Millet and Sorghum Technology Toolkit Catalogue

TAAT Clearinghouse

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Front Cover: Farmer inspecting fields with bio-fortified pearl millet (left) and low-tannin sorghum (right). Photo credits: ICRISAT Stock Pictures.

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Purpose and Introduction

This catalogue describes a suite of technologies related to the modernization of sorghum & millet production in Africa. It is based upon the combined efforts of the Project Platform for Agricultural Solutions (ProPAS), an information internet site, and the Technologies for African Agricultural Transformation, a large collaborative program that is deploying agricultural solutions across the continent. Both activities are based upon the imperative to better connect proven technologies to those who need them, but each undertakes this goal in a very different manner. Millet and sorghum are one of TAAT's priority commodities because of their huge importance to food and nutritional security, and rural development in general across Africa. They are also targeted as an agro-industrial crop for processing and trade within regions markets. In the course of its compilation, ProPAS has accumulated several technologies that specifically address these commodities and we have compiled them into a

“Technology Catalogue” designed to advance understanding and encourage adoption and investment into the proven agricultural solutions that advance these crops. This is one of several catalogues produced as a joint ProPAS-TAAT activity. For more information on the featured technologies or other solutions toward transformative impact on production of small grain crops in Sub-Saharan Africa, contact the Compact Leader Dr. Dougbedji Fatondji from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) by email at d.fatondji@cgiar.org.

About ProPAS. The Product Platform for Agricultural Solutions (ProPAS) provides a mechanism to compile and access innovations, management technologies and products needed for Africa’s agricultural transformation. The platform provides two pathways: it permits users to enter their proven and promising solutions into a database, and then encourages others to sort through its options to reveal the suite of opportunities that can assist their agricultural objectives. ProPAS results from the recognized need by the International Institute of Tropical Agriculture (IITA) to compile and access the full range of agricultural solutions available for modernizing and transforming African agriculture in more systematic manner. Its overall goal is to accelerate the process of agricultural transformation in Africa. Many solutions are available to improve and modernize Africa’s food systems but those who benefit from them most are often unaware of the best options at hand. In addition, more solutions are in the research and development pipeline that are best advanced through wider exposure and validation. Solution profiles are compiled and released in a systematic manner that involves submission by technology holders, entry into a user-friendly software platform, and use by an expanding base of clients. A small committee of agricultural experts oversees this process but recognizes that its strength is through open-ended access to a marketplace of solutions. ProPAS is therefore managed through a three-phase process that involves solution submission, database management, and client access. The database allows for solutions to be identified through selection of several search fields related to the form, type, commodity application and target beneficiaries of a given solution, sequentially narrowing technology recommendations for transforming agriculture production and rural livelihoods.

About TAAT. The Technologies for African Agricultural Transformation (TAAT) is a program led by the International Institute of Tropical Agriculture (IITA) that has pioneered new approaches to the deployment of proven technologies to African farmers. TAAT arose as a common effort of IITA and the African Development Bank (AfDB); and is an important component of the latter’s Feed Africa Strategy. TAAT is currently advancing 76 carefully selected technologies through 88 interventions in 28 countries. It is organized around 15 “Compacts” that represent priorities in terms of achieving Africa’s potential in achieving food security and advancing its role in global agricultural trade. Nine of these Compacts relate to specific priority value chains of rice, wheat, maize, sorghum and millet, cassava, sweet potato, bean, fish, and small livestock. Weaknesses in the production of commodities are viewed as responsible for Africa’s food insecurity, need for excessive importation of food, and unrealized expansion of Africa’s food exports. Together these Compacts design interventions in collaboration with national programs to introduce technologies and management innovations that are designed to meet targets for agricultural development. In many cases, these targets are addressed through the implementation of projects resulting from sovereign country loans awarded by development banks, and TAAT’s role in the planning and execution of these loan projects is becoming a vital element of their success.

The TAAT Top 100 Technologies. The Clearinghouse developed a database of the Top 100 Technologies that are transforming African agriculture. It is based upon the approaches of the TAAT Commodity Compacts but also includes those from the CGIAR Collaborative Research Programs that are recently described as ready for next user. These technologies are divided between those involving improved genetics and plant and animal breeding (23%), manufacturing and use of input products with proven efficacy (21%), management practices for protection of crops and livestock against pests and diseases (27%), labour-saving mechanized equipment available on the market (26%), and applications for distribution of digital information (3%). These technologies have a direct role towards the achievement of the Sustainable Development Goals in relationship to farm productivity, food security and hunger reduction, improved household nutrition and diets, economic growth, climate-smart innovation and improved human equity. These technologies form the basis for selecting entries into ProPAS, including those advancing millet and sorghum.

Dual-purpose sorghum growing in Mali

The Top Millet and Sorghum Technologies. Small-grain cereal crops of millet and sorghum are widely grown for food and fodder across semi-arid regions of Sub-Saharan Africa, particularly the Sahel. It is estimated that 35% to 65% of total cereal food comes from millet in Burkina Faso, Chad, the Gambia, Mali, Senegal, Niger, and Namibia. Traditionally, millet has also been an important crop for drier parts of eastern and central Africa. Sorghum is a key staple across the drylands in tropical and subtropical Africa, spanning from Senegal and Niger in the west, to Ethiopia and Somalia in the east, and Zimbabwe and in the south. Nigeria is the largest producer of sorghum accounting for nearly 40%, Sudan is the second largest grower of sorghum. In Burkina Faso, the third largest producer, nearly 44% of the population depends on rain-fed sorghum crops for food security. This catalogue describes priority technologies to modernize production and processing of millet and sorghum in Africa. These include: 1) Pearl millet and sorghum as wonder crops for food security and rural development, 2) Improved varieties with higher yields, biofortification, market characteristics, and resistance to biotic and abiotic stress, 3) Dual-purpose varieties to promote crop and livestock integration, 4) Contour bunding for water conservation, 5) Fertilizer micro-dosing for enhanced uptake and reduced losses, 6) Sustainable intensification practices through integrated soil fertility management and integrated Striga management, 7) Augmented releases of parasitoid wasps for biological control of the millet head miner and fall army worm, 8) Small and medium scale mechanized equipment for production and post-harvest, 9) Mobile choppers for efficient management and utilization of crop residues, 10) Flour milling and blending for value addition and market access, and 11) Inventory credit system for warranting higher market value. Details on each of these technologies follow.

Technology 1. Pearl Millet and Sorghum: Two Wonder Cereals

Pearl millet and sorghum are the major cereal grains of African dryland agriculture. Agricultural production in these drylands is perilous owing to severe and cyclical droughts and a daunting suite of soil limitations. Drought is the leading biophysical cause of food insecurity and human suffering and increasing attention is placed upon mitigative response to climate change in these drylands. Soil limitations include low water holding and nutrient retention capacities of sandy soils and crusting of clayey soils. Farmers in the African drylands are acutely aware of these risks and rely heavily upon the inherent hardiness of both millet and sorghum within their cropping systems. The suite of accompanying technologies featured in this catalogue allow them to better cope with these difficult farming conditions. For more information about these small grain cereal crops, contact Dr. Dougbedji Fatondji from ICRISAT by email at d.fatondji@cgiar.org.

A highly productive stand of pearl millet, a crop that offers biofortified varieties and improved seed systems

Pearl Millet is the staple cereal in the harshest of the world's major farming areas: the desert margins and semi-arid regions of Africa. Withstanding hot, dry, sandy soils, it is adapted toward survival under harsh conditions while at the same time it demonstrates an ability to respond to management, allowing for yield improvement. Pearl millet (*Pennisetum glaucum*, alternative *Cenchrus americanus*) originated in the Sahel and has been the staple cereal for millennia because of many key traits. It is amazingly drought tolerant; able to germinate at high soil temperatures and in crusted soil; it withstands "sand blasting" and grows under low soil fertility; and it resists pests and diseases such as downy mildew, stem borer and parasitic Striga. It also grows well in both acidic and saline soils. But its most rugged land races are characteristically low yielding and may not respond well to inputs, and for this reason there is need for improved varieties and their accompanying seed systems.

A productive millet crop in the Sahel resulting from climate smart practice

Pearl millet is an extremely nutritious cereal with comparatively high levels of protein and oil, and its energy content is among the highest for whole-grain cereals. These traits are being enhanced (see Technology 1). Improved varieties of millet are now available that maintain the crops hardiness but also offer higher yields and stronger response to management. Breeding efforts have led to increased micronutrients (e.g., iron and zinc), and some improved "sugary" types can be harvested at the milk stage, roasted, and consumed like sweet corn. Because of its ability to cross with other related species and its genetic retention of desired traits, this stream of improved millet varieties will likely continue. One advantage of millet as a crop is its suitability to community-based seed production enterprise and other informal seed system channels. Programs advancing food security in dryland areas are well advised to take advantage of this crop and its new varieties and to innovate around flexible designs advancing millet seed supply.

Sorghum is a physiological marvel and is becoming more so. It is extremely drought tolerant and light efficient, with one of the highest dry matter accumulation rates among cultivated crops. Sorghum (*Sorghum bicolor*) is versatile in its use with some types boiled like rice, others cracked like oats, others malted for brewing, and some milled and baked. The whole plant may be used as forage or hay. Currently available, improved varieties and land races have several favorable characteristics. They have good seedling emergence and rapid early root development, rapid tillering leading to multiple heads, and long growing cycles to make the best of favorable rains. They also offer partial resistance to insects, disease and parasitic *Striga* through a variety of mechanisms. For the most part, these varieties have the appearance, texture, and taste expected for use as traditional foods.

A productive stand of sorghum, a crop that is increasing viewed for agro-industrial processing

Plant breeding has added to these traits in strategic ways providing greater resistance to downy mildew, anthracnose, and smuts; and to insects such as stem borers, midges, and head bugs. Selection for larger panicles, stronger stalks, upright leaves, and stay-green further increase sorghum's productivity. Grains are selected for faster filling, lighter colors, higher protein, and easier threshing. Many improved sorghum varieties are available and the main challenges that remain is to substitute them with currently produced ones through extension campaigns and local seed systems and linking their use to seasonal rainfall forecasts. From a longer-term perspective it is important to regard sorghum as an industrial crop. It can be manufactured into a wide variety of foods and used to substitute for imported grains. Moreover, it can be processed into alcohol, vegetable oil, adhesives, starches, lubricants, and other products. These properties, combined with sorghum's use as an animal feed suggest that planners are advised to regard sorghum as more than a drought-hardy subsistence food.

Technology 2. Varieties for Better Nutrition and Stress Resistance

Summary. The yield of millet and sorghum in Africa remain far below attainable levels, and communities growing the crops are some of the most food insecure and malnourished on the continent. One of the primary causes of this problem is limited access to new varieties that are high yielding, bio-fortified, and withstand drought, heat, and pests. Recent surveys demonstrate that new lines of sorghum are planted on just 3% of farmland in Burkina Faso, 15% in Niger, 20% in Nigeria, and 21% in Mali, leaving great scope for improvement. Delivering quality seed from improved millet and sorghum to farmers is critical to sustainably enhance production and to strengthen the climate resilience of the value chain. Newly developed varieties also have better taste and cooking characteristics that provide greater potential for value addition and marketing, they have multiple uses, from food, feed, and fodder, to brewing and biofuels. For more information on improved varieties, contact Dr. Dougbedji Fatondji of ICRISAT by email at d.fatondji@cgiar.org.

