013).

Compared with developed countries, there are significant limitations to the application of these present day technologies in the mechanisation of agricultural production units in many parts of Africa, Asia, and Latin-America (South America) (Clarke and Bishop, 2002; Kishida, 1984). This could be because of high purchasing cost of advanced technology, unskilled labour, farmer's education, government policies and high cost of maintenance among others.

Nonetheless, modern day technology has also been progressively adopted and applied in certain activities in developing countries. For example, recent agricultural projects in South Africa, Egypt, Malaysia, Brazil, Mexico, Thailand, Philippines and India utilize satellite positioning systems and geographic information systems to aid in farming management. This technology also helps to select appropriate type of fertilizer and application method to the soil (Devi et al., 2011).

Furthermore, one of the important operations in agricultural production is harvesting. Currently, this operation is done manually in many parts of Asia, Africa and Latin-America. However, the situation is different for countries like China, Japan, Korea, India, Brazil and South Africa where most harvesting activities are now carried out with modern machines (Binswanger, 2014; Singh, 2006; Spoor et al., 2000). Harvesting is actually one of the most labour demanding work in crop production, and mechanisation of this activity has greatly improved the agricultural productivity.

1.4 Case Studies

In the following, case studies of agricultural mechanisation in some countries are presented. These include: rice production in Philippines, palm oil production in Malaysia, and implementation of agricultural mechanization development program in China.

1.4.1 Rice Production in Philippines

Rice production in the Philippine is currently carried out using advanced mechanisation. Philippines is considered as one of the world's largest rice exporters, with an average production of 18 million tons of rice in 2013 (Figure 1.7a). From Figure 1.7b it can be seen that rice production in the Philippines occupied almost 4.8 million hectares out of the 9.5 million hectares of land used for agricultural production. In the Philippines, large scale agricultural mechanisation started in the middle of last century, whereby, tractors of both four-wheel and two wheel types were imported and applied in the large-scale agricultural production (Tuong and Bouman, 2003). Recently, agricultural mechanisation has also been applied in small-scale rice production. This includes production processes ranging from land preparation, harvesting, threshing/shelling, and milling of rice.

Ahammed and Herdt (1984) assessed the effects of agricultural mechanisation on the production of rice in the Philippine. They reported that agricultural mechanisation is a necessary part of agricultural production process. They further stated that agricultural production of rice, in order to meet increased demand, requires different levels of capital and labour investment depending on the technologies used. The authors also studied the indirect and direct production effects, as well as the employment impact of alternative technologies for rice production in the Philippines. The direct impact of adapting new mechanised rice production technology simply involves change of production inputs, while the indirect effects can be seen based on the interaction between production and consumption processes.

Ahammed and Herdt (1984) also used the method of social accounting matrix (SAM) to identify and measure the effects of a series of different technologies for rice production. The three techniques used in land preparation are specified in the rice production systems: water buffalo, two wheel tractor, and four wheel tractor, and the 3 threshing techniques are specified: manual, portable thresher and large axial flow thresher.

It was found that the effect of agricultural mechanisation resulted in increased total agricultural production with a reduction of labour requirements - with two wheel tractor this reduction was 15.42 thousand man-years. For the other two options of two wheel tractors and small threshers and four wheel tractors and large threshers, the corresponding reductions were 16.54 thousand man-years, and 19.01 thousand man-years respectively.

1.4.2 Palm Oil Production in Malaysia

In Malaysia, the advancement of agricultural mechanisation in oil palm production has led to increased revenue earnings, and relevancy in the global oil palm market. According to Abdullah et al. (2001), mechanisation of oil palm production in Malaysia involved planting activities, harvesting, storage, processing, and transportation of palm fruits from the farm to the markets. Among these production processes, the most significant contribution of agricultural mechanisation was in the harvesting of fresh fruit bunches (FFB). Figure 1.8 shows the comparison between the harvesting of FFB using advanced harvesting aid (Ckat^{TM}) and manual method (chisel or sickle). From this figure, it can be seen that manual harvesting can only produce 110 FFB hr^{-1}, while Ckat^{TM} produced up to 160 FFB hr^{-1}. This result was further collaborated by Jelani et al. (2008). They reported that manual harvesting can only produce 50 to 60 FFB hr^{-1}. Thus, the productivity of using Ckat^{TM} was 45% higher than that of manual harvesting, with a daily productivity between 3.2 to 6.4 tonnes per man per day.

