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Chapter

Technology Promotion and Scaling in Support of Commodity Value Chain Development in Africa

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Abstract

Strengthening the production and processing of key food commodities forms the basis of agricultural development in Africa. These value chains follow a quasi-linear progression across seven main segments: farm planning > land preparation and crop establishment > field production > harvest > post-harvest handling > marketing > and value addition. Each of these consists of sub-segments whose improvement depends upon promotion and adoption of specific modernizing technologies. The technologies either have commercial application, as with the distribution of production input products and labor-saving equipment, or are related to management of farms and processing. For crop commodities, these products include improved varieties planted with more and better-formulated fertilizers and pest management materials. Management options are primarily directed toward the better conservation of resources and wiser integration of different farm enterprises. Key factors underlying value chain advancement include wider application of digital services, more effective incentives for climate-smart action, increased mechanization and irrigation, improved marketing efficiency and fairness, and incentives for value-creating agro-processing. An analogous set of factors also relate to value chains supporting animal enterprise. Attracting women and youth to meaningful careers in agriculture is particularly important since they are major stakeholders in the scaling of much-needed technologies and business models.

Keywords: cassava, farm mechanization, goats, sheep, technology transformation, wheat

1. Introduction

From a business point of view, value chains provide a means to describe how inputs and services are combined to design, grow, and transform a product. They also describes how products move from producers to consumers; and how they increase in value along the way. Originally, the value chain concept was used to understand business relationships [1], with the main purpose of achieving and maintaining competitive advantage. Later, definitions of value chains were expanded to the complete range of activities for advancing a product through its phases of production, including linkages between similar stage producers, and links to other value chains that provide needed goods and services [2]. The term was quickly adopted within agricultural development circles to guide their interventions [3]. In this context, value chains serve as a reference point for efforts designed to reduce poverty and a means to direct benefits toward them through a variety of initiatives focused on improved productivity and the growth of stakeholder enterprises. The concept grew into the common wisdom that value chains work best when their actors cooperate to generate ever-increasing benefits for all participants working in concert to create value and build trust. This view contrasts greatly from producers operating in more competitive and adversarial modes. At this point, value chains had grown from a useful way to understand manufacture and sales into a solution toward positive social and economic change. The chains were viewed more in terms of the actors operating within them rather than the processes they conduct. In the case of agricultural development, this entails actors with interests in social equity and economic justice in addition to various suppliers, farmers, traders, processors, distributors, and consumers.

Hill [4] proposed three transitional stages toward more sustainable agricultural systems: (i) efficiency; (ii) substitution; and (iii) redesign. The 'Efficiency Stage' focuses on more efficient allocation of existing farm resources and judicious use of available production inputs. It recognizes that many agricultural systems are inherently wasteful, and much is gained from reducing losses and increase efficiency. The 'Substitution Stage' involves the strategic replacement of technologies and practices. It allows for the introduction of new crop varieties and livestock breeds and encourages suites of accompanying technologies that greatly increase productivity. The 'Redesign Stage' focuses on agro-ecosystem function to achieve sustainable impacts at scale [5]. It advocates for recent and future breakthroughs that not only increase productivity, but also manage externalities in positive ways such as greenhouse gas emissions, carbon sequestration, soil and water quality, biodiversity, and dispersal of pests and diseases [6]. Note that 'Efficiency' and 'Substitution' are readily applied to existing production systems, whereas 'Redesign' involves future transformative changes within them. For agricultural value chains to have relevance within the scope of progressive change and improvement, they must consider elements of all three transitional stages. To a large degree, this can be achieved through incremental substitution of more efficient technologies promoted and adopted by various value chain actors. Within the context of development, each transitional stage is best supported through government investment as addressed in Sections 8 and 9 of this paper.

In this Chapter, we examine value chains in terms of the technologies that are available to their actors. This approach is specifically applied to ongoing efforts toward the transformation of African agriculture that places modernization at the very center of economic growth [7, 8]. Under these programs, a host of production and processing technologies is widely disseminated to smallholder farmers and entrepreneurs across major agro-ecological zones [9]. Interventions are based on proven technologies for key food commodities, their positional linkages within value chains, and the accrual of benefits by wider acceptance and practice of such technologies. Most notably, in this way a bridge is formed between the more conventional approach to value chains as consortium of actors [10] and the staged, modernizing transition toward agricultural improvement [4].

2. Technology-based value chains

A generic value chain model for supporting modernized crop-based agriculture appears in **Figure 1**. This chain consists of seven main segments: farm planning, crop establishment, seasonal production, harvest, post-harvest, marketing, and value addition. Consumers are not depicted but they operate at the extreme right of this sequence. Each segment contains three links, corresponding to different technical requirements. Note that planning allows for long-term, seasonal, and immediate access to input and labor allocations. Crop establishment consists of three stages; land preparation, soil fertilization, and planting, although additional early operations may be required. Crop management considers three basic operations: weeding, supplemental fertilization, and pest and disease control. Crop harvest involves the timing, mode of recovery and means of removal from the field. Primary post-harvest operations occur immediately after the crop is collected and involve the separation of edible parts from residues, bagging and storage of produce, and various quality preservation measures intended to protect commodity value. Marketing involves contact with and delivery to buyers, product inspection to ensure expected quality, and the financial transactions through which goods are purchased. In some cases, these buyers or their clients may be processors where secondary products are manufactured, packaged, and distributed. It is important to note that each of these segments are supported by agricultural and food processing technologies and that these technologies improve production and processing efficacy, allowing for substitution of inputs and management strategies over time. Long-term planning allows ecosystem refinements as described by Hill [4] as well as iterative substitution by more advantageous and affordable inputs.

Along these key agricultural commodity value chains, critical "enablers" advance agricultural transformation. Among these are greater use of digital tools for timely and accurate decision-making; judicious implementation of tax benefits and other government incentives for wider scale agro-ecological goals such as those related to climate action; investments in irrigation and mechanized practice for reducing risks and drudgery; greater protection from harvest losses; and improved access to markets, value added processing and exporters. Again, each of the modernization objectives is supported by a "technology toolkit" that allows for substitution of input products and management practices that reward land managers and practitioners over time.

Overall, the value chain for animal enterprises is very similar to that of crop enterprises (**Figure 2**) but has important differences in its details. For instance,

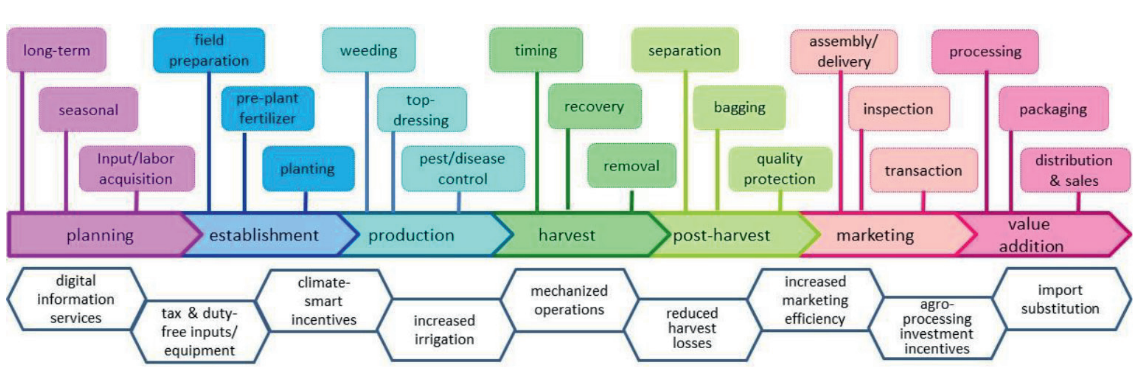

Figure 1.
Modernized generic agricultural crop value chain and expected outcomes.

