Summary Report

of the SWEETFUEL Project

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Logo of the project :

1. Executive Summary

Fossil resources are limited while world energy demand is expected to greatly increase in the next years, especially from China and India. On the other hand, it is tremendously urgent to tackle climate change through mitigation of GHG released in the atmosphere particularly the CO_2 resulting from the use of fossil fuel in transport

Bioethanol is considered today as a valid subsitute to fossil fuels. The current crops used to produce bioethanol are sugarcane under tropical area and corn under temperate climate. SWEETFUEL project proposed to study an alternative energy crop : sorghum. This plant can produce high biomass yield and thus could be used for 2nd generation ethanol (or biogas) production under temperate zone, and as some "sweet " varieties can accumulate sugar in their stalks while producing grain in their panicles, they can also be used to produce 1st generation ethanol from their stalks whitout totally compromising food security under tropical area.

As the main bottleneck for ethanol development from sorghum seemed to be the lack of plant material adpated to the target environments, three breeding programmes were developed in the frame of SWEETFUEL. Taking into account the process of transformation, the first programme targeted a biomass sorghum better adaptated to low temperature suitable for temperate zone and 2G ethanol production, while the two others focussed on a sweet sorghum better tolerant to drought and/or low fertility environments under semi-arid tropical climat, and suitable for 1G ethanol production.

Beside the breeding effort, activities on plant functioning were conducted to identify useful traits for sweet sorghum sugar production and adaptation to drought, and characterize their physiological and genetic bases. Particular attention was paid to evaluate in terms of carbon allocation, the competition between grain filling and sugar accumulation in stalk of sweet sorghum. Based on the data, a structure-function model was developed.

A work progamme was also developed to understand the agronomic determinants of optimized yield to recommand the best cultural and harvest techniques. A crop model was developed for exploring effect of climate change as well as cultural practices on the crop, and identifying target population of environments.

Finally a complete multicriteria evaluation of the sustainability of the sweet and biomass sorghum production uses and routes was completed taking into account technological, environmental, economic and social aspects.

All results were actively disseminated through project website as well as a Project Newsletter, many scientific publications, oral and poster presentations at international conferences and press releases.

2. Project Context and Main Objectives

Fossil resources are limited while world energy demand is expected to greatly increase in the next years, especially from China and India. This will result in rising oil prices and prohibit extensive use of this resource in the future. On the other hand, it is tremendously urgent to tackle climate change through mitigation of GHG released in the atmosphere. CO_2 from the use of fossil fuel in transport sector is the main component of the GHG : in Europe, it could represent 60% of the GHG emitted during the 2005-2020 period. The limits of fossil resources added to the necessity to reduce CGC emission lead many governments particularly in Europe to promote the use of biofuels in transport[1,2].

Bioethanol is considered today as a valid subsitute to fossil fuels. First generation ethanol (1G) can be produced from sugars (sugarcane in Brazil, sugar beet in Europe) or starch (wheat or corn in USA), while second generation ethanol (2G) can be produced from any cellulosic material. Whether bioethanol represents a viable alternative to oil depends on the raw material that is used, the process of transformation and the location of production. Production from sugar cane in Brazil has a positive energy balance and allows great GHG savings, but starch ethanol from corn in USA has less positive balance and may have great negative impact on food security. 2G ethanol should have a much better energy balance and GHG savings without competing directly with food, but this technology is not yet available on the market.

Meanwhile 1G ethanol production must be developed particularly through prospection of new energy crops more efficient than maize in the temperate zone and suitable for marginal lands where sugarcane fails in the tropics.

Sorghum is one of the most efficient crops that convert atmospheric CO_2 into sugar, with great advantages compared to sugarcane in the tropics and maize in the temperate zone : its cycle is short (few months), the crop can be established from seed, the production can be completely mechanized, it can accumulate sugar in stalks and produce grain, it has a high water and nutrient use efficiency, the bagasse produced from sweet sorghum has a high value (as fodder or as fuel in cogeneration) and it has a wide adaptability to environment. Finally, unlike sugarcane and maize, sorghum has a rather short breeding history, meaning that the potential of improvement through genetic enhancement is very high. All these characteristics making it a promising feedstock for bioenergy production while meeting food and fodder needs.

The Sweetfuel project was granted in the 7th Framework programme Call KBBE- 2008-3-1-02 : Sweet sorghum – An alternative energy crop for biofuel production in semi-arid and temperate regions – SICA (Latin America, South Africa, India).

The main objective was to develop ethanol production from sorghum through genetic improvement/selection of new material better adapted to the target regions. Besides breeding for biomass yield and relevant traits, the project also addressed agronomic practices and

[1] Directive 2003/30/EC Promotion of the use of biofuels and other renewable fuels for transport

[2] Directive 2009/28/EC Renewable Energy Directive

harvest technologies, as well as environmental and economic analysis including energy balance and life cycle assessment.

Sweetfuel breeding strategy was defined by taking into account first the two target zones and second the use of the biomass. In temperate regions like Europe, availability of 2G ethanol technology was anticipated and a "biomass" sorghum with a better tolerance to low temperature and lodging added with a low lignin content is targeted. Such material is also suitable for biogas production, which is already well developed in some countries like Germany. Under semi-arid climate, the target ideotype was a "sweet" sorghum, with characteristics differing according to the use of biomass. For example the ideotype targeted by EMBRAPA in Brazil, which must meet expectations of the sugarcane industrial sector was different from those targeted in India, where many smallholders are concerned and the food security issue is essential. In that case, we targeted a dual purpose sweet sorghum combining grain production and sugar accumulation in the stalks. Table 1 summarizes the ideotype characteristics of the three breeding work packages of SWEETFUEL.

Table 1 : Characteristics of the different sorghum ideotypes targeted by SWEETFUEL project

	Uses	Ideotype
WP1	2G ethanol or biogas	**Biomass sorghum** with high biomass (height >3m) <u>good tolerance to low temperature</u> photosensitivity adapted to late flowering good quality of biomass (low lignin content to increase digestibility) good tolerance to lodging good tolerance to water deficit **grain production is not essential**
WP2	1G ethanol + grain & fodder	**Sweet sorghum** with high biomass production (20-30 t DM ha^{-1}) grain production from 1.5 to 3 t ha^{-1} high soluble sugar in stalks, Brix° of 15 to 20 with 80% saccharose juicy stalks high value of the bagasse as fodder (high digestibility = *bmr* trait) adapted to cropping seasons in India <u>good tolerance to drought</u> **grain production is essential**
WP3	1G ethanol + cogeneration	**Sweet sorghum** with high biomass production (40-50 t DM ha^{-1}) high soluble sugar in stalks, Brix° of 15 to 20 with 80% saccharose juicy stalks high energetic value of the bagass for cogeneration (high lignin) <u>adaptation to marginal soils (acidity, aluminum toxicity, P deficiency)</u> adaptation of crop cycles (good complementarity with sugarcane) **grain production is not desirable**

The breeding effort is supported by two work packages. One aims at improving our knowledge on the accumulation of sugars (trade offs between grain production and sugar accumulation, key enzymes…) and the relationship among traits for sugar accumulation, plant phenology, stay green and drought tolerance. It is planed also to develop a model for exploring new ideotypes combining different traits in different environments. The other WP aims at better understanding agonomic determinants of optimized yield to recommand the best cultural and harvest techniques.

Finally, the complete sustainability of the sweet sorghum production and use routes is studied taking into account technological, environmental, economic and social aspects.

Attention is given to disseminate the results achieved by the different teams involved in the work plan.

General organization of the work programme is summarized in Figure 1.

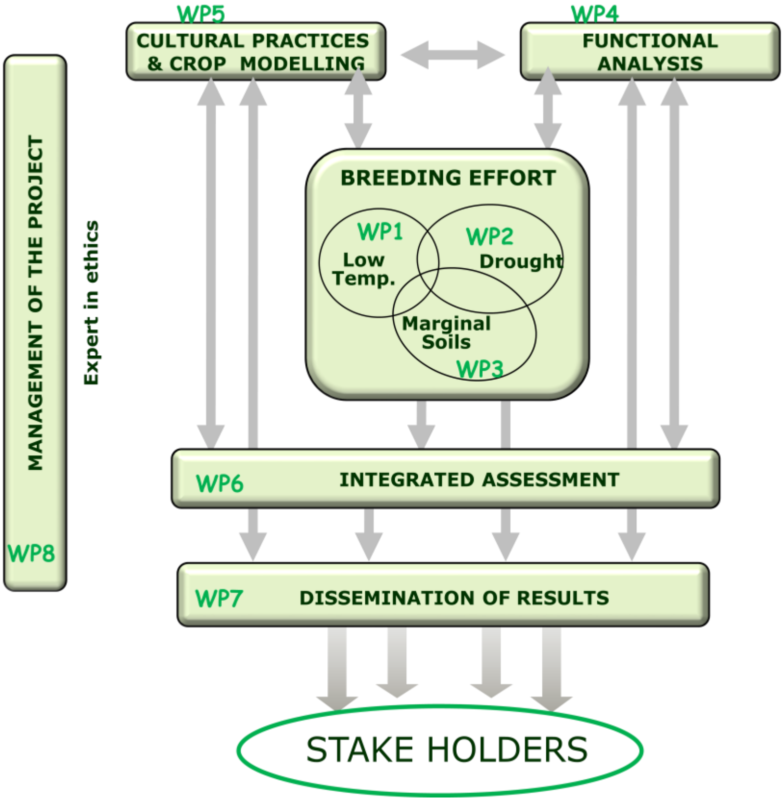


Figure 1 : organization of the work programme

Ten partners coming from seven countries and four continents are involved in the project (Table 2) to achieve the different tasks and goals through a multidisciplinary approach.

One external consultant specialist of ethical issues was included in the consortium at the beginning of the project on the request of the Commission.

