Chapter

Potentials of Wood, Bamboo and Natural Fibre-Reinforced Composite Products as Substitute Materials for Fabricating Affordable Agricultural Equipment and Processing Machines in Africa

Abel Olajide Olorunnisola

Abstract

Modern agriculture depends heavily on technology. Land clearing, irrigation, drainage, crop storage and processing all require technological input. By modernising her agriculture, through wise application of science and technology, Africa can make significant headway in economic growth. However, an agricultural technology that is too sophisticated for a particular country/region is beyond its absorptive capacity. Hence, to achieve the objectives of agricultural mechanisation in Africa, it is imperative to take into account prevailing socio-economic conditions and the level of mechanisation necessary for optimal productivity. One major constraint to agricultural mechanisation in sub-Saharan Africa is the relatively high cost of imported metallic machine and equipment fabrication materials. Taking full advantage of substitute non-metallic materials may lower the cost of production and concomitantly empower rural fabricators with limited access to electricity and welding facilities to engage in local manufacturing of sundry agricultural machines and equipment. This Chapter presents illustrative examples of full and partial substitution of metallic with non-metallic materials in the fabrication of affordable machines and equipment for agricultural production, agro-processing, irrigation and drainage, crop drying and storage. Ways of addressing identified critical challenges of technology diffusion are also discussed.

Keywords: Wood, Bamboo, Fibre-reinforced composites, Agricultural machinery, Modern agriculture

1. Introduction

Africa covers about 6% of the earth's total surface and about 20.4% of the land area. It is the second most populous continent after Asia constituting around 14.72% of the world's total population. All the countries in Africa can at best be referred to as developing countries, with the exception of South Africa, Egypt, Tunisia, Libya and Algeria that take the lead in the stated order as the top five developed countries on the continent. A developing country or less-developed country (LDC) is, in this context, defined as a nation with a low standard of living, underdeveloped industrial base as contrasted with a "More Developed Country" (MDC) that has more a highly developed economy and advanced technological infrastructure [1].

The main engine of economic growth is agriculture. Agricultural development led to the rise of human civilization and a rapidly modernising agriculture produces food without which an economy cannot possibly grow. It also creates demands for many new industries, from fertilisers to farm equipment, from repair shops to farm credit, from transportation and roads to food processing. In the last fifty years, technological developments in agriculture have dramatically changed the performance of farming. For instance, irrigation and drainage have ensured the use of otherwise unusable land for agriculture, while mechanisation has minimised drudgery, improved productivity and decreased farm labour requirement significantly in the more developed countries.

Agriculture has a massive social and economic footprint in Africa where it is practised both for subsistence as well as commercial reasons. It is by far the single most important economic activity, providing employment for about two-thirds of the continent's working population, contributing an average of 30–60% of gross domestic product and about 30% of the value of exports for many African countries. In the last 30 years, Africa's population has doubled overall and tripled in urban areas. The most direct consequence of this exponential population growth rate is that the continent now has more mouths to feed. However, moving from being self-sufficient in the 1960s, Africa has become a net importer of many food items. Indeed, African agricultural exports have fallen by half since the mid-1990s with imports accounting for 1.7 times the value of exports. This is partly due to the fact that over 80% of all farms in Africa are rather small which makes large-scale mechanisation unrealistic [2, 3].

For the foreseeable future, heavy dependence on agriculture is likely to continue being the norm rather than the exception in sub-Saharan Africa (SSA). By modernising her agriculture through wise application of science and technology, the region can make significant headway in economic growth. The modernised agricultural sector can contribute towards major regional and continental priorities, including poverty alleviation, a boost in intra-African trade and investments, rapid industrialisation and economic diversification, sustainable resource and environmental management, job creation, human security, and shared prosperity. The region in particular and the continent in general can thus fulfil the enormous potential of becoming a major player in the global food market.

It is obvious that mechanisation is a necessity in modernising agriculture. To mechanise means to use machines to accomplish tasks, reduce human efforts, and improve timelines and quality of various farm operations. A machine may be as simple as a wedge or as complex as a combine harvester. Hence, there are presently three levels of mechanisation distinguished in agricultural engineering literature: *Hand Tool Technology* (HTT), *Draught Animal Technology* (DAT), and *Engine Power Technology* (EPT) [4]. Agricultural mechanisation cannot, therefore, be restricted to the use of motorised equipment alone. Rather, the term covers the development, maintenance, repair, management, and utilisation of agricultural hand tools, implements, and machines and also applies to agricultural land development, crop production, water control, harvesting, material handling and preparation for storage, on-farm processing and rural transport.

Attempts at agricultural mechanisation in many African countries over the years seem to have failed because of the false notion that mechanisation only implies tractorisation- the use of tractors in agricultural activities which is a mere aspect and level of mechanisation. The performance history of imported tractors and other agricultural machinery has been largely characterised by a chronic chorus of lack of spare parts, repair facilities, capital, skilled operators and mechanics, as well as incompatibility with fragile local soil conditions and farmers' cropping techniques. Adoption of '*appropriate selective mechanisation*', a situation in which HTT, DAT AND EPT are appropriately combined, has therefore been recommended. For example, ploughing may be done with an appropriate type of tractor or draught animal power, while seeding, weeding and harvesting are accomplished with hand or simple mechanical tools [5]. Appropriate selective mechanisation is considered a workable strategy because multiple factors play a role in mechanisation patterns adopted in different countries over time. These include farming systems; agro-climatic conditions, such as soil, terrain and rainfall; institutional environments; and social objectives of societies, such as nation building and modernisation. Since each of these factors differs within and between countries, it is difficult to specify a blueprint of technological change, for all African countries to follow [6]. Other scholars have also recommended the promotion of (i) the use of locally available materials as substitution to high-carbon steel in the manufacture of agricultural machines and equipment and (ii) village level manufacturing of affordable agricultural machines and equipment by blacksmiths, tinsmiths and carpenters [4, 7–10].

In implementing some of the foregoing recommendations, numerous researchers have, over the years, engaged in innovative research culminating in the development of different agricultural equipment and machines.The aim of this chapter, therefore, is to highlight some of the research outputs on the uses of wood, bamboo and natural fibre-reinforced composites as substitute materials in the local fabrication of affordable agricultural machines and equipment in sub-Saharan Africa. However, research results, inventions and innovations have value only when they serve useful purposes in the society. The diffusion of technological improvements, within a country and across international borders, is critical for long run growth. It is most unfortunate that most of the equipment and machines to be discussed are yet to be in common use. Hence, this chapter also discusses ways of addressing the critical challenges of technology diffusion Africa.