Consequently, applying advanced machinery to the production of oil palm have shown to be more efficient than conventional means, increasing productivity, and reducing the cost of human labour (Evans et al., 2004).

Similarly, Cantas machine was also used in oil palm plantations for FFB. Table 1.2 shows the differences between Cantas™ and the conventional method. As it can be seen, the application of Cantas™ reduced the labour demand by almost half, while labour to land ratio was doubled, productivity nearly tripled and harvesting cost reduced by 75%. Trials in many estates produced encouraging results where the average productivity was 14 t/day or 2.8 t per man-day or an average of 50 to 100 bunches/h (cut only). Depending on cropping level and land topography, a team of workers could cover 5 to 10 ha/day (one cutter, one helper, one tractor driver and two loaders) (Jelani et al., 2008).

In a similar manner, El Pebrian and Yahya, (2013) studied the advancement of agricultural mechanisation for oil palm FFB transportation in Malaysia. They designed a mini tractor-trailer with grabber that has a single chassis 50.5 kW universal prime mover, operated at 2600 rpm, and had a 4 wheel drive and a collection-transportation attachment with a 1.5 t payload storage bin. The machine system had an output of 2.526 ton/h or 20.213 ton/day on sloping terrain and 2.620 ton/h or 20.965 ton/day on gently undulating terrain. The machine was found to be more efficient, affordable and easy to maintain when compared to the conventional means of in-field collection-transportation (van, and erreppi buffalo). Furthermore, this machine system presented a good technological solution for in-field collection-transportation of FFB for the oil palm plantation industry in Malaysia.

In addition, the method of collecting and evacuating oil palm bunches from the field to the collecting point affects the quality of the palm fruits (Jahis et al., 2010). FFB can be harvested efficiently and with less damage to the fruits using advanced mechanisation. A survey that was carried out in 2008, revealed that 83% of the in-field collection activity and mainline loading activity were mechanised as compared in 1995, which was only 62% mechanised (Halimah, et al., 2010).

1.4.3 China Agricultural Mechanization Development Program

In China, agriculture has made a tremendous progress since the start of implementing the reform and open-door policies in 1978. In order to further address the problems of limited resource availability, and the widening gap between the urban and rural population, Chinese government began to implement “Agricultural Mechanization Promotion Law” in 2004 (Zhou, *et al.*, 2009; Adekola *et al.*, 2014). The law established the status and role of agricultural mechanization in China. As a result, a significant amount of government fund has been invested to subsidize famers to purchase various agricultural machinery, in particular to promote the machine operations for major crops such as wheat and to enhance the role of agricultural engineering research and agricultural machinery application in agriculture and rural economic development. Overall, it was estimated that by the end of 2008, the total power of farm machinery in China has been increased to reach 822 million kW, and the overall mechanization level in agricultural operations of tillage, planting and harvesting have reached an average of 46% (Gao, 2012). This has further increased to 59% in 2013 (Singh and Zhao, 2016). The machinery power density has also increased from 2.0 kW/ha in 1990 to 5.7 kW/ha in 2013.

Despite these great advancements, China has set a further target to reach the overall agricultural mechanization level of 70% by 2020 (Gao, 2012). To achieve this target, the structure of agricultural machinery industry would need to be optimized. Currently, there is an unbalanced crop mechanization level between different crops and different operations. For example, in 2008, the overall grain crop mechanization level was 87% for wheat, 61% for soybean, 52% for maize, 51% for rice, while for cash crops, they were respectively 21% for potato, 23% for rape seeds, and less than 10% for vegetable and fruit. The overall mechanisation levels for different operation are: tillage 76%, planting and harvesting 48% (Singh and Zhao, 2016). The quality of agricultural machinery in China would also need improvements (Zhou, *et al.*, 2009).

1.5 Challenges of Mechanisation

There are a number of challenges to promote mechanisation in developing countries. These could include: technical challenges, requirements of energy and fuels for machinery operations, government policies, and the adopted technology transfer mechanisms.

1.5.1 Technical Challenges

Over the years, studies on the growth and challenges of mechanisation in developing countries have been reported. In many parts of Africa, Asia, and Latin-American, small scale agricultural fields remain at the centre of most farming practices. According to Viegas (2003), this challenge persists largely due to the farmer's choice of alternative approaches to mechanisation and technical change. Traditional farmers often make use of available resources according to their knowledge of technology, therefore tend to show scepticism about the adoption of new technologies (French and Schmidt, 1985). In fact, empirical evidences suggest that human capital investment through education and training is essential and a very good propeller to the adoption of modern technologies in the mechanisation of large scale agricultural production.