Table 2 : SWEETFUEL consortium

Role	Beneficiary name	Short name	Country
Coordinator + WP4 leader + WP8 leader	Centre de Coopération Internationale en Recherche Agronomique pour le Développement	CIRAD	France
WP1 leader	KWS SAAT AG	KWS	Germany
WP2 leader	International Crops Research Institute for the Semi-Arid Tropics	ICRISAT	India
WP3 leader	Empresa Brasileira de Pesquisa Agropecuária	EMBRAPA	Brazil
WP5 leader	Università di Bologna	UniBO	Italy
WP6 leader	Institut für Energie- und Umweltforschung Heidelberg GmbH	IFEU	Germany
WP7 leader	Wirtschaft und Infrastruktur GmbH & Co Planungs KG / WIP Renewable Energies	WIP	Germany
Participant	Università Cattolica del Sacro Cuore	UCSC	Italy
Participant	Universidad Autónoma de Nuevo León	UANL	Mexico
Participant	Agricultural Research Council-Grain Crops Institute	ARC-GCI	South Africa

3. Main Scientific and Technological Results

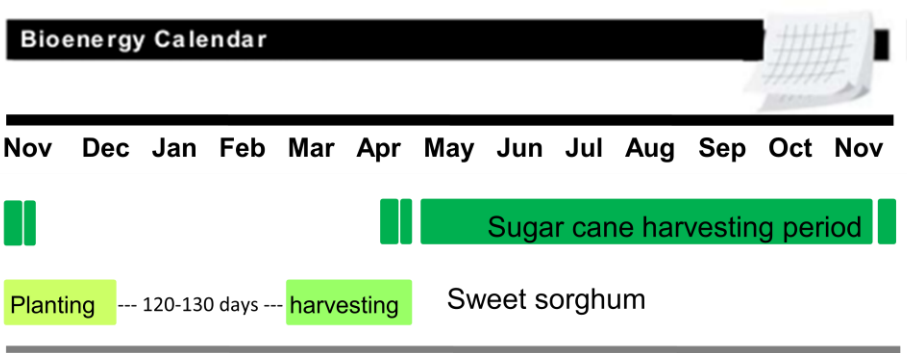
Most of the results are reported in a one page flyer which includes a short description/explanation of the result, exploitation strategy, IPR considerations, further research and the impact of its exploitation.
Fourty one flyers were elaborated by SWEETFUEL consortium and are available from the project website (www.sweetfuel-project.eu).

IMPORTANCE OF THE CROPPING CYCLES

- ***The good complementarity between sugarcane and sweet sorghum***

Sweetfuel through its breeding for low fertility environment programme allowed EMBRAPA to reinitiate its Energy sorghum breeding and improvement programme. It resulted in a clear identification of the expectations from the sugarcane sector, which is the major niche for sweet sorghum in Brazil today, particularly with sugarcane renovation, which is recommended to occur every five years. During sugarcane renovation, a legume crop (peanut, bean…) is frequently planted. The idea is to substitute this legume crop cycle with sweet sorghum, because harvest of sweet sorghum occurs during the sugarcane off-season. By doing this, the sugarcane sector can expect to increase its ethanol production without any additional investment for new equipment as the sweet sorghum stalks are harvested and processed like sugarcane, nor extension of exploited lands, as sorghum is planted between two sugarcane cycles. In addition, plant owners could easily extend the operating window of their plants up to 60 days (see figure 2). This excellent fit between the two crop cycles is the main driving factor, which will lead to the development of sweet sorghum in Brazil (see photos 1 to 6).
This approach can can be deployed to develop sweet sorghum ethanol value chain in other regions where a sugar industry already exists (e.g. India, North Argentina, Haïti…).

Figure 2 : complimentarity between sugarcane and sweet sorghum cycle in Brazil



1. Harvest of sweet sorghum

2. Raw material (30cm pieces, no leaves, no grain)

3. Continuous delivery of the stalks at the plant

4. Sampling for quality controle

5. Juice extraction by the first (of 5) mill

6. Bagasse which will be burnt for ethanol processing or electricity production

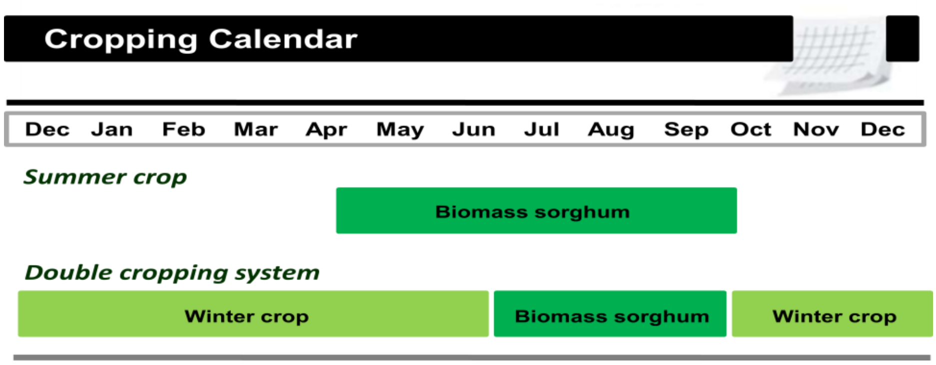
- ***Summer cropping or double cropping system in Europe***

Due to the low temperature constraint in temperate zone, biomass sorghum is usually planted as a summer crop, which means planting in April/May for a harvest period in September/October (Figure 3). During this 4-5 months cycle, farmers can expect a biomass yield of 30 to 40 t ha^{-1} of dry matter.

But there is another option, which is to plant sorghum just after a winter crop for a double cropping and harvest it by September/October (Figure 3). In that case, expected biomass production is less (20 to 25 t ha^{-1}) but this option presents the advantage of incre asing land values with a second harvest per year which allows to combine a food production with a fuel production thus decreasing a potential competition of food vs fuel.

The breeding in SWEETFUEL considered these two targets, added with a third option, which is to produce ethanol from first generation processes.

Figure 3 : the 2 options in Europe



Plant material

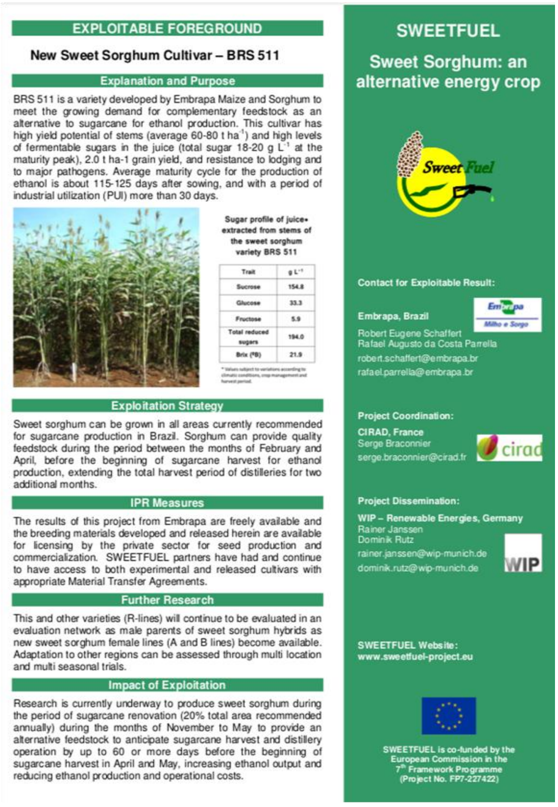
As the core of the project was a breeding effort, new biomass or sweet sorghum material was produced by SWEETFUEL. This material is better adapted to the target environments taking into account the final uses of the raw material. The breeding programme is a continuous process, and even if SWEETFUEL already proposes new cultivars, we expect that better ones will be released in the near future, particularly in Brazil, India and Mexico. Information on the different biomass and sweet sorghum is included in the different flyers produced by the project than can be downloaded from: http://www.sweetfuel-project.eu/exploitable_results.

- ***In Brazil***

EMBRAPA has registered and released ***3 sweet sorghum varieties*** (BRS 508, BRS 509 and BRS 511) in 2012. This material, suitable for 1G ethanol production through the complementation of sugarcane production, meets industrial minimum requirements in terms of length of period of industrial utilization (PIU > 30days), total sugar in the juice (>12.5%) and total sugar extracted (80kg t^{-1}). (Figure 4).

EMBRAPA planned to release ***3 additional sweet varieties in 2014*** and ***2 to 4 sweet sorghum hybrids on 2016 and 2017***, which will reach higher ethanol production per hectare.

One ***biomass sorghum hybrid*** (CMSXS7015) able to produce a good feedstock to burn for electricity production is also available for plant only dedicated to generate electricity. This photosensitive hybrid can produce up to 50-60 tons of dry biomass per ha.



EXPLOITABLE FOREGROUND

New Sweet Sorghum Cultivar – BRS 511

Explanation and Purpose

BRS 511 is a variety developed by Embrapa Maize and Sorghum to meet the growing demand for complementary feedstock as an alternative to sugarcane for ethanol production. This cultivar has high yield potential of stems (average 60-80 t ha^{-1}) and high levels of fermentable sugars in the juice (total sugar 18-20 g L^{-1} at the maturity peak), 2.0 t ha-1 grain yield, and resistance to lodging and to major pathogens. Average maturity cycle for the production of ethanol is about 115-125 days after sowing, and with a period of industrial utilization (PUI) more than 30 days.

Sugar profile of juice* extracted from stems of the sweet sorghum variety BRS 511

Trait	g L^{-1}
Sucrose	154.8
Glucose	33.3
Fructose	5.9
Total reduced sugars	194.0
Brix (°B)	21.9

Exploitation Strategy

Sweet sorghum can be grown in all areas currently recommended for sugarcane production in Brazil. Sorghum can provide quality feedstock during the period between the months of February and April, before the beginning of sugarcane harvest for ethanol production, extending the total harvest period of distilleries for two additional months.