2. Rationale for the use of agro-forestry materials and fibre-reinforced composites in agricultural machine and equipment fabrication

The benefits of using agro-forestry materials and fibre-reinforced composites for agricultural machine and equipment fabrication are many and varied. They include the following:

Wood Products: The major wood products used in machine and equipment fabrication include lumber, plywood, particleboard and fibreboard. Wood remains one of the most versatile materials whose natural structure can be retained, as in lumber and plywood, or can be reduced to its basic fibres and reconstituted to a more uniform product such as fibreboard and particleboard. Besides, wood is renewable, available in various sizes, shapes and colours, affordable, easy to machine and join, durable (depending on the species), and aesthetically appealing [10, 11]. Other advantages derivable from the use of wood and wood products in machine and equipment fabrication include easy replacement of damaged machine/equipment parts and reduction in the weight to enhance portability.

Bamboos: Bamboos grow and reach maturity more rapidly than trees and start to yield within three or four years of planting. Unlike most timbers, bamboo is self-regenerating; new shoots that appear annually ensure future raw material after mature culms are harvested. The ease with which bamboo can be worked, its versatility, strength, and availability recommend it for industrial utilisation. Besides, laminated bamboo products do not retain the characteristic shapes of the bamboo raw material, thus offering more versatility to the machine/equipment designer [12]. The cylindrical hollow structure of many bamboo species with the rigid cross walls gives it resistance to collapse from bending. The jointed culm typically has a very hard external surface which contributes to its strength and impermeability to water - characteristics that satisfy many of the requirements of irrigation and drainage pipes.

Cement-bonded fibre-reinforced composites: These are low-cost materials made from a mixture of cement, water, particles of different sizes (strands, flakes, chips, fibres) obtained from agricultural and forestry products. The incorporation of fibrous materials in the composite improves the fracture toughness of the cement [10, 13]. Some of the admirable properties of cement-bonded composites of significant advantage in equipment fabrication include relatively high strength to weight ratio, durability; high resistance to moisture uptake; ease of sawing; excellent insulation against noise and heat; ability to absorb and dissipate mechanical energy, and high resistance against fire, insect and fungus attack [14]. Being environment friendly, natural fibre-reinforced composite pipes are beginning to attract great attention as substitutes to synthetic fibre-reinforced composite irrigation pipes which are difficult to recycle after their designed service life.

3. Selective examples on the of the use of substitute non-metallic materials in agricultural machine and equipment fabrication

Some of the various aspects of agricultural production in which the foregoing materials have been experimentally used for fabricating affordable machines and equipment are the following:

3.1 Tillage and crop production equipment

Tillage and crop production activities performed on a farm include ploughing, harrowing, seed bed preparation, cultivation, weeding, and harvesting. All these activities require power sources, which on large scale farms are derived from tractors of different sizes. However, the average level of tractorisation in SSA is about 28 tractors per 1 000 ha in contrast to 241 tractors per 1000 ha in other regions [3]. While relevant data are scarce and at times out-dated, there is a general consensus that the level of tractorisation in particular and farm mechanisation in general is still very low in Africa. This is in spite of the efforts made by governments in many SSA countries over the years to promote tractorisation in particular and farm mechanisation in general. Such recent interventions include importation and provision of tractors and farm machinery at subsidised rates to farmers as shown in **Table 1**, and setting up state- owned tractor assembly plants and tractor hiring schemes, e.g., the *Nigerian Tractor Hiring Units*, the *Ghanaian Agricultural Mechanisation Service Centres* and the *Mozambican Agricultural Service Centres* [15]. Again, as earlier mentioned, the failure of many of these interventions is largely attributable to a strong focus on machinery importation and the neglect of knowledge and skills development at the local level, among other factors. Hence, the principal power source for 50 to 80% of the land area under cultivation in the region is still human power.

For centuries, wood has played a prominent role in land clearing, tillage and crop production equipment manufacture in SSA, where it is used as handles for hand tools such as hoes, axes and cutlasses (**Figure 1**). Over the years, a number of other

Country	Time period	Number of machines imported	Number of persons trained in 2017 on mechanisation in regular or project-funded programs
Mali	2016–2018	1500 tractors + implements as well as water pumps, motocultors, threshers, dehullers	None
Nigeria	2010–2018	950 tractors +150 implements as well as groundnut and melon threshers, water pumps, power tillers	560
Kenya	2016–2020	Unspecified number of tractors, implements and other machinery worth US$ 100 million	Unspecified number of persons trained on ad hoc basis (no regular training courses)
Benin	2008–2018	1040 tractors as well as 360 rotor tillers	100
Burkina Faso	2015–2018	800 tractors + implements	300

Source: [6].

Table 1.
State-led mechanisation and training in selected countries in sub-Saharan Africa.

Figure 1.
Hoes, cutlasses and axes fabricated with wooden handles.

simple tillage tools made up of metals and wooden handles have been locally developed. Examples include weeders with wooden boards fitted with sharp metal blades, harrows (made of wooden plank to which wood/iron pegs, handle and bamboo shaft are fitted, typically used for breaking soil crust after rain and also for uprooting weeds), mallots (wooden blocks with attached handles, used for the breaking of clods), and levellers with shafts generally made of bamboo sticks used for land levelling. These and numerous other hand tools are typically inexpensive, easy to manufacture, use, maintain and repair. Besides, they are often times multi-purpose tools employed in several crop production operations and are culturally accepted.

Hand hoes, in particular, are still extensively used for land clearing, ridging, weeding and root crop harvesting across sub-Saharan Africa. It has been noted that '*the peasant farmer and his hoe and cutlass are efficient companions in crop production at the subsistence level where he operates*' [4]. At such subsistence level, the farm sizes are usually about 1.0–3.0 hectares, the farmer's income is typically low, and the farmers practice intercropping which discourages the use of tractors but encourages

Figure 2.
A planter in which wood is used for fabricating selected machine parts.

the use of hand tools, which can reduce drudgery, if not area of cultivated land. Researchers have worked on improving the performance efficiency of hand hoes, focusing attention on the angle of inclination of the metal blade (the soil shearing member) to the handle, length of the handle and the weight ratio between the handle and the blade. These efforts have shown potential improvements in its scooping efficiency and field capacity [2, 5–7]. Introducing improved hand hoes can, therefore, be of tremendous benefit to peasant farmers.