Africa's first bio-fortified pearl millet "Chakti"

Technical Description. A number of improved millet and sorghum varieties were developed by ICRISAT in collaboration with the national agricultural research institutes, farmer organizations, seed companies and non-governmental organizations. They are highly nutritious and fulfil many pressing health needs. These are the last crop growing in times of drought and high temperatures, making them a viable risk management strategy for farmers. New cultivars include open pollinated varieties (OPV) and hybrid lines that offer a grain yield advantage of more than 30% compared to traditional landraces and less improved types. Most of the new millet and sorghum lines are bio-fortified with naturally high levels of iron (45-79 ppm) and zinc (32-64 ppm) and were also selected for early maturation to avoid yield loss where rainfall ends prematurely. Certain varieties possess adaptations that make them tolerant against moderate to extreme drought and heat, and resistant against common diseases and pests. Among the improved cultivars, some have a "stay green" character, making them of good use as animal feed (see Technology 3). The success of breeding programs is best exemplified by the sorghum hybrids Pablo and Fadda, naturally rich in iron and proteins and offering a yield advantage of 30% to 40% over local varieties.

Uses. Specific sets of millet and sorghum varieties are available for different climatic conditions, soil types and food habits in African drylands. Iron and zinc bio-fortified lines with short growth cycle, drought tolerance and disease resistance are popular in the Sahel regions and the drylands of eastern and southern Africa. Improved sorghum cultivars are suitable for regions with an annual rainfall of 400 mm to 1000 mm. Millets are particularly recommended where annual cumulative rainfall is less than 600 mm and unevenly distributed over the season, as well as on sandy soils that retain too little water and on degraded lands with low nutrient availability.

Composition. Breeding programs for millet so far have released two hybrids and 11 OPVs, which include GB 8735 (Gajera Mota), Chakti and ICRI-Tabi. For sorghum, OPVs are dispatched such as Jakunbe, Jiguikala, Soumba, Fambe B and Lata 3. All released varieties and hybrids were registered in the ECOWAS/WAEMU/CILSS regional seed catalogue (2016-2018), and most have been taken up in national seed catalogues. ICRISAT and its partners continue to develop lines of millet and sorghum with higher yield potential, stronger tolerance to drought and heat, greater nutritional value, and better market characteristics.

Application. High-yielding, nutritious and resilient lines are developed through selection of parents with desired traits, conventional crossing and hybridization, and finally extensive field testing. Improved varieties of millet and sorghum (OPVs and hybrids) are multiplied and made accessible to farmers via "Formal Seed Systems" that involve stringent inspection and certification standards. Recommendations of good land preparation, fertilizer and crop management practices are formulated for specific soil types and climate conditions that must be followed to realize high yields and efficient use of nutrients and water. For sorghum, the seed rate is 8 to 12 kg per hectare with a spacing of 75 - 90 cm between rows and 30 - 50 cm between plants. For pearl millet, the seed rate is 5 to 8 kg ha^{-1} with a spacing of 80 - 100 cm between rows and 40 - 100 cm between plants depending on the zones. Generally, it is advised to apply DAP at 62 kg ha^{-1} during planting and CAN at 198 kg ha^{-1} when the crop is knee-high. Weed encroachment needs to be curtailed through physical removal or spraying of pre- and post-emergence herbicides. Farmers should follow integrated striga and soil fertility management (see Technologies 5 and 6), and water conservation techniques (see Technology 4) to maximize grain yields and resource use efficiency.

Hybrid sorghum "Pablo"

Commercialization and Start-up Requirements. Most African countries have a program to produce breeder and foundation seeds by agricultural research centers, and certified seeds by private enterprises, cooperatives, and individual farmers. Realizing widespread use of the new lines however requires extensive campaigns to raise awareness with farmers, processors, and consumers of their yield, nutritional, adaptation and market benefits. For instance, the "Smart Food" initiatives lead by ICRISAT promote improved millet and sorghum in combination with training on food processing skills through TV and radio shows, social media platforms, and small grant and loan programs for private sector. The following are followed to establish a formal seed system for these new varieties: 1) Identify lines that match climatic conditions, soil types, agronomic practices, and market demands, 2) Establish quality assurance standards and frameworks to ensure multiplication of certified seed with high germination rate, 3) Formulate roadmaps for investment and marketing by public agencies and private companies, 4) Train seed producers on bulking methods and agrodealers on stock management to ensure sufficient availability, and 5) Link farmers with credit providers and food processors to finance the purchase of improved varieties.

Production Cost. Developing a high-yield, nutritious and resilient variety attracts substantial costs to pay for facilities, expert knowledge, and skilled labor. The size of investment is however not different to that for other improved lines, allowing the new lines to be sold at standard market prices. Depending on the planting rate, seed for one hectare of land costs between US $14 and $18 for sorghum, and US $8 to $12 for pearl millet. The inorganic fertilizer needed to apply the prescribed rates costs between US $120 to $150 per hectare. A ton of animal manure, which is the minimum recommended for one hectare, is delivered at a price of US $35 to $45. The total cost of labor for land preparation, planting, thinning, weeding, and harvesting commonly ranges between US $230 and $260 per hectare.

Customer Segmentation and Potential Profitability. The multiplication and delivery system for seed of the two small-grain crops involves diverse actors including public and private sectors who multiply breeder seed into foundation seed and use the latter to bulk certified and commercial seed. End-users of improved millet and sorghum varieties are suppliers of agricultural inputs, small-scale and commercial farmers, food processors, retail markets, and nutritionists. Multiplying certified seed or producing grain for food from nutritious and resilient cultivars can generate stable incomes and avoids food shortages during unfavorable seasons. The newly developed millet and sorghum varieties provide higher yields compared to local landraces, allowing sales of surplus grain for cash. Better nutritional quality of food is achieved through bio-fortification, which helps reduce chronic forms of malnutrition. Health studies demonstrate that introducing millet with high iron and zinc increases the hemoglobin level in blood, which is often low for women and children. Replacing a substantial part of maize-based foods with millet and sorghum products decreases the risk of developing diabetes and helps to manage blood sugar levels.

Licensing Requirements. Millet and sorghum varieties developed by ICRISAT, and national systems are classified as Public Goods and are offered royalty-free for multiplication and sales by seed growers and private companies. Production and marketing of certified seed requires compliance with national standards and licenses.

Technology 3. Dual-purpose Varieties for Crop and Livestock Integration

Summary. Diminishing productivity of natural pastures and rangelands across African drylands due to overgrazing, soil degradation and climate change, coupled with increasing livestock numbers, increases the importance of crop residues used as animal feeds. Traditional varieties of millet and sorghum are unable to satisfy demands for food and feed at the same time as they do not have a favorable ratio of grain to stover. Commonly cultivated lines also have a higher lignin content, reducing their digestibility, while some also contain sufficient tannin to lend a bitter taste. New higher yielding, "dual-purpose" millet and sorghum varieties with ideal grain and stover ratios for both human and animal nutrition are now available. These improved cultivars contain less lignin and tannin, and stay green through grain harvest, allowing farmers to obtain greater fodder quantity and quality into the dry season. The new lines of millet and sorghum allow more intensive crop-livestock integration as improvements in fodder availability enhance manure availability for use in soil fertility management. For more information on this topic, contact Dr. Dougbedji Fatondji from ICRISAT by email at d.fatondji@cgiar.org.

Dual-purpose millet varieties in Niger

Technical Description. Varieties for dual-purpose produce about 40% of grain and 60% of stover on dry matter basis. Sorghum lines achieve grain yields of 2.5 - 4.0 ton ha^{-1} and stover yield of 10 - 15 ton ha^{-1}. For millet cultivars, the productivity ranges between 2.0 and 2.5 ton ha^{-1} for grain, and 4.0 - 6.0 ton ha^{-1} for stover. The new cultivars possess traits that help them survive dry-spell and quickly resume growth when moisture returns. In addition, sorghum lines tolerate both drought and cold better than other fodder crops such as maize and Napier grass. The stover of the dual-purpose sorghum cultivars is sweet with a sugar concentration around 15%, matching the energetic value of maize, and its juice can be extracted for syrup or bioethanol production as well. While traditional millet varieties achieve higher production of fodder on dry matter basis, the new dual-purpose lines provide greater digestible stover yield and metabolizable energy per area of land. Improvements of harvestable grain and stover, nutritional quality and stress resistance in millet and sorghum offer greater food and feed security to farmers.

Uses and Composition. Dual-purpose varieties available to seed producers are suitable for a wide range of African agroecosystems through selective adaptation for specific growing conditions. ICRISAT and partners from the Institut d'Economie Rurale in Mali developed and registered more than 15 OPV and hybrid lines of dual-purpose sorghum, including cvs.

Soubatimi, Tiandougou Coura, Jiguikala, Seguifa, Peke, Fadda, Sewa, Nieleni, Grinkan Yerewolo, Sassilon and Sariasso 22. A series of OPV and hybrid cultivars of dual-purpose millet are available, including MISARI 1 and 2, NAFAGNON, ICMV, ICMH, Mil de Siaka, SOSAT-C88, Toroniou C, Synthetique 00-06/03-03 and Thialack 2.

Application. The dual-purpose varieties are developed using conventional techniques of crossing and hybridization and subjected to rigorous field tests before their release. Land preparation, seed rate, plant spacing, fertilizer application, and crop management should follow generally prescribed practices for growing areas and seasons. It is important to note that sorghum stover is wilted for at least 12 hours before feeding to animals so that hydrogen cyanides are broken down, else these they may cause poisoning. Green or dry stover must be chopped into pieces of 2 cm when used as fodder for cows, pigs, and goats, and must be shredded into pieces of less than 0.5 cm for poultry. Motorized equipment is available to reduce the labor of processing the stover and this service may create job opportunities for youth in rural communities (see Technology 10). Millet and sorghum stover can be used for silage in pits or under plastic during which fermentation releases extra sugar and breaks down anti-nutrients. Because of the high sugar content in sorghum, no molasses must be added to silage. Fodder from sorghum, either as green chop or silage, can replace maize at equal amounts for all types of livestock, and provides up to 67% of required roughage and up to 20% of the total diet. Supplemental minerals and vitamins should be added to millet and sorghum fodder when fed to lactating dairy cows to avoid nutritional deficiencies.

Commercialization and Start-up Requirements. Formal seed systems for dual-purpose cultivars are operated by the public and private sector in several African countries. The following actions must be taken to realize widespread adoption: 1) Campaigns to raise awareness about benefits for human nutrition, fodder quantity and quality, and climate resilience, 2) Design of investment and regulatory roadmaps by public agencies and private companies to create formal seed delivery systems, 3) Capacity building of seed producers on quality assurance standards and frameworks essential for the multiplication of certified seed, and 4) Banks provide low-interest credit for seed companies to expand seed portfolio and micro-loan programs for farmers to buy the improved varieties.

Production Cost. Seed and grain of new dual-purpose varieties are sold at the standard market prices and thus do not change the cost of seed for farmers. Overall production costs of dual-purpose varieties are significantly higher than fodder only varieties due to additional labor needs for bird control and threshing. Indian farmers cultivating dual-purpose millet typically spend a total of US $204 per hectare for seed, fertilizer, and labor.

Customer Segmentation and Potential Profitability. The customer base for dual-purpose millet and sorghum varieties are private seed companies, cooperatives, and seed growers that bulk and marketed seed, and small-scale and commercial farmers that also produce animals. A huge market potential for improved lines exists across Africa's drylands as hundreds of millions of households depend on mixed crop-livestock farming. Dual-purpose varieties offer greater returns per area of land than those for grain or fodder only, thus increase incomes. Earnings from dual-purpose pearl millet lay 31% higher than fodder millet, and 63% than grain millet.

Licensing Requirements. Varieties of millet and sorghum for dual-purpose are classified as Public Goods and multiplication and sales is royalty-free but require certification following national regulations. ICRISAT and national research centers are responsible for dissemination.

