Profiling agricultural engineering technologies for mechanizing smallholder agriculture in Uganda

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Abstract: Developing countries are grappling with numerous challenges including feeding rapidly growing populations, alleviating poverty, protecting the environment, and mitigating adverse impacts of climate change. For the coming years, one of the main agricultural development agenda for Sub-Saharan Africa (SSA) should be to increase agricultural productivity and production to achieve food security through agricultural mechanization with Agricultural Engineering Technologies (AETs) as major inputs. However, there is paucity of information on the status of existing AETs and their contribution to mechanizing smallholder agriculture which is crucial to effective planning and strategy formulation. Therefore, the overarching objective of this paper is to review the past and present status, the constraints to adoption and future of AETs in Uganda in the context of mechanizing smallholder agriculture. Several proven AETs developed through research institutions and universities have been profiled in different areas of farm power and mechanization systems, agro-processing for value addition; renewable energy systems; and water harnessing and utilization. Availability and prudent use of these AETs along the value chain has the potential to enhance labor use and efficiency, provide greater precision and timeliness in farm operations, reduce postharvest loses, contributing to adding value to products and profitability of farming through proper handling, drying, cleaning, grading, processing, preservation, packaging and storage. The future of AETs in Uganda is hinged on addressing the aspects on appropriateness of the AETs in the smallholder agriculture context and standardizing of AET. Furthermore, human resource capacity development through enhancement of technical skills in AE, increased private sector engagement, economic incentives and innovation protection should be an integral part of the future strategies for development and increased adoption of AETs.

Keywords: agricultural engineering, mechanization, smallholder farmers, food security

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1 Introduction

Developing countries are grappling with numerous challenges of feeding rapidly growing populations, alleviating poverty, protecting the environment and mitigating adverse impacts of climate change (Kienzle et al., 2013; Mrema et al., 2014). According to UN projections, the population of Sub-Saharan Africa (SSA) is expected to grow from the current level of over 818 million to between 1.5 and 2 billion in 2050 (United Nations, 2013). Some 218 million people in Africa, around 30% of the total population, are suffering from chronic hunger and malnutrition (FAO 2009; Obura et al., 2015). However, Africa has enormous potential, not only to feed itself and eliminate hunger and food insecurity, but also to be a major player in global food markets (Aksoy and Beghin, 2004; Clover, 2003). For the coming years, the main agricultural development agenda for SSA

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should be to increase smallholder agricultural productivity and production to achieve food security through agricultural mechanization with Agricultural

Engineering Technologies (AETs) as major inputs (Collier and Dercon, 2014; Salami et al., 2010). According to Mrema et al. (2014), agricultural mechanization embraces use of appropriate Agricultural Engineering (AE) tools, implements and machines for agricultural land development, crop production, harvesting, preparation for storage, and on-farm processing. In the case of SSA, it is classified into mainly three power sources namely, Hand-Tool Technology (HTT) that encompasses tools and implements which use human muscle as the main power source; Draught Animal Technology (DAT) that encompasses implements, and equipment powered by animals including horses, oxen, buffalo and donkeys and Mechanical-Power Technology (MPT) which is the highest level of mechanization powered by engines using petrol or diesel and/or electric motors to power threshers, mills, centrifuges, harvesters and irrigation pumps (Mrema et al., 2014).

Most developing countries have an economy strongly dominated by the agriculture sector (Intarakumnerd et al., 2002); this is not any different in Uganda. Agriculture sector in Uganda contributes about 24.6% of the Gross Domestic Product (GDP), provides occupation for over 72% of the total economically active population and provides most of the raw materials to the mainly agro-based industrial sector (UBOS, 2015). Nearly all the agricultural production in Uganda comes from the country's smallholder farmers who practice predominantly subsistence rainfed agriculture characterized by small landholdings with a national average holding size of 1.1 ha, low level of mechanization, low use of inputs and low crop yields (UBOS, 2010). It is thus not surprising that agriculture in Uganda is still labour-intensive. The Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) estimated that about 90% of farmers in Uganda are still relying on use of human muscle powered tools and methods for all farming operations and only 10% of the farmers have access to improved mechanized farm power for agriculture; out of 10%, 80% are using DAT purposely for primary land preparations and transport, whereas the remaining 20% use MPT (MAAIF, 2012).