IPR Measures

The results of this project from Embrapa are freely available and the breeding materials developed and released herein are available for licensing by the private sector for seed production and commercialization. SWEETFUEL partners have had and continue to have access to both experimental and released cultivars with appropriate Material Transfer Agreements.

Further Research

This and other varieties (R-lines) will continue to be evaluated in an evaluation network as male parents of sweet sorghum hybrids as new sweet sorghum female lines (A and B lines) become available. Adaptation to other regions can be assessed through multi location and multi seasonal trials.

Impact of Exploitation

Research is currently underway to produce sweet sorghum during the period of sugarcane renovation (20% total area recommended annually) during the months of November to May to provide an alternative feedstock to anticipate sugarcane harvest and distillery operation by up to 60 or more days before the beginning of sugarcane harvest in April and May, increasing ethanol output and reducing ethanol production and operational costs.

SWEETFUEL

Sweet Sorghum: an alternative energy crop

Sweet Fuel

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SWEETFUEL is co-funded by the European Commission in the 7th Framework Programme (Project No. FP7-227422)

Figure 4 : Example of material released by EMBRAPA

These breeding materials developed and released herein are available for licensing by the private sector for seed production and commercialization.

- ***In India***

The different improved (dual purpose) sweet sorghum combining grain and sugar accumulation in stalks, available from ICRISAT are reported in Table 3. Some of these genotypes could be tested in other countries (Brazil, Mexico, South Africa, USA, Philippines, China…) for local adaptation. The stalks or the bagasse collected after juice extraction represents a good fodder for cattle, which lead farmers to easily adopt the new material even if their main purpose is not to produce ethanol or syrup, but rather grain and fodder (Table 3).

Some genotypes were tested during the last cropping season with the sugarcane sector, and based on the first results and discussion with plant owners, sweet sorghum could easily complement sugarcane like in Brazil. Nevertheless in that case, the production of grain would remain essential as a big plant is fed by many small farmers who definitively need the grain production for their own consumption. Similarly, about 12 female hybrid parents (ICSSB 14001-14012) with over 15% Brix were developed at ICRISAT for use in heterosis breeding. Brown midrib allele introgression to the locally adapted sweet sorghum cultivars is in advanced stage which have implications in dairy and lignocellulosic biofuel production.

Table 3: Dual purpose sweet sorghum available from ICRISAT

Name	Grain yield ($t\ ha^{-1}$)	Tolerant to terminal drought stress	Tolerant to mid season moisture stress	Adapted to rainy season	Adapted to post rainy season
ICSV 25311	3.5	yes			yes
ICSV 25308	3.6	yes			yes
ICSV 25300	2.3		yes	yes	yes
ICSV 12012	1.3	yes	yes	yes	yes
ICSV 25339	5.9			yes	
ICSV 12007	4		moderately	yes	yes
ICSV 12008	4.5		moderately	yes	yes
ICSSH 71	4.5		yes	yes	yes

This SWEETFUEL exploitable result are freely available and the breeding material developed is available freely to SWEETFUEL partners and public sector partners, while private partners can avail the material by becoming members of hybrid parents research consortium and complying of appropriate Material Transfer Agreements.

- ***In South Africa***

Through different evaluations of the ARC-GCI germplasm and exotic material collected from the consortium, ARC identified one Open Pollinated Variety, OPV007 (Figure 5) as a very good producer of sugar and fodder, as well as top 5 cultivars regarding biomass, syrup yields and sugar contents. Some of these cultivars showed also a good tolerance to mid-season and/or terminal drought stress (i.e. SSP081 and Hunnigreen).
OPV007 showed also a good potential in India and Mexico.

EXPLOITABLE FOREGROUND

New sweet sorghum cultivar for rainfed growing condition- OPV 007

Explanation and Purpose

This SWEETFUEL exploitable result presents an open pollinated variety selected from the sweet sorghum germplasm collection at the ARC-GCI, South Africa. It flowers in 105 days and grows to 2.5 m height. It records 37 $t\ ha^{-1}$ stalk yield, 12 $t\ ha^{-1}$ juice yield, 19% Brix and 1.7 $t\ ha^{-1}$ sugar yield.

Exploitation Strategy

This variety consistently performed top in sugar yield and related traits over the last 3 to 4 seasons under rainfed conditions in South Africa. It has also shown potential in India and Mexico.

IPR Measures

The seed material can be accessed by signing a Material Transfer Agreement.

Further Research

Further research includes testing for adaptation to other regions, and evaluation for hybrid breeding.

Impact of Exploitation

This variety has shown good potential for biofuel production and high fodder yield.

SWEETFUEL

Sweet Sorghum: an alternative energy crop

Sweet Fuel

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SWEETFUEL is co-funded by the European Commission in the 7th Framework Programme (Project No. FP7-227422)

Figure 5

This material is available from ARC-GCI through a Material Transfer Agreement.

- ***In Mexico***

UANL submitted height genotypes for registration in the national catalogue (Table 4). This material includes parental lines for new sweet sorghum hybrids as well as hybrids suitable for ethanol production. It should be soon available at commercial level.

Table 4 : Genotypes under process of registration to the national catalogue.

Name	Description
7KEY	Sweet sorghum hybrid for Mexico
7ROGER	Sweet sorghum hybrid for Mexico
WROGER	Sweet sorghum hybrid for the Northeastern part of Mexico
ROGER	Sweet sorghum variety for sweet sorghum hybrid in Mexico
MEXINDU	Sweet sorghum variety for sweet sorghum hybrid in Mexico
POTRANCA	Sweet sorghum female line
WYR	Sweet sorghum variety to produce new female forsweet sorghum hybrids in Mexico
38ANE	Grain sorghum female parent in sweet sorghum hybrid for Mexico

***Patent application was initiated at Servicio Nacional de Inspeccion y Certificacion de Semillas (SNICS, the Mexican National System for registration and certification of seeds*.**

- ***In temperate zone***

The breeding effort focused mainly on 2 targets : (1) new biomass sorghum hybrids as a "summer crop", (2) new biomass sorghum hybrids suitable for double cropping cycle.
SWEETFUEL is not able to recommend some biomass hybrids suitable for industrial use (biogas production or 2G ethanol production) as it requires longer time for evaluation and catalog entry. Such material must meet expectations from industrial sector which are first a good stability of biomass yield, and second a constant quality of biomass (high percentage of dry matter). If SWEETFUEL the first biomass sorghum hybrids meet expectations of quality for biogas or 2G ethanol production, stability of biomass yield is not achieved. Indeed, if we were quite satisfied with the evaluations in 2012 where some of our new hybrids performed better than the current commercial checks, the last evaluation in 2013 (with a spring particularly cold) did not result in convincing results as none of SWEETFUEL hybrids reached the level of the commercial checks. This material was evaluated for the target 1 (summer crop), which may be not the best option for European zone. Moreover in 2013 about ten hybrids made with new

Sweetfuel male lines could give dry biomass yields from 18 to 26 t ha^{-1} with a short cycle duration (less than 110 days from sowing to harvest). These hybrids may be promising for the target 2 (double cropping systems), as the yield production is high and the dry matter content is high (>35%).
KWS and CIRAD will continue their breeding effort and test new hybrid combinations to identify material with a better stability in biomass yield for both targets.
Nevertheless SWEETFUEL produced many promising lines with a good ability fro combination, which can be tested in new combinations for new hybrids production. We can mention some A/B lines with low lignin content that can be used as female parents for developing new generation of biomass hybrids with high (enhanced) digestibility, as well as new male and new A/B female lines for biomass hybrids useful for developing new generation of biomass sorghum hybrids with short cycle duration, relevant for double cropping systems in Europe. ***This pre-breeding material is the main result of the breeding programme for temperate zone.*** It is of great value for further developments of any breeding programme targeting the two options in temperate zone. ***This material is available from CIRAD through Material Transfer Agreement.***
Beside biomass sorghum, CIRAD also worked on identifying new sources of sweet and juicy parental lines and testing new sweet sorghum hybrids adapted to South Europe. Several of the new sweet sorghum hybrids tested at Montpellier in 2013 and 2013 summers gave excellent results (up to 5-6 t ha^{-1} of soluble sugars) and performed better than the current commercial checks. Such material is suitable for 1G ethanol production in South Europe where 1G ethanol production from sweet sorghum could be an opportunity according to SWEETHANOL project (Intelligent Energy Europe / http://www.sweethanol.eu).

This material is available from CIRAD through Material Transfer Agreement.

RECOMMENDATION ON CULTURAL, HARVEST AND STORAGE TECHNIQUES

Sorghum is a traditional cereal in Africa from where it originates. In the past, it was cropped to produce principally grain for human or animal consumption, but if we want to use it as an energy crop, we have to consider new cultivars: sweet (for tropical area) or biomass (for temperate zone) sorghums.
Great effort must be undertaken to inform and transfer the knowledge to farmers for giving them the best material and information on cultural practices to optimize sorghum production. This is particularly true in the case of Brazil, where the sugarcane sector has a very limited knowledge on sweet sorghum. This partially explains why they did not decide to intercrop sweet sorghum with sugarcane in the eighties, when the economic situation was quite similar to the current one. At that time, most distilleries were owned by old families that were used to crop only sugarcane and did not want to crop other plants. Nowadays, manager of distilleries are businessmen who rapidly saw the profit they could gain from the complementation of sugarcane production with

sweet sorghum, and they are in favor to introduce sweet sorghum in their sugarcane rotations. But for doing this it was necessary to adapt sorghum cultural practices to a highly mechanized situation. The main challenge was to ***adapt and optimize the geometry of plantation to sugarcane harvester***. EMBRAPA tested different densities and schemes of plantation taking into account the size of the harvester. Based on the results, a density from 120 to 130 000 plants ha^{-1} should be suitable for maximum ethanol production in a system combining both crops in Brazil. In other locations (India, Mexico, South Africa…) recommended plantation densities may be a little different (e.g. 110-120 000 plants ha^{-1} in India).

