Climate-Smart Agriculture Technologies for the Sahel and Horn of Africa

TAAT Clearinghouse

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Climate-Smart Agriculture Technologies for the Sahel and Horn of Africa

The Technologies for African Agricultural Transformation (TAAT) is funded through a grant from the African Development Bank and is implemented by the International Institute of Tropical Agriculture (IITA) in close collaboration with other centers of the Consultative Group for International Agricultural Research (CGIAR) and specialized institutions such as the African Agricultural Technology Foundation (AATF), the Forum for Agricultural Research in Africa (FARA), the International Fertilizer Development Center (IFDC) and others. For more information, email contact: i.musabyimana@cgiar.org or plwoomer@gmail.com.

Front cover photos: Parkland agroforestry with groundnut in Senegal (left) and half-moon bunds water capture and storage technique (right). Photographic credits: P.L. Woomer and Farmbiz Africa.

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TAAT offers to become your broker of modernizing agricultural technologies!

Purpose

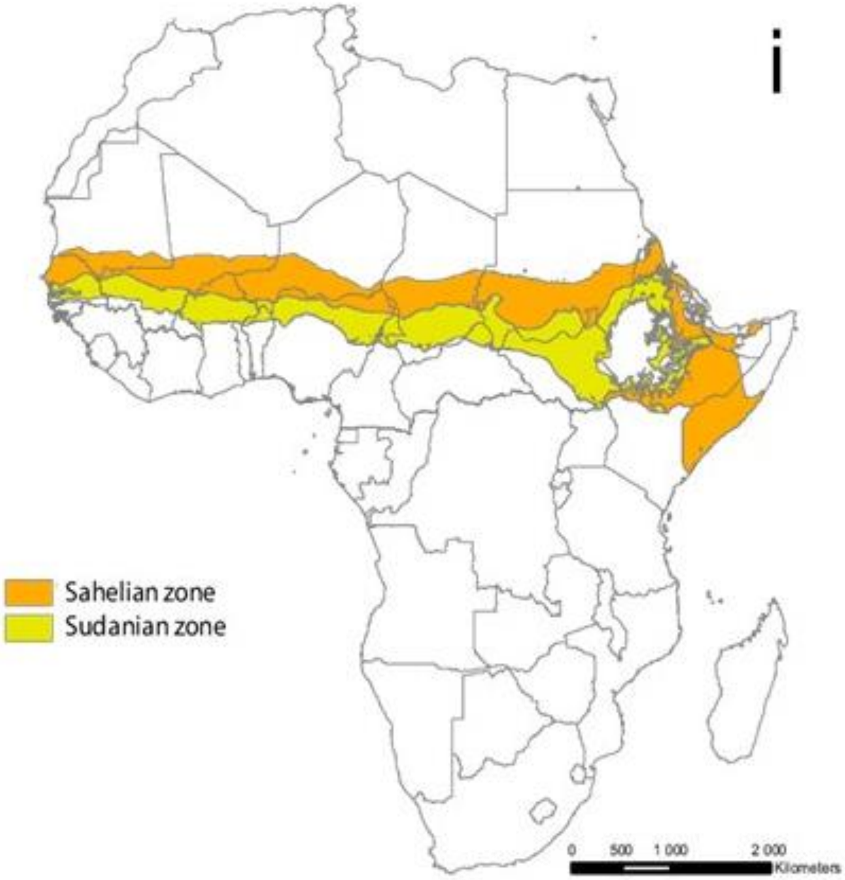
This catalogue describes a suite of farming solutions for drylands in the Sahel and Horn of Africa useful to climate change adaptation and mitigation. It is based upon the interventions of the Technologies for African Agricultural Transformation Program (TAAT). This Program is led by the International Institute of Tropical Agriculture (IITA) that has pioneered new approaches for 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 over 76 technologies through 88 interventions in 28 countries including nine countries in the Sahelian agro-ecological zone: Burkina Faso, Chad, Mali, Mauritania, Niger, Senegal, South Sudan, Sudan and Ethiopia. Innovations brokered by TAAT and featured in this catalogue also extend to countries located in the Horn of Africa (Djibouti, Eritrea, Somalia and Somaliland) as an extension of the Sahel. This zone is hugely impacted by climate change in terms of intensified drought and extreme weather, and this catalogue combines TAAT technologies that are useful within climate action efforts, including those being organized by The African Development Bank.

TAAT 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. This catalogue assists in the designing toolkits for rural development projects in African drylands and is intended for extension supervisors, project managers and investors.

The Programme for Integrated Development and Adaptation to Climate Change in the Niger Basin (PIDACC) operates through the Niger River Authority to directly address climate change adaptation and livelihood improvement in Benin, Burkina Faso, Cameroon, Cote D'Ivoire, Guinea, Mali, Niger, Nigeria, and Chad. This catalogue was produced in part to contribute to its training efforts. Sahelian farmers that adopt and exchange improved crop varieties, proactively manage pest outbreaks, better utilize water resources, and maintain soil fertility are in a much stronger position to secure food and income for their families and participate in meaningful climate actions. Sustainable intensification of dryland agriculture generates mitigative effects by increased biomass productivity and standing carbon stocks leading to carbon sequestration in soil organic matter, actions that further avoid greenhouse gas emissions from fertilizers

Horn of Africa is an AfDB regional project to deploy proven climate-smart agriculture technologies in Djibouti, Ethiopia, Kenya, Somalia, South Sudan and Sudan. This catalogue is intended to assist it to improve agro-sylvo-pastoral productivity and profits and enhance the adaptive capacity of the populations to better prepare for and manage climate risks. An important outcome of better managed and more productive lands is to reduce human conflicts in some of its countries. TAAT partners with Horn of Africa to provide technical backstopping. For more information on the featured technologies or other solutions toward transformative impact on agriculture in the Sahel and Horn of Africa contact Dr. Innocent Musabyimana at i.musabyimana@cgiar.org or visit the TAAT internet site www.taatafrica.org.

Introduction: Land and Water Management in African Drylands



Dryland farming is a necessity in the Sahelian zone of Africa, an area that supports a population of 40 million persons through the cultivation of about 27 million hectares. The Sahel is actually a transition zone about 400 km wide that stretches from the Atlantic Ocean in Senegal to the Red Sea in Djibouti and Indian Ocean in Somalia. It is also known as the drier savannah belt that stretches from West Africa up to the Horn of Africa. Landscapes are flat to gently undulating and rainfall at theses latitudes is concentrated in a single growing season between June and September, with a total annual precipitation of only 150 to 600 mm that is often deposited by only a few heavy storms. Daytime temperatures often exceed 40^{o}. The natural vegetation ranges from semi-desert in the north to woody grassland in the south. Millet is widely grown in the Sahel and Sudanese zones, but so too is sorghum and maize. New varieties of wheat can be grown too, particularly during the cooler months. Semi-nomadic pastoralism is widely practiced and overgrazing has led to extensive land degradation and desertification. The adjoined Sudanese Zone receives greater rainfall (600 to 1200 mm per year), but is confined to a 2-3 month window and its farmers are faced with the same challenges to crop production as their neighbors in the Sahel.

Agricultural production in the Sahel is perilous owing to severe and cyclical droughts. Various soil limitations exist due to low water holding and nutrient retention capacities and are often sandy and acidic. Because of their unfavorable soil physical properties and low nutrient reserves, agricultural soils of the African drylands present a challenge to farmers. Drought is the leading biophysical cause of food insecurity and human suffering. Clearly, farmers in the African drylands are acutely aware of drought as a chronic risk and regularly adjust their cropping strategies accordingly, seeking to take the best advantage of limited moisture availability. Farmers in the Sahel region are typically communal, living in central villages and farming land assigned to their families by local chieftains. Population densities in the agricultural areas remain relatively low, with 0.5 to 1.5 hectare (ha) available per capita. Land availability alone does not assure rural prosperity in the Sahel owing to the poor crop productivity resulting from low rainfall and chronic risk of drought. Indeed, given the severe conditions experienced by farmers in African drylands, large opportunities are presented for employing improved soil and water management technologies, including those important to climate actions.