However, wood is also relevant in the production of modern crop production equipment, especially, seed planters. Metering mechanism is the heart of every planter. Its function is to distribute seeds uniformly at the desired application rate and control seed spacing in a row. Wood products including lumber and plywood are suitable and very highly recommended for the fabrication of not only metering mechanisms but also handles, hoppers of manually operated seed planters. **Figure 2** shows a planter in which lumber and plywood were used for the fabrication of the handle and the metering device with the associated advantages of portability, low cost, and ease of fabrication, while **Figure 3** shows a maize planter with a wooden roller type seed metering device. A rough estimation showed that substitution of steel with wood in the fabrication of the component parts of the planters shown in **Figures 2** and **3** could reduce the cost of fabrication (i.e., material and labour costs) by 30–45%.

3.2 Crop processing machines

Africa produces numerous crops including legumes and cereals. Groundnut is one of such important leguminous cash crops and a major raw material for several industries especially in the food processing and poultry sectors. It is also processed at small- to-medium scale levels for domestic consumption as snacks in roasted and fried forms. Traditionally, groundnut shelling is a manual operation, a slow process with a maximum throughput per person of 2 Kg/hr. and a shelling capacity 15–20 Kg/day [17]. Groundnut shellers are typically fabricated using steel [18]. In a departure from this norm, a wood-steel manually operated groundnut sheller was developed. The hopper, main frame and collection tray of

DOI: http://dx.doi.org/10.5772/intechopen.98265

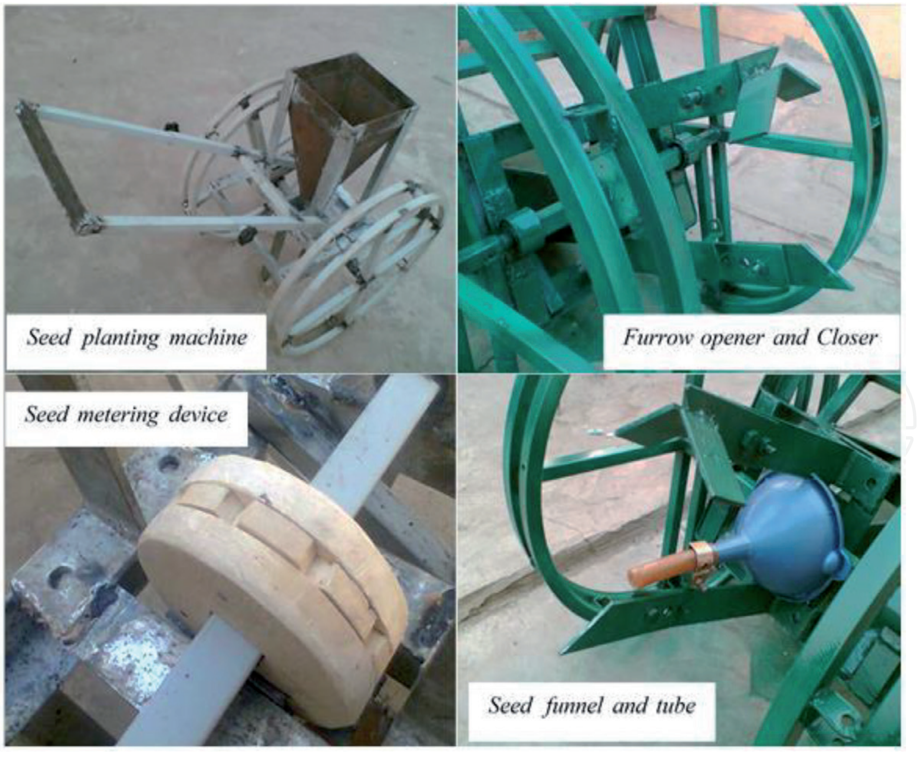

Figure 3.
Component parts of the maize planter. Source: [16].

the sheller were fabricated with the sawn wood of *Cordia platythrsa*. The shelling unit was made up of a combination of a lumber casing, metallic pipe and wooden rasp bars, while the turning handle was made of a hollow steel pipe [19]. Wood was selected for fabricating the casing for the shelling unit in particular because of its exceptionally good acoustic properties, i.e., wood absorbs large amounts sound energy before it resonates. Hence, minimal noise would be experienced during machine operation. When tested, the sheller (**Figure 4**) gave a maximum

Figure 4.
Wooden/metallic Sheller. Source: [19].

throughput capacity of 11 Kg/hr., more than five times the shelling capacity of a person, shelling efficiency of 98.6% and kernel damage of 16.6%.

To upgrade the sheller performance, an improved version (**Figure 5**) was developed that incorporated a cleaning device for separating shelled nuts from the chaffs [20]. The cleaner had a wooden housing and a steel sieve cleaner that gave a maximum cleaning efficiency of 84%. In another improvement of the sheller (**Figure 6**), wood products were used in fabricating all the machine component parts [21]. It is apposite to note that the costs of fabricating one-off units of the three versions of the groundnut sheller decreased with increase in metal substitution with wood from approximately 55% (for version one) to 35% (for version two) of the cost of producing an equivalent metallic sheller.

Another major crop produced and consumed in Africa is maize (corn). *Maize* occupies approximately 24% of farmland in *Africa* and the average *yield* is around 2 tons/hectare/year. The largest *African* producer is Nigeria with over 33 million tons, followed by South *Africa*, Egypt, and Ethiopia [22]. The steps involved in maize processing include harvesting, drying, de-husking, shelling, and (often times) milling. Many of these processes, particularly shelling which is the separation of the grains from the cobs, are labour-intensive and time-consuming for rural farmers who engage in hand shelling. The easiest hand shelling method is to press the thumbs on the grains in order to detach them from the ears. Another simple shelling method is to rub two ears of maize against each other. Other methods include beating with stick, crushing with mortar and pestle, et c. Small tools are also sometimes used.. A worker can hand-shell about 2 kg of maize per hour [19, 23]. With the use of hand tools, the output per worker increases to between 8 and 15 kg/hr. [24].

Figure 5.
Modified wooden/metallic Sheller. Source: [20].

Figure 6.
A completely wooden groundnut Sheller. Source: [21].

Figure 7.
Wood-metal hybrid maize Sheller. Source: [27].