Under temperate climate, even if grain sorghum as well as forage sorghum has been cropped for a long time on limited area and the cultural practices are rather well defined. But to produce biomass for feeding biogas plants, most farmers prefer planting maize. This situation may change taking into account the advantages of sorghum in terms of nutrient and water consumption, added with the recent decision in Germany to limit at 60% the percentage of maize used to feed new biogas plants. The integrated sustainability assessment performed in SWEETFUEL pointed out that several environmental, economic and social advantages of cultivating biomass and sweet sorghum are possible, particularly through a ***better management of fertilizers application***.

Harvest technique itself is not really an issue : in temperate zone, biomass sorghum is mechanically harvested and either used to feed directly the biogas plant, either stored as silage for a later use, while in Brazil, sweet sorghum is harvested mechanically the same as sugarcane, without collecting grain and immediately transported to be crushed in the mill. Big distilleries are well organized to collect and provide a continuous flow of feedstock to the mill that operates 24 hours a day during the high season. It is also recommended to ***harvest sweet sorghum at hard dough stage and defoliate the plant for a higher ethanol yield***.

In countries where grain production is essential (e.g. India, Haïti…), harvesting is currently done manually. In that case, ***logistic can be the main issue***, as the stalks must be crushed rapidly after cutting to prevent any loss of ethanol production. For small units organizing the collection could be easy, but for big units like in India for example, a continuous feeding requires to organize thousands of farmers, which may be a great challenge.

In temperate zone, the ***energetic and conservation properties of ensiled sorghum biomass can be improved through a mixture with lactobacillous bacteria*** (Figure 6).

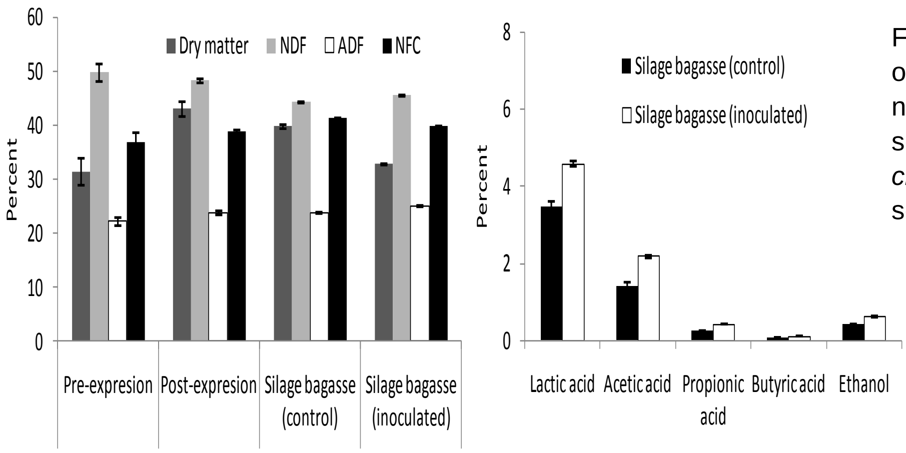


Figure 6: Storage degradability of dry matter and structural and non-structural sugars, and preservative effects of *Lactobacillus bacteria* on ensiled sorghum bagasse

More detailed information related to agronomy and harvest technologies is available from the "Energy sorghum handbook", as well as from Deliverables 5.3 and 5.4.

PROGRESS IN KNOWLEDGE ON PLANT FUNCTIONING

SWEETFUEL identified biological traits of interest for sweet sorghum to ensure sugar production, its combination with grain production and their maintenance under drought stress, as well as contribute to analyze the genetic bases of such traits. The phenotypic behavior of contrasted genetic material in contrasted environmental conditions, was analyzed in order to capture the impact of the variation of putative traits of interest, alone or in combination on the whole plant behavior and performance, considering possible trade-offs among traits. A particular focus was made on their regulation by water deficit and photoperiod, both known to affect plant growth and/or phenology and thus biomass, sugar and grain productions.

- ***Sugar accumulation***

The extension of the vegetative phase due to early sowing enhances sugar production in photoperiod sensitive sweet sorghums as more internodes are initiated which have longer time to accumulate sugar. In addition, studying fertile / sterile sorghum lines pointed out that carbohydrates transported to the grain in the sterile version were not retrieved totally in the stem in the sterile plants. These observations show that ***early***

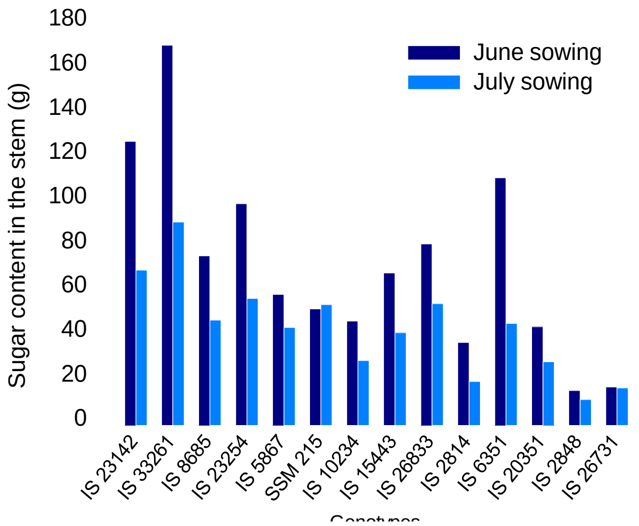


Figure 7: Sugar production by plant stem of the 14 genotypes grown in Mali in 2010 (Sotuba experimental station of IER) with two sowing dates. Genotypes are ordered by decreasing level of photoperiodism from the left to the right

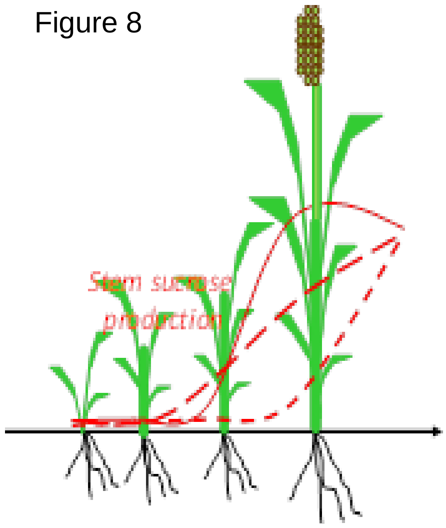
sowing of photoperiodic material is relevant to enhance sugar production and competition between sugar accumulation and grain filling is not so straightforward in the field (Figure 7).

A Recombinant Inbred Line population based on BR501R (Brandes) and BR505R (Wray) was developed by EMBRAPA. Based on genotyping and phenotyping data of this population, QTLs related to high sugar accumulation were identified. ***Molecular markers will be developed for selected QTLs for use in selection of superior genotypes in sweet sorghum molecular breeding programmes***.

- *Modeling*

An existing ***plant growth model, Ecomeristem***, initially developed for rice, was adapted to formalize the processes underlying the genetic and environmental variability of sugar and grain production. In particular, processes related to internode elongation and construction (initiation, growth, sugar accumulation), panicle formation (initiation, development, grain filling), effect of a lengthening of the vegetative phase and of modification of C source to sink relations, were formalized (Figure 8). The model was adapted, calibrated, tested and explored. Its validation and consistent application to explore ideotypes dedicated to dual production (grain, sugar) is still needed. However this modeling work performed provides today a strong cognitive and methodological basis. These results will be published in the year following the end of SWEETFUEL.

Figure 8



A ***crop model, Samara-sorghum***, was also developed in the frame of SWEETFUEL. This model is available for use on sorghum research projects, either for grain, sucrose or biomass productions. It can be used as a decision support tool for agronomists, crop physiologists and breeders as it enables to test many parameters values and see how adjustment processes in the plant (e.g., tillering vs. leaf size), trade-offs among traits (e.g., plant height vs. harvest index) and trade-offs among cultural practices (e.g., plant spacing vs. varietal type) come about and affect the agronomic outcome. As a support to varietal improvement, SAMARA can be used to define the target population of environments (TPE) as well as new ideotypes according to current environments. It can also be used for climatic change mitigation studies.

- *Genetic results*

A study on gene expression in 2 contrasted cultivars and under 2 different water regimes allowed the ***identification of interesting genes linked to drought response***. The next step will be to validate these genes.

QTLs for traits for high sugar accumulation were identified and allowed the development of molecular markers that can be now used in breeding programmes to select superior sweet sorghum genotypes.

Identification of QTLs for tillering, which is a very interesting trait for the development of new sweet and biomass sorghum hybrids, has been initiated, and will be completed in 2015. Molecular markers will be developed and used in breeding programmes.

SUSTAINABILITY OF ETHANOL PRODUCTION FROM BIOMASS AND SWEET SORGHUM

The integrated sustainability assessment combines, joins and extends results and conclusions from the technological assessment (Deliverable 6.2), the environmental assessment (D 6.3), the economic assessment (D 6.4) and the SWOT analysis (D 6.5), which includes social aspects. In the following the main conclusions of the integrated sustainability assessment are presented.

Scenarios on bioethanol production from sweet sorghum and scenarios on biogas production from biomass sorghum were analyzed in the SWEETFUEL project

The whole life cycles of energy sorghum cultivation and use mostly lead to a combination of ***environmental advantages and disadvantages*** (see example in figure 9). Furthermore, local environmental impacts are mostly negative, when compared to idle land. This is a typical pattern that is similarly observed for most energy crops. Effective biomass production, especially with annual or annually cultivated crops, can only be achieved with intensive agriculture including appropriate fertilization, which is the major cause for the observed negative impacts. Any weighting of these advantages and disadvantages necessarily involves subjective preferences. Thus, the precondition for any energy sorghum use is that society accepts the environmental disadvantages in return for the advantages.