Agricultural production using the current level of technology in Uganda is constrained to ensure food security and increase income for a population rapidly growing at about 3% annually. The shortage of farm labour as a result of increasing rural-urban migration by mainly the youth and rising rural wages are forcing farmers to seek for labour saving technologies (FAO, 2013). The Government of Uganda has thus, identified labour saving AETs as key inputs to increasing agricultural production and productivity for ensuring food security and providing surplus produce for sale to earn incomes and afford improved quality of life (GOU, 2010). However, there is paucity of information on the status of existing AETs and their contribution to mechanizing smallholder agriculture which is crucial to effective planning and strategy formulation. The overarching objective of this paper is to review the past and present status, constraints to adoption and future of AETs in Uganda in the context of mechanizing smallholder agriculture.

2 AE research in Uganda

AE research in Uganda was put at the fore front with the establishment of Agricultural Engineering and Appropriate Technology Research Institute (AEATRI) through the National Agricultural Research Organization (NARO) Statute No. 51 of 1995. AEATRI was mandated to carry out applied and adaptive research to develop AETs to address the following constraints: a) inappropriate and inadequate farm tools and implements; b) inappropriate postharvest handling and processing equipment and methods; c) insufficient water supply for agricultural production; and d) scarce energy sources and inefficient energy use. Later, agricultural research was restructured and liberalized to the current National Agricultural Research Systems (NARS) under the Agricultural Research Act (GOU, 2005) leading to the merger of AEATRI with other specialized laboratory based service units at the then Kawanda Research Institute (KARI) to become National Agricultural Research Laboratories (NARL), Kawanda. This restructuring exercise downgraded AEATRI to a research centre (AEATREC) but maintained its original mandate. Universities under their research mandate are also continuously carrying out AE research either individually or in collaboration with AEATREC.

Research in AETs is guided by farmers' derived needs. The research employs a participatory technology development approach that involves participation of farmers in the needs assessment, prioritization and evaluation of technologies (Kiyimba, 2011). Overall, the development of AETs interventions begins with a series of surveys, to collect data on AE from farmers. Based on identified constraints, very often AEATREC and universities link up with both regional and international research institutes to source technologies that could be adapted for local conditions. The design process entails development, evaluation and modification of prototypes. A completed AET undergoes two types of evaluations: on-station evaluation and on-farm evaluation. The on-station evaluation of prototypes allows designers to evaluate the design's overall effectiveness and make any modifications before subjecting it to field conditions. It targets mainly the engineering performance of the AETs, focusing on the efficient operation of the various components, checking for areas of weakness and the output of the machine. On-farm evaluation, on the other hand, allows assessment of the AETs by the users, focusing on operation procedures, maintenance, safety issues as well as rate at which the AETs ease a particular production activity. This enriches the iteration process of technology development with the targeted users' input/modifications, which can enhance the uptake and use of the finished AETs. The need for additional modification of prototypes normally arises from the users' views on the prototypes that emerge during on-farm evaluation. To enhance contribution of AETs to mechanization of smallholder agriculture, the technology development process requires building end users' capacity to demand and strengthening the feedback process between designer and users (Kiyimba, 2011).

3 Proven AE technologies for smallholder farmers in Uganda

Several AE proven technologies have been developed through research at AEATREC and Makerere University in different areas of farm power and mechanization systems, agro-processing for value addition; renewable energy systems; and water harnessing and utilization.

3.1 Farm tools and implements

Several farm tools and implements have been adapted locally in the areas of ploughing, planting, weeding, harvesting and on-farm transport. These technologies have the potential to reduce drudgery in farm operations and promote subsequent timely operations. The attributes of these tools and implements are summarized in Table 1.