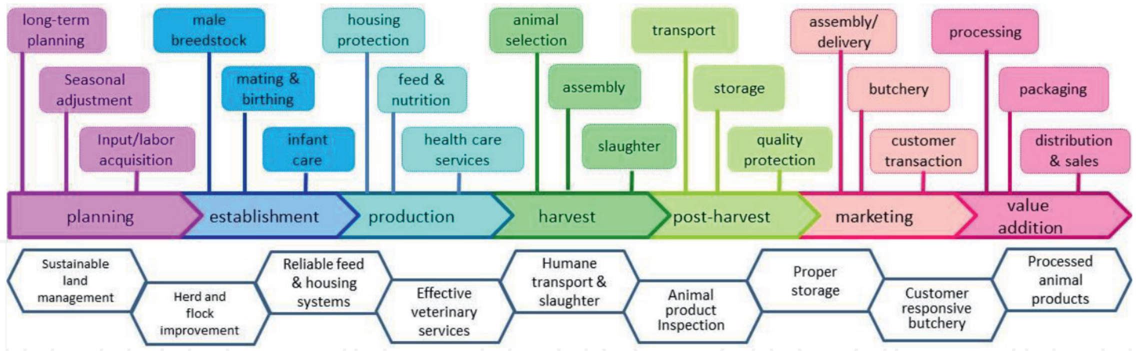

Figure 2.
Modernized generic animal enterprise value chain and expected outcomes.

long-term planning relates to the stewardship of large rangeland areas under increasing threats of degradation by climate change. Similar concerns exist for waste disposal and greenhouse gas emissions from poultry houses and fishponds. Breeding strategies are also enacted over many years. Seasonal adjustments include the needs for containment structures and improved feeding systems. Production inputs such as vaccines and feed supplements require short-term and recurrent consideration. Unlike for crops, animal establishment, production and harvest are not necessarily sequential, most particularly for birds and fish. Herd improvement is continuous in nature but mating and birthing of livestock are seasonal. Demand for housing protection, feed and health care remain constant throughout the year. Animal slaughter involves more stringent moral and public health considerations than for crop value chains. Because livestock produce is readily perishable, post-harvest, marketing and value addition are closely linked to cold storage. The distinctive implications of modernizing technologies for small-ruminant enterprises in Africa are explained later in this Chapter.

While this paper primarily examines value chains from the perspective of the technologies they deliver and how they change over time, it does not ignore the key actors within them such as farmers and their workers, traders and wholesalers, and processors and retailers. These primary actors are owners of raw, semi-processed or finished products, steadily moving them toward consumers. Equally important are actors that assist in agricultural planning and investment, producer associations and the manufacture, distribution and sales of production inputs and equipment. As a rule, the more complex a value chain and its associated technologies, the more actors it engages. When producers sell directly to consumers, its value chains are simpler and actors fewer, becoming increasingly longer and more complex when goods are

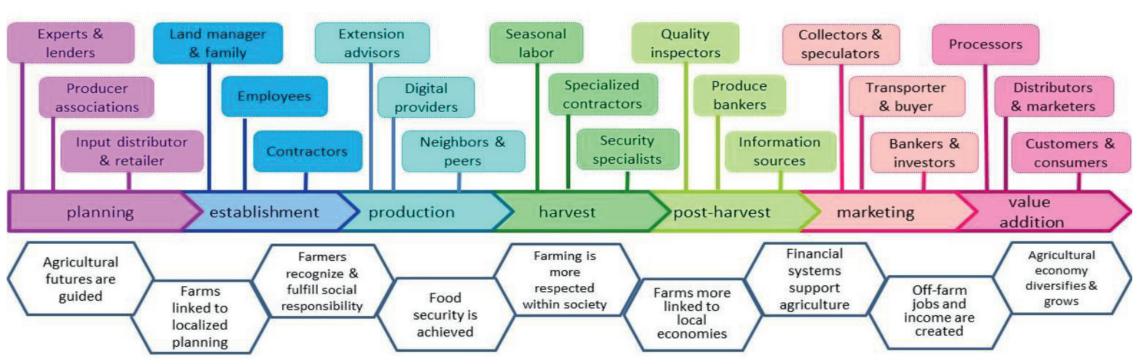

Figure 3.
Key value chain actors within a developmental context and their various roles.

transported, traded, and processed across greater distances. Farmers must understand the roles of other actors within their value chains, so they work effectively with them. In the context of this Chapter, this particularly relates to private sector actors who distribute and market modernizing technologies. Generally, actors most able to benefit from value chains are more entrepreneurial and better communicators. **Figure 3** describes the important value chain actors and their various roles. Upstream actors have the responsibility of securing agricultural futures and advancing new production technologies while downstream actors ensure product quality, add value, and anticipate consumer needs.

3. Cassava technologies

Cassava is one of the most important crops for food and nutritional security in the humid African tropics. It is also an agro-industrial commodity for processing and trade within world markets. Cassava farmers in Sub-Saharan Africa suffer yield losses of 12–23 million ton of fresh roots per year worth US $1200 to $2300 million [11]. The main reasons for shortfalls in production are disease and pest damage, reliance upon unimproved planting material, inappropriate fertilizer management and poor weed control. Further value is lost due to the untapped potentials for biofortification, improved post-harvest handling and agro-industrial processing. Ten technologies are recognized that serve to modernize production and processing of cassava in Africa [12].

3.1 Cassava varieties resistant to disease and pests

Production of cassava by farmers in Sub-Saharan Africa is widely limited by pernicious viruses such as cassava mosaic disease and cassava brown streak disease [13]. Many recently released improved varieties also withstand bacterial blight, green mite, and mealybug, offering major advantages to producers. For example, widespread adoption of improved varieties in southwestern Nigeria improves tuber yield by about 40% [14].

3.2 Higher dry matter and starch contents

The amount of dry matter and starch in cassava roots greatly influences their value in terms of agro-processing options. Cassava varieties are now available that have root dry matter contents of 40–45% [15]. Greater starch content translates into better nutritional value and higher selling price.

3.3 Golden-fleshed cassava

Conventional and advanced breeding approaches resulted in the increase of pro-vitamin A content in cassava, offering substantially improved nutrition within rural communities [16]. Roots of "golden" yellow-fleshed cassava are rich in a beta-carotenoid that give its characteristic color. The sales price for golden cassava roots on markets in Sub-Saharan Africa is up to 20% higher than that of white, non-biofortified types.

3.4 Stem bulking enterprise

Cuttings from cassava stems are the most commonly used planting material by African farmers because this kind of propagule can be gathered from previous crops, it sprouts quickly and reliably, and allows ever-increasing areas of land to be cultivated. Under optimal crop and soil management, it is possible to multiply cassava cuttings in only six to 10 months' time. In general, each cutting may be produced and marketed for as little as US $0.02 each, and sold for up to US $0.04 each, and up to 24 cuttings may be produced on 1 m^2, resulting in revenues of US $4800 per ha [12], above and beyond tuber yield.

3.5 Semi autotrophic hydroponic multiplication (SAH)

This technology involves turning cuttings of cassava roots into small plantlets. A tray of ready-to-market product typically contains 12 to 48 plantlets that can be covered, stacked, and packaged for transport. Multiplication facilities for SAH with an area of 40 square meters can produce 75,000 plantlets per month that are sold for US $0.07 to $0.10 per piece [12]. SAH allows for more rapid introduction of improved varieties.