Several scenarios that depict the use of mature technology turn out to be ***highly profitable*** under the conditions set for the economic assessment.

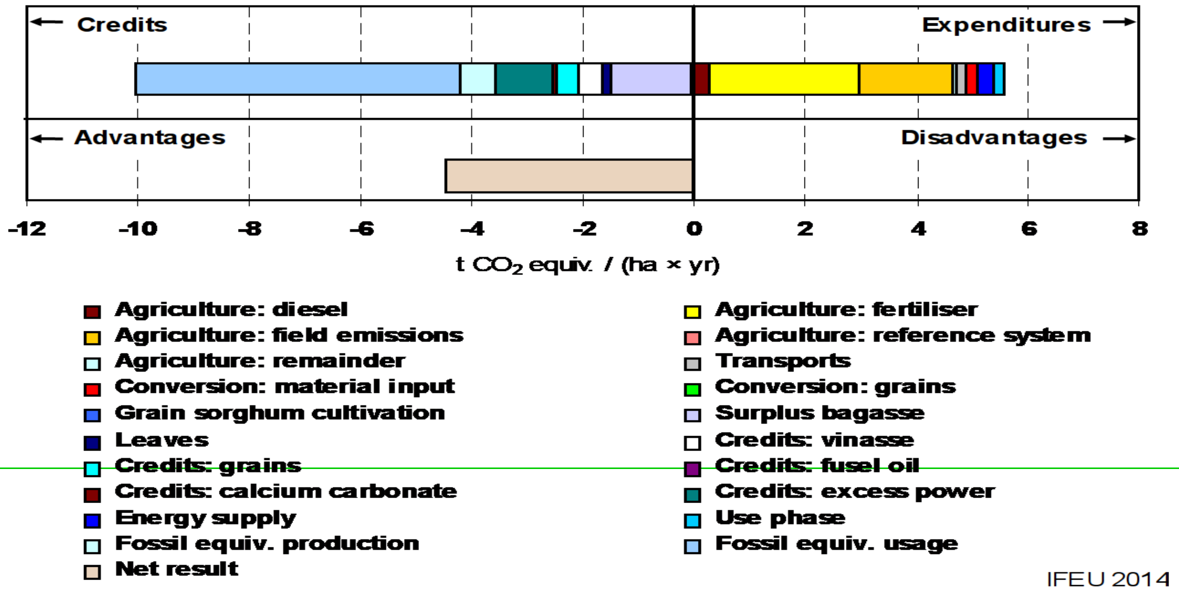


Figure 9. Contributions of individual life cycle steps (coloured sections) to the overall net result (light brown bar) of sweet sorghum ethanol production in the cane fallow scenario for the environmental impact/category greenhouse effect. Results are based on typical cultivation and conversion conditions

Social impacts are vary but are mostly positive as long as conflicts about land rights and access to land can be solved.

Despite these general patterns, quantitative results for environmental impacts and economic profitability can vary widely. Non-optimal scenarios can even deviate from the general pattern and cause e. g. additional greenhouse gas emissions and high economic losses. The high importance of implementation conditions emphasizes the need for optimization. The following examples for ***important optimization potentials*** can be deduced from specific analyses of individual processes and life cycle steps primarily in LCA and economic assessment:

- Yields can and should be increased by breeding ***highly productive sweet and biomass sorghum cultivars*** and by **improving the agricultural management**.
- The ***nitrogen fertilization*** should be reduced by breeding and management if biomass is used for energy or fuel production.

Besides variability that depends on choices of the involved shareholders, all results for future scenarios are necessarily associated with uncertainty due to external factors, which can hardly be influenced or optimized. Nevertheless, robustness of results was verified by calculating bandwidths of results under conditions that experts consider not typical but yet plausible and by sensitivity analyses e. g. on break-even prices or on replaced conventional energy sources. These analyses show the range of conditions under which conclusions based on the presented results are valid.

The integrated assessment primarily analyses whether a mature and large-scale cultivation and use of sweet and biomass sorghum in 2020 provides benefits from environmental, economic and social perspectives primarily compared to the use of fossil fuels. This sustainability assessment applies a generic and scenario-based comparison of whole life cycles from cradle to grave. It collects, joins and extends results of the preceding environmental and economic assessments as well as of the SWOT analysis, which covers further sustainability aspects especially in the social domain, and the ethical assessment. These results are integrated into an overall picture using multi-dimensional comparison metrics and a structured transparent discussion to be able to derive consistent recommendations and highlight potential conflicts.

Several scenarios regarding the production and use of sweet and biomass sorghum were defined as a common basis for all assessments of individual sustainability aspects and for the integrated assessment. ***Three different approaches of sweet sorghum cultivation and use*** are assessed in several scenarios each: cultivation on fallows between cycles of sugarcane with a focus on fuel production also from grains ("***Cane fallow***"), substitution of grain sorghum cultivation with co-production of food and fuel ("***Grain to food***"), and non-mechanized cultivation with a focus on keeping a big part of the fuel value chain in the villages through concentrating sugar juice to syrup ("***Syrup production***"). In all scenarios, the main product is ethanol. The main biomass sorghum scenarios involve cultivation that aims at high biomass yields for biogas production. Alternatively, the combustion of the biomass and the production of second generation fuels is analyzed (second generation ethanol via fermentation and synthetic Fischer Tropsch fuels via gasification).

Results of the integrated sustainability assessment show that the production and use of sweet and biomass sorghum can cause a ***wide spectrum of potential impacts ranging from significant benefits to distinctly detrimental impacts***. Responsible for the individual outcome are factors such as the use of the by-products (for sweet sorghum scenarios), the choice and configuration of the conversion process (for all scenarios) but also external factors like land availability, prices and the way energy is produced elsewhere. ***The observed variability of results leads to concrete recommendations under which conditions and, if so, how sweet and biomass sorghum cultivation and use should be implemented***.

In general, ***social impacts are mostly neutral to positive as long as land rights are respected***. But for "Syrup production" (sweet sorghum) and 2nd generation fuel production (biomass sorghum), profitability is not immediately achievable and requires more or less substantial process improvements or subsidies depending on the assessed scenario. The profitable scenarios mostly also come along with the highest climate change mitigation and energy resource savings potentials because energy efficiency is very important for all of these aspects. To realize these potentials for environmental benefits, further optimizations are needed like the prevention of methane leaks from biogas plants, which may result in some extra costs but should not prevent profitability as such. ***Therefore, an implementation of sorghum-based fuel and energy production does not require continuous financial support beyond existing programs but some regulatory guidelines to improve sustainabilit***y. However, all scenarios lead to additional environmental burdens mainly caused by intensive agriculture such as acidification, excess nutrient inputs into ecosystems or detrimental local effects on soils and biodiversity. A political process is needed in each concerned region to decide how far these disadvantages are acceptable in return for the advantages. A further major limitation for sweet and biomass sorghum cultivation is the availability of agricultural land. In any case, direct or indirect clearing of valuable ecosystems for its cultivation and violation of land rights have to be avoided. In this respect, specific advantages of sorghum should be taken advantage of to mitigate competition about land:

- ***For sweet sorghum, the use of co-products such as grains and surplus bagasse, which is not required for powering the conversion process, as feed or food can reduce the demand of land for separate food/feed production elsewhere***. This way, an integrated production of these products and fuels on the same land using sweet sorghum may in some cases even suffice with less total area than separate cultivation without fuel production.

- ***For biomass sorghum, drought tolerance and resistance against a certain pest may open up opportunities for cultivation, which are not available to competing energy crops such as maize.***

Land availability is a general limitation for cultivation of all energy crops and thus also for energy sorghum. Conflicts about land can be mitigated if land that can be used is not or not very well suited for established crops. This does not only refer to marginal land that would otherwise be entirely abandoned but also includes gradual advantages through specific plant properties. For energy sorghum in particular, these advantages are for example that most cultivars are resistant against infestation with the western corn rootworm and drought tolerant. Opportunities for cultivation in areas where e. g. maize cannot be cultivated every year to manage pests or where other crops produce low yields should thus be used. Further advantages for the energy sorghum variant sweet sorghum arise from its character as a multi-purpose plant as discussed below. In this regard, especially the option to directly replace grain sorghum by sweet sorghum (“grain to food” scenario) reduces the risk of land use conflicts significantly.

In summary, both sweet sorghum and biomass sorghum can be cultivated and used in ways that lead to many environmental, economic and social advantages if sufficient land is available. Necessary optimizations to reach these positive outcomes are highlighted in Integrated Assessment report. However, environmental disadvantages such as increased nutrient inputs into ecosystems, which are typical for biofuels from cultivated biomass, also come along with energy sorghum. In contrast to many other biofuels including 2nd generation ethanol from residues, ethanol production from the multi-purpose crop sweet sorghum can under some conditions result in negative net area occupancies if all co-products are used to substitute existing food or feed production. ***For all these reasons, energy sorghum is a promising new alternative among biofuel and bioenergy crops. Yet, not all energy sorghum pathways are sustainable per se and thus implementation programs – at least when publicly funded – have to be accompanied by specific sustainability analyses***.

Specific results to each scenario are available from Deliverables 6.6.

4. Impacts

SCIENTIFIC AND TECHNICAL IMPACT

Principal objectives of the SWEETFUEL project was to develop ethanol production from sorghum mainly through the selection of new plant material better adapted to the target environments (i.e. temperate zone and semi arid tropics).
SWEETFUEL has achieved and sometimes exceeded most of the goals set in the work plan through the combined effort of the key research groups from 7 countries and 3 continents.
The new plant material described above is available either for a direct exploitation, either for continuing the breeding process.
SWEETFUEL pinpointed the domains in which additional studies must be developed : optimization of cultural practices (i.e. fertilization, adaptation to mechanization…), storage techniques when needed, transformation processes and optimization of by-product use to reach the optimum sustainability of the process.

