Chapter 7
Socio-Economic Impacts of Sweet Sorghum Value Chains in Temperate and Tropical Regions

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Abstract Sweet sorghum is raising considerable interest as a feedstock of either fermentable free sugars or lignocellulosic feedstock with the potential to produce fuel, food, feed, and a variety of other products. Sweet sorghum is a C4 plant with many potential advantages, including high water, nitrogen, and light efficiency, broad agroecological adaptation, as well as a rich genetic diversity for useful traits. For developing countries, sweet sorghum provides opportunities for the simultaneous production of food and bioenergy (e.g., bio-ethanol), thereby contributing to improved food security as well as increased access to affordable and renewable energy sources. In temperate and usually more industrialized regions (e.g., in Europe), sweet sorghum is seen as promising crop for the production of raw material for second-generation fuels or for biogas. This chapter describes some general aspect of sweet sorghum value chains and assesses its socio-economic impacts, including opportunities, risks, and challenges.

Keywords Sweet sorghum · SWOT · Temperate regions · Tropical regions · Ethanol · Biogas

7.1 Introduction

Sweet sorghum (Fig. 7.1) is a promising feedstock plant for different carbon-based renewable energy fuels and materials. Its high contents of fermentable free sugars allow good fermentation processes for ethanol production. Its high biomass productivity makes sweet sorghum a good and land-efficient energy crop that also provides

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Fig. 7.1 Panicle of sweet sorghum. (Source: D. Rutz, WIP)

digestible feedstock for biogas production or lignocellulosic material for second generation biofuels. Sweet sorghum is considered one of the most efficient crops to convert atmospheric CO_2 into sugar with large advantages compared to sugarcane production in some areas of the tropics, making it a promising crop for bioenergy while meeting food and feed needs.

However, despite of these promising characteristics, sweet sorghum is not yet widely cultivated for the production of biofuels. Much less research and breeding activities were implemented on this crop in comparison to other food and energy crops, such as corn or sugarcane. In consequence, the European Commission supported the project SWEETFUEL (Sweet Sorghum: An alternative energy crop) in the 7th Framework Programme to exploit the advantages of sweet sorghum as potential energy crop for bio-ethanol production (Braconnier et al. 2011; Janssen et al. 2010). Thereby, the main objective of SWEETFUEL is to optimize sweet sorghum varieties for different climatic and agroecological regions.

In the framework of this project, a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis was conducted (Rutz and Janssen 2012a) in order to get an overview of the advantages and disadvantages of different sweet sorghum and biomass sorghum value chains. The present chapter is based on these findings and summarizes the main results with regards to the socio-economic impacts of sweet sorghum value chains.

7.2 Sweet Sorghum as an Energy Crop

Sweet sorghum (*Sorghum bicolor* L. Moench) is a grass of the genus *Sorghum*, classified in the family of the *Poaceae*. Sorghum species are among the oldest cultivated crops in the agricultural history. It is believed that it originated from Africa. Wild varieties in the genus sorghum were observed in the northeastern regions of Africa, including Ethiopia and Sudan (Doggett 1988; Khawaja et al. 2013).

Sweet sorghum is similar to grain sorghum, but accumulates high amounts of sugar in the stems that can be used for a variety of uses such as food, fodder, fuel, and fiber.

Today, in addition to its cultivation for energy production, sweet sorghum is still a main food source especially in Asia and Africa and a feed source in developed and developing countries. Sweet sorghum is also valued for the production of commercial products such as alcohol (potable and industrial grade), syrups (natural and high fructose), glucose (liquid and powder), modified starches, maltodextrins, jaggery, sorbitol, and citric acid (downstream products from starch) (CFC-ICRISAT 2004; Khawaja et al. 2013). In addition, due to its fiber content, sweet sorghum can be used for bedding, roofing, fencing, paper, and chewing.

Sweet sorghum is an annual grass that is planted by seeds and can be cultivated in a wide range of climatic conditions, ranging from temperate to tropical regions. It is a C4 plant with many potential advantages, including high water, nitrogen and radiation use efficiency, broad agroecological adaptation as well as a rich genetic diversity for useful traits. A brief introduction in the agricultural characteristics of sweet sorghum is given in Box 7.1 (Rutz and Janssen 2012a). It can be intercropped with various other crops, such as jatropha (Fig. 7.2), pigeon pea, sweet potato, etc.

Box 7.1 Selected Characteristics of Sweet Sorghum

- Sorghum and especially sweet sorghum can grow in a broad environmental range from tropical to temperate regions. Sweet sorghum could be a promising energy crop in both developed and developing countries as well as for small and large scale value chains. As energy crop, it can be cultivated and further processed at very different scales; thus, smallholders but also industry could benefit.
- In tropical regions, sweet sorghum is permitting multiple breeding generations per year due to a short growth cycle of 3–4 months. In tropical and

Fig. 7.2 Intercropping of sweet sorghum with Jatropha in Mali. (Source: D. Rutz, WIP)

subtropical climates, sweet sorghum is very suitable to be integrated with sugarcane cultivation. This leads to strong interest of sugarcane producers (e.g., in Argentina, Colombia) in sweet sorghum cultivation.

- In temperate regions, usually only one harvest is possible, but the total biomass yield is high and it contributes to diversify the crop rotation.
- The high genetic variability of the genus Sorghum provides good breeding opportunities in order to create new improved varieties. The genetics of sorghum are relatively well known.
- Sweet sorghum is characterized by high water, radiation and nutrient use efficiency in comparison to other energy crops (e.g., maize, sugarcane). It is furthermore suitable for the cultivation on degraded soils, thus reducing potential land use change impacts. However, yields are usually lower on degraded or marginal soils.
- As an efficient C4 plant, sweet sorghum is one of the most efficient crops to convert atmospheric CO_2 into sugar and starch.
- All aboveground parts of the plant (stalk, leafs, grain) are valuable products. Since the potential use of sweet sorghum is very broad, it can be used for the production of food (sugar, grains), first and second generation ethanol, biomaterials, electricity from bagasse combustion, thermochemical biofuels and products, biogas, feed, and fodder.
- Bagasse and leaves can be used as fuel for process energy and power generation. It can be also used as fodder, which is an opportunity for subsistence agriculture of small-scale farmers.

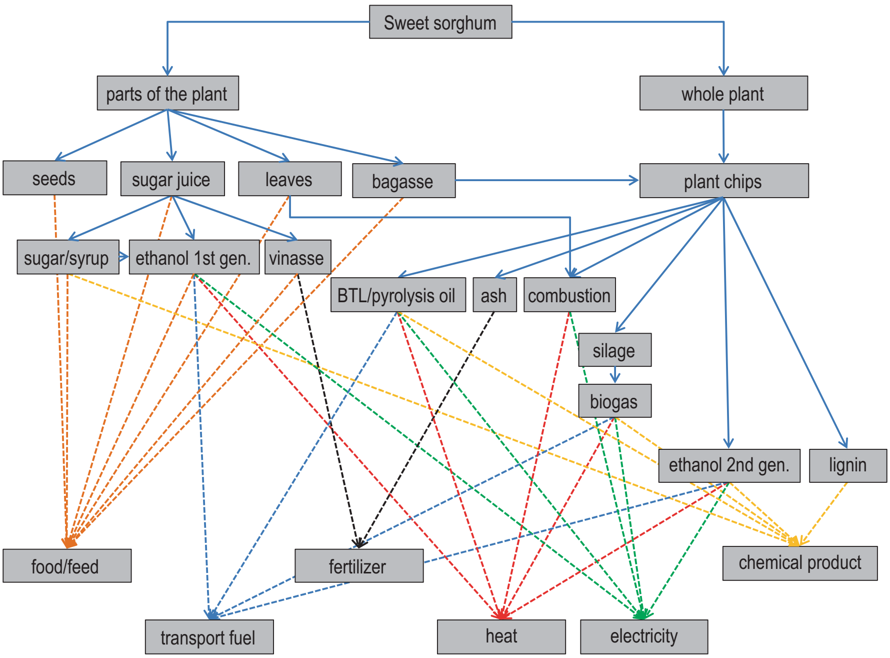

Fig. 7.3 Overview of products that can be derived from sweet sorghum

7.3 Scale of Sweet Sorghum Cultivation and Conversion Scenarios

Sweet sorghum is a promising energy crop in both developed and developing countries. It is suitable for small and large scale cultivation and value chains. The general value chain of sweet sorghum production systems is similar to other bioenergy/biomass production systems:

- Crop cultivation
- Harvesting
- Transport
- Milling (only for ethanol production)
- Processing to the fuel
- Direct use or further transport
- End use

The value chain is characterized by the conversion process and the main and co-products. An overview of the various products that can be derived from sweet sorghum is shown in Fig. 7.3.

The conversion technology and the desired products influence the scale of the production system. Thereby, a differentiation between the conversion steps must be made, as the scale is not necessarily the same for the different value chain steps. However, the border between large- and small-scale is fluent. In general small-scale systems describe value chains that involve many individual farmers that provide feedstock for a small ethanol plant, e.g., operated by the farmer's cooperative. A large-scale system is characterized by the involvement of large investors, feedstock cultivation on modern agro-industrial scale, often done by the ethanol plant company itself. Ethanol produced by large-scale systems is often sold on international commodity markets.

The scale of the value chain steps and production systems is important as this largely influences the socio-economic impacts of the system (Rutz and Janssen 2012b, c). Depending on the perspective of the value chain actors, this includes positive and negative impacts.

Finally, the application of conversion technologies is influenced by the climatic conditions under which sweet sorghum is cultivated, as well as by the status of development of the country.

In tropical climates, the sugar productivity of sweet sorghum is very high and thus, small- to large-scale first generation ethanol production systems are suitable. In temperate regions, the sugar content is less, but the productivity of the biomass is high, so that sweet sorghum is currently used for biogas production. The production of second generation biofuels is still not realized at a fully commercial scale today. In general, production of second generation biofuels is more suitable for temperate regions under the current framework conditions due to the high investment needs.

Generally, the following parameters characterize the agricultural and conversion systems of the sweet sorghum ethanol chain and have a large impact on sustainability issues:

- **Scale of the system:** small-, medium-, large-scale
- **Actors of the cultivation system:** farmers, industrial farming
- **Actors of the production system:** villagers, centralized ethanol plant
- **Business relationships between the actors:** outgrower model, cooperatives, contracted workers
- **Economy of the country:** emerging country, developing country

7.3.1 Tropical Production Systems

The sustainability of the cultivation and conversion of sweet sorghum in subtropical and tropical climate is affected by various factors. Since many potential cultivation areas of these climatic regions are either in developing or emerging countries, socio-economic impacts, negative or positive, are of very high importance. Thereby, "tropical regions" and "developing countries" are no synonyms, of course, but these climatic regions are especially prone to impacts of climate change which may affect the poorest people, namely small-scale and subsistence farmers in developing countries.

A focus of the sweet sorghum value chains in subtropical and tropical climates for energy production is on the production of first generation ethanol. The following list shows production scenarios for first generation ethanol:

- Small-scale feedstock production for a large-scale ethanol plant
- Small-scale feedstock and syrup production for a large-scale ethanol plant
- Small-scale feedstock, syrup, and ethanol production
- Large-scale feedstock production for a large-scale ethanol plant

7.3.2 Temperate Production Systems

The production systems in temperate regions are different to those in tropical regions, as the sugar content of the crop is lower and often too low for sugar extraction and processing to first generation ethanol.

However, it is a good feedstock for biogas production as the high content of sugars, compared to other crops, makes it very digestible. The methane (CH_4) yield of sorghum is assumed at 80 m^3/t of fresh feedstock, as stated in German legislation (BMU 2012; Rutz et al. 2012). In comparison, the methane yield of corn silage (whole crop) is 106 m^3/t and of sugar beet 75 m^3/t of fresh feedstock. Therefore, sweet sorghum is an increasingly applied feedstock plant for biogas, for instance in Germany. For biogas production, the sweet sorghum biomass is chipped during the harvest and then stored as silage until its use. The silage is fed into the digester and during the anaerobic digestion (AD) process, biogas is produced which is used for combined heat and power (CHP) production. Alternatively, the biogas can be further upgraded to biomethane and injected as natural gas substitute into the natural gas grid or used directly as transport fuel replacing conventional gasoline and natural gas. In all AD processes, digestate is produced as by-product and used as fertilizer substituting mineral fertilizer. Typical sizes of biogas plants in Europe have a capacity of about 450 kW_{el}. In agricultural biogas plants, the farmer is often the feedstock producer as well as the operator and owner of the plant.

A future option would be to use sweet sorghum for second generation biofuels for either for thermo-chemical or biological conversion. However, this is not yet commercially applied. Therefore, it is challenging to discuss about its socio-economic impacts, especially as production costs are difficult to predict.

In the second generation ethanol process, the biomass is crushed and pre-treated in order to render the cellulose accessible for a subsequent hydrolysis step. After the hydrolysis of the cellulose for breaking down the long chains into sugars, the substrate is fermented. The ethanol is used as transport fuel replacing conventional gasoline. Vinasse is obtained as by-product and can be either used as feed replacing soy meal or as fertilizer replacing mineral fertilizer. Surplus electricity from the process can be fed into the power grid. The use of sweet sorghum for second generation ethanol production is still not applied at commercial scale today. A general good overview on second-generation biofuels facilities is given, e.g., by IEA Task 39 (2013) and Janssen et al. (2013) (Fig. 7.4).

Fig. 7.4 Typical agricultural biogas plant in Germany using energy crops (corn) and other substrates as feedstock material. (Source: D. Rutz, WIP)

7.4 Socio-Economic Impacts

This chapter addresses selected socio-economic impacts of sweet sorghum value chains. The main focus is thereby on different scales of first generation ethanol production systems in tropical regions of developing countries, as well as on biogas and second generation bioethanol systems in temperate regions of developed countries.

7.4.1 Land Use

Land use is the human use of land which involves the management and modification of natural environment or wilderness into built environment such as fields, pastures, and settlements (Watson et al. 2000). Land use change (LUC) is the change from one use to another use. Often, land use change is also referred to the change of non-used land (virgin land, abandoned land, degraded land) to another use. Thereby distinction is made between direct land use change and indirect land use change (see also Rutz and Janssen 2013, Chap. 5 of this book). Insecurity of land ownership and tenure rights are an important aspect for rural and indigenous communities, especially in developing countries (Mwakasonda and Farioli 2012).

A major advantage of sweet sorghum compared to other crops is that it can grow under harsher conditions. It can still be well cultivated on marginal soils with a wide range of pH, salinity, and soil structure that are unsuitable for food production, although the productivity may be reduced on these lands. Selected land use impacts of sweet sorghum value chains in tropical and temperate regions are presented in Tables 7.1 and 7.2.

Table 7.1 Land-use impacts of sweet sorghum use in large- and small-scale first-generation ethanol production systems in tropical regions

Large-scale cultivation and large-scale conversion	Small-scale cultivation and large-scale conversion	Small-scale cultivation and small-scale conversion
If centralized ethanol plants set-up own large-scale sweet sorghum plantations in developing countries, this may happen by negatively affecting the poor (land grabbing). There is a risk of displacement and marginalization of local communities and smallholders There is a higher risk that sweet sorghum is cultivated in monocultures with negative environmental (e.g., soil fertility, soil compaction, deforestation) and socio-economic (ecosystem services) impacts The land use competition may be high, as larger plants usually select good quality agricultural land The land use efficiency (t per ha) and overall process efficiency of these systems may be higher	Existing agricultural structures and sizes of farms can be maintained. Due to the smaller structures of these systems, the (bio)diversity and ecosystem services may be larger The land use efficiency of these systems may be lower than for large-scale cultivation, but larger ethanol facilities may support smaller farmers, e.g., through training or agricultural equipment	Existing agricultural structures and sizes of farms can be maintained. Due to the smaller structures of these systems, the (bio)diversity and ecosystem services may be larger The land use efficiency of these systems is generally lower due to lack of resources and knowledge. This may be partly compensated if good cooperative structures exist Sweet sorghum cultivation systems can be easily integrated into existing small-scale agricultural structures without negatively affecting small farmers and villagers (no land grabbing) Villagers are themselves responsible for suitable land use and production practices. They are not forced by large companies to adapt to their rules

Table 7.2 Land-use impacts of sweet sorghum use in biogas and second-generation biofuels production facilities in temperate regions

Biogas production	Second-generation biofuels
Sweet sorghum is generally a good alternative to other crops for biogas production, especially as an alternative to corn in drier areas. Thus, it broadens crop alternatives and crop rotation. However, increased energy crop production for biogas has led in some areas to increased prices for land rental.	Sweet sorghum is an annual crop. Thus, for second-generation biofuels production, woody crops or residues may be preferred, as impacts on land use are usually lower for woody crops than for annual crops.

7.4.2 Job Creation, Health and Working Conditions

In general, the production of biofuels generates more employment opportunities and jobs than the production of fossil fuels, as the processing takes place on a smaller scale and involves more stakeholders. This also applies to the use of sweet sorghum for bioenergy production.

Table 7.3 Impacts of large- and small-scale first-generation ethanol production systems from sweet sorghum on job creation, health, and working conditions in tropical regions

Large-scale cultivation and large-scale conversion	Small-scale cultivation and large-scale conversion	Small-scale cultivation and small-scale conversion
In centralized systems (with mechanical harvesting technologies), fewer workers may be needed; thus, less job opportunities are created Mechanical harvesting avoids hard and dangerous work Larger companies must on the one hand comply with stricter rules on health and on working conditions, this is however, on the other hand, often not implemented, especially in developing countries	In the crop cultivation step, more workers are needed than in the large-scale system In the conversion step, only slightly more workers are needed (due to more administration to deal with many smallholders)	Due to general lower mechanization rates of the conversion process, more employment is generated per litre ethanol than in larger systems Ethanol production at small-scale level not only creates direct employment in the value chain, but also indirect employment through related microenterprises Smaller farmers can influence their working conditions

The example of an ethanol plant using sweet sorghum in Uganda shows that up to 250 jobs were expected to be created in Kayunga District for the operation of an ethanol plant with 20 million litres ethanol output per year (Muzaale 2011: Uganda Investment Forum 2013). However, it has to be recognized that these are expected figures; real data are not available to the authors. In addition to the direct workers at the facility, sweet sorghum seeds have been given to 6,000 farmers in order to plant sweet sorghum (Muzaale 2011).

Besides the potential to generate jobs, health issues and working conditions must be considered, especially in developing countries. However, this applies to any business, independently if biofuels or other sectors are considered. It is, in general, not expected that the cultivation and processing of sweet sorghum has larger negative impacts on health issues and working conditions than the cultivation and processing of other crops. In comparison to manual harvesting of sugarcane, sweet sorghum has several advantages, as it is not burned before harvest. Furthermore, the crop is easier to handle during the harvest.

Selected impacts of sweet sorghum on job creation, health, and working conditions in tropical and temperate regions are presented in Tables 7.3 and 7.4.

7.4.3 Profits for Farmers, Plant Operators, and End Consumers

Economic facts of sweet sorghum value chains depend on many factors. A distinction must be made between the profits and benefits for the involved farmers and plant operators and benefits for the end consumers. Economic data are especially available for ethanol production from sweet sorghum in the US (Amosson et al. 2011; Morris et al. 2009). A comparison of the risk and benefits between the alternative plant sizes and locations in the US are provided by Lau et al. (2006).

Table 7.4 Impacts of biogas and second-generation biofuels production from sweet sorghum on job creation, health, and working conditions in temperate regions

Biogas production	Second-generation biofuels
The cultivation of sweet sorghum for biogas production has not per se any impacts on jobs creation in comparison to other crops for biogas production. However, due to the smaller scale of biogas systems, in comparison to second-generation biofuels systems, biogas production generates generally more job opportunities compared to second-generation biofuels Rules on health safety and working conditions are usually implemented in most developed countries	As the whole value chain is on a very large scale, fewer jobs may be generated than in smaller systems Rules on health safety and working conditions are usually implemented in most developed countries

Table 7.5 Impacts on profits of sweet sorghum in large- and small-scale first-generation ethanol production systems in tropical regions

Large-scale cultivation and large-scale conversion	Small-scale cultivation and large-scale conversion	Small-scale cultivation and small-scale conversion
Since smallholders are not involved, there is no revenue generation for local farmers unless contract agriculture can be established The revenues for the plant operators are generally larger in larger plants Due to the higher efficiency and economies of scale, the quality of the products may be better and the prices of the end product lower	Depending on the contracts, small-farmers may have the security that the plant operator buys their feedstock, thus generating a stable income However, the sale of the stalks depends on the centralized ethanol plant which is buying the stalks. If only few local mills exist, farmers have no influence on the stalk prices and are thus vulnerable	A longer value chain for ethanol production on smaller scale generates more local revenues in comparison to the sale of stalks or syrup, only Small-scale farmers can themselves decide if ethanol is sold to external markets or also used for local consumption, e.g., for cooking. Thus, access to modern energy is increased

An economic evaluation for sweet sorghum in Zambia was made by Chagwiza and Fraser (2012).

Selected impacts on profit generation of sweet sorghum in tropical and temperate regions are presented in Tables 7.5 and 7.6.

7.4.4 *Efficiency of the Whole Process*

The efficiency of the value chain depends especially on the scale of the single production steps, as well as on climatic conditions and the agricultural and industrial practices. Overall efficiencies are comparable to ethanol from sugarcane or sugar beet, although they may be little lower (Vecchiet 2010).

Selected impacts on the efficiency of the value chains in tropical and temperate regions are presented in Tables 7.7 and 7.8.

Table 7.6 Impacts on profits of sweet sorghum in biogas and second-generation biofuels production facilities in temperate regions

Biogas production	Second-generation biofuels
Biogas plants are much smaller than second-generation biofuels plants. Thus, more people (farmers) profit from higher revenues, especially as usually the feedstock producer is at the same time the plant operator. However, the revenues depend on public support schemes. The use of sweet sorghum instead of other crops does not have a real impact on the profits	The profits are quite uncertain as no real commercial second-generation biofuels plant exists The use of sweet sorghum instead of other crops does not have a real impact on the profits

Table 7.7 Impacts on the efficiency of sweet sorghum value chains in large- and small-scale first-generation ethanol production systems in tropical regions

Large-scale cultivation and large-scale conversion	Small-scale cultivation and large-scale conversion	Small-scale cultivation and small-scale conversion
The large-scale cultivation and conversion of sweet sorghum increases the overall efficiency of the value chain. This is due to scale effects and due to the general higher investments. Furthermore, access to improved seeds, input materials, and technology is generally available. Harvesting can be done with efficient machinery The conversion process is usually efficient, especially for new and modern plants	Small-scale farmers can benefit from improved input material such as seeds, pesticides, fertilizers, etc. from the large-scale ethanol plant. This increases the overall efficiency of the agricultural production. As the ethanol production is on large-scale, the efficiency is generally higher However, small farmers may be vulnerable to dependencies on improved seeds provided by the large-scale ethanol plant The large-scale ethanol plant may also provide training for the farmers	Farmers are often not trained in best agricultural practices to increase yields. If not properly trained, e.g., on the application of pesticides, negative environmental and human health impacts may occur and efficiency is reduced. Furthermore, access to improved sweet sorghum varieties may be limited for small-scale farmers Small farmers are vulnerable to dependencies on improved seeds (e.g., hybrid and GMO seeds) Sweet sorghum cultivation and ethanol production on small-scale is usually less efficient than on larger scales

GMO genetically modified

Table 7.8 Impacts on the efficiency of sweet sorghum value chains in biogas and second-generation biofuels production facilities in temperate regions

Biogas production	Second-generation biofuels
Land-use efficiency of biogas (biomethane) from sweet sorghum is higher than of other first-generation biofuels (e.g., biodiesel from rapeseed or ethanol from sugar beet), especially in the transport sector If biogas is used in a CHP unit to produce electricity, the "waste heat" should be also used. This is currently a bottleneck in several European biogas plants	Real data on the efficiency of second-generation biofuels are hardly available, especially if sweet sorghum is considered as feedstock

CHP combined heat and power

Table 7.9 Contribution to rural development and national revenues of sweet sorghum value chains in large- and small-scale first-generation ethanol production systems in tropical regions

Large-scale cultivation and large-scale conversion	Small-scale cultivation and large-scale conversion	Small-scale cultivation and small-scale conversion
The contribution of a large-scale system to the rural development depends very much on the implementation of the system. The opportunity exists that investors of large-scale systems bring also investment for general infrastructure into the region However, there is the risk that revenues and income only goes to the investors, which are not settled in the vicinity of the plant, thus not generating any value for the region. This is even worse if investors are settled in other countries	At least a part of the revenues contribute to the rural development in the vicinity of the plant, as small-scale farmers earn from their feedstock sales	Most of the revenues stay within the vicinity of the small-scale system. On the other hand, especially in developing countries, there is often a lack of money available for investment in efficient value chains. Thus, the whole project may not be implemented due to lack of financial sources

Table 7.10 Contribution to rural development and national revenues of sweet sorghum value chains in biogas and second-generation biofuels production facilities in temperate regions

Biogas production	Second-generation biofuels
In several countries in temperate regions, biogas contributes to the rural development, as the farmers are often also the plant operators. There is, however, no difference of sweet sorghum in comparison to other energy crops such as corn.	The contribution of second-generation biofuels to rural development is difficult to estimate as fully commercial plants are not yet available. However, given the large size of the plants and the high feedstock demand, it is estimated that they will significantly contribute to the rural development in the vicinity of the plant.

7.4.5 Contribution to Rural Development and National Revenues

Today, it is commonly agreed upon that the production of biofuels such as bioethanol can potentially generate additional income for rural communities and thus contribute to generate national revenues in developed and developing countries. Sweet sorghum is a crop with versatile options for use, so that uses can be easily adapted to the needs especially of the rural poor in developing countries.

Tables 7.9 and 7.10 present selected impacts of sweet sorghum chains on the contribution to rural development and national revenues in tropical and temperate regions.

Fig. 7.5 Collection of firewood for cooking by a woman in Mali. (Source: D. Rutz, WIP)

7.4.6 Water Availability and Climate Change

In general, sweet sorghum is very water efficient and grows well under dryer conditions (Munyinda et al. 2012), in comparison with, e.g., sugarcane in tropical regions. In water-limited tropical and subtropical environments, sweet sorghum still grows well with precipitation of 600–1,000 mm/year rainfall. Sweet sorghum has thus especially positive characteristics for small-scale agricultural production systems where the installation of irrigation systems is not possible due to the lack of water or financing.

The water efficiency is also a benefit in temperate regions, as rainfall is becoming scarcer in summer in many regions due to climate change. In temperate climates, sweet sorghum has advantages over maize due to its low water requirements as well as lower nutrient (e.g., nitrogen) needs. However, sweet sorghum is sensible to cold temperatures and less productive than maize.

7.4.7 Substitution of Traditional Energy

The global demand for biofuels is continuously increasing (e.g., through mandates and targets) due to the need to substitute traditional energy. Traditional energy consists, on the one hand, of fossil fuels that are depleting and, on the other hand, of firewood that is used in climatic conditions where the trees are not regrowing (nonrenewable wood).

The use of sweet sorghum for ethanol production can substitute petrol and thus contribute to energy security, especially in the transport sector. Thereby, sweet sorghum is especially promising, as it can grow on soils and under climatic conditions where other (food) crops do not grow.

Firewood is mainly used for cooking in dry tropical and subtropical regions of developing countries. The problem is that firewood has to be collected from constantly larger distances, usually by women. Thus, in general, more time is needed for the provision of cooking energy (Fig. 7.5). Furthermore, the cutting of trees in these sensitive regions leads to desertification and loss of ecosystem services. Other

Fig. 7.6 Three-stone fire-place for cooking in Mali. (Source: D. Rutz, WIP)

negative impacts are indoor air pollution (Fig. 7.6), mainly affecting women and children. About 2.7 billion people burn biomass (wood, animal dung, crop waste) using open fires to cook and heat their homes (WHO 2013). Ethanol from sweet sorghum could be used in efficient stoves for these needs, and sweet sorghum can be even cultivated by these people. However, a major problem is often the lack of financial resources of these households to buy the stoves and the ethanol.

7.4.8 Food and Energy Security

In comparison with current sugar and starch crops for bio-ethanol production, sweet sorghum offers important benefits with respect to food security as it can serve as multiple purpose crop for food, feed, and fuel at the same time. Its seeds are valuable cereals and the leaves are high-value feed, thus contributing significantly to enhancing food supply and improving food security, especially in rural areas of developing countries that are prone to food insecurity. However, in larger systems, where sweet sorghum is harvested mechanically, usually only the stalks are removed from the fields, as the simultaneous harvest of stalks and grains is not yet mature. In addition to the grain used for human or animal consumption, sweet sorghum accumulates sugars with little competition between grain and sugar production. The bagasse can be used as animal feed and it is reported to have a better nutritional value than the bagasse of sugarcane (Almodares and Hadi 2009).

The production of bio-ethanol based on traditional food crops may lead to increases of agricultural commodity prices which negatively affect access to food, particularly in net food importing developing countries and for the poorest therein. Significant price increases have already occurred in major bio-ethanol feedstock markets such as corn and sugar.

According to FAO, food security is influenced by four main aspects: availability, access, stability, and utilisation (FAO 2007). Thereby, food availability can be threatened by bio-ethanol production through competition with food production

Table 7.11 Impacts on food security of sweet sorghum in large- and small-scale first-generation ethanol production systems in tropical regions on food and energy security

Large-scale cultivation and large-scale conversion	Small-scale cultivation and large-scale conversion	Small-scale cultivation and small-scale conversion
Large scale systems may contribute to regional development which penetrates to the poorest of the region and it could thus lead to increased food access On the other hand, if the local population is not benefitting from the large-scale production system, there is the risk that food access and also availability in the region is reduced	Farmers could generally also benefit from increasing food prices, as their income from sweet sorghum cultivation is higher. This applies only if the ethanol plant forwards the high prices to the farmers	The cultivation of sweet sorghum may increase the income of small farmers, thus leading to increased food access. Farmers could generally also benefit from increasing food prices, as their income from sweet sorghum cultivation is higher Sweet sorghum enriches the diversity of agricultural products of small farmers, thus reducing risks if only one or few crops are cultivated. Sweet sorghum is edible and can be used as multipurpose crop for own consumption, which is not possible for other (toxic) crops like jatropha

over land, water, and other productive resources. This resource competition concerns present sugar and starch feedstock and will be reduced for second-generation technologies based on lignocellulosic biomass. Access to food (the ability of households to buy food) is affected if food prices rise faster than real incomes, leading to food insecurity.

Finally, sweet sorghum can be associated with existing agricultural (e.g., sugarcane) systems, thereby increasing (energy, food, and feed) productivity and leading to a revitalization of agricultural production which is currently suffering from low investment and low productivity, especially in rural areas of developing countries (Janssen et al. 2009).

Some selected impacts of sweet sorghum in large- and small-scale first generation ethanol production systems in tropical regions on food and energy security are presented in Table 7.11.

7.4.9 Public Acceptance and Acceptance of the Involved Stakeholders

Public acceptance is a prerequisite for the development of biofuels. The public perception largely depends on cultural aspects, history and economy of the producing countries, objectives of importing countries, environmental and social targets, as well as on the positive or negative impacts on individuals and communities. The

Table 7.12 Public acceptance and acceptance of the involved stakeholders of sweet sorghum in large- and small-scale first-generation ethanol production systems in tropical regions

Large-scale cultivation and large-scale conversion	Small-scale cultivation and large-scale conversion	Small-scale cultivation and small-scale conversion
At the local level, the public acceptance of large-scale production systems depends largely on the associated benefits of the local people. If the project is accompanied by sustainable investments in infrastructure, the acceptance is higher At the international level, ethanol from sweet sorghum was not yet widely mentioned in the media, due to the currently low use of sweet sorghum for ethanol	The public acceptance mainly depends on the conditions offered by large ethanol plants to the farmers Manual harvesting of sorghum causes itching. Therefore, farmers often hesitate to cultivate sweet sorghum	The public acceptance of smaller systems is generally high, as long as the system is operational and as long as all involved stakeholders benefit from it The cultivation of sweet sorghum for ethanol production may be relatively new to many farmers, so that awareness campaigns and training is needed Manual harvesting of sorghum causes itching. Therefore, farmers often hesitate to cultivate sweet sorghum

Table 7.13 Public acceptance and acceptance of the involved stakeholders of sweet sorghum in biogas and second-generation biofuels production facilities in temperate regions

Biogas production	Second–generation biofuels
The extension of corn cultivation for biogas production (e.g., in Germany) has led to public protests in areas with high corn density. As sweet sorghum looks similar to corn, the public acceptance of sweet sorghum in these areas may be reduced, due to the negative perception on corn The acceptance of sweet sorghum as energy crop by farmers depends on their experiences with the crop. Especially in temperate regions, sweet sorghum is a relatively new crop for biogas production	If second generation will become commercial, people may wonder why sweet sorghum, an annual crop, should be used for the production of second–generation biofuels instead of woody plants and residues The use of bagasse from sweet sorghum would be good, but will be hardly available in temperate regions in the near future. It is not clear if sweet sorghum will be accepted by plant operators of second–generation biofuel plants, as experience is low. Especially for second–generation ethanol plants, it is difficult to switch from one feedstock to another, as the biological fermentation conditions have to be modified

use of sweet sorghum is so far not very much under public debate, as its use for bioenergy is still small.

Furthermore, besides the public acceptance, also the acceptance of the crop by biofuel market actors is needed. The use of sweet sorghum for bioenergy is still new and has little application in comparison to, e.g., soy, corn, and sugarcane. Thus, some farmers that had no experience with sweet sorghum so far may hesitate to cultivate this crop.

Selected impacts on the public acceptance and acceptance of the involved stakeholders of sweet sorghum value chains in tropical and temperate regions are presented in Tables 7.12 and 7.13.

Table 7.14 Impacts on investments of sweet sorghum in large- and small-scale first-generation ethanol production systems in tropical regions

Large-scale cultivation and large-scale conversion	Small-scale cultivation and large-scale conversion	Small-scale cultivation and small-scale conversion
Large facilities need large investments. Investors in developing countries that are interested in ethanol production are very limited If investors from foreign countries intend to invest in large-scale ethanol systems, they are likely to be named as "landgrabbers." The political instability and lack of suitable infrastructure often makes investments risky	Models exist where the ethanol plant operator provides resources for an efficient cultivation of the feedstock by the small farmers. However, these arrangements may not be done in a fair way, as the involved parties are often not at eye level	Access to agricultural input (fertilizer, pesticide) is expensive and limited for small-scale farmers Equipment for ethanol production (presses, distilleries) may be too expensive for small-scale producers Harvesting machinery for sweet sorghum may be too expensive

7.4.10 Investment Needs for the System Setup and for the Operation

Sweet sorghum can be cultivated with very low financial resources. Farmers need agricultural land and seeds to grow the crop (about 3–6 kg seeds/ha) (Sweethanol 2011). The plant can be easily reproduced by seeds. However, good productivity and efficiency of the cultivation need inputs such as human work, energy, fertilizers, and pesticides, and thus sufficient financial resources.

Even if the feedstock production can be done at a very low cost, considerable financial resources are needed for the further processing steps, such as transport, milling, and conversion to ethanol. However, the availability of financial resources is often a key limiting factor, especially in developing countries.

Table 7.14 shows selected impacts of sweet sorghum value chains in tropical climate.

7.5 Conclusion

The use of sweet sorghum as an energy crop is not only very promising with regards to its high yields and environmental benefits, but especially due to its advantageous socio-economic implications. This is mainly due to the fact that sweet sorghum can grow under soils and climatic conditions that do not allow the cultivation of other (food) crops, such as corn or sugarcane. Furthermore, it is an edible plant with many different use options. Especially, small-scale farmers can quickly change between energy production (ethanol) and food production (sugar and syrup). This advantage is also applicable for ethanol plant operators, similar to the sugar/ethanol bio-refineries using sugarcane (e.g., in Brazil). This allows farmers and plant operators to adjust the production according to best market prices. With regard to its socio-economic benefits, sweet sorghum is an interesting crop, especially for developing countries. Large contributions to rural development can be expected for the cultivation of sweet sorghum in temperate regions, too.

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