Table 1 Attributes of proven farm implements developed at AEATREC and Makerere University

Technologies	Attributes and functionalities	Photos
Manually operated swamp rice seeder	• Weight of implement is 19 kg and has a mean working output of 18 man-h/ha. • Plants 8 rows in a single move. • Saves 117 man-h/ha when transplanting is done in rows and 277 man-h/ha when random transplanting is done. • Saves 50% – 70% seeds over broadcast seeding.	
Manual swamp rice weeder	• The single row has a weight of 6.5 kg and a working output of 95 man-h/ha. • The double row has a weight of 11.5 kg and a mean working output of 50 man-h/ha. • The single row and double row weeder models save 203 man-h/ha and 248 man-h/ha, respectively, when weeding is done by hand.	
Animal drawn light weight plough	• The plough has a weight of only 28 kg as compared to ploughs in the market which have a weight of 45 - 50 kg. • Has a mean field capacity of 0.065 ha/h and works at an average depth of 75 mm and a width of 230 mm • Ideal for the common small East African Zebu oxen and for donkeys	
Animal drawn inter-row weeder	• The weeder has a weight of 32 kg with a mean working output of 0.25 ha/h • Adjustable in row spacing of 30 - 90 cm	
Animal drawn ripper planter	• Developed as an attachment to the normal plough beam. • By changing the seed plate, it plants many large seeded crops, namely, maize, groundnuts and beans.	
Power tiller drawn mouldboard plough	• Works effectively under local soil conditions • Modifications were made so that the shear and mouldboard are easily replaceable	
Low cost	• Three-wheel tractor was designed to use a low cost single cylinder 8.5-9 kW diesel engine and a carriage capacity of 1500 kg	

Technologies	Attributes and functionalities	Photos
Power tiller drawn mouldboard ridger	• Two-row mouldboard ridger that works effectively under local soil conditions	
Low cost multi-purpose tractor dubbed *'MV-Mulimi'*	• Three-wheel tractor was designed to use a low cost single cylinder 8.5-9 kW diesel engine and a carriage capacity of 1500 kg • Capable of performing five functions namely, hauling, threshing, water pumping, phone charging and ploughing • The tractor can achieve a maximum speed of 35 km/h at no load conditions with an average fuel consumption of 0.04 L/km.	

3.2 Agricultural processing and value addition technologies

AETs in agro-processing and value addition technologies are aimed at reducing high post-harvest losses, improving quality and market value of grains and labour productivity of farmers (Candia et al., 2012). The attributes of AE processing and value addition technologies are provided in Table 2.

Table 3 Attributes of proven agro processing and value addition equipment developed at AEATREC and Makerere University

Technologies	Attributes and functionalities	Photos
Hand cranked maize shellers	Removes maize from the cob and uses humans as source of power with an output capacity of 50-60 kg/h. With zero level of broken grain, the hand cranked maize sheller is ideal for shelling home saved seed Ideal for small scale farmers including persons with disabilities who grow up to 1 ha of maize per season	
Motorized maize sheller	Used to remove maize from the cobs Driven by a 7 hp diesel engine with an output capacity of 1.2-1.4 t/h of clean grain for 1 L of diesel fuel Has shelling efficiency of 99.5%, with 1.2% – 1.8% broken grain. Ideal for medium scale commercial farmers who grow at least 20 ha per season Farmers can hire out several units of the sheller at a fee through which they earn additional income	
Motorized rice thresher	A hold-on-and release rice thresher is used to thresh rice Has a weight 85.3 and 70 kg with and without engine, respectively Has an output capacity of 500-600 kg/h, using 1 L of fuel Has threshing efficiency of 99.9% Farmers using the thresher are able to save 102.4 kg/ha of paddy usually lost through beating method, reduce their threshing time by 58% and reduce threshing labour costs by 59.2%. Prevents aflatoxin contamination in rice	