Different types of mechanical maize shellers are in existence in forms of handheld, portable, motorised and large commercial sized units and are almost invariably fabricated using metals including mild steel, stainless steel and cast iron for the various components [24–26]. However, a low-cost wood-steel hybrid motorised maize sheller shown in **Figure 7** was developed [27]. The wooden components of the sheller fabricated with the sawn wood of *Cordia millenni* included the hopper, the main frame, the shelling drum housing, and the cleaning unit housing. The cost of a one-off version of the sheller, driven by a 5 hp. electric motor was US $150 compared to the market price of about US $400 - US $500 for the metallic version in Nigeria. The performance of the sheller was evaluated using yellow maize (*Zea saccharata*) variety at 13% moisture content. Its output capacity (118.9 Kg/hr), shelling efficiency, cleaning efficiency, grain recovery, and total grain losses of about 79%, 96%, 91% and 2.8% respectively at a shelling speed of 536 rpm are comparable to similar shellers made entirely of metallic parts. The findings confirmed that wood is an acceptable and relatively cheaper substitute material in the fabrication of critical parts of a maize sheller.

Cassava is another major crop produced in many Sub-Saharan African countries, with Nigeria being the largest producer in the world. It is a consumed as a major source of carbohydrates in human diet and as starch for industrial applications. The tubers of cassava cannot be stored for long after harvest hence processing tends to follow immediately after harvesting. Cassava processing activities include peeling, grating (i.e., transformation of cassava tubers into pulp), dehydrating, milling and sieving. The traditional method of grating involves placing the grater, typically made of perforated metal sheet on the table where it is convenient for effective use and brushes sheet metal. The cassava turns into pulp and drops into container that is being used to collect the grated pulp cassava. It has been shown that cassava graters can be fabricated with wood products. For example, a cassava grater was fabricated with the use of hardwood for constructing the frame, grating chamber, hopper, grating roller and the outlet [28]. The grater had grating capacity of 102.9 kg/h and a grating efficiency of 90.91%. The cost saving associated with substituting metal with wooden component parts was estimated at about 30%.

3.3 Poultry production equipment

There are two options for poultry development in Africa. One option is to attempt to increase large scale intensive poultry production in order to respond to the urban demand. The other option is to explore new channels for developing small and medium scale semi-intensive poultry production to serve both the urban and rural populations. Where possible, the two options should be pursued simultaneously. One of the core aspects of poultry production is egg incubation- the management of fertilised eggs to ensure satisfactory development of embryos into normal chicks. For very small number of eggs, say 6–12, the easiest and usual way of hatching chicks is the natural method, whereby the broody hen sits on the nest to provide the required warmth. However, for larger quantities of eggs, the most cost effective practice is to use artificial incubators- closed heat-insulated chambers in which temperature and relative humidity are strictly monitored and controlled.

Most small-scale poultry farmers in sub-Saharan Africa still are unable to produce day old chicks by artificial incubation due to the relatively high cost of procuring imported incubators. To demonstrate the use of wood in poultry equipment production, a flat-type wooden incubator was developed (**Figure 8**) which was used to successfully hatch chicken eggs [29]. The component parts of the incubator included a cabinet, fabricated using 6.4 mm thick interior grade plywood for the floor, side walls and the lid; and the sawn wood of *Terminalia superba* for the beams and columns; a transparent glass inspection panel; improvised heaters and humidifiers required to achieve mean ambient incubator temperature of 37-39°C and relative humidity of 58%, vents, instrumentation and egg trays. The choice of wood for fabricating the various component parts was based not only on local availability and relatively low cost, but more importantly on effectiveness in performing the desired functions of insulation and structural stability.

Figure 8.
The loaded wooden incubator. Source: [29].

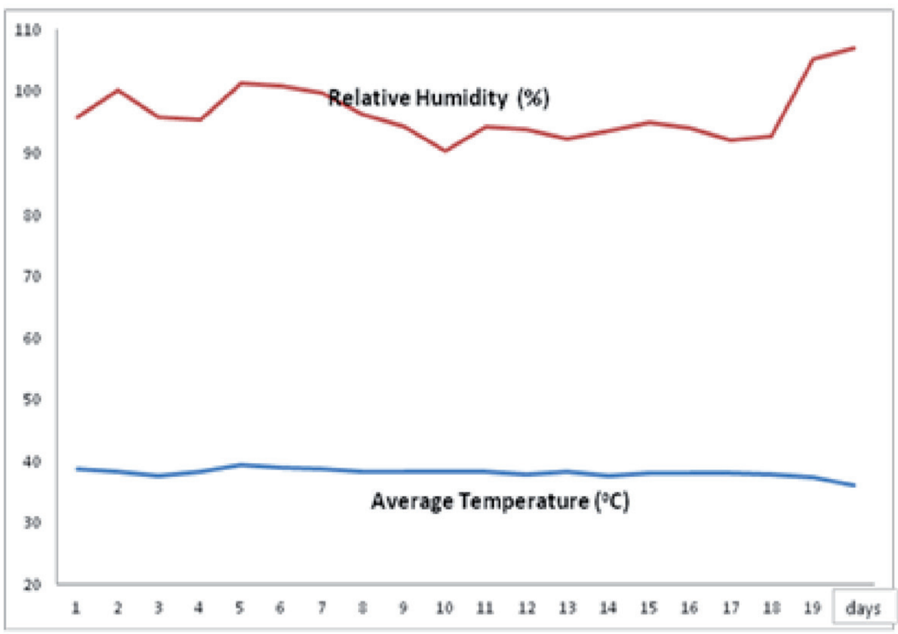

Figure 9.
Temperature and relative humidity variations in the wooden egg incubator. Source: [29].

When tested with 30 chicken eggs, the expected mean internal temperature and relative of 37°C and 58% respectively were achieved by the incubator. It was able to hatch chicks in 20 days with 76% hatchability and 18.5% mortality rates. The temperature and relative humidity variations observed during the incubator loading test are shown in **Figure 9**. The incubation duration was in conformity with observations of Ref. [30] who reported a range of 20 to 21 days for hatching chickens naturally and in artificial incubators. The percentage hatchability and mortality rates were also within acceptable limits. The current cost of producing the incubator is approximately N20,000–25,000 (in Nigerian currency), which is equivalent to US$ 40 – US$ 50.

3.4 Farm irrigation and drainage equipment

Crop production requires large quantities of water. African agriculture, characterised by low levels of productivity relative to population growth, and frequently accompanied by human induced degradation and drought presents special challenges not encountered in other regions. There is draught in many arid or semi-arid parts of Africa, many of which cannot support rain-fed agriculture and hence require irrigation.