Technology 4. Contour Bunds for Water Harvesting

Summary. Availability of water is one of the main constraints to dryland agriculture, and recent declines in rainfall and changes of precipitation patterns caused by climate change severely jeopardize food security. To enhance yields and resilience of crops across Africa's semi-arid areas, it is of major importance that soils intercept maximum available rainwater, and that surface runoff is minimized. Contour Bunding Technique (CBT) involves short walls that are arranged in specific patterns along the field contour, creating micro-catchments. Bund structures intercept runoff and increase rainfall capture, water storage, and deep infiltration, and reduce soil erosion and gully formation. Planting trees on top of the bunds permanently marks and reinforce them, help to improve soil fertility, and can provide quality forage for animal feed when using agroforestry species that have high fodder yield and nutritive value. CBT keeps the soil moist for longer which extend the window for field preparation and planting by 7-10 days. The harvesting of water results into higher grain yield of sorghum and millet, and substantially reduces soil erosion. More information about this technology can be obtained from Dr. Dougbedji Fatondji of ICRISAT at d.fatondji@cgiar.org.

Recently installed contour bund on a farmer field in Mali

Technical Description. A majority of soils across African drylands do not effectively store rainwater for crops and too often exhibit high levels of surface runoff and soil erosion. Constructing sequences of parallel bunds along the soil contour lines of farmland allows capture of water and creates slow infiltration areas and safer drainage of excess runoff. Some bunds have a parabolic shape, so rainwater is distributed toward the center. Two types of micro-catchment structures exist, contour bunds (or contour ridges) and semi-circular bunds, and the choice between these depends upon topography and socio-cultural contexts. Installing and maintaining contour bunds is most effective at larger scale through coordinated action among neighboring farmers. Semi-circular bunds can be used at smaller scale for individual fields and are staggered along the contour lines of fields with the bow pointing down the slope. The space between bunds depends on the topography of a field, the steeper the slope, the closer together the contour bunds. Soil inside the bunds must be evenly levelled, otherwise water will stagnate at the lowest point and damage crops. Planting trees on top of bunds or perpendicular ties extends the performance of the CBT and its benefits for crop production and better resists the heavy downpours that could otherwise wash away the water harvesting structures.

Uses and Composition. Applying CBT is most pertinent in farming systems of the semi-arid drylands but is also suitable for wetter areas. In places or seasons with low rainfall, CBT helps to harvest water and increase availability of moisture for crops. In places or seasons with high rainfall, CBT helps to reduce the runoff and erosion, and risks of flooding downstream.

Contour bunds are appropriate for terrains with a low uniform slope (<5%) and gentle, even runoff. Semi-circular bunds are used on fields that have a higher slope (>5%) and uneven surface where runoff flows are strong and irregular. Where rock material is abundantly available, bunds can be reinforced with stone, making them more stable and requiring less maintenance. Where rock material is limited, bunds can be made of soil ridges that usually require annual maintenance. The correct placement of CBT is critical and lines of equal elevation within a field can be identified by a technician using a laser level tripod, or a farmer with an A-frame or water/spirit level. Demarcating the contours requires about 50 stakes per hectare. Ridges may also be formed using draught animals. A range of fast-growing agroforestry species can be planted on top of soil bunds as reinforcement, the most common ones being nitrogen-fixing forage trees such as gliricidia (*G. sepium)* and leucaena (*L. leucocephala).*

Land surveying tools for correct placement of contour bunds:
laser level tripod (left) and A frame (right)

Application. The first step of installing bunds is a joint field visit by farmers and an experienced technician to understand the direction of slopes, the movement of water, farmer's practices, community bylaws and relationships between neighbors. In this way, unwanted water drainage is avoided and synergies for collaboration are created. The second step is to identify contour lines with land surveying tools and demarcate this with temporary markers. Next, bunds can be constructed by hand or with an ox-drawn plough. Three or four passes of a plow are needed for heaping soil to form a sufficiently tall bund (e.g., 50-80 cm). The standard distance between bunds is 50 m if the slope is less than 1.6% and is 20-30 m when the slope is between 1.6% and 5%. Seedlings of fast-growing trees to reinforce bund may be planted at a spacing of 3 meters on the crest. Bunds made of soil need to be regularly maintained and strengthened using a plough or hand hoe.

Commercialization and Start-up Requirements. Large-scale implementation of CBT is conducted as part of an agricultural development and environmental protection program conducted by national and non-governmental agencies in various African countries. For instance, more than 100,000 ha of degraded land in Burkina Faso was equipped with contour bunds. Because of its simplicity and many benefits, there is considerable potential for mass-adoption of CBT. In many areas, local NGO's and companies offer land surveying services at a fee that can be hired by individual farmers or associations to ensure the correct placement of bunds. The following preconditions must be fulfilled to realize widespread deployment of CBT: 1) Awareness raising about the advantages of engineered micro-catchments for crop production, soil fertility improvement and watershed management, 2) Training of extension agents and farmers in the use of the land surveying equipment and methods for constructing bunds that reduce investment costs, 3) Consultation between neighboring farmers to understand water movement across the landscape and determine the best placement of bund structures, and 4) Access to animal-drawn or motorized plough, low-cost stone resources, and seedlings of fast-growing trees for building and reinforcing bunds.

Semi-circular bunds reinforced with stones

Production Costs. Land surveys for drawing the contour lines in the field cost about US $9 per hectare. The work to move earth or stones represents the largest cost of CBT, with labor requirements varying between 30 to 120 person days per hectare for different types and dimensions of bunds. If animal-drawn or motorized ploughing equipment is available, the construction time and workload reduces substantially, but costs may rise when machinery must be hired or maintained. Seedlings from fast-growing trees must be purchased, or farmers need to establish their own nurseries, incurring costs for labor and materials. Training extension agents and farmers on methods for CBT requires considerable investment from national or non-governmental programs to provide training and information materials.

Customers Segmentation and Potential Profitability. Small-scale and commercial farmers, as well as local authorities involved with agricultural development and water management, are the main target groups of CBT. Land surveyors, tractor owners and nursery keepers are involved in scaling as commercial entities. Engineering micro-catchment structures on farmland offers multiple benefits for crop production, environmental protection, economic livelihoods, and social welfare. In Mali, grain and straw yields of sorghum for CBT plots were three time higher compared to lands without CBT. Implementing CBT reduces the amount of runoff by 40%, and decreased sediment loss from erosion by 20%. Planting fast growing trees species on the crest of contour bunds provides shade for crops and regulates temperatures during heatwaves. Up to 100 kg of dry biomass is accumulated in trees on an area of 100 m^2, which contributes to fuelwood supply and carbon sequestration. The enhancement of food production from crops inside the bunds and provision of animal feed from trees directly lead to better farmer livelihood. Large-scale implementation of CBT and tree planting on bunds in West Africa promotes gender equality and social cohesion within farmer communities, particularly when implemented through community-based collective action.

Licensing Requirement. No official permits are needed for installing bunds on farmlands in most countries. Approval from local authorities or chieftains is best obtained to avoid conflicts and ensure alignment with communal land and watershed management. Knowhow about the technology is disseminated as a public good by ICRISAT.

Technology 5. Fertilizer Micro-Dosing to Enhance Yield and Use Efficiency

Summary. Most small-scale millet and sorghum farmers do not use recommended rates of mineral fertilizers. Those who so usually apply too little fertilizer by surface broadcasting, an inefficient approach. Risk of crop failure due to drought further discourages investment in fertilizer. As a result, insufficient nutrient replenishment and gradual soil fertility decline takes place, driving a vicious cycle where unproductive land is abandoned and additional natural habitat is cleared for agriculture. Micro-dosing is a form of precision agriculture based on the application of small amounts of fertilizer in a shallow hole at the base of each plant. The method offers a low-risk strategy for farmers as it uses small and affordable quantities of inputs. Because fertilizer is placed close to active plant roots, the crop establishes more quickly and can better absorb nutrients and water, circumventing problems of soil degradation. In this way, micro-dosing decreases investment costs of farmers and increases yield responses to lower rates of fertilizer application. Proportionally less nutrients from mineral inputs are lost to the environment and more are assimilated by sorghum and millet, especially if the practice is combined with input of organic matter, water harvesting in zaï pits and contour bunding techniques (see Technology 4). When performed by hand, the task of applying small amounts of fertilizer at each plant is time consuming and labor-intensive. Simple mechanized equipment is available to reduce this labor and making the practice suitable for larger-scale production (see Technology 9). Applying a small amount of fertilizer with the right formulation at the right time can increase the yield of millet and sorghum by 40% to 120% as compared to traditional surface broadcasting. For more information on this topic, contact Dr. Dougbedji Fatondji of ICRISAT by email at d.fatondji@cgiar.org.

Use of a bottle cap for fertilizer micro-dosing

Technical Description. Large areas of land across millet and sorghum growing areas in semi-arid areas of Africa are severely depleted in nutrients like nitrogen, phosphorus, and potassium, reducing yield and nutritional quality. Conventional fertilizer application methods rely upon top-dressing on the soil surface, posing a financial risk due to lower returns per unit input and land. Alternatively, concentrated placement of mineral fertilizer inside the planting hole or near the base of the plant by micro-dosing make more nutrients available to the crop and thereby enhances the growth of roots, grain and stover. This results in healthier crops that are better able to counteract mid- and late-season drought, increasing the climate resilience of food production. Promoting fertilizer micro-dosing among small-scale farmers requires that input supply companies provide appropriately formulated blends or compounds in 2-5 kg package sizes that match the nutrient requirements of crops and soils, making fertilizers affordable to more farmers. On the other hand, fertilizer micro-dosing should not be implemented over extended periods of time if it results in negative nutrient balances. It rather must be considered as an avenue towards integrated soil fertility management by assuring good return on near-term investment, less financial risk, and minimal environmental pollution.

Uses and Composition. Micro-dose fertilizer application can be practiced in all millet and sorghum growing areas of Sub-Saharan Africa, including drylands in the Sahel, Eastern Africa, and Southern Africa. Mineral fertilizers formulations used for micro-dosing are based on availability of single, blended or compound types from local suppliers and nutrient deficiencies of croplands. The technology of micro-dosing is particularly suitable for resource limited farmers working on degraded lands, who cannot afford "recommended" amounts of mineral fertilizers. It offers an effective strategy to replenish nutrient stocks in small-scale farming systems by allowing for gradually increased investment and improved organic matter recycling through greater availability of stover.

Fertilizer micro-dosing by hand

Application. Micro-dosing is as simple as applying a couple pinches or a bottle cap full of fertilizer to each planting hole at the time of sowing or drilling it next to the base of the plants two weeks after emergence. Fertilizers must be covered with soil to prevent surface runoff and rapid volatilization. The total amount of fertilizer used in micro-dosing varies depending on the crop type and planting density. For instance, millet grown at 16,666 plants per ha requires about 50 kg of fertilizer whereas sorghum cultivated at a density of 26,666 plants per ha requires about 100 kg of fertilizer per ha. Applying compound fertilizer NPK (15-15-15) at a rate of 60 kg ha^{-1} is equivalent to 6 g per plant/hill, and DAP (18-46-0) at a rate of 20 kg ha^{-1} corresponds to 2 g per plant/hill. It is advised that nitrogen fertilizer be applied in 2 or 3 splits over the growing season by micro-dosing urea at times when rainfall is received. This strategy allows for high yields and reduces financial losses in drought-stricken years by avoiding wastage of fertilizers.

Commercialization and Start-up Requirements. The practice of fertilizer micro-dosing is actively disseminated to millet and sorghum farmers in many African countries, mainly by agricultural extension services, NGOs, and input suppliers. Initiatives to scale the technology must consider the following steps: 1) Raise awareness about the advantages on crop yield, soil nutrient management and climate adaptation, 2) Make sure the right formulation and package size is provided at local markets close to farmers, and 3) Conducting training of trainers among extension agents about the methods and schedules for micro-dosing fertilizer.