Technologies	Attributes and functionalities	Photos
Manual forage chopper	Used for cutting forage to small pieces of 25-50 mm Has an output of 170-220 kg/h of chopped feed of equal size and chops all types of common fodder in the country Ideal for smallholder dairy farmers with a maximum of 20 heads of cattle when it is operated 6 h per day Reduces forage wastage and chopping time by about 15%	
Motorized forage chopper	Chops all types of common fodder and cereal stovers Used to cut forage to small pieces varying between 25-50 mm for 60% of feed material Driven by a 3.5 hp petrol engine, with an output capacity of 350-450 kg/h depending on fodder type and operator's experience, using 0-5-1 L of fuel. Best for dairy farmers having at least fifteen zero-grazed animals	
Motorized cassava chipper and grater	Used for slicing cassava to small pieces to increase rate of drying Driven by a 3.5 hp engine, with an output capacity ranging from 450 – 600 kg/h of grated/chipped tubers for 1 L of fuel	
Manual groundnut decorticator	Uses T-bars as the decorticating mechanism providing a very small surface area with the kernels as opposed to the ordinary U-belly groundnut decorticator which causes very high level of broken kernels often reaching 35%. Reduces the level of broken grain percentage from 35% to 5%.	
Cocoa seed de-huller	Powered by a 2 hp single phase electric motor Has capacity of 30-45 kg/h with an average output efficiency of 72% compared to less than 10 kg/h by hand Eliminates human contact with seeds after roasting thus improving hygiene	
Manual soya milk machine	Ninety (90)% wooden and good for any household without electricity to buy the powered ones which are expensive Good for daily soya milk production at household level since 0.5 kg is able to give 2 L and above depending on the concentration one needs leaving the cake that can be used as food either for human or animals.	
Double ribbon feed mixer	Feed mixer capacity is 120 kg/h. It is powered by a single phase 1.5 hp geared motor 98 r/min output speed A mixer that blends animal feed ration uniformly unlike the traditional mixers A reasonably bigger capacity, appropriate for large-sized farms Ergonomically variable machine Reproducible and affordable	
Green house type solar dryer	Able to dry high valve products within a short time	

Technologies	Attributes and functionalities	Photos
Green house type solar dryer	Able to dry high valve products within a short time Has a fan driven by wind or by a 60 W solar panel	
Biogas powered milk cooler regenerator	Helps farmers who are not on the national grid to cool their milk for the next day With a capacity of 20 L, milk can be cooled to 4^{o}C for 12 h by a 3 m^3 biogas digester	

3.3 Water harnessing and utilization technologies

Agriculture frequently suffers from water stress despite Uganda having vast natural water resources (Nsubuga et al., 2014). To adapt to this phenomenon research initiatives have focused on developing technologies to provide water for crops, livestock and fish. The water harnessing technologies are aimed at improving access to water, saving time and labour for collecting water. Attributes of water harnessing and utilization technologies are described in Table 3.

Table 3 Attributes of water harnessing and utilization technologies developed at AEATREC and Makerere University

Technologies	Attributes and functionalities	Photos
Treadle pump	Can pump to total head of 6 m and discharge of 80-100 L/min Can be operated by all gender Contributes to reducing the rate of silting in the water reservoir dams which is due to bad traditional livestock watering practices Adaptable for small-scale irrigation	
Wind powered pump system for water delivery	Developed for livestock watering from communal dams. The total capacity of the system is 83 to 97 L/min for wind speeds (3-4 m/s) and (5-6 m/s) respectively, all based on a water head of 6 m. Consists of four interconnected plastic water storage tanks with total capacity of 40 m^3 situated at about 6 m elevation from the water source. By gravity flow, water from the storage tanks goes through a control gate valve to the drinking troughs situated at a lower level Consists of an array of five watering troughs sparsely distributed at 60-70 m apart with a total water holding capacity of 15 m^3 The system is scheduled to provide 100-120 m^3 of water over a 24 h period and able to service about 4,500-5,000 animals per day Reduces silting rate of the dams Cost effective since animals are watered at zero energy and labour cost	
Low head hydraulic ram pump	Pump is powered by water Water can be raised to a delivery head of 45-50 m at a fall of 2-5 m Pumps 0.5-1 L/s and can thus irrigate 0.2-0.4 ha per day Easy to maintain and service. All serviceable parts can be fabricated locally using simple tools	

4 Private sector in AET development, use and dissemination

The AE technology private sector is made up of local equipment producers, importers of equipment, suppliers and service providers of spare parts and repairs. The key private sector players are categorized in Table 4.