3.6 Specially blended fertilizers

Mixes of common inorganic fertilizers have been specifically developed for cassava and other root crops that create balanced availability of nutrients for the crop's below ground production. Fertilizing cassava with the correct balance of nutrients at the right time and placement improves the productivity and quality of tubers, and strengthen resilience to drought, and pests and diseases, while avoiding undesired losses to the environment. Smaller, more labor-intensive blending systems may be developed for localized operations, and even operated as a community-based operation once specific formulations are known and component ingredients mobilized [12].

3.7 Mechanized planting and harvesting

Mechanical planters can plant 7 to 10 hectares daily, making it much faster and less expensive than manual planting. Similarly, mechanical lifters can harvest up to 3 to 5 ha of cassava in a day. Mechanical harvesters range in complexity from simple lifters to multipurpose tractor attachments that lift, shake and gather roots from multiple rows. Mechanical planting and harvesting greatly reduce labor bottlenecks that undermine cassava production [12].

3.8 Cassava weed management

The wide spacing and slow initial canopy development in stands of cassava make it susceptible to weed encroachment during early cultivation. The "Six Steps" approach is a complete package for weed management that incorporates multiple key control measures, including site selection, weed identification, herbicide application, tillage operations, plant spacing, and post-emergence weeding. Weed removal following this method costs US $28–46 per hectare. Well-weeded cassava provides 30–50% greater root yield than a poorly weeded operation [17].

3.9 Cassava peels for animal feed

Processing cassava roots into food products results in massive amounts of peels. Typically, 1 ton of fresh cassava roots results in 200–300 kg of peels. Peels made

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into mash or meal can serve as an ingredient for feed formulations of poultry, cattle, and other livestock. The crude protein content of cassava peel animal feeds is low, amounting to only 4–6% for wet meal, but the starch content is high at 77–78% [18]. Processing cassava peels provides a low-cost, energy-rich feed that is ideal for substituting higher-cost cereals in feed blends.

3.10 High quality cassava flour (HQCF)

Roots of cassava are made into HQCF through a series of industrial steps and is suitable for manufacturing a wide range of foods. Flour blending allows for partial substitution of wheat flour and other imported foods. HQCF requires fresh roots with high dry matter and starch content and needs to take place within a day or two after harvest. HQCF is a gluten-free product that can be used within non-allergenic foods, a market segment that attracts rapidly growing global demand [19].

4. Wheat technologies

Sub-Saharan Africa produces only 30% of its own wheat. This massive reliance upon imports creates a crippling but largely unnecessary trade imbalance, resulting in allocation of foreign reserves that might otherwise be directed toward more strategic developmental purpose. Geographic information, simulation modeling and economic analyses indicate that less than 10% of the potential for profitable wheat production is currently exploited on the continent [20]. Intensifying and growing this sector along the lines of agricultural redesign [4] requires changes in attitudes and policy, and developing reliable value chains for seeds, production inputs and equipment, and output markets. Ten technologies hold great promise for increasing the production and processing of wheat in Africa [21].

4.1 Heat and drought tolerance

Heat and drought stress are two major constraints to wheat production in Sub-Saharan Africa. Diurnal temperature spikes above 36°C undermine flowering and grain filling leading to low yields or crop failure. Recently developed varieties of wheat that withstand heat offer real opportunity to expand wheat production [22]. Farmers can now grow the crop in non-traditional areas such as drylands in the Sahel characterized by temperatures of 30–40°C and rainfall below 250 mm, or in savanna areas currently targeting maize. Costs for seed multiplication are low since the crop is self-pollinating.

4.2 Rust resistance

Yellow rust and stem rust are devastating diseases in major wheat production zones of Sub-Saharan Africa [23, 24]. Wheat varieties that are resistant to yellow rust and stem rust now exist that can be grown at the same planting density and agronomic recommendations as other cultivars. In some cases, fungicide spraying may also be required to ensure season-long protection of the crop. Producing wheat resistant to rusts costs about US $440 per hectare and grain yields commonly exceed 4 ton ha^{-1}.

4.3 Hessian fly control

Wheat in Northern Africa is threatened by infestations of the Hessian fly (*Mayetiola destructor*), and this pest is increasingly common in Sub-Saharan Africa as well [25]. The larva of this insect causes substantial losses, mostly by feeding on the growth apex. Planting wheat varieties that possess a natural defense mechanism against the Hessian fly larvae and releasing and promoting natural enemies are two highly effective control methods for this pest [26].

4.4 Expanded irrigation

Growing wheat during the cool season in African drylands, referred to as "winter" production, avoids adverse effects of heat stress and allows production of two or more crops in a year. Low rainfall during the cool season requires irrigation for which efficient options are available [27]. The success of irrigated wheat production in several "breadbasket" regions of Africa offers great promise to advance self-sufficiency and reduce expensive importation.

4.5 Raised bed cultivation

Furrow irrigated, raised bed cultivation is a technique that enhances water use efficiency and avoids waterlogging. Beds and furrows are relatively easy to construct with locally available tools and can be maintained for several growing seasons. Compared to conventional flood irrigation, water use efficiency in raised beds improves by about 25% as the wetted area is less [28]. These engineered surfaces also promote the collection and infiltration of rainwater and decrease soil erosion.

4.6 Conservation agriculture (CA)

This sustainable land use technique involves a set of soil and crop management practices that offer major advantages for wheat production [21]. The strategy has a low implementation cost, saves on fertilizer, labor, and irrigation, and provides higher, more stable yields and profits under reduced rainfall. Practicing CA is based on reduction of soil disturbance, residue retention of the previous crop, and timely weed and fertilizer management. Different types of no-till seeders are available, including manually or animal power devices and small to large tractor-drawn attachments. Adopting CA enriches soil biodiversity, reduces gaseous emissions, and sequesters carbon in soils, benefiting the environment and mitigating climate change.

4.7 Integrated pest management strategies (IPM)

Combinations of varietal, cultural, biological, and chemical methods for crop protection reduce yield damage and costs for farmers. IPM strategies involve carefully selected techniques that are tailored to local conditions. A wide range of biological measures are available that target pests. A full IPM package that includes increased fertilizer, precision herbicide application, and seed treatment costs about US \$515 ha^{-1} [29]. Adopting these strategically bundled technologies boosts average productivity to by 3.5–4.8 ton ha^{-1}.

4.8 Combine harvesters

Motorized equipment that cuts wheat crops and separates grain are available in a broad range of sizes, from small units that can handle a few hectares per day to very large units for major operations that harvest several hectares per hour. Smaller units with a cutting width of 1.2 m cost as little as US $12,000. Harvesting cost is about US $25 to $33 per hectare, or US $4.7–9.2 per ton of grain [30]. Costs of cutting, threshing, straw disposal, winnowing and overall grain losses during harvest are substantially reduced by combine harvesting.

4.9 Hermetic storage bags

This technology greatly reduces post-harvest loss of grain by using sealed bags that exclude air and moisture, creating an environment that is non-conducive for insects and rots. The bags preserve the quality of grains and obstruct the entry of insects and microorganisms through depletion of oxygen levels and accumulation of carbon dioxide. Threshed grains are dried and placed into high-density polyethylene bags. Wheat grain can be stored for up to 2 years with this preservation technology. The raw material and labor to manufacture hermetic grain storage bags costs between US $1 to $1.5 per piece and are sold at US $2 to $3 by suppliers [21].