Production Costs and Customers Segmentation. The cost of the fertilizers for micro-dose application is lower compared to conventional surface broadcasting since less inputs are used. A survey in Burkina Faso showed that fertilizer micro-dosing without mechanized equipment has a labor opportunity cost of about US $43 per hectare, while that of conventional broadcasting by hand is only US $26 per hectare. Campaigns for dissemination and capacity building to scale the technology require substantial investment that must be covered by agricultural development programs from national and non-governmental agencies. Fertilizer micro-dosing appeals to small-scale and commercial producers of sorghum or millet from an operational and financial perspective as well, but the methods and pathway of implementation may vary. Input suppliers can realize major growth of sales by including specialty packages for fertilizer micro-dosing among their product lines.

Potential Profitability. Farmer field experiments with sorghum in Ethiopia showed that micro-dosing fertilizer 5 cm away from the plant instead of spreading it along the entire row saved 25% to 50% on the recommended nitrogen and phosphorus dose while increasing yields by 15% to 28%. Research of ICRISAT at other pilot sites found that micro-dosed application enhanced the efficiency of fertilizer use by 13% to 27% compared to the conventional practice of broadcasting. Fertilizer micro-dosing was disseminated to 170,000 Zimbabwean households, increasing grain production by 40,000 tons despite lower-than-average rainfall. The intervention significantly improved household food security and saved US $7 million in food imports, generating a net present value of US $26 million and an internal rate of return of 36%. Farmers become more willing to invest in fertilizer upon seeing the benefits on crop production from micro-dosing.

Licensing Requirement. Knowhow about this technology is a Public Good and is freely available from ICRISAT and others. The manufacturing of fertilizer blends or compounds intended for micro-dosing to different crops and soils may be subject to intellectual property licenses and trade secrets.

Technology 6. Proactive Management of Striga Infestation

Summary. Striga, also known as witchweed, is a parasitic plant that has invaded all major sorghum and millet production zones of Africa. The damage begins underground where the weed latches onto the roots of the crop and feeds on water, nutrients, and sugars causing twisted, discolored, and stunted growth. Striga is a major biological constraint to millet and sorghum production and is difficult to control. There is a strong link between soil fertility depletion and yield losses of sorghum and millet by the parasitic weed because as less nutrients are available in a farmer field; the more crops are attacked and the more the pest siphons off sugars and other substances from the host. A downward spiral arises when fields are continuously cropped with sorghum, millet and other cereals, insufficient mineral fertilizer and organic inputs are applied. Depending on the severity of pest infestation, yield losses range from 20% to complete crop failure. Seeds of the parasitic weed remain in the soil for up to 20 years and thus simple weeding and routine field sanitation procedures are not enough to eradicate it. Farmers who are badly hit by the pest end up suffering food insecurity

Sorghum severely infested by Striga

and are forced to shift crops and abandon fields. ICRISAT and other CGIAR centers have responded to this problem by developing proactive technologies and strategies that reduce Striga infestation and its yield losses and halt the spread of the pest. Widespread uptake of approaches for controlling Striga and improving soil fertility is achieved through technical training and advisory services. For more information contact Dr. Dougbedji Fatondji from ICRISAT at d.fatondji@cgiar.org.

Technical Description. Problems of low crop productivity, Striga infestation and soil fertility decline in sorghum and millet farming systems must be simultaneously addressed by combining multiple technologies, pest biology, and adaptations to the local environmental and socio-economic contexts. Various agronomic practices are used for this, which include fertilizer micro-dosing (see Technology 5), organic matter recycling, crop rotation and intercropping, Striga tolerant varieties, seed dressing, pre-emergence herbicides, and hand weeding and burying of emerged shoots. Overcoming the parasitic weed with these technologies only succeeds if efforts by stakeholders are well informed because too many believe that control measures are futile. Farmers must know how to effectively implement practices and need to mobilize resources and labor for investing in control measures. Extension services play a very important role to disseminate information, implementing field demonstrations and coordinating grassroots activities. Besides this, development agencies must organize large-scale campaigns designed to overcome Striga in worst affected areas and preventing it from spreading. Commercial seed companies and agro-dealers must include new technologies for Striga management in their product ranges and market them. Farmer associations must engage in bulk purchase of inputs and community-based seed production to combat the weed. Finally, national authorities must fully recognize the threat of Striga on food security and enact priority policies for integrated management practices.

Uses and Composition. Available technologies and practices for controlling Striga can be applied in all major millet and sorghum production zones. The approaches can be used to combat different Striga species that parasitize these crops; *Striga hermonthica*, *S. asiatica*, *S. forbesii*, and those that affect cowpea (*S. gesnerioides*). Practices for Striga management are easily adapted to soil fertility conditions, Striga infestation levels, availability of agro-inputs, farming habits, and socio-economic contexts, which vary substantially in sorghum and millet growing areas.

Application. Participatory approaches such as Farmer Field Schools are efficient in disseminating technologies and practices for combatting Striga. There is a need for Training of Trainers in Farmer Field Schools. Capacity building focuses on site characterization, cultivation of resistant varieties, fertilizer micro-dose application, production of organic fertilizers and timing of Striga uprooting. ICRISAT and other research centers have identified and released a range of sorghum and pearl millet varieties with defense mechanisms against Striga that keep it from attacking roots, and which are able to grow on nutrient depleted farmland. Common mineral fertilizers can be used to alleviate soil nutrient depletion and reduce Striga emergence. Animal manure, compost and fresh crop residue are suitable organic matter inputs for improving nutrient and water availability, but also stimulate abortive germination by Striga seed stocks. Crop rotation or intercropping to combat Striga involves different non-cereal crops like cowpea, groundnut, soybean, cotton, sesame, or sorrel. Desmodium, a pasture legume, was packaged into an agro-ecological approach to Striga management referred to as Push-Pull. Uprooting Striga before it flowers is realized through community mobilization, but by itself offers an incomplete control measure.

Commercialization and Start-up Requirements. National agricultural research centers and commercial seed companies in several African countries market Striga tolerant lines of sorghum and millet. Use of improved varieties, mineral fertilizer, broadleaf herbicides, and agronomic advisory services present opportunities for combatting and even eliminating this scourge. Different elements must be in place to realize appropriate and widespread uptake of these technologies: 1) Adaptation of practices according to farming practices and cultural customs, 2) Establishment of farmer field school, training of trainers and collective action programs, 3) Access to tolerant varieties, mineral fertilizers, and broadleaf herbicides from local suppliers in affordable packages, and 4) Loan facilities for producers that are adopt control technologies and practices.

Production Costs and Customers Segmentation. Use of improved varieties with Striga tolerance, organic and mineral fertilizers, and post-emergent broadleaf herbicides to manage the parasitic weed and enhance sorghum and millet yields requires investment by farmers. Micro-dose fertilizer application and pulling of weeds by hand are labor intensive and involve necessary opportunity costs if this parasitic weed is to be eliminated. Training of trainers, farmer field schools and community mobilization involve substantial expenses by committed specialists that requires investment by national agricultural programs and NGOs. Tolerant varieties of sorghum and millet must be multiplied and delivered to farmers through commercial seed companies or community-based schemes.

Community action to uproot Striga

Potential Profitability. Uprooting of Striga and micro-dose fertilizer application through collective input purchase by farmers in Mali led to an increase of sorghum and pearl millet yield by up to 60% within four years. The use of improved variety and fertilizer micro-dosing in sorghum production has shown to double revenues to US \$241 ha^{-1} whereas conventional practice earned farmers US \$122 ha^{-1}. For millet, the use of premade mixes of seed and fertilizer generated an income of US \$209 ha^{-1} and micro-dosing of fertilizer between US \$168 ha^{-1} and \$180 ha^{-1}. The higher production of small grain crops achieved through proactive Striga management on infested and nutrient depleted croplands directly improves the food security and livelihood households. Crop rotation and intercropping with cowpea or groundnut provide a more nutritious diet and a secondary source of income. Decreases in Striga infestation and improvements of soil fertility create long-term benefits and higher returns on investment along the entire value chain.

Licensing Requirement. Multiplication of tolerant varieties must comply with national requirements on seed systems. Marketing herbicides often requires approval by pesticide regulators. The interventions and practices for Striga management in sorghum and millet systems are a Public Good disseminated by ICRISAT and other organizations.

Technology 7. Biological Control of Insect Pests with Natural Enemies

Millet Head Miner

Summary. The millet head miner (*Heliocheilus albipunctella*) is the most important insect pest of pearl millet in the Sahel. These moths deposit their eggs on the heads of millet and hatched caterpillars mine into the seeds of the millet head. It can cause complete crop loss but more often losses occur in the range of 40% to 80%. Without control measures, the population of millet head miner accumulates over time, leading to food scarcity even during years of better rainfall. Infested plants often exhibit a spiral-like pattern of damage to the grain head. Young caterpillars are light yellowish and become reddish as they grow. Later the caterpillar drops to the ground and burrows into the soil to pupate and emerge as adults. Early planted crops or early maturing millet varieties are more prone to severe infestation. Cultural and chemical approaches offer partial control, particularly deep plowing during the dry season to expose pupae to natural enemies and desiccation. The Fall Armyworm (*Spodoptera frugiperda*) is an invasive moth species spreading across Sub-Saharan Africa since 2016. It attacks sorghum and other crops, consuming leaves and causing yield loss of 50% or more. Adult moths of this pest can fly large distances and infest farmlands by depositing its eggs into the soil and on the plant. In response to the fall armyworm outbreak, international agencies and governments promoted chemical pesticides through seed coating and spraying services. These actions were moderately successful in containing the invasion but are not sustainable over the long-term. Promoting natural enemies offer more lasting protection against the Millet Head Miner and Fall Armyworm that do not pose dangers to food safety and the environment. For more information contact Dr. Dougbedji Fatondji of ICRISAT at d.fatondji@cgiar.org.

Technical Description. Biological control strategies for Millet Head Miner and Fall Armyworm are based upon natural mechanisms. It involves indigenous enemies and predators of the pest and releasing these in the field to prevent outbreaks and severe crop damage. The principle is maintaining an active population of beneficial predatory and parasitic organisms through informed stewardship. In addition, when the population of natural enemies becomes too low it may be increased through simple rearing techniques and augmentative release. Biological control of the Millet Head Miner is accomplished using the parasitoid wasp *Habrobracon hebetor*, which attacks the caterpillar. Recent work in Africa shows that the parasitoid wasp *Telenomus remus* is a promising biocontrol organism to prevent outbreaks of the Fall Armyworm as it parasitizes eggs of the pest. The acceptance and skillfulness of farmers are key for using natural enemies in millet and sorghum production systems. Farmer Field Schools train stakeholders on identification and surveillance of insect pests and their natural enemies as well as on rearing and release techniques of the parasitoids. Biological control techniques can readily be combined with other practices such as use of pest-resistant varieties, shifting planting dates and removing early affected plants as part of an Integrated Pest Management strategy.

Uses and Composition. The principles of biocontrol strategies against the Millet Head Miner and Fall Armyworm are applicable in all millet and sorghum growing areas of Sub-Saharan Africa, ranging from semi-arid (dry) to sub-humid climates. Augmentative releases however must align with the physiological traits of natural enemies and the native communities of beneficial organisms. In semi-arid regions, parasitoid wasp populations may fall to critically low numbers during the dry season because of a shortage of hosts and benefit from release each year. Another limitation of the biocontrol technology is its incompatibility with spraying of pesticides. This is especially the case when chemicals are applied early in the season, as they negatively affect biocontrol agents. Releases of beneficial organisms can be performed in two ways; 'inoculative' where a limited number are introduced and populations build over time, or 'inundative' where mass rearing takes place and large numbers are dispersed. The inoculative technique is suitable for long-term intervention, whereas the inundative technique immediately results in suppression of pests. Reproduction and survival of natural predators and enemies can be enhanced by providing alternative hosts or favorable nesting and feeding sites.