Table 4 Private sector in AE technology development, use and dissemination as of 2015

Category	Name
Local /domestic manufacturers of agricultural mechanization and processing equipment & spares	• Soroti Agricultural Implements and Machinery Manufacturing Co. Ltd. (SAIMMCO) focusing on Draught Animal Power (DAP) implements and postharvest technologies such as oil presses, rice hullers and nut shellers, • Tonnet Agro Engineering Co. Ltd. currently manufacturing an assortment of postharvest equipment such as maize mills and hullers, groundnut shellers and paste grinders, seed cleaners for all cereals, cassava a chippers and graters, feed mixers and feed mills and forage choppers. • Bora Agro-Technologies Ltd. specialized in the design and manufacture of post-harvest handling equipment.
Importers, distributors and dealers in farm machinery, equipment and their-spares	• Engineering Solutions: Massey Ferguson and other agricultural equipment • Akamba Enterprises: Itimco tractors • Cooper Motors Corporation - New Holland • Farm Engineering: Sunalika • Agrotec - Mahindra • Wavaholdings - Deutz, tried tractor hire & failed • Heavy Duty (Uganda) - Massey Ferguson • Car and General - Tafe tractors • Chinese Machinery (U) Ltd. - walking tractors and post-harvest technologies such as wheat & maize milling equipment, rice hullers and juice extractors • Farm Rite Machineries & Equipment Ltd. - New Holland tractors and other agricultural equipment. • JBT Engineering Works - manufacturing and marketing the motorized Maize sheller and the rice thresher; • Agro-machinery and Equipment Manufacturing Company - manufacturing and marketing the hand cranked maize sheller among others
Non-Government Organizations (NGOs) engaged in agricultural mechanization	• Sasakawa Global 2000 • Soroti Catholic Diocese Integrated Development Organization (SOCADIDO) • Appropriate Technology AT (U) • Vredes Eilanden Country Office East Africa (VECO EA) • Heifer International, • SNV (Dutch Development Organization)
Lead buyers of advanced AE technology	• Large sugar cane, rice, and tea estates • Sugar Estates: Kakira, Lugazi, Kinyara • Tea Estates: Mcleod Russel, Igara, Mukwano
Informal sector	• Informal-sector small-scale enterprises and artisans *'jua kali'* with no formal education or training plays a key role in the development of AETs such as rice hullers, fire fuelled ovens, rice hullers, maize mills, coffee de-hullers, maize graders, feed mixers, nut crashers, chuff cutters etc.

5 Constraints to adoption of AETs

Adoption of AETs has remained very low in Uganda despite documented benefits (Kasirye, 2012). The major challenges include:

5.1 Lack of financial resources by farmers

Most small-holder farmers do not have the financial capacity to effectively invest in AETs. The high cost of AETs has led to many technologies remaining on shelf instead of benefiting farmers to promote food security. Farmers' capacity to invest in mechanized farming is affected by the low producer prices. This is partly because agriculture is considered a high-risk venture to attract development loans for purchase of AETs. Most banks in Uganda attach stringent conditions and high interest rates to agricultural loans making borrowing very difficult. In the past, governments and donors provided credit through agricultural development banks and credit projects, but all these were phased out, resulting in a funding gap. Although leasing and hire purchase are becoming increasingly available they still are relatively unknown or inaccessible to most of the farmers.

5.2 Inadequate trained and skilled personnel

According to MAAIF (2012), the country lacks trained and skilled machinery operators, mechanics and equipment managers, and hence, poor equipment repair and maintenance service in Uganda. Many technical institutions have been converted into universities which has affected the pool of skilled personnel. Lack of well-trained operators and mechanics for agricultural machinery usually leads to poor workmanship and more frequent break-downs of the machinery. This leads to added costs of repair and reduced life spans of the machinery making the whole venture very expensive and unattractive. An average number of 15-20 agricultural engineers are passed out yearly from each of the three universities of Makerere, Gulu and Busitema. However, not all AE professionals are currently employed in agricultural mechanization activities. In addition, many potential employers are yet to adequately appreciate the role of AE graduates since it is a relatively new profession in Uganda. Thus the apparent “miss-employment” of a proportion of AE skilled personnel into other areas develops a shortage of required man-power to successfully support the integration of AET with farmers’ activities.