4.10 Flour milling

Small- to large-sized equipment for milling and blending are available that allow manufacturing of premium wheat flour near to production areas. There is a wide range of equipment for sorting wheat based on size, shape, and density of grains, as well as cleaning and annealing. A mill with an output capacity of 300–500 kg flour per hour costs around US $3500. Fully automatic flour mills with a capacity of 30 ton flour per day are sold from US $38,000. Modern equipment achieves high recovery of flour at 80–82% and 18–20% bran, much higher than traditional techniques [21].

5. Small ruminant Enterprise

Raising goats and sheep is an important source of food and income across Africa. These types of livestock are easy to rear, multi-purpose and valuable, especially within subsistence and pastoral communities. Small ruminants supply protein in form of meat and milk, generate income for their owners and create employment for millions of others in the value chain as herders, traders, butchers and processors. Ten technologies are most important to intensify small ruminant production systems in Africa [31].

5.1 Herd improvement through community-based breeding

Traditional breeds of goats and sheep exhibit useful adaptation to environmental stress and partial resistance to common diseases but are often lower in meat and milk production compared with improved breeds. A community-based approach to breed improvement builds upon these traits of interest relying upon hardy stock performance [32]. Herds of selected ewes (female sheep) and does (female goats), and a few recognizably superior rams (male sheep) or bucks (male goats) are steadily improved through community-based action. This approach creates an enabling environment for goat and sheep enterprise that strengthens local cooperatives and market linkages.

5.2 Reduced overgrazing and rangeland rehabilitation

Rising population and increasing demand for animal products place excess pressure on land leading to overgrazing and rangeland degradation. Climate change exacerbates this situation, yet technologies exist to conserve and restore rangelands. Successful management involves monitoring the vegetative growth of grazing areas and level of water points; and regulating herd numbers and movement. Available technologies to combat rangeland degradation include rotational grazing, afforestation, fodder production, soil and water conservation, and policy interventions [33]. Appropriate stocking density reduces overgrazing and allows for land recovery.

5.3 Small ruminant containment

Housing protects animals from inclement weather and provides better feed, waste management and biosecurity conditions. A shed can be built from locally available materials such as timber, bamboo, or lumber off-cuts in combination with wire and fencing. These sheds usually include access to nearby daytime grazing. Proper shelter includes feed and water troughs that may be wooden, metal or plastic, sometimes fed through automated devices. Where farmers have access to inexpensive wooden posts and planks, a suitable shed can be constructed for as little as US $200. More elaborate buildings are constructed for about US $20 per m^2. Every young goat or sheep protected through improved housing reflects a savings of about US $150 [31].

5.4 Pasture improvement

Pastures are tracts of land producing fodder grass and other vegetation for confined and free-grazing animals. Usually such parcels are fenced and receive inputs such as fertilizers and irrigation. Several approaches are followed in the establishment of pastures such as control of weedy patches, partial land disturbance and sowing of improved grasses and legumes, under sowing croplands with grazing plant species allowing for the establishment of crop-pasture rotations, and establishment of shrub hedgerows along pasture margins. The cost of new pasture establishment is approximately US $500 per ha, offering additional feed worth between US $250 to $500 per ha per year over the next many years [31].

5.5 Cut-and-carry fodder systems

Cut-and-carry describes a system where feed is gathered and offered to confined animals. It facilitates more efficient feed management by reducing wastage; but also places greater demand on labor and nearby vegetation resources. It also secures maximum advantage from crop residues and seasonally available vegetation. Under this system, a lamb worth US $80 consumes fresh chop worth $30, supplements and medicines costing $40 and then produces meat worth $250 over six months [31].

5.6 Short-term fattening

Goat and sheep finishing involves intensive and nutritious feed regimes that promote fast growth, attaining desired carcass growth and quality. It maximizes the value of livestock with minimum time and space, which offers a business opportunity through value addition of purchased stock. It requires moderate investment and offers minimal risks; allowing peri-urban dwellers to become engaged in small ruminant value chains. Young adult animals are purchased and finished to slaughter weight by limiting their movement and providing them with a concentrated diet [34]. Fattening is readily visible, resulting in a profitable cycle of 3–6 months, often targeting festive seasons. This practice in turn creates increased demand for fattened animals and more rapid turnover of stock [34]. This operation may be repeated three times per year over several years once facilities are secured, offering an estimated profit margin of US $ 149 per sheep [31]. Fattening operations are associated with a transition toward raising larger animals [35] and increasing asset ownership [36].

5.7 Universal vaccination against diseases

"Peste des Petites Ruminants" (PPR) is a serious disease of goats and sheep across Africa. This is a fast-spreading viral disease with high mortality rates, especially among younger animals. Its symptoms are rapidly elevated body temperature, with affected animals displaying discharges from the eyes and nose, sores in the mouth, troubled breathing, coughing, and foul-smelling diarrhea [37]. There is no cure for PPR but vaccination is available to protect herds. The vaccine is thermostable and inexpensive, costing US $0.5 to $1 per animal [31]. It is also important that all producers be aware of this disease and isolate any infected animals at an early stage of development.

5.8 Manure processing

Goat and sheep manure has economic value but realizing market opportunities requires expertise. Some advantages of manure from small ruminants are its relatively high and balanced nutrient content, and naturally pelleted form. These may be applied fresh to soil without damaging plants, or as a mulch or compost ingredient. Commercial technologies are available to produce organic fertilizers from manure. After composting, production involves crushing, granulating, drying and screening for pellet uniformity. Processed manure is sold for US $200 to $1500 per ton depending on the level of processing and quality of packaging [31].

5.9 Humane slaughter

Humane slaughter refers to the killing of an animal instantly or rendering it insensible until death follows, without pain, suffering or distress [38]. When slaughtering animals for food, they must be stunned by electricity prior to bleeding out so they become quickly unconscious. Another approved method of stunning involves percussion bolt pistols. Humane slaughter is based upon principles of animal rights whereas those with utility as human food have moral worth and must be protected from unnecessary suffering. Modest investment of US $2000 is adequate to set up humane slaughter, allowing an abattoir operator to earn a profit of US $15 to $20 per animal as they operate in regulatory compliance [31].

5.10 Hide curing and secondary leatherworks

Hides are a valuable product from livestock production. For this value to be realized, animals and their hides must be properly treated, and artisans require skill sets and appropriate materials. Hides are processed by local communities, stockpiled, sold, and fabricated by leatherwork industries into a variety of products for both domestic and export markets. Foremost among those products are shoes, handbags, and leather clothing, with premium value obtained through greater craftsmanship. A modest investment of about US $1000 establishes a local leatherwork business [31].

6. Small-scale farm mechanization

Small-scale mechanization is the key to reducing drudgery and increasing productivity among African farmers. For too long, farming in Africa remains regarded as a path to poverty rather than a profitable agribusiness. This is due in large part for dependency upon tedious hand labor, poor returns to effort and lack of investment into farming systems. A wide range of small-scale equipment is available to improve returns to labor and change this poor image of farming. This equipment serves the entire value chain including tillers, power weeders, power sprayers, soil augers, irrigation systems, multi-crop threshers and a host of other equipment that are becoming commercially available for the first time [39]. An example of modernized post-harvest and processing technologies is the axial-flow thresher and GEM parboiling system. The thresher may be locally fabricated and results in high quality milled rice while the parboiler uses rice husk as fuel, is smokeless and produces a rapidly prepared grain [40]. Description of eight other important machinery follows.