Natural enemies of millet head miner (top, Credit: Nils Linek) and fall armyworm (bottom, Credit: ICIPE)

Application. Implementing biological control of the Millet Head Miner and Fall Armyworm starts when critical thresholds of harmful and beneficial populations are exceeded. Monitoring may be performed with simple tools such as traps and magnifying glasses, or with advanced high-resolution cameras fitted onto drones that allow rapid surveillance of large areas. Mass rearing of *H. hebetor* or *T. remus* is possible in laboratories or on-farm using an easy and low-cost technique. This involves a jute bag of 10 cm long and 7 cm wide that is filled with 50 g of millet grains, 30 g of millet grain flour, and 25 larvae of the rice moth *Corcyra cephalonica*, and two mated females of the parasitoid wasp. It takes about 8 days for biocontrol agents to reach adult stage, and on average 70 parasitoids are produced from one jute bag in 10 days' time. Mated females for rearing biocontrol organisms need to be supplied from local multiplication centers. For release, three jute bags containing the parasitoids are placed in the field with one bag in the middle and the others at both ends at the beginning of the heading stage of millet. Parasitoids exit through the meshes of jute bags and disperse through flight. Rearing *T. remus* is done by collection of sorghum leaves that are infested by fall armyworm eggs and exposing to a mated female wasp in plastic flasks for 2 days using a ratio of 20 eggs to 1 wasp. The female *T. remus* can be given fresh egg masses every 2 days to parasitize until her death. Each female produces approximately 200 adults. Release of *T. remus* on farms is conducted from the windward side of the field. Augmentation of biocontrol organisms from only a few locations provides effective protection to an area of 5 km^2.

Commercialization and Start-up Requirements. Mass releases of parasitoid wasps is currently used for combatting Millet Head Miner in Burkina Faso, Mali, and Niger. Biocontrol techniques for insect pests are usually offered as part of a public extension campaign. A number of steps must be taken to enable widespread implementation of this technology: 1) Determine critical levels of the insect pest and its natural enemies when risks of outbreaks and crop damage occur, 2) Establish monitoring protocols and schemes that guide the planning of parasitoid rearing and release, 3) Run awareness campaigns about the advantages of biological pest control over the short- and long-term, 4) Train extension agents and farmers about mass-rearing and augmentative release techniques, and 5) Organize supply of low-cost materials, substrates and mated females for starter colonies.

Distribution of biocontrol agents (left) and training of farmers for mass release (right)

Production Costs. Implementing biocontrol strategies for head miner and armyworm in millet and sorghum production systems has several capital and operational costs. Surveillance of pests and their natural enemies requires substantial labor and is best conducted by specialists from national agricultural research center in collaboration with lead farmers. Rearing parasitoid wasps requires investments in jute bags, grain and flour substrate, and mated females, as well as cost of labor. A facility for rearing colonies of parasitoid wasps that serves more than 10,000 farmers can be built for only US $5,000 and needs US $6,000 per year to operate. The full cost to assemble "ready-to-use" bags is approximately US $3-$4 each but this can be reduced when operating at larger scale. It is possible to transport these bags for up to 500 km without losing the viability, which allows sales across large areas but with additional cost for shipment.

Customers Segmentation and Potential Profitability. A diverse set of stakeholders engages in the deployment of biocontrol agents. Extension agents or agrodealers supply starter colonies, rearing equipment, and technical advisory. Lead farmers take charge of the rearing and release. Programs in Niger and Senegal show that the release of *H. hebetor* leads to mortality of 60% to 80% of miners and yield increase of at least 30%. Augmentative release of *T. remus* accelerates parasitism of fall armyworm eggs in sorghum fields by a factor of 4.7. A business model showed that rearing *H. hebetor* was financially viable when 12,000 bags were sold across 500 villages. The net return of parasitoid rearing enterprises strongly depends on the market price of millet grain and transactional fees charged by aggregators or cooperative societies. Scaling programs of "ready-to-use" bags and increased demand for parasitoids stimulate the rearing of parasitoids by community-based businesses.

Licensing Requirement. Permits from national plant health agencies are needed for the rearing and release of natural enemies. Biological control techniques for millet and sorghum are a Public Good that is commercialized by ICRISAT in collaboration with local partners.

Technology 8. Mechanized Tillers, Planters and Fertilizer Applicators

Motorized walking tractor for tilling and ridging

Summary. Farm activities such as land preparation, sowing and fertilizer application are largely performed by hand in small-scale millet and sorghum production systems. Farmers endure physical drudgery to cultivate their land and bear the cost of maintaining draught animals or services. Low and erratic rainfall in millet and sorghum growing areas narrow the window for planting without, intensifying labor demand. Recommended practices such as precision sowing and fertilizer micro-dosing (see Technology 5) are time consuming when performed by hand. These different factors counteract the intensification of agriculture on existing croplands and its expansion into new areas, which are needed to improve food and nutritional security. Mechanizing tedious farm activities is of key importance to decrease labor costs, allowing more timely field operations, improving crop productivity, and generating higher profits. For more information on available mechanization technologies, contact Dr. Dougbedji Fatondji of ICRISAT at d.fatondji@cgiar.org, or Dr. Adama Coulibaly of the Institut d'Economie Rurale at adamacz097@gmail.com.

Technical Description. A large range of mechanized and motorized equipment is available that reduces the workload of farming for millet and sorghum producers. This includes walking-style power tiller, hand pushed planters, fertilizer applicator, small engine backpack brush cutters and paddle weeders, and power sprayer for applying chemical control agents. A power tiller has multiple uses. It performs shallow ploughing, rotavate to break large soil clumps, and build ridges and furrows for planting. Most walking-style tractors also pull carts for local transportation. Some also have power takeoff that connect to water pumps and threshers. A motorized planter and fertilizer micro-dose applicator, locally called "Sénékéla", was developed by Institut d'Economie Rurale in collaboration with ICRISAT as an alternative for manual and animal-drawn seeders. It ensures precise and fast placement of seeds and mineral inputs on finely harrowed soils or pre-made ridges. Agricultural machinery requires skillful use to make investments financially viable. Sharing equipment through rental services provides access to larger numbers of farmers who would otherwise not be able to afford this equipment.

Uses and Composition. Small-scale mechanization of land preparation, planting and fertilizer application is suitable for farmers growing millet and sorghum limited access to markets and infrastructure. The ideal size of land for power tillers and motorized planters is between 0.25 and 2.5 acre (0.1 to 1 hectare), for larger farms a four-wheel tractor is better suited. Equipment can be purchased by individual farmers or their associations or obtained through rental or contract services. The most efficient equipment is powered by internal combustion engines. The Sénékéla machine consists of a hopper containing the distributor disc, a four-stroke petrol engine of 6.8 HP and a 4-liter tank, two rear wheels that move the machine forward, and two front wheels that spin the distributor disc. Spacing between plant stands is adjustable and seed and fertilizer is placed in pockets at regular intervals by the distributor disc. A following skimmer and press wheel ensure that seed and fertilizer are adequately covered with soil.

Application. Hand operated planters for millet and sorghum and fertilizer micro-dose applicators are readily fabricated by local metal workshops. Motorized tillers, weeders and planters are imported, mostly from China or India. The use of power tillers, weeders and motorized planters requires a trained operator to ensure safe and effective use. Every day the engine oil levels must be checked. Settings of the rotor blades must be adjusted according to the desired tillage depth and width. To construct furrows, an opener must be set according to space between planting lines. Clearing straw and stones from rotor blades is crucial to prevent jamming that may damage the engine. Using mechanical hand planter is simple when there are no large clumps of soil following ploughing and harrowing and can plant on either a level surface or on top of pre-made ridges. The seed meter must be regularly checked and calibrated to ensure appropriate spacing and planting depth. Metering devices of planters and fertilizer applicators play a vital role by distributing the inputs uniformly at desired rates and row spacing. By rule of thumb, sowing a farm of one hectare requires walking 10 km. Since the machinery is lightweight, it is easily transported between fields. Maintenance of small-scale equipment is relatively easy because their engines are serviced like those of motorbikes, and many spare parts are locally available.

Mechanical planter for small grain crop

Commercialization and Start-up Requirements. A gradual shift is taking place from manual and animal farm operations to wider use of mechanical and motorized equipment. Private companies are increasingly importing this machinery and started manufacturing the Sénékéla motorized planter as demand from farmers grows. Actors seeking to enhance the uptake of modern farming equipment must: 1) Build public-private partnership for scaling and investment of small-scale mechanization, 2) Demonstrate labor saving and agronomic benefits of equipment to incentivize uptake by farmers, 3) Train farmers and operators in the maintenance and use of the planters and fertilizer applicators, 4) Establish local hiring centers for machinery and technical support that provides access in remote communities, and 5) Link community-based organizations, youth groups and individuals to credit facilities for purchasing or hiring small equipment.

Production Cost. Prices of tillers, planters, and fertilizer applicators largely vary depending on size, engine power, and manufacturer. Imported models are generally more expensive than locally fabricated types. A single-row planters for millet and sorghum pushed by hand cost between US $250 and $350. Suppliers in Africa sell power tillers with 7 to 12 horsepower engines for US $1,200 to $2,500 depending on the make, power, and attachments. The Sénékéla motorized planter and fertilizer applicator costs about US $1,000 and comes with one year warrantee on engine and parts. Fuel consumption is about 2 liters per hectare if regularly and appropriately serviced, and the machine has a lifespan of 10 years. The maintenance and repair costs for machinery is about 70% and 100% of its price.

Sénékéla planter and micro-dose fertilizer applicator

Client Segmentation and Potential Profitability. A diverse market exists for modern agricultural machinery in millet and sorghum growing zones. Motorized tillers, planters and fertilizer applicators are fit for agricultural service companies and larger associations. Hand-pushed planters and fertilizer applicators can be operated by individual producers or shared among farmers that cultivate a few hectares. Satisfying increased demand for mechanization services is a rapidly growing business investment opportunity. Manual and engine powered equipment is profitable because of low maintenance cost and fuel and labor expenses, the increased area of land cultivation, and improvement of yields by more optimal planting time and density. Sowing and fertilizer micro-dosing with the single-row Sénékale machine cuts the working time down to 2 hours per hectare whereas the same operation takes 8 hours with an animal-drawn machine and more than 64 hours when performed by hand. Substantial reductions in drudgery and labor costs are achieved through use of mechanized tillers, planters, and fertilizer applicators, which enhance income opportunities and livelihoods of farmers, especially among women and youth. Access to modern equipment makes agriculture more appealing as a choice of employment and promotes investments in other technologies described in this catalogue.

Licensing Requirements. There is no patent covering the production of the Sénékéla planter and fertilizer applicator. Blueprints and detailed building plans for some hand planters are freely available and may be fabricated without license. Manufacturers hold the intellectual property of equipment that is commercially fabricated and marketed. Training manuals for modernized operations are developed as a Public Good by ICRISAT and its partners and warrants replication throughout Africa.

Technology 9. Motorized Crop Residue Processing of Animal Feed

Forage chopper with in-built engine

Summary. Crop residues and stover from millet and sorghum offer an important source of livestock feed. When animals are herded over croplands only 20%-30% of stover is grazed since they prefer the leaves that are sweeter and easier to digest. Farmers normally chop stems into small pieces by hand so it can be fed to cattle, but this task is time consuming. The manual process limits the amount of millet and sorghum stem residues that farmers utilize for livestock. What is not fed to animals is often burned in the field, a practice that contributes to soil carbon depletion, local air pollution and unnecessary CO_2 emissions. To address the challenges of feed cost and seasonality, and to improve the management of agricultural resources, ICRISAT and its partners developed a mobile processor for millet and sorghum stover. It allows materials to be chopped or crushed for use as either feed or mulch. It is self-powered, easy to operate, low-cost and easily transported between fields. A large amount of crop residues can be processed with the machine by only just two people. It is suitable for different materials available during the wet and dry seasons. By increasing resource use efficiency, the chopper facilitates better integration of crop and livestock enterprises. More information on this equipment is available from Dr. Dougbedji Fatondji at d.fatondji@cgiar.org.