5.3 Weak linkages between technology developers and end users

There is a weak link in the research and development systems between technology development agencies, manufacturers, distributors and the farmers leading to poor commercialization of developed technologies. Significant research in agricultural mechanization has been undertaken by NAROs AEATREC, Makerere University's Department of Agricultural Engineering, private sector and NGOs. However, most of the research findings in appropriate machinery and equipment have not been put into production for effective application due to limited linkages between the researchers, the technology users, the private sector and industrialists.

5.4 Limited awareness on proven AETs

Experience has shown that end-users adopt technologies after seeing that the technology works. It is therefore essential for the company to carry out wider demonstrations and sensitization for effective uptake of the technologies. There is also need for media education on mechanization (radio, television, newspapers and all potential education media) covering such aspects of machinery use, safety, efficiency, regulations and standard; and energy saving devices to the farmers.

5.5 Weak extension with respect to knowledge of mechanized agriculture and limited after sales services

AETs in rural areas often breakdown and are rendered unusable due to lack of after sales services. Repair, maintenance and servicing workshops / agricultural machinery shades both fixed and mobile need to be established closer to areas with high agricultural machinery populations for service provision.

5.6 Land tenure systems and fragmentation

Sitting tenants and bone-fide occupants in Mailo lands are faced with land ownership insecurity, which limits investment in mechanization and AETs. Communal and customary land tenure systems lead to fragmentation with increasing population and inheritance culture. The fragmentation does not favour efficient field mechanization and exploitation of economies of scale in the use of Agricultural Mechanization. Small and fragmented farm holdings need to be consolidated if the benefits of AETs are to be realized.

5.7 Poor rural infrastructure

Many areas of Uganda lack affordable transportation to transport agricultural produce in a proactive manner to respond to market needs and demands. Transportation connects products to markets, people to education, and supplies to businesses and farms. However, SSA generally has poor road infrastructure (Tiffen, 2003). As such 90% of the transportation of agricultural produce from field to home and/or local markets is done on the heads of women and children (Boserup and Kanji, 2007). Habitants spend a significant percentage of their time transporting agricultural products and water manually, over rough terrain and long distances, and it can be difficult to get fresh produce to markets where it can be sold before spoilage occurs. In sub-Saharan rural Africa, where adults on average spend 1.0 to 2.5 h/d to transport their produce, the transportation problem can be solved by improving the roads (Lumkes, 2015).

6 Future strategies for development and increased adoption of AETs in Uganda

The future of AETs in Uganda is hinged on the interaction of these technologies with key drivers that include policy, social, economic, environmental, research and institutional partnerships. The future strategies for development and increased adoption of AE technologies should address the following aspects:

6.1 Appropriateness of the AETs

In the context of smallholder farming appropriate AETs should be as simple as possible, cost-effective, replicable in numerous units, readily operated, maintained and repaired and readily accessible to low-income people (FAO 2013). Locally-available materials must be incorporated in fabricating machines to reduce the manufacturing costs. Gender considerations in the design and use of these AETs should also be taken into consideration (Lubwama 1999).

6.2 Standardizing of AETs

Standards on material selection and production of AETs should be developed and enforced by the Uganda National Bureau of Standards (UNBS) for quality control and as a means for easy access to spare parts and repairs in the open market. The standards will help in organizing the informal sector and standardizing their production. Testing standards are necessary for agricultural machinery and implements to verify the manufacturer's claims as outlaid in the technical specification and assess its performance under local conditions.