6.1 Hand tractors for land preparation

Hand tractors are two-wheeled machines that range in power from 5 to 20 horsepower. They are most often attached to a rotavator that tills soil, but other attachments are available, including those that create furrows and plant and bury rows. These tractors are guided by handlebars that provide control over their direction. High-power hand tractors can break new ground and dry, crusted soil, while the least powerful ones are best suited to preparing previously cultivated soils. Depending on the source and size, these tractors cost between US $200 and $1500 [39].

6.2 Mechanized weeder

Two basic types of power weeders are available; ones that are worn on the operators back where weeds are cut and buried to shallow depths through arm movement, and others that resemble small walking cultivators that pass between crop rows (i.e., mini-cultivators). These machines require skillful use and maintenance so that crops are not injured and equipment remains in good working order. Using mechanized weeders, it is possible for a single operator to greatly reduce weeds from 0.5 to 1.0 ha per day. These units are available at a cost of US $200 to $380 each, depending on the size of the engine and the number of different attachments included with the purchase [39].

6.3 Power sprayers

This equipment is used to apply herbicides, pesticides, and fertilizers to crops. Sprayers range in size from portable units, to towed sprayers that are connected to a tractor, to self-propelled units with boom mounts many meters in length. Backpack sprayers are extremely useful in agricultural applications. These machines are easy to carry and use, but require that they be used with skill and caution. Power backpack sprayers cover about 0.5 ha per hour and cost about US $250, with larger and more expensive trolley options also available [39].

6.4 Earth augers

Also called post-hole diggers, this machine can be used to make planting pits and basins that collect rainwater. It consists of an engine powering a vertical shaft that rotates screw blades to displace soil, resulting in a cylindrical hole. A skilled operator can prepare a 40 cm deep hole of 25 to 30 cm wide in less than a minute, much faster and less strenuous than excavation by hand. Commercially available earth augers sell for about US $230, including an assortment of screw blades [39].

6.5 Drip irrigation

This system slowly delivers water onto the roots of plants in a way that strategically places moisture and minimizes evaporation. Drip irrigation distributes water through a network of valves, pipes, tubing, and emitters that operate at a relatively low water pressure. While complicated in design and expensive to install, the savings in water and yield improvement are substantial. One hectare of land can be placed under drip irrigation for about US $2400 [39]. The technology is typically associated with horticulture production but is also applicable to staple crops.

6.6 Rain guns

Imitating natural precipitation, this technology involves extended "water throw" through a sprinkler. Rain guns can cover large areas of field from relatively few stations and are portable which allow them to be moved between field locations according to needs and schedules. These guns require high water pressure and flow and can project water for up to 60 m in distance, covering a circular area of 1.1 ha. Its coverage is adjustable in terms of distance, droplet size and completeness of circular angle, with 360^o projection most common. A complete rain gun irrigation system, including a high pressure pump, may be purchased for about US $670 [39].

6.7 Mechanized threshers

Unlike traditional hand separation of seed and grain from crops, this power equipment is more time-efficient and less laborious. Thresher machines are powered by small engines and consist of a feed chute that results to a spinning drum where crop residues are separated from seeds, and then a blower that removes lighter chaff. Operators put in dried harvest materials and can process between 150 and 500 kg of product per hour. Multi-crop threshers that handle numerous crops or specific ones for maize are sold by suppliers for about US $780 [39].

6.8 Residue cutters and choppers

Motorized processing of stover is ideal for mixed crop-livestock farming, particularly where wastes are plentiful and underutilized. Small, motorized cutters are easy to move, allowing residue recovery from several hectares in a day. Use of motorized choppers and crushers make it possible to provide suitable feed and mulch for soil cover while saving time and effort. Depending on the model, throughput capacities range from 1 to 1.5 ton of stover per hour and cost between US $1000 and $1500 [39].

7. Value chains in African agricultural transformation

Major efforts are underway to transform African agriculture [7]. This goal is extremely complex [9] as it involves different value chain segments and the technologies they depend on [8]. This chapter describes these value chains in terms of key modernizing technologies and the manner they benefit approaches to efficiency, substitution, and redesign over time [4], focusing upon four distinct models of value chains supporting cassava, wheat, small ruminants, and small-scale farm machinery. Cassava illustrates a value chain that strengthens primarily through the process of substitution [4] in that it progresses through the iterative introduction of a stream of different technologies along an entire value chain over time. Earlier in this Chapter, we describe 10 key technologies critical to this progress that are positioned along the entire cassava value chain. A net effect of modernizing the value chain is a transition of cassava from a subsistence crop to an agro-industrial export commodity [11]. The substitution of wheat in the bakery industry by high quality cassava flour is critical to reduce wheat import across the continent. At the same time, the technologies are suited to a wide variety of farmers, allowing them to adopt what is suited to their household and socio-economic needs. Many other agricultural commodities follow this pattern such as rice, maize, and sweet potato, where new technologies are streaming toward agricultural input supply markets in response to improved agricultural production strategies.

Wheat is a different case in that its introduction is largely the result of the intended redesign of agricultural systems. Admittedly, wheat is grown in the African highlands, and it represents an important commodity there, but the demand for wheat products in Africa greatly exceeds what can be produced. This led to massive imports that burden many economies, and the best solution is to greatly expand wheat production to new, warmer areas. The recent availability of heat tolerant varieties opens this possibility but only in conjunction with other accompanying production inputs and management strategies. Many African countries are now looking at ways to grow these new varieties of wheat in places traditionally reserved for other cereals [20]. The possibility of producing irrigated wheat in the Sahel during the relatively brief cool and dry season will have profound effects upon entire economies, but to achieve this vision requires that entire technology toolkits be adopted [21]. Growing wheat in rotation with maize and sorghum in sub-humid areas raises similar opportunities. The importance of mechanized bed preparation, planting, and harvesting suggests that larger, commercial operations are better positioned to enter new wheat production. Conservation Agriculture practices and their focus upon residue management and herbicides reinforces this likelihood. The challenge is to design wheat production systems that do not exclude smaller-scale producers, and this is achieved in large part by the availability and packaging of key production inputs and the ability of households to work together through collective operation of equipment. In much the same way, soybean is a commodity requiring strong elements of production system redesign [4] and offering strong agro-industrial economic advantages.

Another critical agricultural value chain is that of goats and sheep, and the technologies that support its transition from pastoral subsistence to commercial enterprise. Great effort is devoted to planned improvement of these systems as they are often situated within fragile drylands. Most of this improvement is related to assuring reliable supply of feed and water and building the quality of animal herds with time. To a large extent, this improvement relies upon collective management, but many key products related to health and feeding of animals become increasingly important. An important gain becomes disease prevention through veterinary products and services. With time, animals progressively move toward greater care by their managers in terms of protective confinement, feeding and health protection. Intensified management results in faster weight gains and improved meat quality. Processing crop residues into feeds, and supplementing them with blended grains, vitamins and minerals becomes a separate economic activity, as does short term fattening, resulting in greater differentiation along the value chain. This in turn results to de-risking of these value chains, leading to more sedentary lifestyles and higher standards of living.

Small-scale farm machinery is a distinctive value chain. Power equipment are not a commodity in themselves, but rather provide labor saving services along the production and processing value chain that are critical to the modernization of small-scale farming operations across Africa. Virtually every task currently performed by hand labor may be accomplished with greater ease by machine; be it tillage, weeding, planting, pest control, threshing and chopping. Note that these tasks are spread along the value chain, suggesting that these services are performed by different machines throughout the season. The ease of machine operations is extremely important to re-attracting youth to career paths in agriculture, a crucial component to the larger agricultural transformation equation. The challenge before the agricultural development community is how to make these machines more available and affordable to less affluent farmers, suggesting that collective ownership or service contracting may be in order. Many of these less affluent farmers serve as laborers on other farms, delaying the preparation of their own lands. Access to machinery helps to resolve this inequity.