For example, the design, development and manufacturing of agricultural robotic technologies for harvesting crops in agricultural production involves several issues like: (a) engineering design, (b) employment of comprehensive architectural control and fixed technology for measurement and sensing, and (c) integration of data computing platform with communication systems (Suprem et al., 2013; Blackmore and Griepentrog, 2006; Kyriakopoulos and Loizou, 2006). The integration of sensors into automated and controls system have also been reported as a major challenge (Suprem et al., 2013), because of (a) needed measurements and precision for controlling the rate of operation, and (b) the utilization of an electronic system of operation in a tough agricultural field (Seelan et al., 2003).

Land degradation has been reported as one of the challenges in the mechanisation of agricultural fields (Fonteh, 2010). This problem can be found in 'hotspots' region of Asia such as the foothills of the Himalayas, sloping areas in Southern China, South-East Asia and the Andes, forest margins in East Asia and the Amazon, rangelands in Africa and West and Central Asia, and in the Sahel. Such places have concentrations of rural poor, often as ethnic minorities. Improved land management technologies can thus be applied to maintain the quality of the natural resources which is often needed in mechanised agricultural production. Examples include: range management to reduce overgrazing; soil organic matter restoration through composts; animal-crop rotational grazing; crop rotation; agroforestry and fallowing systems; land reclamation; and earth or vegetative bunds against erosion.

1.5.2 Requirements of Energy and Fuels for Machinery Operations

Due to problems in the availability of petroleum products in many developing countries, especially due to the recent fall in the price of crude oil which has led to reduced global production, there is a corresponding reduction in the use of fuel dependent equipment for farming.

According to Jain and Sharma (2010), the increasing industrialization and modernization of many developing countries caused increased demand of petroleum products. They reported that economic development in these countries has led to huge increase in the energy demand. In India, the energy demand is increasing at a rate of 6.5% per annum (Jain and Sharma 2010). However, petroleum-based products are limited due to a heavy dependence on importation of 80% of the total required crude oil. This has led to the country's focus on alternative fuels, which can be produced from feedstocks available within the country. Biodiesel, an eco-friendly and renewable fuel substitute for diesel has been getting the attention of researchers/scientists of all over the world. This can be seen in various studies as reported in the scientific literature (Solaimuthu et al., 2015; Bietresato and Friso, 2014; Janaun and Ellis, 2010; Sarantopoulos et al., 2009; Barnwal and Sharma, 2005; Dorado et al., 2003).

Apart from the many vegetable oils that can be used to fuel diesel engines, which unfortunately induce some potential technical problems to the engines, recent studies demonstrated the potentiality of using biodiesel derived from these oils (environment friendliness, easiness of production, no need for adaptations to the existing engines, normal wear of metallic components). Overall, it is suggested that biodiesels can present a genuine opportunity as the future of renewable fuel for agricultural and other machinery, both to eliminate the further depletion fossil fuels and to provide a significant reduction in greenhouse gas emissions (Chen et al., 2016).

1.5.3 Impact of Government Policies

Another limiting factor to the adoption of the present day technologies for agricultural production in developing countries is the government policies (Onwude et al. 2016). These policies include financial aids, importation, standard procedures to training programs and land tenure system. In Nigeria and Mali, for example, the government is the primary importer of farm machinery and it on-sells to farmers at subsidized prices (Fonteh, 2010; PrOpCom, 2011). Similarly, the Tanzania Government has sold more than 5000 sets of imported advanced agricultural machinery at subsidized prices since 2009 (Lyimo, 2011). Rijk (1989) reviewed the growth of mechanisation in developing Asian countries, and recommended the use of computer software (MECHMOD) for developing effective mechanisation policy that will depend on data from economics of use of mechanisation levels for different field operations.

However, despite the effort from the Government to encourage mechanised agricultural production in most African countries, the distribution of the machinery to farmers there has been reported to be ineffective.