6.3 Human resource capacity development through enhancement of technical skills in AE

There should be a deliberate strategic invention by Government to develop technical skills as a key aspect in ensuring sustainable development, safe and correct use of AE technologies. Comprehensive practical programs should be provided to enhance the skills of agricultural machinery operators, agricultural mechanics and farmers to effectively utilize the agricultural technologies for farm production. The Government should liaise with institutions responsible for mechanization training to ensure that curricula are periodically reviewed to address the mechanization needs of different levels of farmers. Targeted rural artisan training for personnel to handle fabrication, maintenance and repair of smallholder mechanization technologies should be carried out. Carry out systematic training of farmers in mechanization aspects related to their farming. Effective agricultural sector mechanization requires well trained technicians and operators to provide appropriate maintenance. Technicians are a key linkage to the farmers to relay holistic knowledge not only about the AET but also best farming practices. Farmers not having enough training about the principles and application of mechanization results in failure of an agricultural mechanization program. Government institutions need to take the lead in the process of imparting agricultural mechanization knowledge to the farmers. The farmers need training programs to provide the required principles and understanding of agricultural mechanization and business aspects of farming. Government input in this regards should be in various ways including setting up model farms, sponsoring the training of “champion” farmers, establishment of farmers training centers provided with demonstration land and equipped with tractors and implements, funding higher institutional extension services and development of agricultural information desks at the local government level.

6.4 Increased private sector engagement

Working partnerships with private sector agricultural machinery and agro-processing equipment manufacturers, rural artisans and blacksmiths is very vital for mass production, marketing and after sale service of proven AETs for the beneficiaries especially farmers. Consequently, Public–Private Partnerships (PPPs) are proposed where objectives, efforts and benefits are shared. This arrangement allows synergies to develop through the Public Sector leveraging Private Sector strengths. This arrangement provides favorable policy frameworks, innovativeness, flexibility and efficiency with the ability and possibility of the Private Sector to tap into the public resources in a socially responsible way. PPPs offers ways for government to lower costs and risks in the provision of services, and by enabling better efficiency and effectiveness, and promoting equal access, as well as good accountability. A lot of innovations in AE never see the light of the day because they remain at prototype stage. The private sector is profit driven but it is very hard for any technology to make profit at the onset. Government should be willing to invest money in an innovation before private sector picks interest. Therefore sustained support to researchers in the domain of AE is very key in stimulating innovations. Another proven model is when the private sector sponsored research delivers a product whose market is already developed or can be developed. This has inroads with IPRs enforcement and protection.

6.5 Enforcement of Intellectual Property (IP) rights

Enforcement of IP rights is inevitably an incentive for innovation and creativity which is crucial in the development and improvement of AE technologies (De Beer et al., 2014). Moreover, the developed prototypes have not been subjected to tests, scrutiny and approval for patenting by local, national, and international professional bodies.

6.6 Economic incentives

Government needs to consider economic incentives towards credible farmers and farming communities that have the potential to and are making efforts towards agricultural mechanization (Sims and Kienze, 2015). Such incentives may vary from setting up mechanization funds for long term financing, establishing special financing rates for bankable farmers to acquire tractors and working with banks to guarantee bankable farmers

6.7 Proven models of introducing mechanization to farming communities

Government engages a lead farmer who is in essence a business person who takes ownership for the AET. The Lead farmer uses the AET to farm personal land while at the same time hiring it out to other farmers. Financing for the lead farmer is organized by the Government and the arrangement is strictly executed as a business. Due to the relatively low average land area for the Ugandan farmers, economic viability of owning some AET is limited to a small proportion of the farmers' population. Thus, establishment of AET hiring centers enables the small land area farmers to access the benefits of using AETs at a fee. In addition, technical desks should be formulated that avail required information for the farmers, not only about agricultural mechanization but also agronomic and business requirements of farming.

7 Conclusions and recommendations

There is a general consensus that the availability and prudent use of AETs along the value chain has the potential to enhance labour use and efficiency, provide greater precision and timeliness in farm operations, reduce postharvest loses, contributing to adding value to products and profitability of farming through proper handling, drying, cleaning, grading, processing, preservation, packaging and storage. The need to maximize agricultural productivity and profitability on a sustainable basis and with minimum drudgery on the farmers necessitates engineering interventions in form of appropriate AETs. The future strategies for development and increased adoption of AETs should address the aspects on appropriateness of the AETs in the smallholder agriculture context and standardizing of AET. Furthermore, human resource capacity development through enhancement of technical skills in AE, increased private sector engagement, economic incentives and enforcement of intellectual property rights should be an integral part of the strategies. Government should formalize an exclusive agricultural mechanization policy and create portfolio for AE professionals at District Local Governments' to promote AE. Furthermore, technical skills development to carry out farms operations that are technology driven will improve the face of AE and its relevance to national development.

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