Socio-economic impact

Impact of SWEETFUEL may be contrasted from country to country, as situation is quite different.

However, on a general point of view, even if technically the production of ethanol from sweet and biomass sorghum is feasible, the concept of a “mono-feedstock plant“is usually not economically sustainable. As sorghum is an annual crop and due to its limited window for harvesting, either it must be combined with other crops, either efficient storage techniques must be used, to be able to feed a plant all year long. But in the second case, the logistics of biomass may represent the limiting factor for profitability.

- ***In temperate area,*** majority of units producing biogas or biomethane already use multi-feedstocks including maize, sunflower, sorghum, silage, sweet potatoes… According to FAO Stats, In Europe, the area dedicated to sorghum production in 2013 was very limited with less than 350 000 ha planted mainly with grain sorghum. In spite of its great advantages, farmers prefer to crop maize than sorghum. The new hybrids produced by SWEETFUEL are not ready to be released and requires additional breeding effort. But in regions, which are subjected to recurrent drought period, it can represent a good opportunity. By continuing the breeding effort beyond the project to provide new hybrids adapted to low temperature with a good stability in biomass production, the development of biomass sorghum will be possible. In the future, if the second generation process to produce ethanol are available at economic level, the big plants will probably operate with different feedstock, giving opportunity to develop biomass sorghum.

- ***Under tropics,*** the most favorable situation for sweet sorghum development is when a sugarcane sector is already present. As explained above for ***Brazil***, the complementation of the sugarcane with sweet sorghum may result in a 25% increase of ethanol production without investing in new equipment and without enlarging the production area. This is possible because each year, 20% of the sugarcane area is replanted and a sweet sorghum could be intercropped between two sugarcane ones. SWEETFUEL already experimented with the sugarcane sector this possibility. According to the first results, the new material provided by the project met the minimum expectations from the industrial sector. As new better performance hybrids will be released in 2015 and 2016, the development of sweet sorghum to produce ethanol may be huge in Brazil. ***The total sugarcane sector in Brazil is closed to 9 million hectares, which means that each year, 1.8 million hectares are potentially available for sweet sorghum production***. This represents a potential production of ***an additional 5 billion liters of ethanol with the same infrastructure already in place for sugarcane***.

In India which has the second sugarcane area in the world, environment is quite different as the harvest is generally done manually, the time for renovation of the sugarcane is shorter (2 years), the grain production is essential and the mills are fed by thousands of farmers (problem of logistics). Nevertheless, based on first results of collaboration with the sugarcane sector initiated in the frame of SWEETFUEL the complementation is possible and SWEETFUEL selected dual-purpose sweet sorghum hybrids suitable for Indian environments. As the Biofuels Policy of India targets ambitious goals (indicative target of 20% blending of biofuels, both for bio-diesel and bio-ethanol, by 2017 is proposed), we can reasonably expect that ***sweet sorghum will play a significant role to achieve this goal.*** As many as 7 sugarmills in North India are conducting sweet sorghum adaptation trials in rainy season of 2014. The Department of Biotechnology, Government of India, came forward to fund a project aiming to promote sweet sorghum in sugarmill areas as bioethanol feedstock.

In general, the complementation with sweet sorghum is possible in every area where a sugarcane sector is already installed, which represents close to 20 million hectare in the world.

In other countries, the development of sweet sorghum to produce ethanol in the near future seems difficult. In South Africa, recently, the policy makers decided that sweet sorghum was not an ideal crop to produce ethanol while in Mexico, results of SWEETFUEL lead the National Research to fund a project including a pilot plant to demonstrate the sustainability of ethanol production from sweet sorghum.

5. Dissemination

In order to increase the visibility of the SWEETFUEL project and to facilitate dissemination activities, a ***project logo*** (Figure 10) was created upon project launch.

Figure 10: The SWEETFUEL logo

Furthermore, a ***website*** for the dissemination of SWEETFUEL project activities and results was created under ***http://www.sweetfuel-project.eu*** (Figure 11). Basic project data such as project objectives and activities as well as consortium partner contacts are made available. The website also serves as a communication platform for project partners. The password protected internal section is used for file sharing and document storage.

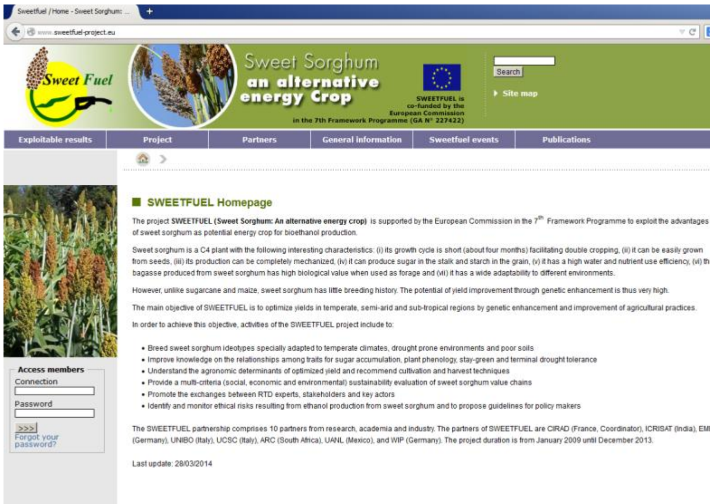
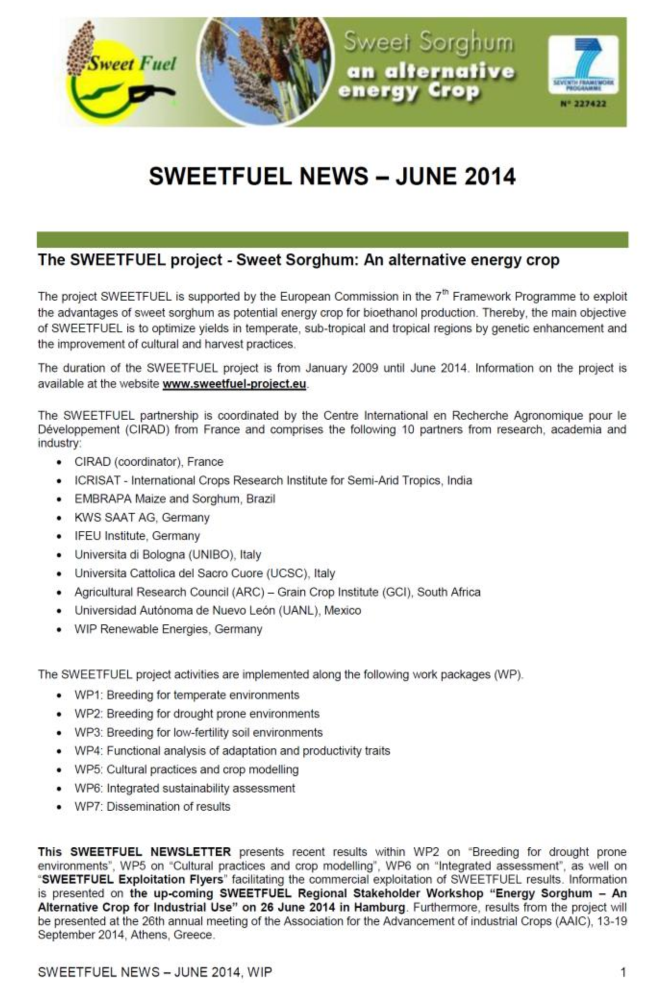


Figure 11 : SWEETFUEL Website (June 2014)

The SWEETFUEL website (Figure 11) was continuously updated and expanded as the project developed. The project website will be maintained and updated for at least 2 years after the project duration.

A ***SWEETFUEL flyer*** was elaborated at the beginning of the project to provide



Sweet Fuel — Sweet Sorghum an alternative energy Crop — N° 227422

SWEETFUEL NEWS – JUNE 2014

The SWEETFUEL project - Sweet Sorghum: An alternative energy crop

The project SWEETFUEL is supported by the European Commission in the 7th Framework Programme to exploit the advantages of sweet sorghum as potential energy crop for bioethanol production. Thereby, the main objective of SWEETFUEL is to optimize yields in temperate, sub-tropical and tropical regions by genetic enhancement and the improvement of cultural and harvest practices.

The duration of the SWEETFUEL project is from January 2009 until June 2014. Information on the project is available at the website **www.sweetfuel-project.eu**.

The SWEETFUEL partnership is coordinated by the Centre International en Recherche Agronomique pour le Développement (CIRAD) from France and comprises the following 10 partners from research, academia and industry:

- CIRAD (coordinator), France
- ICRISAT - International Crops Research Institute for Semi-Arid Tropics, India
- EMBRAPA Maize and Sorghum, Brazil
- KWS SAAT AG, Germany
- IFEU Institute, Germany
- Universita di Bologna (UNIBO), Italy
- Universita Cattolica del Sacro Cuore (UCSC), Italy
- Agricultural Research Council (ARC) – Grain Crop Institute (GCI), South Africa
- Universidad Autónoma de Nuevo León (UANL), Mexico
- WIP Renewable Energies, Germany

The SWEETFUEL project activities are implemented along the following work packages (WP).

- WP1: Breeding for temperate environments
- WP2: Breeding for drought prone environments
- WP3: Breeding for low-fertility soil environments
- WP4: Functional analysis of adaptation and productivity traits
- WP5: Cultural practices and crop modelling
- WP6: Integrated sustainability assessment
- WP7: Dissemination of results

This SWEETFUEL NEWSLETTER presents recent results within WP2 on "Breeding for drought prone environments", WP5 on "Cultural practices and crop modelling", WP6 on "Integrated assessment", as well on "**SWEETFUEL Exploitation Flyers**" facilitating the commercial exploitation of SWEETFUEL results. Information is presented on **the up-coming SWEETFUEL Regional Stakeholder Workshop "Energy Sorghum – An Alternative Crop for Industrial Use" on 26 June 2014 in Hamburg**. Furthermore, results from the project will be presented at the 26th annual meeting of the Association for the Advancement of industrial Crops (AAIC), 13-19 September 2014, Athens, Greece.