A failed cereal crop in the Sahel, use of drought tolerant crop varieties is becoming a necessity

This catalogue is designed for assisting farmers in the Sahel to achieve food security and tackle environmental challenges posed by drought, land degradation and climate change. Featured technologies may be bundled into toolkits offering solutions to those seeking to modernize and transform dryland agriculture by combining improved crop varieties, more effective water conservation practices and proven approaches for soil fertility management. Varietal improvement is focused on millet, sorghum, maize and wheat that are more drought and heat tolerant. Better water management is achieved through water storage by contour bunds, water harvesting with zaï pits, diversion of seasonal floods, and small irrigation schemes. Practices for integrated soil fertility management involve rotation with legumes, fertilizer micro-dosing, strategic timing of nitrogen application and effective use of organic resources. Larger scale impacts are achieved through transition from open fields to agroforestry parklands, improved rangeland management and other climate actions specifically targeted to semi-arid agro-ecologies. These technologies are presented in a manner that makes them readily understood by development planners and impact investors seeking to enhance the lives and livelihoods of farmers in the Sahel and Horn of Africa.

Note that the 17 technologies included within this catalogue are those viewed as particularly important to the mitigation of climate change among the poorest farmers. The Sahel is one of the areas of the world that is unfairly penalized by industrial polluters in developed countries and the impacts of climate change it suffers are not of its own making. Inclusion of these technologies into international programs serves to correct this disparity.

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

Technology 1. Improved Varieties of Pearl Millet

A highly productive stand of pearl millet, a crop essential to farmers in the Sahel and that now offers biofortified varieties and improved seed systems

Pearl millet is the staple cereal in the harshest of the world's major farming areas: the arid and semiarid region extending between Senegal to Somalia. Withstanding hot, dry, sandy soils, it is adapted toward survival under harsh conditions rather yet it increasingly demonstrates an ability to respond to management, allowing for yield improvement. Millet evolved 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.

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. 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. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is responsible for millet improvement. ICRISAT varieties ICRI-Tabi, Mil de Siaka and ICMV-IS 89305 were selected for greater yield potential. Varieties GB 8735 and ICTP 8203 were selected for higher iron content. Many other improved varieties are available for testing by national systems or release to development efforts. 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 into the future. 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 the Sahel are well advised to take advantage of these new varieties and the flexible designs advancing millet seed supply.

Technology 2. Improved Varieties of Sorghum

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

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. It 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.

Plant breeding has added to these traits in strategic ways providing greater resistance downy mildew, anthracnose, and smuts; and to insects such as aphids and head midges. Selection for larger seed heads, stronger stalks, upright leaves and stay-green non-senescence further increase sorghum's productivity. Grains are selected for faster filling, lighter colors, higher protein and easier threshing. New lines of dwarf sorghum improve the crops harvest index. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is responsible for sorghum improvement, including in the Sahel. ICRISAT's SAMSORG breeding lines 47, 48 and 49 have many desired agronomic characteristics that are available through national systems. New varieties 12KNICSV-188 and Improved Deko have higher iron contents. 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 national planners are well advised to regard sorghum as more than a drought-hardy subsistence food.

Technology 3. Drought Tolerance in Maize

Considerable gains in maize improvement have been achieved in the area of drought tolerance and now make this crop less risky in the southern reaches of the Sahel. These gains are the result of conventional and marker-assisted breeding by partnerships between national breeding programs and international seed companies. The main solutions on the market are drought tolerant maize (DTMA) that has enhanced ability to withstand periods of acute soil drying, its successor projects Stress Tolerant Maize for Africa (STMA) and water efficient maize (WEMA) are even better adapted to growing under low supply of water.

A maize crop produced under drought conditions

Breeders develop these seed technologies so they outperform common non-tolerant varieties under severe to modest levels of water stress that occur routinely in drier agro-ecosystems. They also assist crop performance in sandy soils with low moisture holding capacity. In general, drought tolerant maize varieties have a 20% to 35% larger grain harvest under moderate drought conditions but may not respond as favorably to occasional years of excellent rains due to their shorter maturity times. Hybrid varieties of DTMA and WEMA are marketed under commercial license, while open pollinating varieties can be multiplied and sold free of royalty by farmers and community-based producers. Hybrid seed production is best conducted by commercial seed producers but requires that the hybrid parents be released to them through national systems and is certified following regulatory compliance for seed systems.

IITA is responsible for the development of drought tolerant and water efficient varieties that are released royalty-free. The African Agricultural Technology Foundation has sub-licensed 22 seed companies to produce Drought TEGO™ for commercial distribution, and more will follow; but these hybrids have been slow to reach West Africa. Given the importance of maize as a food crop, and its response to improved management, these drought-tolerant maize varieties and their accompanying inputs and management practices are well situated within agricultural development and climate action projects.

Drought
TEGO™

TEGO, a licensing mechanism for drought tolerant seed

Technology 4. Heat Tolerance in Wheat

Heat sensitive (left) and heat tolerant (right) varieties of wheat

Owing to the trait of heat tolerance incorporated into improved varieties of wheat, it is possible to grow this crop in new locations including the Sahel. Development of these heat tolerant wheat varieties have increased wheat production in the Sahel region, characterized by high temperatures ranging between 33° to 36°C and frequent droughts. Heat stress and drought are considered the most predominant stresses affecting wheat, especially at the reproductive stage during flowering and grain-filling, leading to low grain yield or even crop failure. Wheat production has however increased significantly in the Sahel over the last couple of years due to the rapid increase of area planted to the newly released heat-tolerant varieties that have replaced low-yielding and less adapted genotypes. Varieties that can withstand temperatures up to 4°C greater than previous lines are available that offer real advantage when planting in areas subject to heat at critical times during crop development. Studies have reported a decrease of 3% to 10% in wheat yield for every 1°C increase in temperature and a shocking 34% decrease in further increase in temperature to 4°C. The innovation of heat-tolerant wheat varieties is providing a breakthrough for African farmers to boost wheat production, despite rising temperatures and increasing water scarcity. Farmers are achieving higher and more stable yields over successive growing seasons, reaping up to 6 t/ha.

Breeding approaches employed to improve heat-stress tolerance in wheat include multi-location screening, shuttle breeding, double haploids, marker-assisted selection and key location phenotyping. Varieties possessing heat stress tolerance and water use efficiency are also resistant to major diseases and pest, including yellow stem rust, and have been widely released in Sahelian countries. The International Center for Agriculture Research in the Dry Areas leads in the development and distribution of these varieties across the Sahel, working closely with National Agricultural Research Systems in their respective countries. It is a great thing for farmers in the Sahel since wheat is now being produced in non-traditional areas during the cool season, and in conjunction with irrigation. This has been made possible by breeding wheat for heat-stress tolerance in combination with irrigation interventions alleviating drought stress. The success also has policy implications by convincing country decision-makers that domestic wheat production is a solution to massive dependence upon wheat imports. The improved wheat production in Sahel can be attributed to not only heat tolerance varieties but a package of interventions aimed at transforming wheat production including optimal land preparation and sowing rates, integrated pest management, sound soil fertility management and more efficient irrigation systems.

Combine harvester operating in Sudan

Several additional technologies must accompany heat tolerance when wheat cultivation is introduced on a large scale. Use of wheat varieties that are resistant to yellow and stem rust prevents disease outbreak. Planting wheat varieties that possess a natural defense mechanism against the Hessian fly larvae is the most effective control method. Crop surveillance and extension messaging ensures the best use of these resistant varieties. Furrow irrigated, raised bed cultivation is a highly efficient technique that ensures farmers efficient water use. These beds are relatively easy to construct with locally available tools and can be maintained over several growing seasons. Conservation agriculture, including reduced tillage and surface cover, offer major advantages for wheat production in dryland farming systems. The strategy has a low implementation cost, saves on fertilizer, labor and irrigation, and provides reliable yields and profits. Combine harvesters are available in a broad range of sizes, from small units that can handle a few hectares per day to very large units for major operations that harvest several hectares per hour. Careful selection and efficient management of combine harvesters is key to optimize performance and minimize costs and it is possible to design a fleet by considering the technical and technological parameters of the machines.