Efficient use of water in African farms does not necessary require large scale, energy-intensive irrigation schemes. Small pumps have had an important beneficial effect on irrigation in small-scale farms in a number of African countries. Where surface water is available, this technology represents a well-distributed and energy efficient option. Also, in recent times, the concept of "affordable micro-irrigation" systems has been identified as a corresponding drip irrigation technology for low-income farmers [31, 32]. Bamboo drip irrigation system (**Figure 10**) is a very old but relevant system of tapping stream and spring water by using bamboo pipe and transporting water from higher to lower regions. The advantages of using bamboo are two-fold: it prevents leakage, increasing crop yield with less water, and makes use of natural, local, and inexpensive material.

It has now been scientifically proven that bamboo pipe can be used in both gravity and pressurised conditions for irrigation and drainage pipes provided the transmission pressure do not exceed 13.5×10^5, 13.1×10^5 and 12.9×10^5 N/m^2 for base, middle and top portions respectively. Values of head losses obtained are generally high for a bamboo pipe length of 6 meters. However, head losses can be reduced by proper node removal, increasing velocity of flow; and increasing the pressure head among others. It has also been recommended that node removal mechanism be improved upon so as to reduce the overall roughness size of the bamboo pipe [33].

Some of the hydraulic properties of *Oxytenanthera abyssinica* bamboo species have been investigated with a view to determining its potentials as irrigation piping material [34]. The properties tested included burst strength, head loss and friction factor. These properties were found to vary, some of them significantly, along the culm height. The bursting pressure was found to be about 13×10^5N/m^2, which is higher than that of PVC pipes (11.2×10^5 N/m^2) which are currently in common use as irrigation and drainage pipes. The mean friction factor, determined within the turbulent range ($N_{Re} < 2000$) in a 6 m length, 2.6 mm internal diameter bamboo pipe discharging at about 5.3×10^{-4} m^3/s was 0.020 giving a mean head loss of

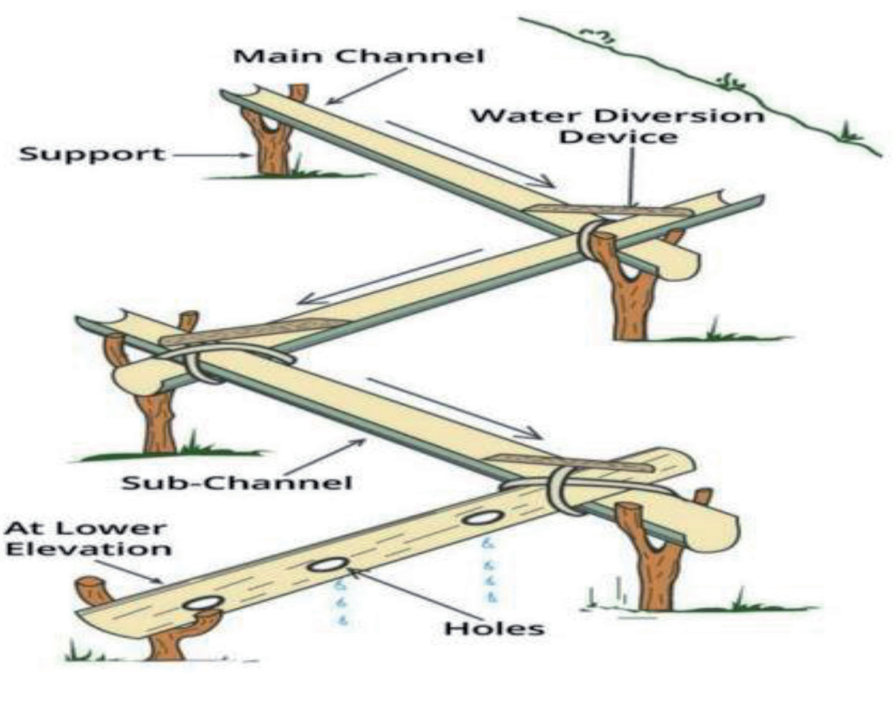

Figure 10.
Bamboo drip irrigation system.

Figure 11.
Bamboo winding composite pipes.

0.14 m/m. However, bamboo has a few limitations to its use in micro irrigation water piping. These include its non-straightness, roughness, existence of the nodal plates that make water flow naturally impossible, non-uniformity of the stalk diameter, jointing problems, strength and durability. These are problem areas requiring further studies.

In a recent development, bamboo winding composite pipe, i.e., ordinary bamboo cut into thin bamboo strips winded by machines and turned into a strong composite pipe, has been developed in China for water conveyance as a green alternative to traditional pipeline materials. Such pipes shown in **Figure 11** have characteristic lightweight, high axial tensile strength and good flexibility which make them suitable for application for urban water supply, farm irrigation and drainage, etc.

Cement-bonded composite pipes are another potential alternative. A study was reported on the possibility of using 6 mm and 8 mm thick cement-bonded sawdust-reinforced composite pipes for water conveyance [35]. The maximum burst strength of the composite pipes, 1.0×10^5 N/m^2, was, however, lower than those of polyvinyl chloride ($8.6–13.8 \times 10^5$ N/m^2) and aluminium pipes (13.8 and 32.4×10^5 N/m^2). The composite pipes shown in **Figure 12** were, therefore, recommended for use in low pressure water drainage.

Figure 12.
Cement-bonded composite pipes. Source: [35].

3.5 Drying equipment

Drying which is an important preservation process for many agricultural crops and food products. It is the phase of the post-harvest system during which an agricultural product is rapidly dried until it reaches the safe-moisture level to guarantee conditions favourable for storage or for further processing of the product. Traditional methods of drying as practised in many SSA countries include direct exposure of agricultural products to sun radiation by spreading the products on ground, polythene sheets, mats, tarred surfaces including roads, cement courts or hanging on eaves. These methods suffer from numerous inadequacies such as infestation by insects, contamination by dirt, loss through rodent attack, and spoilage due to exposure to rain, among others. Modern artificial dryers are generally relatively costly and un-affordable to small-scale farmers. The use indirect solar dryers, where practicable, would be comparatively cheaper and equally efficient.