SWEETFUEL NEWS – JUNE 2014, WIP 1

Figure 12 : SWEETFUEL NEWS – JUNE 2014

interested stakeholders of the specific target audiences in the scientific and industrial community with an overview of the aims and objectives of the SWEETFUEL project. In order to keep stakeholders updated on project activities and results, ***four SWEETFUEL Newsletter Issues*** (Figure 12) have been sent to a stakeholder database with more than 2.600 stakeholders. The database was continuously updated and extended during the project implementation. Furthermore, a ***SWEETFUEL Associate Partnership*** was established in order to facilitate exchanges and transfer of information with selected interested stakeholders and experts. In June 2014, 49 international stakeholders have registered as SWEETFUEL Associate Partners (34 Associate Partners from Africa, 2 from Asia, 3 from Latin America and 10 from Europe).

Furthermore, SWEETFUEL project results have been disseminated via publications in scientific and trade journals as well as via presentations and posters at national and international conferences and other events. Thereby, targeted ***SWEETFUEL dissemination activities*** comprised an impressive number of close to ***30 scientific peer-reviewed publications***, ***42 presentations at international conferences, 22 presentations at national conferences***, ***51 posters*** at international events, as well as ***6 scientific Thesis and Masters*** and ***14 technical documents***. Tables 5 to 8 present selected SWEETFUEL scientific publications, presentations, posters, and scientific thesis. The full list of SWEETFUEL dissemination activities is presented in the Final Plan for Dissemination and Exploitation of Foreground (D7.7.).

Table 5: SWEETFUEL scientific peer-reviewed publications (selection)

Title	Main author	Periodical	Year
Water uptake efficiency and above- and belowground biomass development of sweet sorghum and ethanol maize under different water regimes	W. Zegada-Lizarazu, UniBO	Plant and Soil 351: 47-60	2012
Are we ready to cultivate sweet sorghum as a bioenergy feedstock? A review on field management practices.	W. Zegada-Lizarazu, UniBO	Biomass and Energy 40: 1-12	2012
Characterization of brown midrib mutants of sorghum (Sorghum bicolor (L.) Moench)	P.S. Rao ICRISAT	The European Journal of Plant Science and Biotechnology	2012
Adaptability and stability of sweet sorghum cultivars	Vander de Souza *et al.* EMBRAPA	CBAB 13: 144-151	2013
Grain, sugar and biomass accumulation in photoperiod-sensitive sorghums.II. Biochemical processes at internode level and interaction with phenology.	S. Gutjahr CIRAD	Functional Plant Biology 40: 355-368	2013
Microarray analysis of differentially expressed mRNA and miRNAs in young leaves of sorghum	L. Pasini	J. Plant Physiol.	2014

under dry-down conditions	UCSC	171 (7): 537-548	
Mining Genetic Diversity of Sorghum as a Bioenergy Feedstock	C.M.B. Damasceno, EMBRAPA	Plants and Bioenergy, Advances in Plant Biology 4., pp81-102	2014

Table 6: SWEETFUEL presentations at international conferences (selection)

Title	Partner	Location	Date	Audience
SWEETFUEL presentation in the framework of the Twinning programme ”Soil, Plant and Food Research between the EU, Argentina and MERCOSUR”	CIRAD	Buenos Aires, Argentina	7-8/05/2009	>50 scientific
Sweet sorghum: an alternative energy crop	WIP	Lyon, France	3-7/05/2010	>50 scientific & industry
Population development and phenotyping of important traits in sorghum	EMBRAPA	Atlanta, USA	15/11/2012	>150 scientific & industry
Overcoming impediments for improving agronomic and industrial traits of sweet sorghum	EMBRAPA	Orlando, USA	24/01/2013	>150 scientific & industry
Potential of sorghum for bioethanol production	ARC	Potchefstrom, South Africa	13/03/2013	>50 scientific & industry
Sweet Sorghum as an alternative energy crop	UniBO	Washinton, USA	22-26/06/2014	>100 scientific & industry
Environmental assessment of 1st and 2nd gen ethanol: an overview	IFEU	Cape Town, South Africa	25-27/03/2013	>300 scientific & industry
Improvement of sweet sorghum for drought tolerance	ICRISAT	Orlando, USA	07/11/2014	>50 scientific & industry
Sweet sorghum as an alternative energy crop: results from 5 years of research (SWETFUEL Porject)	CIRAD	Hamburg Germany	23-26/06/2014	>800 scientific & industry

Table 7: SWEETFUEL posters (selection)

Title	Partner	Location	Date	Audience
Field validation of near isogenic lines and hybrids contrasting of tolerance to aluminum toxicity and comparison of parameters derived from nutrient solution and field evaluation at various levels of aluminum	EMBRAPA	Guangzhou, China	02/11 2009	>100 scientific
Functional analysis of sugar accumulation in sorghum stems and its competition with grain filling among contrasted genotypes	CIRAD	Montpellier, France	28/08 2010	>100 scientific

Definition of new sorghum iodeotypes to meet the increasing demand of bioenergy	CIRAD	Berlin, Germany	6-10 06/2011	>150 scientific & industry
Identification of Midseason moisture stress sweet sorghum material	ICRISAT	Hyderabad, India	03/04 2012	>100 scientific
Sweet sorghum root and canopy responses to water deficit occurring at different growth stages. Roots to the Future	UniBO	Dundee, Scotland	26/06 2012	>100 scientific
Quantitative trait loci mapping for sugar-related traits in sweet sorghum based on high-density SNP markers	EMBRAPA	San Diego, USA	12/01 2013	>200 scientific
Sustainability assessment for sweet and biomass sorghum as energy crops	IFEU	Hamburg Germany	23-26 06/2014	>800 scientific

Table 8: SWEETFUEL scientific thesis

Title	Partner	Name	Thesis	Date
Adaptabilidade e estabilidade de cultivares de sorgo sacarino	UANL	De Souza, Vander Fillipe	Master of Science	April 2011
Heterosis en caracteristicasasociadas con la produccion de etanol en sorgo dulce (Sorghumbicolor L. Moench)	UANL	Jose Alonso YerbesVazquez	Master	June 2011
Analysis of useful morphogenetic and biochemical traits for the development of dual-purpose “grain-bioethanol” sweet sorghum	CIRAD	Silvain Gutjahr	PhD	July 2012
Caratterizzazione di genotipi di sorgo in funzione della tolleranza allo stress idrico	UCSC	Boccassi Marco	Magister in Scienze e Tecnologie Agrarie	April 2013
Evaluation of the photosynthetic efficiency of sweet sorghum under drought and cold conditions	UniBO	Dario Fernando Luna	PhD	April 2014

Five regional SWEETFUEL workshops have been organized in India, South Africa, Brazil, Mexico and Europe during 2012-2014. All stakeholders including representatives of National Agriculture Research Systems (NARS) and/or Extension services, seed companies, farmers, farmers' organization, NGOs, entrepreneurs, policy makers have been contacted for their participation to the following events:

- **Brazil**: The regional workshop in Brazil “Seminar on the Agro-Industrial Production and Processing of Sweet Sorghum for Ethanol Production” took place in Riberão Preto, São Paulo on 9-10 August 2012.
- **Mexico**: The regional workshop in Mexico took place on 24-25 September 2012 in Monterrey on the occasion of a scientific meeting organized by UANL.

- **South Africa**: The regional workshop in South Africa took place in Potchefstroom on 21 February 2013 on the occasion of the ARC farmers day.
- **India**: The regional workshop in India took place on 3-4 March 2014 in Hyderabad on the occasion of the final SWEETFUEL meeting in India.
- **Europe**: The regional workshop in Europe took place on 26 June 2014 in Hamburg, Germany on the occasion of the 22nd European Biomass Conference and Exhibition.

Detailed information on the five SWEETFUEL regional workshops is presented in dedicated workshop reports available on the project website in Deliverable 7.2.

Three additional workshops were organized in Brazil with the sugarcane sector and one training workshop was organized in Montepllier to transfer SAMARA-sorghum model.

In the framework of the SWEETFUEL project an ***Energy Sorghum Handbook*** (Figure 13) was produced in June 2014 with the aim to provide interested stakeholders, namely policymakers, NGOs, scientists and researchers, entrepreneurs, and farmers with an up-to-date overview of important facts and figures on energy sorghum. The handbook includes information on energy sorghum characteristics (botanical classification, morphology, growth stages, specific properties), cultivation (soil preparation, sowing, fertilization, plant pest and control), harvesting and logistics, promising applications (food and fuel production, syrup production, advanced biofuels and biogas production), as well as social (e.g. smallholder benefits, health, food security), environmental (e.g. emissions, soil and water), and economic sustainability aspects (e.g. efficiency, competitiveness). This document is available from the project website in three versions (i.e. English, Spanish and French).