Technical Description. Access to quality feed is the most important factor in successful livestock rearing. Many farmers feed whole stover from millet and sorghum to animals, which reduces their digestion and leads to sub-optimal animal diets. Motorized choppers and crushers make it possible to provide suitable feed while saving time and effort. The technology serves both animal and crop production since crop residues fed to livestock produce manure which in turn improves soil fertility when returned to the field. Farmers obtain particularly large gains by combining dual-purpose millet and sorghum varieties (see Technology 2) with this chopper technology. Mechanized crop residue processing benefits storage and preservation of feed products by making it possible to compact the material in bags that can tightly packed instead of piling whole stover into a shed. Packing enhances flavor and nutritive value as well. Increased availability of chopped and shredded crop residues from millet and sorghum in addition to legumes such as cowpea is fundamental to local production of well-balanced feed rations. Chopped and crushed stover of millet and sorghum is also suited to produce silage. Through mechanized crop residue processing, farmers can earn additional income, rear larger numbers of animals, increase milk and meat yield, and avoid feed shortages during dry seasons or prolonged drought.

Uses and Composition. Motorized crop residue processing is ideal for drylands in Sub-Saharan Africa where people heavily rely on mixed crop-livestock farming and where availability of feed biomass is limited owing to lower levels of annual rainfall and frequent drought. The machinery can be used for either fresh and dry plant materials from a wide range of crops including sorghum, millet, maize, and cowpea. Chopping works best for green stover before fibers harden, while crushing is mostly done when crop residues have dried. Machines have four main parts; a pair of horizontal rollers that moves stover forward, a hexagonal shear cutter with knives, a hammer for crushing the chopped stover, and a 7 to 13 horsepower engine running on petrol or diesel. The small, two-wheeled motorized cutter makes collection of stover from the field easy and fast. This equipment may be offered as a package to individual farmers, their associations, other service providers or feed producers.

Use of motorized stover cutter (left) and mobile chopper (right)

Application. Crop residue processing machines are easily transported between fields and farms using a donkey cart of motorbike. Most models are fitted with wheels. Depending on the model, throughput capacities range from 1 to 1.5 ton of stover per hour. Choppers and hammers work at the same rate as the roller to ensure uniform sized feed material. The top and bottom roller turn in opposite directions so the stover moves steadily through the machine. After chopping, materials fall into the crushing chamber where hammers mounted on a rotating shaft revolve at high speed. Material is further ground through the beating action of the hammers until it passes through holes in an adjustable screen. Crushed material is pushed forward by the motion inside the chamber. The size, number and positioning of hammers is very important for desired and efficient operation. Regular checks of engine oil and moving parts must be performed for ensuring that the machine does not clog or become damaged. Operators must be trained on maintenance and safety to keep running costs low, obtain the desired size of feed and avoid physical injuries.

A bale prepared from dried, chopped sorghum leaves and stems

Commercialization and Start-up Requirements. The mobile chopper has been successfully commercialized with mixed crop-livestock farming communities in Mali, Niger, and Nigeria. Demand for the technology is rapidly growing thanks to its many advantages and dissemination by ICRISAT and national agricultural development agencies. To enhance agricultural productivity of crop-livestock farming system, the following steps are required: 1) Promote the stover chopper/crusher through demonstration sessions at community level, 2) Train operators in the maintenance and use of the machine, and 3) Link community-based organizations, youth groups and individuals to animal feed producers.

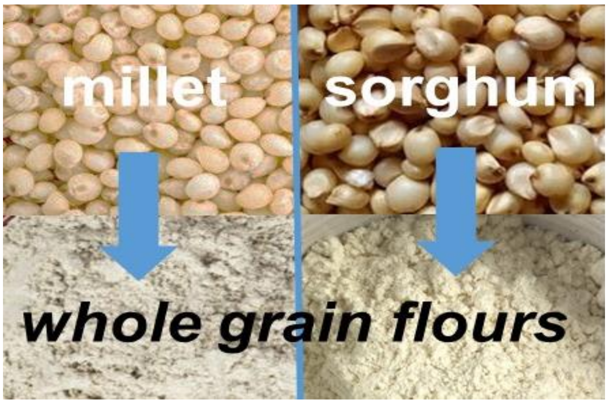
Removing cured silage prepared from sorghum leaves and stems

Production Cost. The price for a self-contained stover chopping and crushing machine ranges from US $1,250 to $1,700 depending on the size, the manufacturer, the country of origin. Imported models also exist but are more expensive than local fabricated ones. Machines usually come with one-year guarantee and have a lifespan of 10 years if well maintained. In the dryland belt of northern Nigeria, whole sorghum stalk costs between US $100 and $170 per ton on animal feed markets depending on the quality. The main operating expenses of chopping and crushing stover are the labor to collect materials on the field, carry it to a processing site, operating the machine, and loading bags with chopped or crushed feed. Fuel consumption ranges from 2.5 to 3.5 liter per ton of stover for different sized choppers. Alternative motorized cutters that can handle all types of cereals costs about US $ 1,000 to $1,500 on international markets.

Client Segmentation and Potential Profitability. These machines can be used by farmer associations and youth groups for service provision, or by animal feed processors. Processing stover from millet and sorghum offers an attractive business opportunity since added value is created and a market demand exists. Return on investment depends on the cost of whole stover, labor, fuel, and maintenance, which vary between locations and times of year. Machines provided to farmer associations in Niger led the production and sales of more than 100 tons of stover worth US $22,000 in less than six months. On animal feed markets in the drylands of Northern Nigeria, one ton of crushed sorghum stover sells for US $330 to $500 depending on the quality.

Licensing Requirements. Blueprints and detailed building plans for some mobile crop residue processors are offered as Public Good and may be fabricated without license. For commercially marketed models, the intellectual property is held by manufacturers. Training of manufacturers and farmers on the chopper machine across Sub-Saharan Africa is offered by ICRISAT and its partners.

Technology 10. Flour Milling and Blending Systems

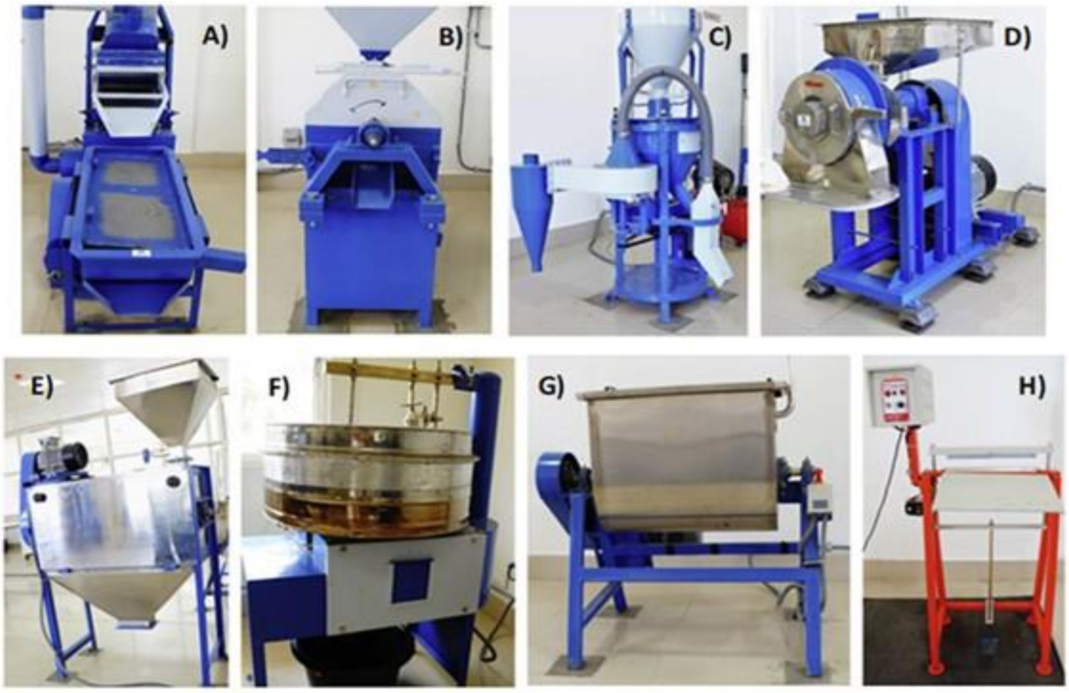


Flours prepared from pearl millet and sorghum

Summary. The time and energy required for grinding and cooking the grains of millet and sorghum for consumption poses a burden in home kitchens and restricts its appeal in urban centers. Farmers and traders can quickly add value to millet and sorghum by milling their grains into flour that is easy to use and ready for blending with other flours. Millet and sorghum flour are gluten-free and suitable for a variety of food products such as bread, biscuits, cakes, porridges, and even pasta. Techniques for flour milling however must meet industry quality standards and consumer preferences. Different small- to large-scale milling and blending systems are available that allow production of premium flour products in both rural and urban areas. The advantages of local flour processing are the reduction in transport and costs to rural consumers and value addition to raw grain of products sold to urban markets and food processors. Building capacity of rural communities for millet and sorghum milling and its blending into multi-purpose flour can massively boost output, value addition and competitiveness of local processors. Further details on this topic can be obtained from Dr. Dougbedji Fatondji of ICRISAT at d.fatondji@cgiar.org.

Technical Description. Millet and sorghum as food crops have a high protein content and well-balanced amino acid ratios, allowing for expansion of their agro-industrial applications. At the same time, whole millet and sorghum have long cooking times that can be considerably reduced through processing. In this way, practical and economic advantage is derived through milling millet and sorghum into flour. Producing flour may be considered a business art that begins with selecting the right factory location, followed by procuring the right variety at the right price, followed by cleaning, milling, and blending. Locations for processing should be close to major growing areas that can provide a reliable supply of quality grains and have convenient transportation routes for easy delivery of raw and shipping of final products. In selecting the millet and sorghum varieties for milling and blending, it is important to take the hardness into consideration because it strongly affects annealing strategies of heat treatment to relax starch structures. Blending procedures must also be conducted in accordance with sedimentation and index values that determine flour quality which are closely watched by food manufacturers. Another purpose of annealing ensures the optimum moisture level for milling and to enhance flours wetting ability. Modern milling equipment ensure that a very high proportion of flour is obtained by sequential crushing of the grain leading to size reduction of the flour by steel rollers.

Uses. Sorghum flour is a gluten-free flour with a mild, sweet flavor and smooth texture. It's commonly used to make gluten-free cakes, breads, and other baked goods, either on its own or in combination with other gluten-free flours such as rice and cassava. It can be used as a 1:1 all-purpose flour substitute in just about any recipe. Sorghum and wheat flour blends are well suited to baked products, including yeast-leavened bread, flatbreads, cakes, muffins, cookies, biscuits, and flour tortillas. Millet flour has a subtle, slightly sweet flavor. It is used in the same way as sorghum flour and as a 1:1 substitute for wheat flour, particularly in pancakes, flatbreads, muffins and cakes. It works well in savory recipes such as pizza crust and fritters, and makes a good thickener for stews. In addition, millet flour is used in a wide variety of Indian recipes. In comparison to conventional preparation by lengthy boiling, use of flour offers substantial savings on cooking time and fuel cost, and improves the bioavailability of vitamins and micronutrient in derived food products. Flour milling and blending technologies for millet and sorghum improve African food self-sufficiency and promote business development in rural communities. Millet and sorghum flour blended with wheat flour reduce dependence upon imported wheat. Small-scale equipment is relatively simple to install but require reliable sources of electricity.