The proportions of different modernizing technologies across key commodities reveal the importance of balance between new and better varieties and breeds, production inputs, improved management practice and agro-processing innovations (**Table 1**). In large part, crop improvement is a lead innovation, but without good use of accompanying production inputs and management practices, the returns to investment from improved germplasm is reduced. At the same time, agricultural intensification requires that value be added to crop surpluses, and these require processing innovations. A weakness is found in the inconsistency of digital tools, with some commodities supported by relevant tools and others not. Across all six commodities under discussion, the distribution of modernizing technologies in support of value chains in sub-Sahara Africa is Production Input Product > Genetic Innovation Product > Agricultural Management Practice > Agro-processing Innovation > Digital Support Tool.

A unique framework to assess yield improvement for different commodities undergoing agricultural transformation in Africa is presented in **Table 2**. In this case, the nature and cost of improvements are compared to the resultant yield increase to

Commodity	Genetic innovation product	Production input product	Agricultural management practice	Digital tool	Agro-processing Innovation
			------------------------------------- f -------------------------------------		
Cassava	0.25	0.25	0.08	0.17	0.25
Rice	0.30	0.30	0.10	0.10	0.20
Maize	0.30	0.50	0.10	0.10	0.00
Wheat	0.30	0.20	0.40	0.00	0.10
Soybean	0.20	0.30	0.20	0.00	0.30
Goats & sheep	0.10	0.30	0.30	0.00	0.30
All commodities	0.24	0.31	0.20	0.06	0.19
Farm machinery	0.00	1.00	0.00	0.00	0.00

Table 1.
The proportion of priority modernizing agricultural technologies based on commodity and type.

Commodity	Improvement	Increased cost (US$ per ha)	Yield increase (ton per ha)	Cost per ton increase (US$ per ton)
Cassava	improved cuttings, increased fertilizer, mechanized harvest	$614	23.4	$26
Maize	additional N topdressing, additional grain bags	$76	0.70	$109
Rice	irrigation and additional fertilizer, additional grain bags	$159	1.20	$133
Wheat	adapted seed, additional fertilizer, mechanization, irrigation, additional grain bags	$440	2.47	$178
Soybean	inoculant, blended fertilizer, herbicide, additional grain bags	$91	0.62	$147

Table 2.
Approaches and costs of yield improvement, resultant increase and the cost per ton of yield increase for five key commodities in Sub-Saharan Africa.

calculate the cost per ton of yield increase. In these scenarios, cassava requires considerable investment but results in considerable yield improvement, in part because the harvest of tubers is relatively high in moisture. This investment requires introduction of 10,000 cuttings of improved cuttings per ha, application of an additional 200 kg per ha fertilizer and conversion to mechanized lifting of tubers but is more than offset by massive increase in tuber yield. Cereals benefit from nitrogen topdressing (maize), irrigation and fertilizer (rice) and system redesign (wheat), resulting in yield increases ranging from US $109 to $178 per ton. Considering the world price of these commodities and the need for their massive importation to Africa, intensification of cereal production through strengthening value chains remains an important developmental objective. Substantial increases of soybean yields result from combining legume inoculant, blended fertilizers and pre-emergence herbicides, all production inputs that require the establishment of input manufacturing capacity and expanded delivery capacity. Note that both wheat and soybean require considerable redesign of current cropping systems as these are for the most part introduced crops in areas of expanded production, and not well known to producers.

8. Positioning technologies within development projects

As small-scale farmers continue to move toward commercial farming practices, their level of engagement with value chains continues to grow, and this is a unifying principle underlying agricultural transformation. This reliance also requires accompanying support to and from governments and successful integration of key technologies through value chains via development projects becomes a critical piece of the transformation equation. Projects awarded by multilateral donors such as the World Bank, African Development Bank and International Fund for Agricultural Development among others, provide loans and grants to countries to modernize agriculture as highlighted in **Figure 4**. Positioning the right mix of commodities and technologies within those projects becomes critical to their success, as is the meaningful inclusion of the various value chain actors depicted in **Figure 3**.

The Technologies for African Agricultural Transformation (TAAT) Project [8] led by IITA in collaboration with several other research and development organizations [9] serves as a mechanism to identify and promote proven modernizing technologies

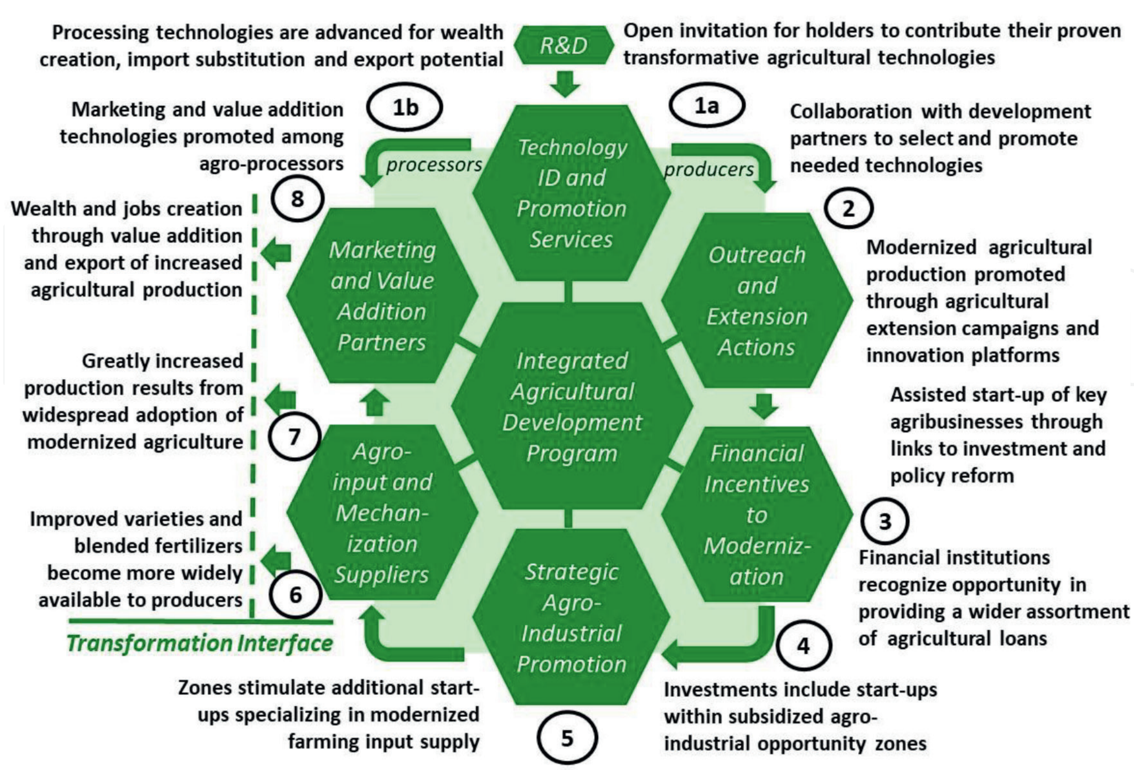

Figure 4.
A stepwise model of coordinated roll-out of modernizing agricultural technologies.

and to systematically match them to the projects of development organizations. This is a relatively new function of the CGIAR (formerly the Consultative Group for International Agricultural Research) as it seeks to work more effectively with national counterparts and Sub-Regional Organizations [41]. These development projects must engage and benefit three parties: rural communities, the private sector and government agencies [42]. Their design and implementation requires problem-solving and strong alliances with clear agreement on which difficulties exist and how best to resolve them, and TAAT offers growing expertise in this area. Examples of how TAAT has contributed to the design of several value chain interventions within recent projects follows (**Table 3**).

8.1 Multi-sectoral Approach for Stunting Reduction Project (MASReP)

This Ethiopian project advances agricultural technologies related to value addition to sweet potato with particular focus upon pregnant and lactating women and children under 5 years old.

8.2 Projet d'Appui au Programme Graine Phase 1 (PAPG1)

This project in Gabon focuses upon multiplication systems for cassava and plantain, including the capacity development of national partners. This effort includes the rehabilitation of two laboratories for SAH production (see Section 3.5) and building capacities in developing and multiplying new cassava varieties [12].

8.3 Agricultural Markets, Value Addition and Trade Development Project (AMVAT)

AMVAT addresses fundamental constraints to agricultural growth in South Sudan by taking an agricultural value chain approach in support of maize, sorghum, groundnuts, and sesame. The project works through 20 aggregation centers, 100 producer associations and 10 seed enterprise groups. It also provides food safety training. TAAT assists with the maize and sorghum value chains.

8.4 Program to Build Resilience for Food and Nutrition Security in the Horn of Africa (BREFONS)

This regional project operates across several countries (Djibouti, Kenya, Somalia, South Sudan, and Sudan) and select value chains (maize, millet and sorghum, livestock). Technologies holding commercial potential include climate-smart maize and bio-fortified sorghum and pearl millet varieties.

8.5 Le Projet d'Appui au Développement des Chaines de valeurs Agricoles dans les Savanes (PADECAS)

This project in Central African Republic focuses upon bean and cassava commodity value chains. Commercially viable technologies for beans include production of bio-fortified varieties, seed coating with agro-chemicals, wider distribution of herbicides, distribution of hermetic bags for safer grain storage, and milling of beans for use in blended flours. The cassava value chain multiplies plantlets and cuttings; relying upon imported agrochemicals for pest and weed management [12].

Development project	Investment	Commodities	Technologies	Comment
Multi-sectoral Approach for Stunting Reduction Project (MASReP)	$31 million over 4 years (Ethiopia)	1	3	Sweet potato value addition
Projet d'Appui au Programme Graine Phase 1 (PAPG1)	$106 million over 6 years (Gabon)	2	4	Cassava and plantain multiplication
Agricultural Markets, Value Addition and Trade Development Project (AMVAT)	$10 million over 4 years (South Sudan)	2	5	Focus upon value addition
Program to Build Resilience For Food And Nutrition Security In The Horn Of Africa (BREFONS)	$138 million over 5 years (Djibouti, Kenya, Somali, South Sudan)	4	7	Climate-smart and pest management of dryland commodities
Le Projet d'Appui au Développement des Chaines de valeurs Agricoles dans les Savanes en RCA (PADECAS)	$11 million over 7 years (Central African Republic)	4	7	Cassava, rice, bean, livestock
Projet d'Appui au Developpement Integre de l'Economie Rurale (PROADER)	$28 million over 6 years (DRC)	3	9	Not including five target perennial cash crops
Programme De Développement De La Zone Spéciale De Transformation Agro-Industrielle De Ngandajika (PRODAN)	$70 million over 5.7 years (DRC)	4	19	Agro-industrial park pilot operation in DRC
Cabinda Province Agriculture Value Chains Development Project (CPAVCDP) in Cabinda - Angola	$101 million over 6 years (Angola)	5	29	Cassava, maize, aquaculture, livestock, cowpea, soybean
Programme intégré de développement et d'adaptation au changement climatique dans le bassin du Niger (PIDACC)	$283 million over 6.5 years (9 countries)	3	25	Rice, maize, wheat
DRC Agricultural Transformation Agenda (DRC-ATA)	$24 million over 2 years (DRC)	6	40	Nationwide agricultural transformation program
Total (Mean ± SEM)	$803 million	(3.2 ± 0.5)	(14.8 ± 4.0)	Average 4.6 technologies per commodity

Table 3.
Selected agricultural development projects in Africa and their number of component commodities and technologies.

8.6 Projet d'Appui au Developpement Integre de l'Economie Rurale (PROADER)

PROADER promotes a dynamic and prosperous rural economy by improving agricultural and rural socioeconomic services, and by diversifying and enhancing agricultural production. It operates in seven Provinces of DRC by providing agricultural extension services and inputs, as well as adding value through agro-processing.

8.7 Programme De Développement De La Zone Spéciale De Transformation Agro-Industrielle De Ngandajika (PRODAN)

PRODAN is a pilot operation aimed at implementing national policies and strategies for the development of agro-industrial parks in 22 provinces. It is intended to stimulate growth in the agricultural sector, ensure food and nutritional security for the surrounding population, and generating sustainable jobs and income.

8.8 Cabinda Province Agriculture Value Chains Development Project (CPAVCDP)

This Angolan project leverages upon 29 best bet technologies across six key commodities (cassava, maize, cowpea, soybean, aquaculture, and livestock) by promoting the introduction of new crop varieties, seed certification, and improved farm management practices.

8.9 Programme intégré de développement et d'adaptation au changement climatique dans le bassin du Niger (PIDACC)

This project covers nine countries in the Niger River Basin (Benin, Burkina Faso, Cameroon, Cote D'Ivoire, Guinea, Mali, Niger, Nigeria, and Chad) and promotes 25 technologies related to rice, maize, and wheat focused upon training of extension workers and farming communities.

8.10 Agricultural Transformation Agenda in DR Congo (ATA-DRC)

This project includes cassava, rice, maize, bean, wheat and aquaculture value chains. Through the project, improved crop varieties were introduced through a combined approach to seed systems improvement that includes large state-run farms, local entrepreneurs, and international seed companies. The project also includes mechanization, agro-processing and youth empowerment activities at multiple locations. Its immediate goal is to reduce dependence upon wheat imports (see Sections 3 and 4).

Ten development projects appear in **Table 3** to describe their number of commodities and technologies they support. Overall, these projects represent an investment of US $803 million (mean $80.3 ± SEM 26.6 million) resulting from 21 country agreements supporting 32 commodity value chains and 148 technologies. Project participation ranged between one and nine countries (mean 2.1 ± 0.8) and project durations varied between two and seven years (mean 5.2 ± 0.5 years). Each project supported an average 3.3 commodities (SEM ± 0.5) and 14.8 technologies (± 4.0). When the number of projects, countries and duration are considered, each country receives $8.7 ± 1.8 million per year (calculated from **Table 3**). Under these same conditions, each commodity receives $5.0 ± 1.4 million per country/year and each technology receives $1.5 ± 0.5 million per country/year to fund its value chain support. Together these projects represent a massive developmental investment that is ultimately intended to modernize the value chains of key food commodities.

These agricultural development projects follow a variety of approaches in terms of the number of commodities and technologies they advance, and the relative importance of capacity development between grassroots and private sector efforts that support them. The design of these projects and their level of funding depend upon their objectives, but there appears to be a limit to the number of technologies per commodity value chain (=4.6 calculated from **Table 3**) any given project can advance within a developmental context. This number of accompanying technologies is considerably less than the number of "toolkit technologies" considered essential to agricultural modernization (see Sections 3 to 5). In that case, careful consideration and balance must be applied to the selected technologies within any given project, too often limited to a few production inputs, or better yet the projects themselves could be designed in a more comprehensive manner by supporting modernizing technologies along the entire commodity value chains. In fairness, many of these projects are designed from a humanitarian rather than a value chain perspective and their component technologies fully emerge only as they are implemented, suggesting an important backstopping role for projects such as TAAT [8, 9] and organizations such as the CGIAR [41].

9. A coordinated approach for rollout of modernized agriculture technologies

Our promotion and scaling model operates upon the assumption that African small-scale farmers seek to acquire the best crop varieties and animal breeds for their production and market conditions, raise them with recommended accompanying inputs, conduct their production through sound management advice, and do so in a labor- and cost-effective manner [8]. In this way, agricultural transformation is the process that leads to increased farm productivity, making farming commercially viable and strengthening linkages with other sectors of the economy, particularly agro-processors. This responsibility requires more than simply promoting individual agricultural technologies within value chains; rather it advances suites of proven input products, production practices and conducive policies in a coordinated manner as transferable developmental assets. These Transferable Assets are proven innovations that address known constraints and have high potential for scaling across a wide range of settings and form the basis for an Integrated Agricultural Development Program (**Figure 4**).

Agricultural transformation is carefully designed and sequential. Many needed technologies are identified through past agricultural research and development efforts, and more are in the process of refinement (**Figure 4**). Within the context of an Integrated Agricultural Development Program, a call is issued to technology holders across the research and development community, inviting their participation and technical contributions. These include both production (**Figure 4(1a)**) and value-added processing technologies (**Figure 4(1b)**) positioned along the entire value chain (**Figures 1** and **2**). Those production technologies deemed proven and ready for scaling [43] are promoted through agricultural extension campaigns and stakeholder innovation platforms (**Figure 4(2)**). Those technologies deemed most worthy of investment are offered incentives through assisted agribusiness expansion or startup (**Figure 4(3)**). In many cases, this involves strengthened placement within value chains through strategic investments within development project activities. As these businesses gain recognition and clients, banking institutions are expected to offer further opportunity for investment through an increasing number and volume of financial instruments and ventures [44].

Providing incentives for and directing the course of that investment is a major responsibility of the Integrated Agricultural Development Program as a means of agricultural transformation (**Figure 4(4)**). A critical next step is the strategic establishment of agro-industrial centers, particularly those that manufacture and distribute production inputs and equipment necessary to modernized agriculture. These Centers must be flexible and scalable, but in general they include seed multiplication and processing, fertilizer blending and packaging, feed blending for different animal enterprises, and the fabrication and distribution of machinery needed to eliminate the drudgery associated with small-scale farming (**Figure 4(5)**). These Centers may range in scope and size from modest agribusiness incubations promoting relatively few enterprises and technologies [45] to colossal Special Agro-Industrial Processing Zones supported by a consortium of development institutions [46] as either serves the same modernizing purpose. They not only function to increase the availability of proven production inputs and equipment, but also to train others in required skills so that parts of the Center may be propelled by the private sector, leading to a proliferation of Agro-Input and Mechanization Suppliers. In this way, the Centers operate as agribusiness incubators and are particularly attractive to youth empowerment efforts.

At this point, an agricultural transformation interface emerges. Improved varieties and blended fertilizers become more widely available to producers (**Figure 4(6)**). Greatly increased production results from widespread adoption of modernized agriculture (**Figure 4(7)**). Wealth and jobs are created through value addition and export of increased agricultural production (**Figure 4(8)**). Value chains are positioned to more positively interact with the larger agricultural and financial communities to transform agricultural production in alignment with large national programs. The immediate effect is to greatly increase production, so it is important to anticipate marketing requirements [47]. This anticipation involves the establishment of commodity collection points, the distribution of packaging materials, systems of quality assurance and the scaling of agro-industrial capacities. The impacts of successful application are measurable over the near- and mid-term. An immediate effect among smallholder communities is increased food supply and diversity. A mid-term goal is the reduction of food imports and an increase in agricultural exports, both leading to an increase in foreign reserves and the creation of decent jobs within the agricultural sector. All these achievements are reflected in stronger and more diverse commodity value chains.

Finally, a critical element within an Integrated Agricultural Development Program is the ability and need to undertake agricultural policy reform, particularly as it relates to investment in modernizing agricultural technologies by the private sector and client farmers. Opportunities for policy interventions stimulating national investment appear throughout this model (**Figure 4**) without being specifically recognized within this narrative. Strong political will for reform should not be equated with strong government intervention, as the most effective course of action is often to allow for greater commercialization through reduced government intervention; albeit within an enabling policy environment [7]. It is particularly important that governments do not excessively tax their early transformational successes [48]. This does not suggest that there are not many needed reforms; particularly those that open the seed and fertilizer sectors to investment, increase the movement of agricultural inputs and equipment into and between countries, and in many cases provide the needed financing to strengthen rural infrastructure. Instead, it implies the need for more strategic thought by governments to implement the right policies at the national and regional levels to support agriculture transformation.

10. Conclusions

This Chapter describes value chains from a technology perspective. This approach is particularly valuable within the context of development where agricultural systems are expected to modernize and transform and be able to respond to the economic and climate shocks we are seeing today. This is the case across all three transitional stages leading to sustainable management of agricultural systems involving: (1) greater production efficiency with current resources, (2) strategic substitution with more potent production inputs and managements, and (3) the redesign of systems that allows previously unobtainable types and levels of production.

Distinctions were drawn between the cassava commodity value chain, where current systems are steadily improved and commercialized, and wheat production in new production areas across Africa. In the latter case, excessive economic reliance upon imported wheat creates an economic burden that must be relieved. Similar types of technologies are required across both of these commodity value chains, but the manner of their integration varies within the scope of systems redesign; and in this case is much greater for the introduction of wheat as a product of a new and expanding cropping system. Interestingly, cassava flour resulting from agro-industrial processing of raw tubers can partially substitute for wheat flour; whether that wheat is domestically produced or imported.

Distinctions were also drawn between crop and animal enterprise value chains, in this case the intensification of goat and sheep production. The proportions of technologies as they are divided among genetic innovation products, production input products, agricultural management practice, digital agricultural tool and agro-processing innovation provides a technological signature useful to agricultural development strategies. The need for greater reliance upon mechanization, particularly the use of small-scale farming equipment as a means to reduce unacceptable levels of drudgery, was raised and a wide selection of these machines were identified for use across entire agricultural value chains.

Agricultural development projects and the interests that foster them seek to achieve agricultural transformation across Africa, and this involves the selection, promotion, and scaling of modernizing technologies. These intentions result from the resolve to both secure the continent's food self-sufficiency and to better propel its agro-industries. These projects are often based upon projected increases in production founded upon the potency and adoption of incrementally improved management technologies and products. This paper presents such modernizing technologies for cassava, wheat, and small ruminants as examples, but many other interventions are known [9, 42]. The African Development Bank recently identified the need for an additional 70 million tons of cereal grain (wheat, maize, rice and sorghum), 30 million tons of fresh cassava (= 10 million tons of cassava flour), 10 million tons of soybean, and 5 million tons each of domestic animals (poultry, beef, sheep, goats and swine) and fish (in aquacultural systems) to secure continent-wide food and nutritional security and to fully launch its agro-industries upon the world stage [49]. Agricultural value chains and the technologies they rely upon and distribute occupy a critical role in securing this target.

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