In Ghana, the approach to mechanisation focuses on mechanised agricultural production of selected commodities as a business based on their comparative and economical advantage (Diao et al., 2014). Agricultural mechanisation in Ghana is presently carried out under the national development process plan, even without the adoption of any formal strategy (Fonteh, 2010). Some limitations in the approach have already been highlighted by Diao et al. (2014). These included that some principal stakeholders have been left out from the planning and implementation stages, especially large scale farmers.

Furthermore, in Asia, Government presently supports the advancement of farm mechanisation through policies on financing farm machinery advancement and research, as well as subsidies to farmers at half the purchase price (Mondal and Basu, 2009). In Thailand, India, Indonesia, Sri Lanka, Malaysia, Vietnam, and the Philippines, the governments have been responsible in supporting special projects for research, training and programs for farm mechanisation (Viegas, 2003; Deininger and Byerlee, 2012; Mondal and Basu, 2009). However, the overall level of mechanisation is still medium to low because of factors such as: inadequate resources, dilapidated infrastructure, and institutional arrangements; dominance of manual operations; and lack of policies that encourage and help the general economic wellbeing of the different stakeholders in the agricultural mechanisation and manufacturing industries. Thus, the government policies should be appropriately designed so that these policies serve their intended purposes. It was reported that in some countries, a significant proportion of tractors actually go for transport, because agricultural tractors in these countries have a reduced import tariff as opposed to trucks that can have over 100% tariff.

Furthermore, no corrupt government officer should be allowed to distort and make money out of these subsidy schemes.

1.5.4 Technology Transfer Mechanisms

There are two broad modes of technology adoption in agricultural mechanisation technologies. The first is the “drop-in” technologies which can be easily adopted or modified (Schueller, 2016). For this method, developing countries may either just adopt or try to scale up and out with small mechanisation equipment used in developed countries or they can scale down existing equipment and concepts with some necessary modifications.

The second mode of technology adoption is for the “system” technologies which may take longer to be adopted because many changes and supporting infrastructure may be required. One of the examples of this method may be some of the precision agriculture technologies being researched today.

FFTC (2005) classified the limitations of the application of present day technologies to the agricultural mechanisation as technological constraints, socio-cultural and behavioural limitations, financial and economic challenges, and environmental issues. Based on contemporary research findings, Viegas (2003) highlighted four key factors limiting the application of the present day technologies in developing countries as follows: (1) technology compatibility with the environments, (2) availability of resources to expedite the adoption of technology, (3) suitability of the technology to deal with the needs and yearnings of the target population (4) appropriateness of the technology transfer mechanism.

In order for a technology to be adopted, the first three factors have to be met and channelled through an efficient transfer process (Francks, 1996). Thus, the level, adoption and subsequent use of present day technology as mechanised agricultural inputs have a direct and significant effect on land productivity, cost reduction, production profitability, and eventually the quality of life.

Generally, for traditional farmers to adopt modern technology, they need firstly to improve or change the current farm practice. Secondly, the accessibility and affordability of the modern technology transfer mechanism must be within the reach of the farmer.

Detailed analysis of the results (Mottaleb et al., 2016) showed that machinery ownership is positively associated with household assets, credit availability, electrification, and road density. Donors and policy makers should therefore not focus only on short-term projects to boost machinery adoption. Rather, sustained emphasis on improving physical and civil infrastructure and services, as well as assuring credit availability are also necessary to create an enabling environment in which the adoption of scale-appropriate farm machinery is most likely.

1.6 Future Outlook

FAO (2014) predicts that there will be over 9 billion people globally by 2050. In order to feed them, agricultural production should increase by 60 to 70% by 2050. The prospects for mechanisation in the Asian, African, and Latin-American continents is based on the projections of high economy growth rate on income per capital indices and given conditions of political stability (Clarke and Bishop, 2002). The process of mechanisation can therefore be facilitated by the development of local manufacturing capacity in the region. For example, India is becoming the world’s largest manufacturer of tractors and China is a major source of affordable tractors and power tillers.

In Africa, the process of urbanisation will also stimulate a switch to higher mechanisation level (Onwude et al. 2016). The movement of rural populations to urban areas will see a switch to advanced mechanisation of agricultural fields due to shortage in the available labour input in the rural areas (Viegas, 2003). This trend could adversely improve the rural economy.