Technology 5. Conservation of Water and Soil with Bund Walls

The establishment of contour bunds, note short perpendicular ridges that prevent runoff

Bunds refer to a micro-catchment technique where low raised walls are arranged in specific patterns on farmlands to collect and conserve water, and to reduce soil erosion and gully formation. The method has major advantages for enhancing crop production and climate resilience in drylands but is too seldom employed by farmers across the Sahel. Bund walls are constructed with soil and/or rock, either by hand or tractor. Designs of bund walls are adjusted to local conditions and socio-cultural contexts, but the two main types are: contour bunds (or contour ridges) and semi-circular bunds (or half-moons). Contour bunds are installed along lines with equal elevation in fields at a spacing of 5 to 10 m between parallel walls, and with ties perpendicular to bunds for structural reinforcement and greater water capture. Contour bunds are suitable for uniformly sloping terrains with even run-off, and the retaining walls can stretch hundreds of meters across the landscape.

A network of half-moons reinforced with stones and intended to capture and direct limited rainfall

The installation of contour bunds typically requires coordinated action among neighboring farmers as the method is most effective when implemented at larger scale. Semi-circular bunds operate in a more localized manner, are installed with the bow pointing down the slope and are staggered along the contour lines of fields. Using half-moon bunds designs is prescribed for fields with a higher slopes (>7%) and uneven surface where runoff flows are strong and irregular. The diameter of half-moon bunds can vary from 1 to 20 m depending on terrain features, rainfall conditions and crop type. Parallel lines of semi-circular bunds should be connected to each other on fields with a very high slope or high rainfall, while the micro-catchment structures can be spaced by 2 to 5 m when run-off is less strong. These half-moon bunds should be at least 25 cm tall in order to keep them from eroding or becoming rapidly filled with sediment. Semi-circular bund wall designs are effective when implemented at small-scale on a single plot and hence can be initiated in single fields by individual farmers.

The main cost of installing bunds on croplands involves the work for moving earth or stones, and constructing the contours or semi-circles, with labor requirements amounting from 30 to 120 person days per hectare for different types and dimensions. Considerable skill in landscape architecture is required for designing bund walls to ensure adequate water collection and structural integrity so that investments are paid back through gains in crop production. Studies across dryland areas of eastern Africa have shown that installing contour bunds can increase grain yields of sorghum by 80% and maize by 300% compared to traditional land management without micro-catchment. Perennial vegetation may be placed into larger and wider-spaced bunds as well. Community works that stabilize slopes and better harness seasonal rainfall by constructing and reinforcing bunds are an important element of agricultural development projects in the Sahel, and increased biomass resulting from them can lead to greater sequestration of soil carbon when properly managed (see Technology 12).

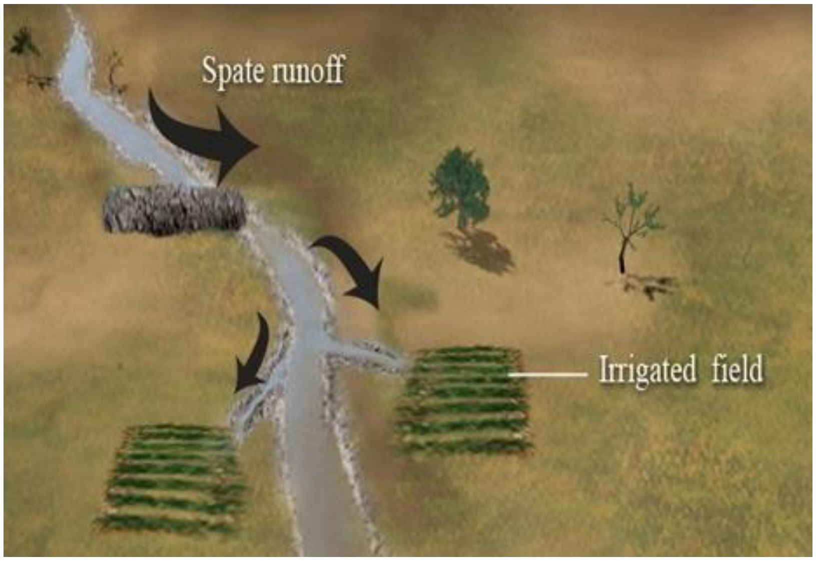
Technology 6. Water Harvesting and Soil Improvement by Zaï Pits

Capturing rainfall and soil fertility management is essential to successful farming in the harsh and changing climate across the Sahel. Micro-catchment approaches to water harvesting in the Sahel include planting pits, locally known as zaï, as well as half-moon bunds, tied ridges and rock lines described elsewhere in this catalogue (see Technology 5). Zaï pits are an ancestral approach to dryland farming developed in the Sahel for rehabilitating crusted and degraded lands used mainly for cultivating millet and sorghum. These structures are made by digging shallow basins of 20 to 40 cm diameter and 10 to 20 cm deep into the soil. The pits are prepared during the dry season by farmers allowing the shallow holes collect water, wind-driven soil particles and plant debris. The number of pits typically ranges from 12,000 to 25,000 per hectare depending on their size and slope. Soil that is excavated is placed down slope of the pits to divert and capture additional runoff. Moisture becomes collected inside and below the pit that allows crops to better cope with dry spells. Organic resources such as cereal straw, well-decomposed manure, compost are placed into the pit to improve nutrient and water retention. A minimum of two handfuls of organic material should be applied in each zaï pit. Mineral fertilizers are worked in the base together with organic resources to avoid nutrient deficiencies, with a recommended rate of 5 to 6 g NPK or DAP per pit; this amounts to between 72 and 144 kg per ha (see Technology 9). Seeds are planted in the center of the pit at usual depth. The zaï technology improves water use efficiency by crops in dryland areas and can make the difference between cropping success and failure in drier areas when compared to flat culture. By improving soil physical and chemical properties that benefit its moisture status, water infiltration and nutrient availability the technique can improve millet and sorghum production by 60% to 90% depending upon precipitation and soil fertility. In this way, the zaï technology allows for sustainable cropping on marginal lands and when combined with other dryland technologies can lead to rehabilitation of severely degraded land. When properly managed, these pits become a permanent feature of the field that collect off-season or early rainfall.

Establishing zaï pits into a field using a hand hoe

Millet growing in zaï pits, note differences in nitrogen management

Technology 7. Spate Management of Seasonal Flood Plains



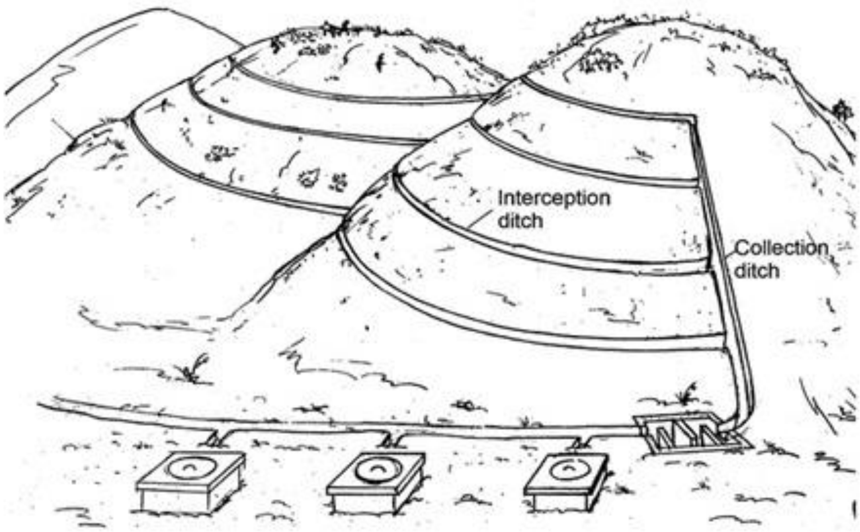
The design of a spate irrigation system

Exploiting water from rivers and streams during the rainy season to fill channels and direct them to adjacent fields by construction of spates is a small-scale irrigation system is unique to African drylands. This is an ancient method that can be traced back beyond recorded history but under some circumstances it remains relevant today, particularly through community-based actions that assure equitable distribution of seasonal water resources. In this system, water is diverted from normally dry river beds at the onset of seasonal rains, and directed to croplands, basically converting them into seasonal flood plains. This diversion is achieved through the placement of spurs or bunds that are built across or into the river bed. These seasonal flood waters typically last for only a few hours or days and are directed through a network of channels and ditches to fields typically a few hectares in size.

Diversion of a seasonal stream to feed spate irrigation

Spate water management requires particular geographic conditions, but where it is applicable it offers a major improvement over dryland cropping. Community consensus is needed to determine that these seasonal flood waters are being equitably distributed, including those further downstream that also rely upon this water. The system is gravity fed and in some cases requires dams to lift water to the point where it spills over into feeder canals. At the same time, spate irrigation systems require substantial management effort to control and optimize the flow of water. Floods often contains large amounts of sediment that pose both a risk and opportunity. These sediments can fill channels and require maintenance for removal. At the same time, these sediments are nutrient rich and when deposited onto irrigated cropland improves their fertility. It is important to note that managing flood waters is inherently difficult because of the kinetic power they hold but the rewards to managing these waters in arid and semi-arid areas is great. For this reason, opportunity exists in public support of spate irrigation as a civil engineering challenge.

Technology 8. Small-Scale Irrigation Schemes



Interception and collection ditches used to feed a localized irrigation scheme

Soil moisture is essential to plant growth and conversely erratic moisture availability greatly reduces the productivity of crops. Irrigation assures that the water requirements of crops will be met and the development of community-based irrigation schemes is an essential component of agricultural development in the Sahel. Irrigation consists of two phases, the first where water is diverted from its source and delivered to the vicinity of croplands, and the second where it is applied to fields in a scheduled and calculated manner. Application strategies vary with the volumes, quality and pressure of water delivery and may be grouped into flood, furrow, sprinkler and drip irrigation. Flood irrigation requires large quantities of water and that the fields being irrigated are enclosed to prevent water loss. This approach is described further in Technology 7. In furrow irrigation water is channeled along raised planting rows and gravity-fed water of low quality and pressure is used. Sprinkler irrigation spreads water across a larger area of field and requires piped, clean water be available at relatively high pressure. Drip irrigation delivers water along crop rows through tubing with discrete emitters at set intervals, relying upon very clean water delivered at low pressure. Each of these four irrigation types may be considered a separate technology in addition to basic hand watering performed at a gardening scale. All of

Furrow irrigation with piped water (left) and sprinkler irrigation (right) these technologies serve to upscale crop production through irrigation in areas characterized by low precipitation. The adoption of small irrigation systems by farmers in the Sahel has, to a varying degree, improved their livelihood since this region experiences erratic precipitation and lengthy dry seasons.

Hand irrigation is feasible for high value crops but is labor intensive

Irrigation allows for year-round cropping and encourages investment in agriculture by reducing the major risk to farming. Irrigation presents a key solution to addressing present and future crop production constrains due to the effects of climate change on weather patterns. The potential expansion of irrigation is attributed to the significant levels of both ground and surface water that remain under-exploited because irrigated areas are less than 30% of their potential. Within the context of practical rural development, a focus upon small-scale irrigation schemes in addition to larger, centralized schemes as major infrastructure development projects should be considered. Traditional micro-irrigation technologies used in the Sahel are broadly categorized into four areas: bucket watering of gardens, operations of smaller pumps by manual labor or animal power, motorized pumps used to lift and transport water for modest distances, and more complex delivery through water lifting combined with gravity fed canals. Recently, more attention has been directed to developing drip irrigation systems which have considerable success in efficient use of water and fertilizer, saving time, increasing crop yields and enhancing flexibility in production. Small-scale irrigation systems of this type require equipment and expertise that is not widely available. Flexibility in design and operations is required however because there is no single universal approach to providing irrigation. There is need of promoting initiatives that enable rural stakeholders to opt for affordable technologies appropriate for their water resources, landscapes and fields that increase crop yields in a reliable and profitable manner. Note that irrigated field often require fencing to protect them from grazing domestic and wild animals. The International Water Management Institute (IWMI) operates as the TAAT Water Enabler Compact to support farmers with gaining access to low-cost irrigation and water management technologies. Small-scale irrigation schemes and spate management of seasonal floods (see Technology 7) are part of their 'Smart Valley' approach which involves participatory stepwise procedures that focus on the design of water-control infrastructure based on contexts and farmers' knowledge.

Irrigated areas may require fencing to protect their crops from grazing animals, note the use of woven millet stalks for fence building

Technology 9. Fertilizer Micro-Dosing

Use of a bottle cap for fertilizer micro-dosing

Smallholder farmers in the Sahel use lower than recommended rates of mineral fertilizers and apply them by broadcasting. As a result, crop yield, especially sorghum and millet yields are low. The fertilizer micro-dosing technology is based on the application of small amounts of mineral fertilizer about one week after planting in a shallow hole (3 to 5 cm depth) and spaced about 5 cm away from the stem. After placement, the fertilizer is covered with soil. When available and affordable, it is advisable that urea fertilizer is dressed on the side of plants about 30 days after emergence in the same manner. This fertilizer application technique allows crops to establish quickly and to better take up nutrients and water from soils. Micro-dosing is as simple as applying one bottle cap filled with fertilizer (3 to 5 g) to each planting hole. The total amount of fertilizer used in micro-dosing can vary significantly depending on the planting density. For example, millet is typically cultivated at 16,666 plants per ha which requires about 50 kg of fertilizer whereas sorghum usually has a density of 26,666 plants per ha and requires about 100 kg of fertilizer per ha. This addition results in healthier crops that are better able to counteract mid- and late-season drought as a means to adapt to increased climate variability.

A well-timed dose of fertilizer results in increased crop yields ranging from 40% to 120%. The micro-dosing technique significantly increases the use efficiency of nutrients and water, particularly when combined with other climate-smart practices like zaï pits (see Technology 6). It is particularly effective in areas suffering from land degradation because unless lost nutrients are replaced, soils become further depleted and crop yields enter into decline. This technology is suited to resource limited farmers working on degraded lands, who cannot afford the full rate of fertilizers and other inputs recommended by extension services. Micro-dosing should not be implemented over extended periods of time if it results in negative nutrient balances. It rather has to 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. Micro-dosing is best combined with other the addition of organic materials (see Technology 12).

A mechanical device that delivers micro-dosed fertilizers

Technology 10. Strategic Timing of Nitrogen application

Nitrogen topdressing placed upon a recently weeded bed

The key to achieving high crop yields and maintaining soil fertility is to apply the right fertilizers at the correct rate and time. Too often, however, the element of time is not well considered, particularly in relation to nitrogen (N) topdressing of field crops. It is very common for N deficiency to take place after heavy rains, seen as yellow discoloration, but farmers seldom respond to this with split application of fertilizer. Input of mineral N is very important to dryland cereal farmers, and represents a substantial investment, so it must be used in an efficient manner. Typically N fertilizer is added to soils once or twice over the season, first as a pre-plant addition and second as a single topdressing, but more frequent and smaller doses are more efficient.

Frequent occurrences of drought and low soil fertility across the Sahel undermine the agronomic efficiency and financial profitability of inorganic N fertilization unless it is used properly. Crops require adequate supply of N throughout their growth cycle and especially during reproductive stages to reach attainable yield levels, yet N is highly mobile in soils and can be easily lost to the environment before crops are capable of absorbing this nutrient. To improve the use of N fertilizers in dryland regions, agronomists recommend a flexible system where the mineral nutrient is added to crops over a series of three or more split applications. The basic principle of this approach is to apply a small quantity of N at planting and progressively add moderate amounts as topdressing during periods with sufficient rainfall when plant nutrient demand is largest.

Administering N fertilizers to crops in this strategic manner ensures that nutrients are available in soils at critical stages of the growth cycle unlike with only one or two applications. The suitable time for staggered N fertilization starts at two weeks after emergence and extends up to the stage of grain filling. Farmers can top-dress N using readily accessible types of fertilizers such as urea and calcium ammonium nitrate, and the total application rate is based upon yield targets and regional recommendations. The practice is advantageous under all rainfall conditions; it allows for high yields during normal years by enhancing nutrient uptake, and reduces financial losses in drought-struck years by avoiding wastage of fertilizers. Ideally, N application is carried out shortly after weeding so the nutrient is maximally available to crops. In some cases, N can be added just prior to, and worked into the soil during weeding. The response by cereals on nutrient-poor sandy soils in cultivated drylands to strategic timing of N inputs results in larger yields and profits compared to existing application schedules, and the innovation is readily appreciated by farmers. This technology can be easily deployed and stands to make huge advances in food security and fertilizer investments by small-scale farmers across Africa's cultivated drylands.

Technology 11. Legumes, Inoculation and Biological Nitrogen Fixation

Legumes are very important to the rainfed cropping systems of the Sahel. These systems are typically dominated by mixtures of pearl millet, sorghum, cowpea and groundnut. Intercropping is sometimes used by farmers to minimize risks and maximize returns during years of most favorable rainfall, mostly by growing understory grain legumes between cereal rows at very low densities. More common are crop rotations of cereal and legumes, with a few (e.g. two to four) cycles of cereals punctuated by legumes. These rotations have multiple beneficial effects. Legumes access atmospheric nitrogen through symbiosis with rhizobia, a process that provides both additional protein to the household and residual nitrogen to the land. Other benefits include improved soil physical properties, the ability of root exudates to solubilize bound phosphorous, and interruption of cereal pest and disease cycles. Livestock operations are closely integrated with cropping, allowing cattle and smaller animals to feed upon crop residues and then provide sources of traction and manure.

The most important grain legumes are cowpea (*Vigna unguiculata*) and groundnut (*Arachis hypogaea*). Cowpea is preferred by many households because it offers edible leaves, green pods, green seeds and dried grain. It is attacked by many pests and diseases but Integrated Pest Management strategies are available. Some spraying with insecticides is often required. One useful strategy is to over-plant cowpea seeds, and then remove many of them as leafy vegetables before using pesticides. Nigeria is the first country to approve open cultivation of genetically modified Bt cowpea to control insects such as pod borer (*Maruca vitrata*). Bt cowpea is facing opposition in Nigeria due to fears of adverse impact on health, and these GM varieties are slow to be approved in other countries. The rhizobia needed for biological nitrogen fixation are often native to Sahelian soils but these populations may be suppressed in hot, dry soils and prove less effective as microsymbionts. Bright red nodule interiors signify effective nitrogen fixation due to the presence of leghaemoglobin. Unfortunately, legume inoculants are not widely available across the Sahel. When well nodulated, nitrogen fixation is sufficient to secure a cowpea harvest and contribute about 50 kg or so organic nitrogen to the following crop. Cowpeas are a very important dietary complement to millet and sorghum as staple food for communities in drylands.

Dense pod fill by cowpea

Large spherical root nodules on cowpea

Groundnut is best grown in rotation with cereals on lighter soils or on raised beds to facilitate recovery of their woody underground pods. Besides phosphorus and potassium, groundnut has a high demand for calcium for its pegs to enter the ground. Its deep roots resist short-term drought. In the past, groundnuts were often stunted and twisted by the Groundnut Rosette virus but some new varieties are resistant to this virus. Groundnut does not perform very well as a shaded understory of cereals. Groundnut nodulates with rhizobia in most soils but it often responds to inoculation with elite strains. It forms small, spherical nodules closely attached to the tap and main lateral roots. Its leaves remain green through harvest and are excellent livestock feed. Markets for groundnut are strong whether harvested as fresh pods or dried, shelled nuts, and it is regarded as an export commodity in some areas of the Sahel.

The woody pods of groundnut must be uprooted at harvest

Abundant, small, spherical root nodules on groundnut

Other useful legumes include soybean (*Glycine max*) and pigeon pea (*Cajanus cajan*). Massive quantities of soybean are currently imported, mostly for animal feeds, and local processors are seeking domestic suppliers. BNF by soybean is high and cereals perform well with it in rotation but it is poorly suited as an understory intercrop because of poor pod filling. In general, soybean is resistant to pests and disease and some varieties are highly resistant to Asian Rust. Soybeans are drought and waterlog tolerant, and do well in acid soils. It has a specialized rhizobium requirement and responds very positively to inoculation. Soybeans remain hard after boiling but may be processed into a variety of nutritious foods. Pigeon pea is a shrub that may be planted at wide spacing with cereals and then carry through to the next growing season, or planted around field boundaries. Some shorter statured varieties behave as row crops. Rhizobia needed for nitrogen fixation by pigeon pea are present in most soils. Its green pods, green seeds and dried seed may be consumed, but weevils (bruchids) are often attracted to dried grain.

Need exists to develop the capacity to manufacture and distribute legume inoculants in the Sahel. The needed capacities for industrial microbiology and equipment required to produce liquid microbial broths are in place. The elite strains required for different grain legumes are available from research institutes, including IITA. Carrier material that is mixed with broth is less available and sources and sterilizing procedures require attention. Once in place, an increased capacity for nitrogen fixation offsets need for imported industrial nitrogen fertilizers and contributes to a reduction of nitrogen-bearing greenhouse gas.

Technology 12. Managing Organic Resources for Soil Fertility

Well mulched cereal seedling using residues from the previous crop, a practice with multiple benefits

A majority of soils in the Sahel are characterized by low water holding capacity and limited availability of plant nutrients because of their low clay and high sand content. These unfavorable soil properties require that farmers make best use of organic resources for the management and improvement of soil fertility. Soils which are converted from secondary woody vegetation into agriculture, as is common across this dryland belt, rapidly lose organic matter, up to 1.1 ton per hectare each year when not replenished with adequate amounts of plant residues and animal manure.

Steady reduction of soil organic matter leads to decline in soil health as related to reduced cation exchange capacity and soil aggregation that in turn undermine fertilizer use efficiency and water retention. Soil organic matter depletion exacerbates the negative impact of drought on crop production. To modernize their practices, farmers across these cereal-based drylands must better manage organic resources in ways that optimize limited rainfall and costly inputs of mineral fertilizer. The maintenance of soil organic matter and carbon stocks is strongly determined by the amount of crop residues available for addition to soils and the competing need for livestock feed and stalks as cooking fuel and building material. High labor requirements for recycling biomass wastes to farmlands may also cause farmers to burn crop residues, leading to huge losses of carbon from the farming system.

A series of practices are known to stimulate organic resource management by farmers in dryland areas by increasing crop yields, livestock production, and water and nutrient use efficiencies. Mulches that cover soil surfaces greatly reduce soil erosion, runoff and evaporation, leading to 70% increased cereal harvest. An initial soil cover of at least 30% is needed for effective benefits on crop production to be realized, requiring about 3 ton of cereal residues (dried leaves and stalks) per hectare. Soil mulches may act as a refuge for some harmful insects that require spraying with pesticides but also suppress weeds, simplifying field operations. Incorporating fresh plant materials or animal manure is another option to compensate for unfavorable soil physical properties. For example, incorporating millet residues into soils may result in much greater yield in the following crop. Small amounts of cattle manure applied to zaï pits may double grain production of sorghum. At the same time, mineral fertilizers applied in conjunction with organic resources have greater nutrient use efficiencies. These examples of Integrated Soil Fertility Management illustrate the need for farmers to make best and balanced use of crop residues and other available organic resources and means found to better quantify gains in soil organic carbon as a climate mitigation action.

Technology 13. Control of Insect Invasions

Devastating effect of locust invasion of cropland

The Sahel is characterized by major invasions of insect pests such as the yellow desert locust (*Schistocerca gregaria*) and fall armyworm (*Spodoptera frugiperda*). These outbreaks pose a major threat for farm households and undermine larger efforts to strengthen food systems. Locusts are notoriously difficult to control once large swarms accumulate and spread over expansive areas. Following favorable rains, vegetation is sufficient for multiple generations of locust to spread across agricultural landscapes, devouring everything in their path. Early warning and preventative control are of key importance to stop locust populations from reaching epidemic proportions. The size and development of these voracious insect populations are closely monitored by the Desert Locust Information Service based on remote-sensing weather and vegetation data combined with real-time surveys by national teams through digital platforms like FAO's eLocust3. Controlling populations of desert locust or fighting outbreaks when they occur is achieved by spraying infested areas with chemical insecticides in concentrated doses. To be effective, the insecticide must be applied directly onto locust swarms that in turn require knowledge of their whereabouts and direction. Spraying interventions for smaller areas can be performed by teams on foot with knapsacks, whereas for larger areas there is need for vehicle mounted nebulizers or sprayer planes.

Several types of chemical and biochemical substances are used in locust control and may be differentiated by their mode of action. Some quick-acting insecticides kill the flying adults by impairing their nervous system. These insecticidal agents must to be sprayed onto locust swarms in a safe and accurate manner as they have hazardous effects on mammals and the environment as well. Some products can be applied on vegetation as a barrier to block the movement of insect bands but this method typically results in unwanted harm to non-target organisms. The most commonly used groups of chemicals for controlling locusts include carbamates, pyrethroids, pyrethrins and phenylpyrazoles. Different insecticides that contain organochlorines, neonicotinoids and organophosphates have been banned in some countries but are also quite effective.

Combating a locust swarm with a power sprayer, insecticides and protective gear

Another type of chemical useful in the fight against locusts is growth regulators that disrupt the moulting process and cause the insect to die when shedding its exoskeleton. Growth regulators act slowly and have no use on swarms of flying adults, but their persistence allows them to be used as barrier sprays, and they are relatively safe to operator and environment. Pheromones cause behavioral or developmental changes in locusts which prevent them from reaching adulthood, but these substances do not kill directly, and are thus slow acting. Biochemical substances extracted from plants like neem oil can be sprayed on crops to repel locust and inhibit feeding but the kill rate is low and incomplete. Different beneficial organisms such as predatory wasps and flies, parasitoid wasps, predatory beetle larvae, birds, and reptiles help to keep locust populations from exploding, but have little useful effect after the outbreak has occurred because their increase as predators cannot keep pace with their prey. Nonetheless, biocontrol is possible by rearing and releasing natural enemies of destructive insects, or by providing alternative hosts and favorable nesting sites that enhance their reproduction and survival. Integrated Pest Management of dessert locust involves the use of beneficial organisms, growth regulators and pheromones and insecticides. Some mechanical techniques exist for killing locusts as well such as digging and burying trenches containing baits, but this practice is rather expensive and ineffective when combating swarms.

Are you a victim of the Fall Army Worm invasion?

Announcing the

Fall Army Worm Rapid Response

Let our teams of trained army worm control operators manage this threat to your maize cropland

- Timely and affordable: Mobile service dispatched to your farm from our local Youth Agripreneur shop
- Application using power sprayers and recommended pesticides
- Operations comply with health and environmental safety guidelines
- Treat cropland for only KES 1500 per acre plus modest transport costs
- Special 15% discount for treatment of 3 acres of more: *Tell your neighbors!*

A poster announcing services for fall armyworm control in Kenya

The invasion of fall armyworm across cereal croplands throughout Africa, including the Sahel also represents a major threat to food security. TAAT offers a rapid response kit consisting of a custom-built cargo tuktuk, power sprayers, safety equipment, commercially recommended pesticides, farmer information and communication materials. These are operated by youth groups operating from agrodealer shops and extension offices. Training is offered on: fall armyworm control as a business opportunity, understanding insect invasion, control options and access to rapid response equipment and supplies, operation and maintenance of control equipment, and costs and expected returns from contract control services. This capacity building prepares operators for efficient and safe fall armyworm control and reinforces local commitment and investment. Cropland is treated for as little as $33 per hectare. Syngenta MATCH (66%) and Amiran PROVE (25%) were the most frequently applied insecticides. Youth trained in control operations conformed to approved agro-chemicals and 54% of their clients were women. Early control of armyworm is also achieved through maize seed treatment with Syngenta's FORTENZA DUO. This systemic treatment offers protection to maize crops up to 4 weeks after germination, a critical stage in crop growth, and ensures that use of chemical sprays is kept to a minimum. Authorities in countries worst affected by fall armyworm are encouraging all maize seed producers to treat their seed with this product.

Technology 14. Overcoming Parasitic Striga

Striga hermonthica parasitizing sorghum

Striga is a parasitic weed attacking cereals and other grasses that has invaded croplands of the Sahel. The damage inflicted by striga begins underground where its roots enter the host, feeding on its nutrients and moisture and releasing toxins into the plant causing twisted, discolored and stunted growth. After feeding belowground for 4 to 5 weeks, a fast-maturing shoot emerges that produces attractive spikes of violet (*Striga hermonthica*) or red (*Striga asiatica*) flowers that mature into capsules containing abundant, tiny, long-lived seeds. Parasitism results in stunted, twisted growth and greatly reduces the yields. Striga attacks millet and sorghum but these crops show some tolerance to its effects; maize is more severely affected. Farmers respond to striga by hand weeding and, less often, burning affected fields but the efficacy of these practices remains questionable considering the large numbers of tiny seed that a single, mature plant produces and returns to the soil. These seeds remain dormant in the soil for up to 20 years and herein rests the dilemma, simple weeding and routine field sanitation procedures, even when combined with improved soil fertility management, appear insufficient to eradicate striga once it has established within a farmer's field.

Striga control by legume suppression (center) and herbicide resistance (back) compared to current practice

The agricultural community has responded by developing several new approaches to striga control. These approaches involve crop resistance to systemic herbicides, striga tolerant cereal varieties, striga suppression by non-hosts and trap cropping. Each of these approaches has demonstrated potential for adoption by small-scale farmers. Farmers identified striga tolerant land races and these were collected by plant breeders and the traits incorporated into improved maize populations. There are two types of tolerance; some maize expresses rapid early growth and deeper root systems, thus evading striga seeds residing within the cultivated soil horizon while other maize varieties appear to be less susceptible to witching symptoms, so that normal but reduced plant growth and development occurs despite striga parasitism. Tolerance alone is an insufficient control measure because crops eventually become overwhelmed in highly infested soils. Several legumes adversely affect striga through allelopathy and induced suicidal germination. Desmodium, a pasture legume possessing both attributes, was packaged into an agro-ecological approach to striga management referred to as Push-Pull. Several grain legumes possess this trait as well including cowpea, soybean and groundnut, providing the basis for striga management through cereal-legume rotation and intercropping. An exciting new approach to striga management has emerged that allows farmers to grow maize and kill striga at the same time. Herbicide resistance by maize permits the application of relatively small amounts of imazapyr to maize seeds that in turn provides several week's chemical protection from parasitic striga. Striga control is best achieved through combinations of these technologies.

Striga expression in a heavily infested soil (left) and maize crop failure due to heavy parasitism from striga

Farmers must become aware that striga infestation is a solvable problem and gain experience in the use of breakthrough technologies. Extensionists should disseminate information packages and install field demonstrations promoting these technologies. Development agents must organize large-scale campaigns designed to overcome striga in affected areas and prevent it from spreading elsewhere. Agro-dealers must be trained in new striga management products and incentives found to more effectively market them. Commercial seed producers must recognize the market opportunities posed by the new striga suppressive crop varieties and include them within their business strategies. Farmer associations must rally their members to combat striga by expanding the range of services provided, including bulk purchase of inputs and undertaking community-based seed production. Local and national authorities must fully recognize the threat posed by striga and prioritize efforts to overcome it within rural development agendas. By attacking this plant parasite through a combination of approaches it is now a solvable problem and offers an important element within rural development packages.

A farmer discovers that striga roots are attached to maize (left) and an exhibit offering striga control information and technologies

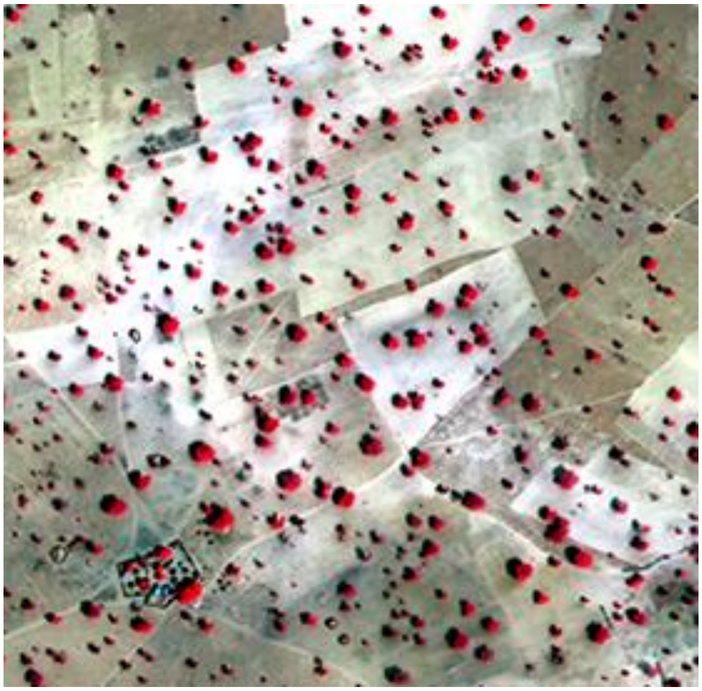
Technology 15. Transition to Agroforestry Parklands

An agroforestry parkland of groundnut growing beneath Faidherbia albida

Great potential for agricultural transformation exists through the conversion of open field cropping to agroforestry parkland. These parklands appear as well-spaced trees that serve to protect the soil and contribute to soil fertility renewal. Because of these benefits, the crops that grow near or below these trees often perform better than those in an open field. This is largely attributed to leaf drop as nutrient inputs to soil and partial shading resulting in moisture conservation. Some of these trees also yield harvestable products such as shea and gum Arabic. The parklands also hold and sequester significantly greater carbon stocks than open croplands in a way that mitigates emissions of greenhouse gasses. These increased carbon stocks may be 20 or 30 MT C per ha greater than that retained by open cropland. The agroforestry parklands that appear in the cultivated drylands are often the result of clearing trees rather than planting them, and this creates difficulty in carbon accounting, but when open cropland is transitioned to agroforestry parkland the carbon gains are clear and attributable to the efforts from tree planting and protection.

Establishing parkland trees in open cropland requires nurturing and protection

The afforestation of croplands is best practiced at the community level because of the demand for quality tree seedlings, the need to plant them at scale, and the collective responsibility to protect them until these trees are well established. Effective tree seedling technologies are available, usually by planting the seeds of desired species in planter bags containing soil improved with compost or manure and watered until large enough for transplanting into the field. Transplanting may be performed in conjunction with the establishment of water harvesting, particularly on the back side of bunds where deeper soil moisture accumulates. Young seedlings must be protected from drought by watering for a few years until able to survive on their own. The greatest threat to seedling establishment is browsing by domestic animals and wildlife, and seedlings must sometimes be protected by the erection of barriers and community bylaws related to grazing. The transitioning from degrading open cropland to productive agroforestry parkland should be considered within agricultural development efforts as sound from both the food security and climate action perspectives but also involves capacity development at the community and extension advisory levels. The tree biomass resulting from the parklands is readily attributed to carbon gains at the landscape level and applied to country commitments toward greenhouse gas reduction.



A satellite image from NASA showing trees in red and cropland boundaries; note the village compound to lower left of the map

Technology 16. Improved Dryland Range Management

The rearing of livestock is a critical enterprise across the Sahel and other African drylands but overgrazing has resulted in severe land degradation. Cattle, sheep and goats are regarded as wealth among pastoralists living in areas too dry for farming and strategies are available to improve the grazing and forages that these lands provide. The water harvesting technologies presented in this catalogue may be practiced on non-cultivated lands planted with improved grasses and browse species, particularly near watering holes where animals are likely to concentrate during the dry season. Some new species such as the thornless Opuntia cactus can also be planted in these areas to act as an emergency food during droughts. Because of the importance of livestock enterprise, much of the cultivated lands in

Improved grazing established near a watering hole the Sahel are farmed in rotation with grazing land. Furthermore, the stover and stubble of cereal fields are grazed following the harvest of millet, sorghum and maize, and these lands are then fertilized by the manure that is deposited. While this system is robust as long as rotational intervals are of sufficient length, these systems begin to degrade if cropping becomes to frequent. One means to strengthen the crop-livestock system is to improve these rotational pastures using either annual or perennial grasses. These grasses not only provide feed for livestock but they provide ground cover that resists wind and water erosion. The greatest threat to land degradation tends to be around watering holes where animals congregate. Technologies are available to rehabilitate and better manage these more susceptible areas.

Improved rangeland management falls into four general categories that are best applied in packages. Agronomic measures are associated with annual crops in a rotational sequence and are impermanent and of short duration. Vegetative measures involve the use of perennial grasses, shrubs or trees and are of long-term duration. Structural measures reduce erosion and capture water, and may result in a permanent change in slope. Management measures involve a fundamental change in land use and may be directed through policy intervention.

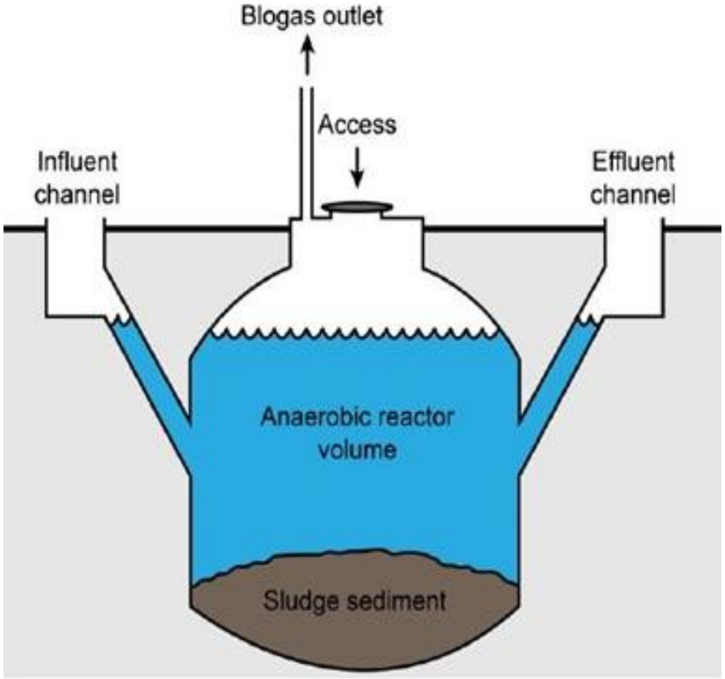
Improved pasture management is best conducted at the community level where lands are collectively managed. To a large extent, this reduces the risks of conflicts between farming and livestock that often lead to larger social misunderstandings. In the case of communally managed lands, areas closest to the village are used exclusively for cultivation while areas further away are rotationally farmed and grazed, and it is these lands that should be targeted for pasture improvement. Community members may be offered incentives to commit labor and resources toward pasture improvement following cropping. Rangeland improvement is more applicable to the large tracts of land situated between communally managed lands, or in the drier extremes of the Sahel where cultivation of millet is considered too risky.

Rehabilitation of rangeland is best undertaken on a landscape scale, starting around watering areas and then moving outward. Incentives developed around this rangeland improvement may also be directed to livestock markets where pastoralists congregate. Charcoal production is also an enterprise among pastoralists that complicates the land degradation issue. Strategies for sustainable charcoal production are also available, and are applicable as credible carbon offsets. In some cases, the most severely damaged lands must be placed off limits to pastoralists so that they can recover. So too, the margins of conservation lands must be actively protected. Land rehabilitation is a very complex issue and an entire catalogue of technologies could be prepared around it, so this particular catalogue entry serves more as an introduction to the problem. To a very large extent, degradation of land resulting from overgrazing presents a massive and difficult challenge across the Sahel and projects must consider them as critical livelihood and climate action activities.

Strategies are available to control land degradation around watering points

Technology 17. Local Production and Use of Biogas

This technology refers to the production of combustible gas within small-scale digesters at the household level. It is based upon the utilization of plant and animal residues as organic wastes that are decomposed in anaerobic tanks in a way that leads to the formation of gasses, such as methane, and a digested slurry byproduct useful as an organic fertilizer and soil amendment. The principles behind anaerobic digester systems are quite simple, diluted organic substrate are added to an anaerobic reactor that separates the inputs into gaseous and solid fractions. The gasses rise and are collected through an outlet for burning as cooking gas and the sediments sink into sludge for later manual collection.



A schematic diagram of an underground anaerobic reactor producing biogas from farm wastes

Attraction to this technology is growing across the Sahel because of its socioeconomic and environmental benefits, and it has a proven ability to improve the lives of rural households that would otherwise burn wood and charcoal, or cook using purchased kerosene. The diversification of energy supply creates economic opportunity to those who build and equip these digesters, it reduces local air pollution and deforestation due to firewood collection and charcoal making, and increases sequestration of carbon into soils amended with the digested organic sludge. Carbon sequestration is also achieved by the substitution of renewable energy production from methane as compared to reliance upon fossil fuels.

An aboveground biogas reactor; note the pipe used to bleed gasses at the top of the reaction vessel

Cooking with biogas generated from farm wastes; note the pressure gauge and valves

Biofuel is any fuel that is derived from biomass, in this case crop and animal residues produced within small-scale farming systems. Gasses may be produced in a variety of vessels located above or belowground. These reactors may be fashioned from metal tanks, built from concrete or purchased as complete units. There are several preconditions for biogas production: it must be conducted in a sealed, airtight environment otherwise gasses will be lost to the atmosphere; digestion must be conducted in a water-rich environment to ensure that the preferred gaseous products are generated; temperature conditions must not be too cool (e.g. $<20^{o}$ C) or too hot ($>50^{o}$ C); the vat must maintain a near neutral or slightly acidic pH to favor methanogenesis by microorganisms; and the added feedstock should contain a carbon to nitrogen ratio of about 25:1. When these conditions are met, gasses are produced and collected in a reliable manner. In cooler areas, the digesters are positioned belowground to protect against temperature extremes. The pH of the vats tends to decrease with time because of the production of organic acids and may be periodically ameliorated with liming materials. Animal manures perform well as feedstock because of their balanced nutrients. In more advanced systems, a second tank is added where the gas is collected and its pressure maintained through displacement by water.

An electricity generator powered by biogas

Biogas generation is best considered among a suite of rural development options that are designed to educate stakeholders and supply the infrastructure it requires. This technology requires considerable investment and skills compared to other adaptive and mitigative practices, but once it enters a rural community it attracts considerable momentum based upon its desirable outcomes. In more advanced settings, methane gas may be pressurized and used for alternative purposes such as the generation of electricity. This catalogue item addressing production and use of locally produced biogas serves as an introduction to its feasibility and more detailed accounts of reactor design and biogas use are available elsewhere.

Conclusion: Climate Action Technologies in African Drylands

There is a strong relationship between dryland soil and water management technologies available to small-scale farmers and the need for climate action in the Sahel and elsewhere. Within the context of risk reduction, many of the technologies appearing in this catalogue are intended to adapt to climate extremes, particularly higher temperatures, moderate drought and erratic and intense rainfall. These adaptive technologies are particularly important at the field and household level. Farmers that better capture rainfall (see Technologies 5, 6, 7 and 8) or protect their cropland soils from wind and water erosion (see Technology 12) are better able to feed their families. The same is true for communities that adopt and exchange improved seed of open pollinated cereals such as millet and sorghum (see Technologies 1 and 2). In this way, adaptation to climate extremes offers a "drawdown" of greenhouse gasses that are accumulating in the atmosphere.

The most direct mitigative effects are to increase standing biomass and to manage that biomass in ways that become sequestered into soil organic matter. This is readily feasible through the use of improved soil and water management practices across large areas of land over sufficient times to realize the gains. In general, about 50% of increased productivity is carbon and a small proportion of that enters the soil as residues for longer-term retention. One means to greatly increase standing biomass is to move from rainfed to irrigated agriculture, another is to rehabilitate lands that are degraded and overgrazed. It is possible to combine adaptive and mitigative technologies as when bunds intended to capture water and reduce erosion are planted with perennial vegetation. Also the same contour structures used to protect croplands may be constructed in adjacent rangeland to assist in the re-establishment of native vegetation. At the same time, carbon gains in rangelands must be weighed against the increased livestock carrying capacity and the methane they release through digestion.

Groundnut understory in a cultivated parkland of Senegal

Substantial opportunity for carbon gains across landscapes is the steady transition from open field cultivation to managed parklands, often through the introduction of economically useful trees. The agroforestry techniques to achieve this transition are well described. Re-vegetation has a transnational dimension through the ambitious Great Green Wall for the Sahel and Sahara Initiative to act as a barrier to further desertification. Another proactive mitigation response occurs through bio-digestion in terms of fossil fuel replacement. One huge advantage of mitigation over adaptation is that quantified carbon gains may then be offered for sale and traded with polluters as a condition of their continued emissions. Another is that they can be applied to the Nationally Determined Contributions of countries within climate agreements (e.g. UNFCCC, the Paris Accords).

Make TAAT Your Technology Broker of Choice

TAAT 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 will serve as the main engine for economic growth in Africa’s cultivated drylands. 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.
☑ **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 follows:

1. **Access to improved dryland crop varieties:** The latest improved varieties of cereal are available from TAAT for testing and approval, as well as assistance in the design of seed systems. *These services are arranged by TAAT with its partner Compacts.*
2. **Conservation of water and soil:** Water harvesting and soil conservation are critical to dryland farming in drought- and erosion-prone soils. *TAAT can assist in the incorporation of incentives for stakeholder participation in community-based public works.*
3. **Optimizing irrigation opportunity:** Irrigation is the key to year-round agricultural production in the drylands. *Whatever the scale and purpose, TAAT and its partner IWMI are well positioned to assist infrastructure projects and their beneficiary communities.*
4. **Integrated Soil Fertility Management:** Many dryland soils are low in nutrients and require innovative approaches to fertility management. *TAAT can assist in the design of integrated solutions to soil fertility management through its partnerships with IITA and IFDC.*
5. **Systems-level transformation:** TAAT offers technologies that are ready to benefit farmers today, but it also recognizes the larger need to transform agricultural and food systems over time. *Indeed, TAAT and all of its partners hold expertise in and are committed to climate action as it relates to rural development.*

Be assured that TAAT is prepared to partner with development investors, national projects and the private sector in a demand-driven manner.

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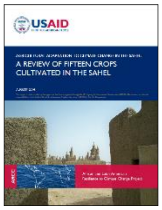

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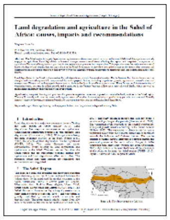

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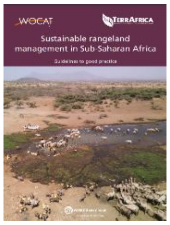

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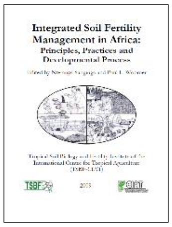

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The TAAT Technology Toolkit Catalogue Series

Additional technologies for six crop commodities are available through the TAAT Technology Toolkit Catalogue series. Catalogues for Orange Fleshed Sweet Potato, Cassava, Rice, Maize, Bean and Wheat are available from the TAAT website through the link https://taat-africa.org/deployment-of-appropriate-technology-2/.

Orange Fleshed Sweet Potato Technology Toolkit Catalogue. This catalogue presents ten technologies that modernize biofortified sweet potato production and processing (24 pp).

Cassava Technology Toolkit Catalogue. This catalogue presents twelve technologies that serve to modernize production and processing of cassava in Africa (32 pp).

Rice Technology Toolkit Catalogue. This catalogue presents ten technologies that serve to modernize production and processing of rice in Africa (32 pp).

Maize Technology Toolkit Catalogue. This catalogue presents ten technologies that serve to modernize production and post-harvest processing of drought-tolerant maize (32 pp).

Bean Technology Toolkit Catalogue. This catalogue presents twelve technologies that serve to modernize production and post-harvest processing of High Iron Bean (36 pp).

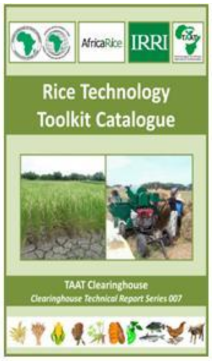
Wheat Technology Toolkit Catalogue. This catalogue presents ten technologies that serve to modernize production and post-harvest processing of wheat bean in Africa (36 pp).

Orange Fleshed Sweet Potato: Technology Toolkit Catalog

TAAT Clearinghouse
Clearinghouse Technical Report Series 005

Cassava Technology Toolkit Catalogue

TAAT Clearinghouse
Clearinghouse Technical Report Series 006

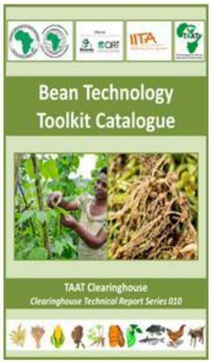


Rice Technology Toolkit Catalogue

TAAT Clearinghouse
Clearinghouse Technical Report Series 007

Maize Technology Toolkit Catalogue

TAAT Clearinghouse
Clearinghouse Technical Report Series 008



Bean Technology Toolkit Catalogue

TAAT Clearinghouse
Clearinghouse Technical Report Series 010

Wheat Technology Toolkit Catalogue

TAAT Clearinghouse
Clearinghouse Technical Report Series 011

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 important roles of sound policies, empowering women and youth, strengthening extension systems and engaging with the private sector is implicit within this strategy. The Clearinghouse is the body within TAAT that decides which technologies should be disseminated. Moreover, it 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 photos: Pearl millet at harvest maturity (left) and sorghum at harvest maturity (right). Photographic credit: Riki Trader and BioInnovate Africa

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