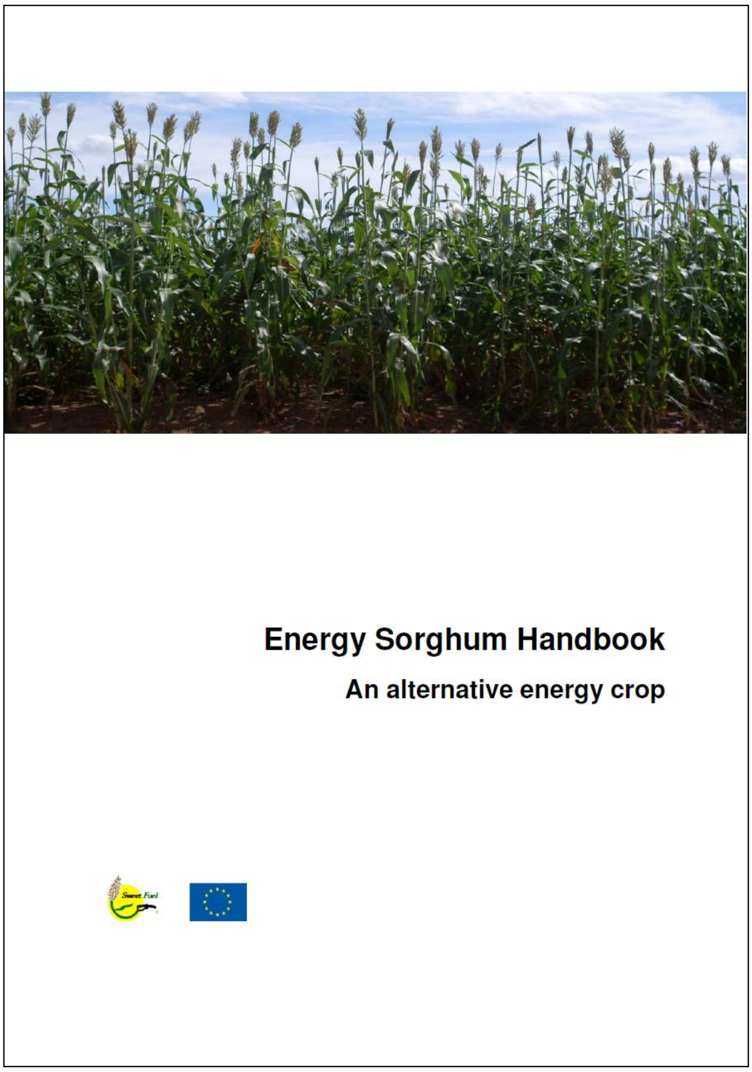


Figure 13 : SWEETFUEL Handbook (June 2014)

Finally, a film showing how sweet sorghum is used in Brazil to complement the sugarcane production is available from the project website at the address : http://www.sweetfuel-project.eu/sweetfuel_events/complementation_of_sugar_cane_by_sweet_sorghum_in_brazil

6. Recommendations

The following recommendations were made as an outcome of the integrated sustainability assessment based on the results of the environmental and economic assessments as well as the SWOT analysis including the ethical assessment.

SPECIFIC RECOMMENDATIONS FOR SWEET SORGHUM

The following specific recommendations refer to various areas of the entire life cycle:

- Because especially large sustainability benefits are associated with the use of the co-products, care should be taken that as much of the plant as possible is machine-harvestable. Technical advances in ***harvesters*** should therefore be supported, with a focus on harvesting both co-products, the grains and the leaves.
- Where grain of sweet sorghum is not demanded for food purpose, distilleries crushing sugarcane for ethanol should ***utilize both stalk and grain*** of sweet sorghum by increasing the crushing window during the lean periods. Use of both stalk and grain for ethanol is more profitable than stalk alone. Concepts and programs for the use of both grain and stalk should be implemented.
- When planning a new ethanol plant, a ***concept for full utilization of the leaves and the surplus bagasse*** should be compiled as any use of these co-products improves both profitability and environmental impacts. Even if ethanol plants should be profitable without using the co-products, investors should opt for their use as higher environmental benefits in this case come along with increased profitability. To increase incentives, ethanol plants with an integrated use of by-products should e. g. be given priority consideration in authorization practice. Whether surplus bagasse should be used for energy generation or as feed should be decided based on regional markets and / or conditions. Priority should however be given to the use as feed if regional availability of land for feed production is an issue.

- The cultivation of sweet sorghum on land with natural vegetation often influences the carbon stock and biodiversity of the land negatively and should therefore be avoided. Initiatives and programmes supporting the establishment of sweet sorghum as an energy crop should therefore promote ***integration in existing cultivation systems, or cultivation on low-carbon soils, or soils of relatively little ecological value***, and to this end raise incentives and query farmers and investors about convincing concepts. This also applies to the case of sweet sorghum cultivation in sugarcane cycles or, even more so, instead of grain sorghum, because indirect land use changes are actually occurring in practice, whose negative impacts must be minimized.
- ***Syrup processing***: Converting juice to syrup at village level is ***neither economical nor environmentally beneficial*** unless significant improvements compared to the assessed scenarios are realized. If decentralized syrup production from sweet sorghum still should be followed further, particular attention should be paid to the concept for provision of the energy source for centralized processing of the syrup to ethanol. Only those concepts should be promoted or approved that can demonstrate a positive energy and greenhouse gas balance.
- In order to ensure that the ***leaf harvest*** is sustainable, i. e. the organic soil substance is not negatively impacted, an appropriate research project should be established with the aim of identifying how the maximum sustainable leaf harvest can be determined across a variety of sites. In addition, a process for implementing the results in the field must be developed.

SPECIFIC RECOMMENDATIONS FOR BIOMASS SORGHUM

Specific recommendations for the cultivation and use of biomass sorghum apply predominantly to the following two areas:

- ***Biogas production***

Combined production and utilization of ***power and heat*** should be preferred over power production only. Instead, biogas plants are often built in areas where there are no noteworthy heat consumers. This is neither sustainable from an environmental nor from an economical perspective. Thus, a heat utilization concept should be taken into account at the planning stage. To increase incentives, biogas plants with a conclusive heat use concept should be given priority consideration in authorization practice.

In terms of the production of biogas from biomass sorghum, a legal obligation should be introduced to cover the digestate store gas-tight.

Emissions from the application of digestate to the field should be minimized. To this end, the digestate should be worked into the soil in the shortest possible time (e. g. one hour) after application. Legal regulations and monitoring of this practice should be introduced where not yet in place. Furthermore, a research project should be established with the aim of identifying whether nitrification inhibitors should be added to the digestate in order to reduce emissions following application of the digestate.

- ***Alternative use options***

Direct combustion of biomass sorghum for combined heat and power production is the environmentally most beneficial use option and is profitable. As this scenario was not in the primary focus of this study, further research should be supported on implementation barriers, issues of nutrient recycling from ashes and long term perspectives in a changing energy system.

Production of ***2nd generation ethanol*** is promising to become economically viable in the medium term and more environmentally advantageous than competing direct combustion in the long term. Thus, maturation and optimization of the technology should be further supported in individual industrial scale plants. Given the currently achievable environmental and social benefits as well as the associated avoidance costs, it does not seem justified for society to finance a large scale implementation of this technology e. g. via direct subsidies or mandatory blending quota – at least not if mainly annually cultivated biomass is used.

As ***2nd generation ethanol and synthetic FT fuels*** are rather medium to long term options, biomass sorghum should not be developed with high priority as feedstock for such fuels but may find an additional market in this use option later.

GENERAL RECOMMENDATIONS FOR ENERGY SORGHUM

The general recommendations for both investigated energy sorghum variants biomass and sweet sorghum are relevant to a variety of areas of the entire life cycle and affect both environment and economics positively:

- Support for breeding programmes for general ***yield*** optimization differentiated into geographical, climatic and soil conditions, in order to reap the full benefits of the sorghum variants.
- Promotion of techniques for optimizing cultivation methods (e. g. improved fertiliser and pesticide application) for ***yield stability or the optimized use of resources***.

Reduction in applied ***mineral fertilizer***:

- Continuation of appropriate breeding programmes for reducing the nutrient content in the harvested biomass that is intended for energy use.
- Establishing research projects for optimizing suitable cultivation methods (e. g. optimizing the time of harvesting) for reducing the nutrient content in the harvested biomass that is intended for energy use.
- Integration of sweet sorghum and biomass sorghum cultivation respectively in existing, established crop rotation systems should be aimed for, because sorghum is capable of utilizing nutrients from deeper layers, which remained unused in the previous cultivation systems. Appropriate research projects should be established, in particular with the aim of identifying promising multi-crop rotations.

Furthermore, limited land availability causes competition between various land use options, which also affects energy sorghum cultivation. This ***competition about land*** needs to be politically managed to avoid a high risk of environmental, social and on the long run also economically unsustainable developments:

- In the mid- to long-term, biomass and land use allocation plans should be developed at national and pan-national level. Due to the fact that environmental implications including resource scarcity in particular do not possess an adequate price, market mechanisms cannot replace these plans.
- Based on these national plans, regional plans, which include regulations for project planning should be developed. In this context, the cultivation of crops adapted to local conditions should be supported. For instance, the environmental impacts of the cultivation of a crop with a high water demand depend on water availability at the specific location. Furthermore, regional planning is vital due to the fact that also public funds to date have created market actors with considerable local demand for biomass and significant market power. Further ethanol producing facilities could potentially exacerbate the process. This can create distortion of competition and thus create displacement effects that can be environmentally and socially unsustainable. In some regions, especially land rights of smallholders need to be protected. With appropriate planning, unfavorable developments can be, and must be, avoided.
- As long as no appropriate planning is in place, preventive measures should include binding land use and cultivation-related sustainability criteria for uniform application across all purposes, i.e. for bio-based materials, chemicals, fuel and energy carriers as well as feed/food production.
- The political decision process in each concerned region should take into account ***how far unavoidable environmental disadvantages*** mainly caused by intensive agriculture ***are acceptable*** in return for the advantages. This understanding is needed as a basis for the development of above mentioned land use allocation plans.
- ***Knowledge transfer*** in terms of experience in cultivating energy sorghum should be supported.
- ***Quality control***: All appropriate support programmes or implementation concepts and programmes should be accompanied scientifically in order to identify the impacts on sustainability and to facilitate optimization in the course of the running project.
- An early ***involvement of stakeholders*** should be ensured in planning processes especially for bigger industrial projects that will affect agriculture in the region. This helps avoiding conflicts and increases the public acceptance.