Furthermore, future design of advanced farm machinery should take into consideration the nature of operations and the need to utilize the use of effective control solution devices (sensor, actuator, drive, switch etc.). Although literature has been widely published on the approach to designing individual control systems for a simple lab based automation machines (Mondal and Basu, 2009; Lee et al., 2010; Blackmore and Griepentrog, 2006; Kyriakopoulos and Loizou, 2006; Cox, 2002), there is little improvement in tackling problems associated with complex agricultural robotic machines. Overall, for wide adoptions, machines should be low-powered, multi-purpose, precise, compact, light and affordable. Locally-available materials should be incorporated in fabricating machines to reduce the manufacturing costs. Lastly, the overall recommendations on factors to be considered for efficient and effective application of present technology to the mechanisation of agricultural production of countries in Africa, Asia, and Latin-America are highlighted as follows:

- The needs of famers (both large and small scale) should be met by manufacturing automated tractors, power tillers, and other large farm equipment locally. More so, Operator's safety and comfort must also be considered.
- Energy efficient machines should be developed by harnessing the non-conventional sources of energy. This is because the cost of fossil fuel in many African, Asian and Latin-American countries is very high.
- Information and communication technology through multi-media, fairs and exhibitions should be actively engaged in strategic locations where agricultural mechanisation programs will be carried out.
- Training local craftsmen in manufacturing technology, machine operation, repair and maintenance which would promote the local agricultural machinery manufacturing, should be encouraged.

- Small groups, organizations or cooperatives for farmers can also be harnessed, particularly in setting up joint use of farm machinery and other modern farm facilities in agricultural production.
- Government agricultural policies should be private sector driven and should have a direct impact on the farmers and stakeholders in agricultural production.
- Government-private sector partnership in advocating agricultural mechanisation should be embarked upon. Service centres should be established in rural areas. Financial assistance and subsidies should also be provided to machinery owners and stake holders of large, and small scale agricultural fields.

1.7 Conclusion

Agriculture is the main source of income, employment and livelihood of a significant proportion of population of developing countries. Agricultural mechanisation has now been in progress for several decades. However, it has been mainly confined to the developed countries and a small number of developing countries. Some of the developing nations have still continued with little or no progress in this area of agriculture production until recent times. Particularly, in Sub-Saharan Africa, 65% of agriculture is still carried out by manual labour, 25% by animal traction, and only 10% is mechanised (Esdaile, 2016). This is compared with the rapidly improved situation in countries like China, Sri Lanka, and Cambodia.

Mechanisation of agricultural production requires the applications of modern technologies. These technologies are however generally associated with relatively well developed economies or large scale farms. The application of these technologies in many developing countries in Africa, Asia and Latin-America is limited by factors such as technology compatibility with the environment, availability of resources to facilitate the technology adoption, cost of technology purchase, government policies, adequacy of technology and appropriateness in addressing the needs of the population. As a result, many of the available resources have been inadequately used by farmers. This has led to low productivity and high cost of production.

The chapter has emphasized that the success of agricultural mechanisation will require a clear institutional framework, and also a coherent strategy based on the actual needs and priorities of the farmers. To increase the level of mechanisation, all basic farm machinery requirements must be met, such as: suitability to farm type and scales; simple engineering design and technology; affordability of technology in terms of cost to farmers; versatility for use in different on-farm operations; and significantly, the provision of support services from the government, private sector and manufacturers. With good implementation, the overall mechanization level in agricultural operations of tillage, planting and harvesting in China has now reached over 59% (Singh and Zhao, 2016). The machinery power density has also increased from 2.0 kW/ha in 1990 to 5.7 kW/ha in 2013. Thus, the model of China experience may be consulted and adapted to advance agricultural mechanisation in other countries (Adekola, et al., 2014).

As another example, the use of mechanised agricultural equipment in Cambodia has doubled in the past five years and over 90 percent of farming land preparation in that country is now done by machinery instead of draft animals (Cheng Sokhorng, 2017). Overall, the use of agricultural machinery is rapidly increasing in Cambodia and most farming has transformed from manual labour or cattle-driven equipment to machinery. Almost every household has now a two-wheeled tractor for their daily activities in the field, while for larger jobs, member farmers can hire the cooperative’s single tractor for use. As a result, mechanization in Cambodia plays an important role in furthering the productivity of farming.

It has been highlighted in this chapter that cost and also local recommendation are the two most important factors in any mechanisation scheme. This is because not all farming activities can have acceptable cost and can be assisted by machinery. Therefore, before implementing a mechanisation scheme, it is important to seek the inputs of local farmers and identify the agricultural tasks that are considered critical and strenuous to workers, so that they can be prioritized to be assisted by machines (Nawi, et al, 2012). In many countries, low-cost 2WT could be the most basic step one in farm mechanisation. While many Asian fields are often small, Africa has usually more space and room around the fields. Currently, smallholders manage over 80% of 500 million farms in the world.

This chapter has also reviewed the applications of some of advanced mechanisation technologies. Precision agriculture which combines the use of information and technology will further promote agricultural productivity. Research and development in post-harvest technology and also mechanisation of vegetable and fruit production is also very important (Bowman, 2015).

Overall, it can be concluded that proper mechanisation in agriculture is one of the most important factors underlying high productivity. Proper mechanization and its appropriate use is necessary for economic, environmental, and social sustainability, and is an effective strategy to achieve food security. Translating and adapting technical knowledge to local applications should consider local and regional resources, both physical and human, as well as cultural acceptability. Appropriate technology rather than advanced technology should be promoted as a first priority. In some African, Asian, and Latin-American countries, the first step may even be to have farmers progress from the hand hoe and bullock to a simple form of mechanisation.

Acknowledgements

Authors would like to thank the Department of Biological and Agricultural

Engineering and the Department of Electrical and Electronics Engineering, Universiti Putra Malaysia, for the contributions and facilities rendered in making this work a success.

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Figure captions:

Figure 1.1, Index of total agricultural output per capita by region (index 1961–2005) Source: (Hazell and Wood, 2008).

Figure 1.2. Variations in the use of tractor for different regions in Asia, Africa, and South America in the year 2003. Source (FAO, 2015).

Figure 1.3. Available agricultural areas and arable land in selected African and Asian Countries.

Figure 1.4. 1930's Planet Junior Garden tractor, 1940's David Bradley tractor and Holder two wheel tractor.

Figure 1.5. A 1950's Howard two-wheel tractor equipped with standard rotavator.

Figure 1.6. Agricultural "treadmill" based on present day technological boosts achieved through mechanisation, plant breeding for high-yielding varieties, the use of agrochemicals and genetic engineering etc. Source: (IFAD, 2010).

Figure 1.7. (a) The paddy yield measured in tonne per hectare from 1961 to 2014 and (b) rice area measured in hectare from 1961 to 2014 in Philippines; Source: Ricepedia in Philippines.

Figure 1.8. Performance comparison between the harvesting rates of fresh fruit bunches (FFB per hour) using advanced harvesting aid (CkatTM) and manual method (chisel or sickle) (Source: Shuib et al., 2011).

Tables:

Table 1.1. Percentage of power sources usage for farming in some Asian, African, and Latin-American countries between the years 1997-2005

Continent	**Country**	**Tractors %**	**Animal %**	**Human %**	**Reference**
Asia	China	52	-	22	Sims *et al.* (2006)
	India	87.6	10.4	2	Singh (2007)
	Iran	96.48	1.28	2.24	Sharabiani (2008)
	Nepal	23	41	36	Shrestha (2012)
	Turkey	58.7	23.2	6.4	Ozkan *et al.* (2004)
	Oman	75	6	19	Ampratwum (2004)
Africa	Mali	0.98	81.89	17	Fonteh (2010)
	Nigeria	10	-	85	Sims *et al.* (2006)
	Zimbabwe	55	-	15	Sims *et al.* (2006)
	Tunisia	66.67	29.63	3.70	Fersi (2012)
	Ethiopia	2	85	13	Gebresenbet (1997)
	Kenya	5	15	80	Gebresenbet (1997)
	Sub-Sahran	10	25	65	Opara (2013)
Latin-America	Mexico	14.0	-	-	Clara (1997)
	Ecuador	59	32	9	Hetz (2007)
	Brazil	75	10.2	14.8	Jasinski (2005)
	Latin America	28	16	56	Gebresenbet (1997)

Table 1.2. CantasTM compared to the use of conventional harvesting pole at Tereh Selatan estate (Epa, Kluang, Johor)

	Cantas™	Conventional
Total workers (harvester + helper)	8	16
Land: labour (ha)	1:37	1:18
Average productivity (t/team)	11.60	4.19
Harvesting cost (RM t^{-1})	RM 20	RM 33

Note: 626 ton FFB per month for 292 ha. (Source: Jelani et al., 2008).