Key equipment for rural community-level millet and sorghum processing enterprises: A) Destoner with Aspirator and Grader, B) Dehuller, C) Mill, D) Pulveriser, E) Flour sifter, F) Roaster, G) Blender, and H) Bag sealer (Source: Alavi et al., 2019)

Composition. Pearl millet's average composition is 70% carbohydrates, 16% protein, 5% percent fat and 3% ash. It is higher in phosphorus, iron, and calcium than maize or wheat. Sorghum typically contains 63% carbohydrate, 11% protein, 3% fat and 2% ash, with varieties containing lower amounts of tannin most suitable to flour production. Both grains are gluten-free and have numerous documented health benefits including boosted immunity and reduced blood cholesterol.

Application. Before establishing a flour milling enterprise, there is need for market research to identify viable business models. One must be sure about location, supply, and market so investments are not made at the wrong location. One also needs to perform a comprehensive analysis of the investment needs for capital equipment, labor costs and other fixed and variable costs. Based upon this information, suitable finance mechanisms can be identified for approaching investors. When funding is secured, then equipment for cleaning, annealing, and milling must be purchased and assembled into a flour processing line. Reliable supply of electricity is very important and backup systems should be in place. There is need for continuous quality assurance of the flour to ensure product compliance with market standards on sedimentation and index values. There is a wide range of equipment for processing millet and sorghum grain. A typical air-screen cleaner consists of four screens that are located beneath a hopper. Grader machines that sort out impurities based on width and thickness are comprised of cylindrical screens that are horizontally positioned and have round perforations. Separators that select grains by length, density or gravity use angular sieves and forced air, which can be adjusted according to specific needs. An abrasive grain mill has a feed-in hopper, roller table for grinding, rotary sieve for bran separation, and a conveyor belt.

Commercialization and Start-up Requirements. Equipment for cleaning, annealing, blending, and milling of millet and sorghum are available from manufacturers and retailers in many African countries, though some equipment must be imported or modified. The following steps are needed for enterprise development around flour milling and blending: 1) Raise awareness with farmers, agri-food companies and investors on the economic benefits of the technology, 2) Formulate appropriate product standards, packaging sizes and prices based on consumer demand, 3) Identify profitable, durable and equitable strategies for taking flour products to local, regional and international markets, 4) Establish reliable supply of high quality grain to processing plants through nucleus farming or sub-contracting, 5) Set up equipment and production lines that make efficient use of energy and labour, and 6) Train operators and workers on safety and quality adherence throughout the manufacturing process.

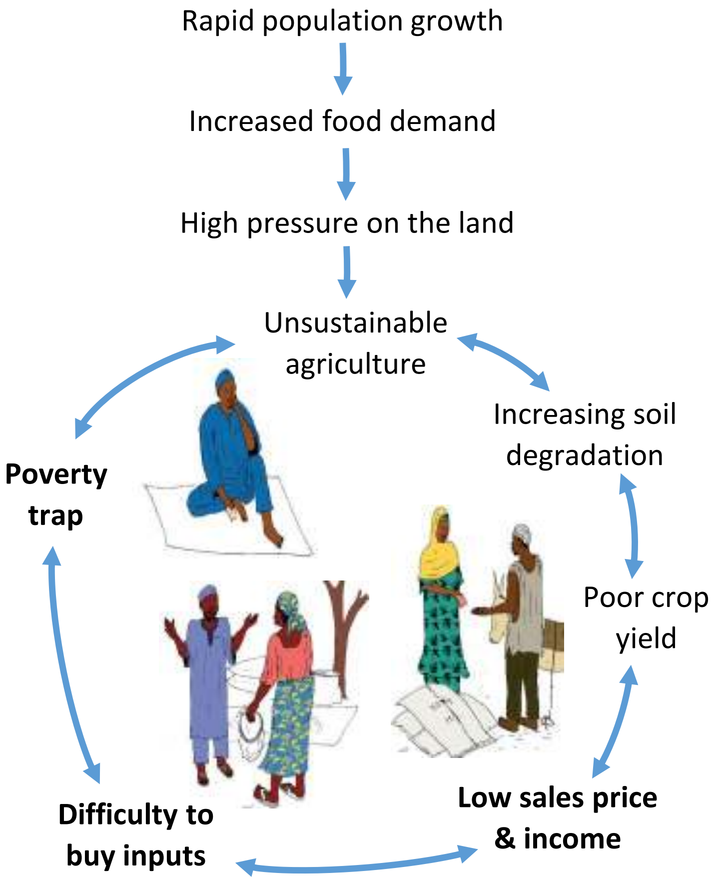
Production Costs. The prices of millet and sorghum at the farm gate are a major determinant of the economic viability of a milling enterprise. Exact costs of a flour milling depend on the geographic location, size of operation and equipment selection. In general, 60% of the capital investment that is required to set up a processing plant goes into equipment, while the rest to construction and marketing. A small flour mill that is manually refilled with an output capacity of 300 - 500 kg flour per hour costs around US $3,500. The base price for a fully automatic flour mill with a capacity of 30 ton flour per day is about US $38,000. Operating a flour mill requires skilled labour to ensure that production runs smoothly, and equipment is properly maintained and a manager to keep track of expenses, supply, inventory, and sales. Regular inspections of equipment by a professional technician and replacement of high-wear parts ensures continuity of operations.

Customer Segmentation and Potential Profitability. Flour milling and blending systems are applicable to industrial flour processors and food manufacturers and can be modified to suit the needs of more localized processors and community-based activities. It also requires that consumers accept the products resulting from blended flours. High-performance cleaning systems for ensure very low percentages of non-millable material that would otherwise reduce milling efficiency and revenues. In general, a 1% reduction in non-millable fraction provides an additional US $3 per tonne of flour. Modern equipment for annealing and milling wheat grain achieve maximal recovery of flour at 80%-82% and 18%-20% bran, whereas traditional manual techniques and older milling systems recover only 65%-70% flour. Better annealing and milling realized from modern equipment improve flour quality and market price. Altogether, the effect of running at higher efficiency versus lower milling efficiency provides additional net profit of about US $30 per ton of flour.

Licensing Requirements. Obtaining a license from regulators and registering your factory is important to the success of a flour milling business. This involves periodic inspection to assure that quality standards are met. Techniques for production of sorghum and millet flour are a Public Good, and ICRISAT and other organizations, including National Bureaus of Standards, are actively involved in disseminating this information across Sub-Saharan Africa.

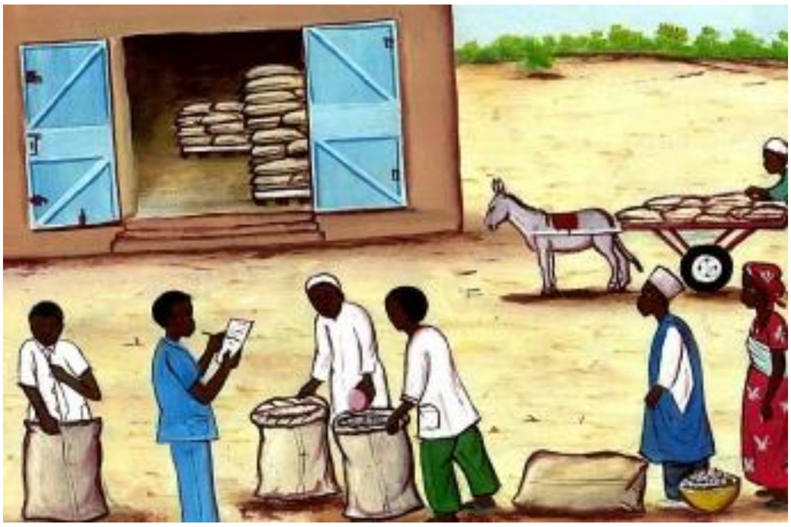
Technology 11. Warrantage Inventory and Credit System

Summary. Limited access of small-scale farmers to favorable markets and reliable storage facilities is one of the key causes of food insecurity and pervasive poverty across millet and sorghum production areas. As a result, farmers are forced to sell their grain at peak production times for low prices. Later in the year, food prices increase but poorer households are unable to save their produce until then. Reduced income makes it difficult for farmers to purchase inputs for the next season without acquiring commercial loans, but these demand collateral that are difficult to meet. High interest rates set by commercial credit systems can lead to debt traps and food insecurity loops. In response, the warrantage inventory and credit system was designed to provide sustainable financing of investments in agricultural production across communities of small-scale farmers. Details about this solution can be obtained from Dr. Dougbedji Fatondji of ICRISAT at d.fatondji@cgiar.org.



The vicious food insecurity loop

Technical Description. Warrantage is a warehouse receipt system that provides inventory credit for stored grain that is adapted to rural areas and smallholder families. It is limited to 'non-perishable' agricultural produce that have a track record of rising prices in the months following harvest such as millet, sorghum, and other grains. Through the inventory system, farmer organizations and their members obtain loans against the stored commodity that is gaining value during over the borrowing period. This security agreement governing the credit between Warrantage managers and depositors stipulates that in the event of non-payment by the farmers group, the financial partner will be entitled to sell the stored product to recover what is due. This allows the lender to avoid loss in the case of repayment failure, which drastically reduces risk and interest rates. Households acquire financial capacity without altering their household budget, since they benefit from the price differential between the time of harvest when produce is abundantly available and the dry season when there is short supply of food leading to higher prices. Loans enable households to address some urgent financial needs, engage in collective fertilizer and seed purchase, and start income-generating activities like fattening of small ruminants, vegetable gardening and small trading during the dry season. The approach also encourages farmers to work together in protecting stored grains from insect damage and engage in bulk purchase of inputs followed by repackaging in smaller, more affordable quantities. Warrantage systems bypass intermediary traders without disrupting supply of wholesale and urban markets, and without hiking prices. The approach does burden farmer organizations with a large risk of post-harvest damage by insects and other pests. A well-functioning inventory credit system requires support from local financial institutions and a country's banking regulations must accept agricultural produce as a guarantee for lending.



Farmers deliver grain to warehouse, and an officer registers the quantity and quality

Uses and Composition. Warrantage credit systems are highly suitable for smallholder farming communities from Sub-Saharan African that lack favorable bank lending for agricultural investment and where debt leads to poverty and economic marginalization. In addition to being a cash management tool, the warrantage system also manages larger economic risk. This approach offers major benefits for millet and sorghum growing areas in semi-arid humid climates. The main actors collaborating in the implementation of a warrantage operation are the umbrella farmer unions and federations, and the grassroots producer organizations and their members. These link with private lenders such as decentralized financial systems or public extension services. All these bodies have an "inventory credit committee" with a chair, a treasurer, and a warehouse manager. The inventory credit committee of the different grassroots producer organizations plays an active role in all stages of inventory credit, especially in the management of warehouses and their stored products. Those that do not own warehouses have to negotiate the hire premises. Inventory credit committees and their executive bureaus handle the general coordination, set the purchase price of products, negotiate, sign contracts with lenders and buyers, and distribute credit. They also support members in training, monitoring, accounting, and arbitration. Some unions and federations contribute to the financing of inventory credit from their own working capital.