In a typical indirect solar dryer, a black surface heats the incoming air instead of directly heating the substance to be dried. The heated air is then passed over the substance to be dried and exits upwards often through a chimney, taking moisture released from the substance with it. Indirect solar dryers can enhance the effect of insolation and minimise loss of collected energy to the surroundings. They can also generate higher temperatures and lower air relative humidity than in direct sun drying, both of which are conducive to improved drying rates and lower final moisture contents of dried products. This reduces the risk of spoilage during the drying process and in storage. The higher the temperatures attainable in these devices are deterrent to insects, and microbiological infestation. Also protection against dust, insects and animals are enhanced by drying in an enclosed structure. The use of lumber and other wood products for fabricating solar dryers has been explored by the author, culminating in the development of an indirect solar dryer for seeds, fruits and vegetables shown in **Figure 13**. It is an absorber-type collector device that comprises a double-walled wooden box with a double-glazed tight-fitting glass lid.

Figure 13.
A passive solar dryer for seeds, fruits and vegetables developed by the author.

The gap between the walls of the box was stuffed with dry sawdust. A soot-coated, metal plate was attached to the bottom of the box as the heat absorber.

Another type of solar device that can serve dual purpose of drying and cooking has been developed [36]. For the dying test, beef samples initially at 73% moisture content dried to 17% in 5 hours and cassava samples at 56% moisture content dried to 14% in 5 hours all in bright sunshine.

3.6 Grain storage equipment

Despite the fact that many African countries are blessed with arable land and suitable climate for the production of a myriad of food and cash crops, the major problems with food supply involve not only relatively low agricultural production but also considerable poor storage-induced post-harvest losses incurred in the food supply chain from the farm gate to the final consumer. The major food crops– maize, millet, sorghum, cowpea, et c- are seasonal and require storage if they will be available all year round or as seed until the next planting season. Grain losses of up to 50% have been reported in some sub-Saharan African countries where farmers store their farm produce in rhombus, local cribs, bags, pots, calabashes, baskets, or earthen pots [37, 38].

In reducing the considerable losses associated with traditional grain storage techniques, grain silos are indispensable. However, metallic silos, the most common type of silo employed today, are unsuitable for long-term grain storage in sub-Saharan Africa for several reasons including cost of acquisition and maintenance as well as over-sized capacities [38, 39]. Besides, metallic silos tend to promote moisture condensation, caking and insect infestation of stored grains, as well as the development of hot spots under the prevailing warm and humid climatic conditions in the region [40–42]. The heat flow into the silo may in some cases be sufficiently high to roast the grains directly in contact with the silo wall

Figure 14.
A 1.4 m^3 capacity wooden grain silo. Source [43].

surfaces [39]. To address the afore-mentioned challenges of affordability, inappropriate capacity and material suitability, several interventions have been made by various researchers. For example, a double-walled metallic silo was developed using wood sawdust as insulating material which lowered the interior temperature of the silo [43]. In another series of interventions, 1.4–7 m^3 capacity grain silos that are more efficient in reducing moisture condensation and hot spots and suitable for small-and medium-scale farmers were fabricated with wooden beams and columns and plywood sheathing [43, 44].

An example of the grain silo, shown in **Figure 14**, and erected in Minna, Niger State, Nigeria, retained its structural integrity after four years of erection except for mild peelings of sheathing materials, nail slip and colour change [43]. Nutritional quality of the maize (*Zea mays*) stored in the silo for a period of nine months was also preserved with minimal reduction in crude protein, crude fibre and lipid contents. The use of wood products in grain silo construction has the potential of reducing construction cost by at least 40%. The simplicity of construction and maintenance, and the possibility of small unit capacity recommend such wooden silos for small- and medium-scale farmers in Africa.

4. Addressing the factors militating against agricultural technology diffusion in Africa

The factors responsible for non-adoption of a wide variety of innovative agricultural technologies such as those discussed above are many and varied. Some of the factors and ways of mitigating them are highlighted below:

- **Lack of standardisation**: It is common knowledge that standardisation is a viable tool for achieving high quality, reliability and international competitiveness. However, Africa is still lagging behind in the development of standards for locally developed agricultural equipment and machines. To facilitate mass production and adoption, industry, national and regional standards must be promoted to codify terminologies, basic production techniques and safety rules, dimensions and permissible tolerances, functional requirements and test methods.

- **Dearth of engineering extension workers:** There is a dearth of engineering extension workers in Africa, thereby hampering technology transfer to the society. Hence, many farmers are not aware of the research and development outcomes. A few research institutions and non-governmental organisations have blazed the trail through circulation of research briefs, regular exhibitions, as well as newspaper, radio and television advertisements to promote public awareness about new inventions and innovations. The radio and the television, in particular, are major strategic instruments for extension services. Mounting educational programmes on radio and television is a proven means of reaching out to adults in both rural and urban settings.

- **Illiteracy**: The literacy level in many African societies is generally low. This makes technology diffusion rather difficult. Rapid technology diffusion requires eradication of illiteracy among the adults engaged at various levels in the agricultural production value chain who may be rather too old to participate in the conventional schooling system. One way of doing this is by promoting adult literacy programmes to facilitate the adoption of modern agricultural technologies.

- **Institutional and policy barriers:** In many countries, institutional and policy barriers limit the adoption of technically superior technologies. There has to be a radical departure from the conventional approach which focuses on household characteristics that predispose farmers to technology adoption without taking into account the value chain level or institutional factors and national or regional policy issues that hinder technology adoption, entrepreneurship and commercialisation [45].

- **Sociocultural and Lifestyle factors**: Adoption of new technologies is often limited because interventions fail to adequately account for sociocultural and lifestyle factors that are important to farmers. While they share some common characteristics, of which size is the most obvious, not all smallholder farmers are the same There is considerable diversity across and within regions and countries with regard to their backgrounds, histories and environments. Farms also have different assets, needs and objectives. Furthermore, biophysical, institutional, social and economic drivers also differ between contexts, resulting in different responses from farmers. Hence, the conceptualisation of small farms in theory and policy with emphasis on the dichotomy between market orientation and subsistence has to be modified in line with current realities. It should be understood that some of the small-scale farmers that engage in a high level of self-provisioning do so not necessarily out of poverty but as a lifestyle choice; some small farmers are successful commercial entrepreneurs, while for others farming is a household coping strategy to reduce the risk and poverty [46].

- **Financial Constraints**: The foregoing point notwithstanding, in many instances, small older farmers lack the resources and sometimes the incentives to adopt new technologies. Despite the availability and validation of various agricultural technologies, financial constraint continues to be a major cause of low adoption of new technologies by numerous small-scale farmers in SSA. Subsidising the procurement of selective appropriate technologies is a way out.

- **Dearth of Entrepreneurs**: Another key ingredient in the transformation of innovative ideas to innovative products is entrepreneurship. However, there are very few individuals, organisations, strategic investors and venture capitalists willing to invest in the commercialisation of the numerous agricultural technologies developed in Africa. One major way of promoting entrepreneurship is by the establishing business incubation programmes and facilities. Business incubation has been proven to be a dynamic process of business enterprise development for the purpose of nurturing young firms, new products and technologies as well as helping SMEs upgrade and undergo transformation [47].

5. Conclusion

Africa has all it takes to develop its agriculture and achieve self-sufficiency in food and agro-industrial raw material production. The missing link in sub-Saharan Africa in particular is the non-adoption of appropriate technologies that are compatible with multiple farming systems in use, the environment, socioeconomic status of the proposed users, level of maintenance skill available, as well as construction materials and facilities available for fabrication. Many African countries will for some time to come continue to have a mixture of small, medium and large scale farmers, with perhaps small-scale farmers constituting the majority. While prices have dropped due to the entrance of companies from China and India in the African market, a wide range of agricultural machinery still remains expensive relative to the incomes earned in African agriculture [6].

The use of locally available non-metallic materials as partial or full substitution in manufacturing is, therefore, advocated as a means of making available to small- and medium- scale farmers, suitable and affordable machines for crop production, irrigation systems to supplement natural rainfall, drying and storage facilities to minimise post-harvest losses. This is imperative because smallholder farmers, in particular, are not only key to agricultural development in Africa, excluding them from mechanisation would also result in unequal land and wealth distribution [6, 48, 49]. It is instructive to note also that while '*small farms are typical of the rural landscape in the Global South, small-scale farming continues to exist –and even thrive—in the Global North, including Europe. Small farms are crucial for global food security, producing between 50% and 75% of food calories consumed globally. Small-scale farming also provides key opportunities for employment and livelihoods, is a crucial part of rural communities and landscapes and plays an important role in environmental sustainability and supporting agricultural biodiversity*' [46]. To promote widespread adoption of appropriate agricultural mechanisation, the critical factors militating against technology diffusion have to be addressed. Technology development has to be participatory and coupled with extension efforts that recognise agro-ecological and socio-economic contexts and incorporates knowledge from various sources (e.g., sociologists, economists, historians, etc), rather than from scientists or researchers alone. An enabling environment that supports and/or rewards technology adoption by farmers is also an important prerequisite for success.

Conflict of interest

The author declares no conflict of interest.

Author details

Abel Olajide Olorunnisola
University of Ibadan, Ibadan, Nigeria

*Address all correspondence to: abelolorunnisola@yahoo.com; ao.olorunnisola@ui.edu.ng

References

[1] Anonymous. Africa [Internet]. 2021. Available from: https://en.wikipedia.org/wiki/Africa , [Accessed: 2021-01-02]

[2] Okatahi S.S, Yusuf D.D.: Development and performance evaluation of selected tillage tools for farmers in the middle belt zone of Nigeria. In: Proceedings of the Nigerian Society of Agricultural Engineers Annual Conference on the challenges facing Agricultural Engineering in a depressed economy; 19-22 November 1996; Obafemi Awolowo University, Ile-Ife, Nigeria; 1996. p. 77-86

[3] Lowder SK, Skoet J, Raney T: The Number, Size, and Distribution of Farms, Smallholder Farms, and Family Farms Worldwide. World Development. 2016:87, 16-29.

[4] Odigbo EU. Level of agricultural mechanization in Nigeria. In: Ajav EA, Raji AO, Ewemoje TE, editors. Agricultural Engineering in Nigeria: 30 Years of University of Ibadan Experience. 2nd ed. Aluelemhegbe Publishers; 2002. p. 42-56.

[5] Igbeka JC. Agricultural Engineering and the society. In: Ajav EA, Raji AO, Ewemoje TE, editors. Agricultural Engineering in Nigeria: 30 Years of University of Ibadan Experience. 2nd ed. Aluelemhegbe Publishers; 2002. p. 34-41.

[6] Daum T, Birner R. Agricultural mechanization in Africa: Myths, realities and an emerging research agenda. Elsevier Journal of Global Food Security. 2020: 26: 1-10.

[7] Ige MT. Indigenous machinery development: the challenges before the Agricultural Engineers. In: Proceedings of the Nigerian Society of Agricultural Engineers Annual Conference on Mechanized agricultural production for sustainable development; 9-11 September 1998; Lagos Airport Hotel, Ikeja, Lagos, Nigeria; 1998. p. 50-56

[8] Odigbo EU. Confronting the challenges of agricultural mechanization in Nigeria in the next decade: some notes, some options. In: Proceedings of the Nigerian Society of Agricultural Engineers Annual Conference on The challenges of Nigerian Agricultural Engineers towards Vision 2010; 2-6 September 1997; Federal University of Technology, Owerri, Nigeria; 1997. p. 7-17

[9] Igbeka JC. Review of the indigenous machinery manufacturing industry in Nigeria. In: Proceedings of the Nigerian Society of Agricultural Engineers Annual Conference on Mechanized agricultural production for sustainable development; 9-11 September 1998; Lagos Airport Hotel, Ikeja, Lagos, Nigeria; 1998. p. 37-49

[10] Olorunnisola AO. Harnessing the forester's harvest for sustainable development. An Inaugural Lecture published by the University of Ibadan Publishing House, Ibadan, Nigeria; 2013, 102 p.

[11] Forest Products Society, Wood Handbook. 2010 ed., Forest Products Society; 2011. 600 p.

[12] Anonymous. Transfer of technology model, laminated bamboo furniture manufacturing. International Network For Bamboo And Rattan [Internet]. 2013. Available from: www.anancy.net/documents/file_en/BambooFurniture.ppt, [Accessed: 2013-04-05]

[13] Wolf RW, Gjinolli A. Durability and strength of cement-bonded wood particle made from construction waste. Forest Prod. J. 1999; 4924):24-31

[14] Ramirez-Coretti AC, Eckelman CC, Wolf RW. Inorganic bonded composite

wood panel systems for low-cost housing: A Central American perspective. Forest Prod. J. 1998: 48(4):62-68

[15] FAO. Agricultural mechanization:a key input for sub-Saharan Africa small holders.Int.Crop Manag. 2016:23.

[16] Ikechukwu IB, Gbabo A, Ugwuoke IC. Design and fabrication of a single row maize planter for garden use. J. of Advancement in Engineering and Technology. 2014: 1(2):1-7

[17] Musa HL Peanut Sheller Design Parameters. [Thesis] Department of Agricultural Engineering, Kansas State University, Manhattan, Kansas, USA, 1975

[18] Ademiluyi YS. Performance test for improving of IAR groundnut sheller/ decorticator [Thesis], Department of Agricultural Engineering, University of Ibadan, Nigeria, 1997

[19] Olorunnisola AO, Hamilton OA. Performance evaluation of a manually operated groundnut decorticator. International Journal of Applied Tropical Agriculture.1998:3(2): 109 – 113.

[20] Olorunnisola AO. Improvement of an existing low cost wooden groundnut sheller Journal of Applied Science, Engineering & Technology. 2005: 5(1 & 2): 71 – 74

[21] Kharashy A. Design modification and evaluation of a manual groundnut sheller [Thesis] Department of Wood Products Engineering, University of Ibadan, Nigeria, 2021

[22] IITA. Maize. 2013. Available from: iita.org/cropsnew/maize/, [Internet] 2021. [Accessed: 2021-01-02]

[23] Aremu AK, Olorunnisola AO. Ergonomic evaluation of a maize sheller. Ife Journal of Technology. 2001: 10(1): 25 – 31.

[24] Nwakaire JN, Ugwuishiwu BO, Ohagwu CJ. Design, construction and performance analysis of a maize thresher for rural dweller. Nigerian Journal of Technology. 2011: 30(2):49-54

[25] Ghadi, AJ, Arunkumar P. Design, Development and fabrication of a low cost corn deseeding machine. International Journal of Research in Engineering and Technology. 2014: 3(8):242-248

[26] Aremu DO, Adewumi IO, Ijadunola JA. Design, fabrication and performance evaluation of a motorized maize shelling machine. Journal of Biology, Agriculture and Healthcare. 2015: 5(5): 154-164

[27] Olorunnisola AO, Ogbu BE. Development and performance evaluation of a low-cost motorised wooden maize sheller. Journal of Applied Science, Engineering & Technology. 2017: 17: (1):1-6.

[28] Yusuf KO, Akpenpuun TD, Iyanda MO. Design and fabrication of a simple pedal operated cassava grater suitable for rural dwellers. J. Appl. Sci. Environ. Manage. 2019: 23 (6) 1007-1011

[29] Olorunnisola AO, Ewemoje TA. The development and evaluation of a flat-type wooden incubator. International Journal of Applied Tropical Agriculture. 1998: 3(2): 14 – 19.

[30] Oluyemi JA, Roberts FA. Poultry production in warm wet climates. Macmillan Publishers Limited, London; 1988. 300p.

[31] Masinbe B. Drip irrigation helps small holders. In: Phelan J. editor. African Farming and Food Processing. Alain Charles Publishing Ltd., London. July/August 2003 ed.

[32] Mofoke ALE, Adewumi JK, Mudiare OJ, Ramalan AA. Design,

construction and evaluation of an affordable continuous-flow drip irrigation system. J. Applied Irrig. Sci. 2004: 39:253-269

[33] Baqui MA, Angeles HL. Construction, operation and test of a Bamboo Drip Irrigation System. Journal of Agric. Mech. in Asia, Africa and Latin America. 1994: **2**: 41-44.

[34] Umara BG, Audu I, Ogedengbe K, Omobowale MO. Development of bamboo (*oxytenanthera abyssinica)* stem as irrigation pipe. Journal of Applied Science, Engineering & Technology. 2010: 10: 18 – 24

[35] Nta SA, Olorunnisola AO. Experimental production and evaluation of cement-bonded composite pipes for water conveyance. International Journal of Composite Materials. 2016: 6 (1):9-14.

[36] Akinoso R. The development of a solar device for crop drying and cooking. LAUTECH Journal of Engineering and Technology. 2009: 5(1):75-79.

[37] Alabadan BA. Housing and food security: Now and in the future. Lessons from termites. An Inaugural Lecture, published by the Federal University of Technology, Minna, Nigeria; 2013, 64 p.

[38] Mijinyawa Y. Farm structures and environment: The bedrock of food security. An Inaugural Lecture published by the Publishing House, University of Ibadan; 2019, 81 p.

[39] FAO. Technical cooperation programme: Assistance to the strategic grain reserve scheme in Nigeria. United Nations, Rome, Italy. 1995. 9p.

[40] FAO. Rome declaration on food security and world food summit plan of action. November 13-17, 1996. United Nations, Rome, Italy.

[41] Talabi AE. Implementation of national food security programme: experience so far. In: Proceedings of the National Workshop on strategic grain reserve storge programme: Nucleus for national food security; 19-22 November 1996; Abuja, Nigeria; 1996. p. 67-73

[42] Adejumo BA, Ola FA, Odubiyi AA, Oyefeso AO, Aje JO. The potential of sawdust as an insulator in a double walled metallic silo. J. Agric. Engrg. & Technology. 2010: 18(2):1-6

[43] Alabadan BA. Modelling the performance of a hexagonal wooden silo during storage of maize (*Zea mays*). [Thesis], Department of Agricultural Engineering, University of Ibadan, Nigeria, 2002

[44] Mijinyawa Y. The use of wood products in the design and construction of a grain silo for the humid tropics. [Thesis], Department of Agricultural Engineering, University of Ibadan, Nigeria, 1989.

[45] Balehegn B, Duncan A, Tolera A, Ayantunde AA, Issa S, Karimou M, Zampaligré N, André K, Gnanda I, Varijakshapanicker P, Kebreab E, Dubeux J, Boote K, Minta M, Feyissa F, Adesogan, AT. Improving adoption of technologies and interventions for increasing supply of quality livestock feed in low- and middle-income countries. Elsevier Journal of Global Food Security 2020:26:1-11.

[46] Guarín A, Rivera M, Pinto-Correia T, Guiomar N, Šūmane S, Moreno-Pérez OM. A new typology of small farms in Europe. Elsevier Journal of Global Food Security 2020:26:1-9.

[47] Olorunnisola AO. Challenges of commercialising engineering research outputs from Nigerian universities. Acta Academica Supplementum 2011: (2): 217 - 238.

[48] Birner R, Resnick D. The political economy of policies for smallholder

agriculture. Elsevier Journal of World Development 2010:38(10):1442-1452.

[49] Hazell P, Poultton C, Wiggins S, Dorward A. The future of small farms: Trajectories and policy priorities. Elsevier Journal of World Development 2010:38(10):1349-1361.