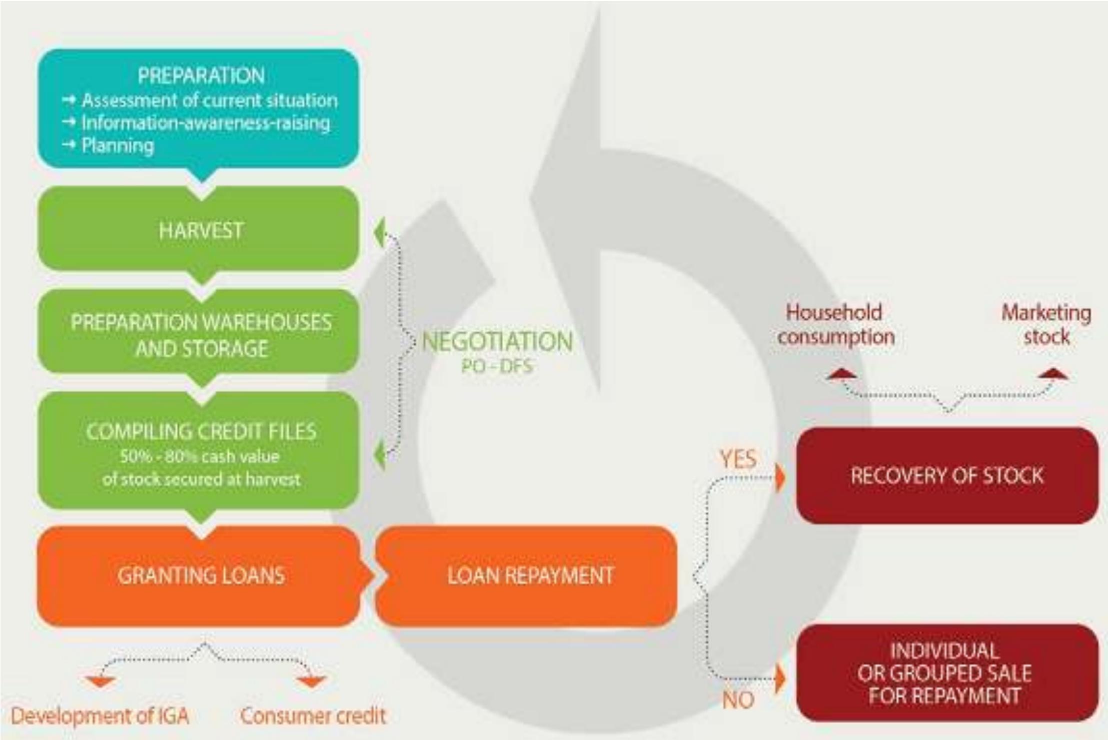
Application. The operational framework to implement a warrantage inventory credit system involves several key steps. Just after harvest, a fair purchase price for farm produce is established during a meeting of the inventory credit committee and representatives of the grassroots organization. Prices follow local market rates. It is at this stage that detailed timetables for storage and withdrawal of stock are agreed upon. Once these arrangements have been made, the union requests a loan from a financier for the inventory operation. Prior to each harvest season, warehouses are cleaned and organized to receive the new stock. Each farmer arranges the transport of produce that he or she is placing under inventory. The operation is supervised by the inventory credit committee of grassroots producer organization who check and register the quality and weight of crops, and the packaging used. New sacks must be used to ensure optimal protection against pests and need to be distinguish each season's produce. In the process, the inventory credit committee officers secure the warehouse. Once stocks are verified, the warehouses are closed with two padlocks. Keys for one lock remain in possession of the inventory credit committee secretary, and keys for the other lock are kept by the financing body. Based upon the contract, grassroots producer organizations or farmer groups receive cash funds from the loan for distribution to its members as per the amount and the type of stored produces. Warehouses are opened periodically during an inventory credit season by the producer organization and lender to check the condition of stored produced. Owners of sacks that have been attacked by pests are alerted and must have the contents treated before their return. About five months after depositing produce, farmers must settle their loans before withdrawing sacks from the warehouse. The borrowed sum is reimbursed to the lender in a single payment, though unions or producer organizations may accept partial repayments over the warrantage period. If the loan settlement is delayed, penalties are charged to farmers.

Commercialization and Start-up Requirements. Warrantage inventory credit, often tied to seasonal micro-dose fertilizer supply (see Technology 5), has been taken up by more than 350,000 farmers in Burkina Faso, Mali, and Niger. For the system to be implemented there is need to: 1) Strengthen the capacity of farmer associations on price negotiation, loan investments and input delivery, 2) Support supervising unions and federations in efficient and transparent registration and maintenance of guaranties, 3) Build or rent clean secure warehouse facilities and provide quality sacks so grain is safe from pests and thieves, 4) Inject private and public equity into decentralized financial services for lending to farmer associations, and 5) Harmonize government and banking policies that recognize agriculture produce as collateral and avert excessive dumping onto local markets during the lean season.

Production Cost. Implementing a warrantage inventory credit system involves different direct and indirect expenses. Farmers must appropriately prepare the grain of sorghum and millet, separating chaff and stone, and drying it to 10% moisture, so warehouse space is optimally used, and price and quality standards are met. Sacks for packaging produce must be purchased by farmers; woven polypropylene 90-kg bags cost between US $0.25 - $0.5 each. Alternatively, hermetic bags with a high-density plastic inner liner are used that prevent mold formation or insect attacks, costing US $1 - $2 per 90-kg bag. Unions, producer associations or farmer groups need to rent, build, or repair storage infrastructure that exclude storage insects and dishonest persons. Hiring guards to secure the warehouse usually costs US $75 to $150 per month and is a cost borne by the borrowers. Training of inventory committee members on warrantage and credit management requires support from extension services and NGOs.

Inspection of a warrantage warehouse

Lenders incur travel costs to register and monitor stocks, but these are reduced under the warrantage system as producer organizations are partially responsible for this task. Administrative procedures for inventory management, funds disbursement and loan repayment form an indirect cost for farmers and lenders.



Operational framework and implementation stages of warrantage (Credit: FAO)

Customer Segmentation and Potential Profitability. The warehouse receipt system has a diverse set of partners, including farmer organizations, microfinance institutions, technical extension services, agro-input suppliers, and food processors. Small-scale producers must unite in a group to access this type of credit. Warrantage credit systems established by ICRISAT and other institutions show large potential for enhancing the access of farmers to credit and cash, as well as more affordable production inputs and fairer commodity buyers. Farmers in Burkina Faso, Mali, and Niger saw their income grow by 52% to 134 % owing to a higher market price, additional income generating activities, and reduced fertilizer costs. Profits from the warrantage system allows farmers to purchase better seeds and fertilizers, which increase crop yields by 44% to 120%. Surveys with 58 inventory warehouses in Burkina Faso reported that 60% of members were women and served as key recipients of agricultural credit. The warehousing system also increases the food sufficiency period of benefiting rural communities from six to more than ten months. Further advantages of the credit scheme for farmer communities and rural development are avoidance of high interest rates, diversification of income streams, increased food supply and earning from agriculture outside the rainy season, and economies of scale by better structured demand for inputs. The inventory credit approach has major scope for transforming livelihoods in small-scale farming systems of Sub-Saharan Africa.

Licensing Requirements. Operational frameworks and manuals for this innovative credit system have been developed by ICRISAT and its partners as a Public Good and can be reproduced without a license.

Make TAAT Your Technology Broker of Choice

The TAAT Program offers its services toward the advancement of modernized agriculture. It brokers a wide range of needed technologies and bundles them through a process of co-design into winning solutions. It recognizes that modernized agriculture must serve as the main engine for economic growth in Africa and operates accordingly. Change is intended to achieve not only food and nutritional security but also to meet obligations under climate agreements allowing collaborative efforts to better combine global, national, and community-level interests. TAAT operates from a unique perspective to mobilize innovative solutions through better partnering that includes honest technology brokerage and effective, scalable skills development through five key mechanisms.

- ☑ **Unique understanding:** Expertise is offered in the areas of site characterization and problem identification.
- ☑ **Innovative solutions:** Leadership is provided in technology brokerage and solution bundling based upon a dynamic portfolio of candidate technologies.
- ☑ **Better partnering:** Assistance is offered in the better co-design and management of projects prompting agricultural transformation.
- ☑ **Replicable approaches**: Assistance is available to advance skill sets in technology brokerage and project management through customized Training of Trainers activities.
- ☑ **Honest brokerage:** An independent capacity for impact assessment and constructive learning is achieved through standardized monitoring and evaluation.

These partnership mechanisms are applied to the technologies featured in this catalogue as:

1. **Improved Varieties of Sorghum and Millet** offering the latest advances in breeding for heat and drought tolerance, rust, and insect resistance, as well as biofortification.
2. **High-quality and Timely Seed Systems** offering accelerated multiplication and delivery of elite millet and sorghum varieties via community-based and commercial avenues.
3. **Sustainable and Resilient Production Systems** suited to both small-scale and commercial producers through the bundling of proven technologies.
4. **Farm Mechanization and Service Contracting** will increase access and use of power equipment for labor-efficient field operations crucial to reducing production costs and work drudgery and increasing yield.
5. **Market-Oriented Value Addition** allows increased opportunities in agro-industrialization and reduction in costly food imports through product substitution.

The TAAT Clearinghouse and Compacts are ready to assist in the design of national programs seeking to improve food and nutritional security, reduce importation of food and develop greater capacities to enter world trade through agricultural exports.

Conclusions

This catalogue provides a wide variety of options for modernizing millet and sorghum production and processing in Africa. It identifies means to improve yield, increase production, and reduce post-harvest losses for both crops. It provides options to improve household diet, improve animal feeding quality efficiency and enhance crop-livestock integration likewise reducing farmer vs herder conflicts. It also provides options to rehabilitate lands initially lost to agricultural production, hence contributing to empower rural women who can contribute to household welfare. Special attention is given to biological control as the most environmentally friendly means to control the major pests of both crops. This catalogue is not an exhaustive one in terms of millet and sorghum production innovations; however, it is meant to show some of the major ones. Millet and sorghum are very nutritious staple crops for the Sahelian population and play an important role in the diet of the people as well as an important contributor to the people's health. This catalogue was prepared with contribution of scientists with proven expertise in the millet and sorghum research domain. It is meant for a variety of users whether they be producers, agents of agricultural development or private sector investors. Farmers can use many of these catalogue items as production guidelines. Those from the public sector can utilize the catalogue as a whole and design agricultural projects involving millet and sorghum technology toolkit. Members of the private sector, including seed companies, input manufacturers, processors and investors can also benefit from the contents of this catalogue. Indeed, the Technologies for African Agricultural Transformation Program's Clearinghouse welcomes feedback on its contents.

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Acknowledgements

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Technologies for African Agricultural Transformation (TAAT) and its Clearinghouse Office

The development objective of TAAT is to rapidly expand access of smallholder farmers to high yielding agricultural technologies that improve their food production, assure food security, and raise rural incomes. This goal is achieved by delivering regional public goods for rapidly scaling up agricultural technologies across similar agro-ecological zones. This result is achieved through three principal mechanisms: 1) creating an enabling environment for technology adoption by farmers, 2) facilitating effective delivery of these technologies to farmers through a structured Regional Technology Delivery Infrastructure and 3) raising agricultural production and productivity through strategic interventions that include improved crop varieties and animal breeds, accompanying good management practices and vigorous farmer outreach campaigns at the Regional Member Country level. The Clearinghouse is tasked with the responsibility to guide the deployment of proven agricultural technologies to scale in a commercially sustainable fashion through the establishment of partnerships that provide access to expertise required to design, implement, and monitor the progress of technology dissemination campaigns. In this way, the Clearinghouse is essentially an agricultural transformation incubation platform, aimed at facilitating partnerships and strengthening national agricultural development programs to reach millions of farmers with appropriate agricultural technologies.

Dr. Innocent Musabyimana, Head of the TAAT Clearinghouse

Back Cover: Sénékéla planter and fertilizer micro-dose applicator (left), and Bracon parasitic wasp on moth caterpillar (right). Photo Credits: ICRISAT Stock Photos and Nils Linek.

Millet and Sorghum Technology Toolkit Catalogue

In collaboration with: