Diffusion of a sustainable EU model to produce 1st generation ethanol from sweet sorghum in decentralised plants

Manual for Trainers
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Sweet Sorghum Manual for Agricultural Associations

Project website:
http://sweethanol.eu
Online community:
http://esse-community.eu
Project partners:

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FOREWORD

This manual has been developed in the framework of the “SWEETHANOL” project which is funded by the Intelligent Energy programme of the European Commission.

The aim of the “SWEETHANOL” project is to diffuse a model of producing 1st generation bioethanol from sweet sorghum. Sweet sorghum is an energy crop well known in the scientific field for its advantages in comparison to other energy crops for the sustainable production of bioethanol.

As the European bioethanol plants use mainly cereals and less maize as primary sources for their needs, the project seeks to change the current situation and disseminate the use of sweet sorghum as the sole or supplementary feedstock. Moreover the project is concentrated in the decentralisation and sustainability of 1st generation bioethanol from sweet sorghum, which can be grown in the southern regions of the EU.

This specific manual was developed in order to provide assistance to the trainers during the courses to the agricultural associations. It contains information regarding the cultivation of sweet sorghum, the processing of the fresh biomass, supply chain details and other valuable info extracted from the “Early”, “Technical”, “Administrative” and “Inter-Sectorial” Manuals of the project. It is electronically available for free downloading, at the website (http://sweethanol.eu) and at the online community (http://esse-community.eu) of Sweethanol project, together with the other manuals, in four languages: English, Italian, Spanish and Greek.

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SWEETETHANOL PROJECT

SWEETETHANOL is a project financed and supported by the European Commission in the ambit of the program IEE-II 2009 (Intelligent Energy Europe), action “ALTENER” – New and Renewable Energies sources.

It is a project related to the diffusion of a sustainable EU model to produce 1st generation bioethanol from sweet sorghum in decentralised plants. The project is organised in the following actions:
- know-how refining about the bioethanol production from sweet sorghum. The more interesting data (e.g. investment costs, energy consumption, production costs, bioethanol yield, by-products exploitation) are collected visiting the agricultural research institutes, the plant construction companies and the existing plants;
- sustainable model discussion of the EU model with representatives of each chain player. The chain players (i.e. farmers, agricultural associations, fuel processors, SMEs, seeds and agricultural companies, investors, policy makers and public authorities representatives, energy agencies) are engaged in an EU model discussion through sectorial and intersectorial workshops at national and international level;
- chain actors training through tailor-made courses per categories of chain actor;
- creation and management of the online community (i.e. “Esse community”, link: http://esse-community.eu/), a virtual place where all the chain actors may create the network in order to share and gather information about the sweet sorghum bioethanol chain: articles, info about events, blog, forum, social network, teleconferences and reputation management are performed.

The project covers the following priority activities:
- encouraging market players in the bioethanol supply chain to increase the economic competitiveness and environmental sustainability of the biofuel itself;
- supporting and promoting the application of sustainability criteria for bioethanol;
- addressing the issues under discussion in the current debates on land use and sustainability;
- facilitating and promoting the well-informed debate and the balanced attitude among decision makers and the general public.

The main objectives of the project are:

- know-how diffusion about the sustainable EU model. The sustainable EU model is shared among the chain actors which accept it through the discussion of the technical, logistic, economic, financial, energetic, environmental and administrative aspects and it will be widely spread by each target group. Consequently, as market players, they are encouraged to start up new entrepreneurship to increase the economic competitiveness and at the same time the environmental sustainability of bioethanol. The changes in the bioethanol market are the enhanced raw material diversification, decentralisation of the production and sustainability of 1st generation bioethanol (mainly as GHGs saving). The proposed wide discussion about the production of 1st generation bioethanol using sweet sorghum contributes to address the current debates on land use and sustainability and to facilitate and promote a well-informed discussion and a balanced attitude amongst decision makers and the general public.
- daily updating through the network building and the supply chain co-ordination. The market players are able to count on daily updating of the legislative, administrative and technical aspects
related to the bioethanol production and market (in general, and specifically using sweet sorghum) through the “Esse Community”. The daily offered updated service simplifies the market analysis necessary for the start up of new entrepreneurship; consequently the diversification of the bioethanol market is stimulated and the market centralisation among few numbers of chain actors is contrasted. Moreover, the network building contributes to address the issues under discussion in the current debates on land use and sustainability and to facilitate and promote a well-informed debate and a balanced attitude amongst decision makers and the general public.

Join the ESSE Community
http://esse-community.eu/

Find out more about SWEETHANOIL project on web
http://www.sweethanol.eu/
SWEETHANOL PARTNERSHIP

CETA – Centre for theoretical and applied ecology - Italy
CETA was created in 1987 in Gorizia (Italy) and is a non-profit association which carries out research, applied experimentation and innovative technology development in four areas: environment such as sustainable management of environmental and natural resources (water, soil, landscape) and environmental balances and models of environmental accounting; energy such as promotion and diffusion of renewable energy technologies (biomass, biogas, biofuels, solar energy – photovoltaic, geothermal, hydroelectric), energy efficiency, energy planning, analysis and models of territory management, costs-benefits and multi-criteria analyses; territory such as strategic planning and programming, Government of the territory (large area and local level), studies of environmental impacts and strategic environmental evaluation, and knowledge such as experimentation of production and innovation models for fuel biomasses and biofuels of 2\textsuperscript{nd} and 3\textsuperscript{rd} generation, research and development of energy crops with low environmental impact for energy production. CETA carries out its own multidisciplinary activities employing high-degree professionals such as engineers, agronomists, biologists, naturalists, economists, architects.

Foundation CAR TIF – Technological centre - Spain
CARTIF was created in 1994 as the Automation, Robotics, Information and Manufacturing Technology Centre, a non-profit association focused on applied research and based in Boecillo Technology Park, Valladolid (Spain). From October 2005, CARTIF is legally established as a Foundation keeping its main goals: identifying technology needs and developing R&D based knowledge, supporting technological innovation in Industry mainly among SMEs and disseminating R&D and innovation results.

REACM – Regional Energy Agency of Central Macedonia – Anatoliki S.A. - Greece
The Region of Central Macedonia together with the Local Development Agency - Anatoliki S.A. established REACM in 1997, through the European Union’s SAVE programme. The main activities include: data acquisition for energy production and consumption in the region, support to the region’s local authorities in energy policy planning, dissemination activities for RES and RUE technologies, training and education, mobility management on municipal level, promotion of biofuels, support to local industry and SMEs, Energy audits, promotion of RES technologies to the agricultural sector, definition of Municipal Sustainable Action Plans (SEAPs) according to the Covenant of Mayors initiative, collaboration with neighbouring countries in energy savings, participation in regional planning for development and utilization of geothermal fields as well as waste management.

INIPA- Coldiretti - Italy
INIPA is the research, training and development National Department for agri-food, environmental and services sectors of Coldiretti (the national confederation of farmers - Italy), and it is a legally recognized non-profit organization. It is a unitary structure distributed throughout the country, with associated institutes at regional level and territorial divisions. INIPA promotes, organizes and participates (in partnership with leading agencies at both national and European Community level) in research, scientific information and training for farmers, organizations and territories pointing out the results in favour of the continuous innovation of the agri-food system.
ADABE – Association for the diffusion of biomass - Spain
ADABE is a national association, no-profit, founded in 1986 according to the Directorate General of Domestic Policy of the Ministry of Interior. It is a founding member of AEBIOM based in Brussels, founded in 1990. It brings together individuals and entities involved in research, technology and/or dissemination of the use of biomass in Spain.

Agricultural co-operative of Halastra - Greece
The major activities of the agricultural co-operative of Halastra include: services related to agricultural products (e.g. rice, corn, cotton, wheat, cereals), collection, drying and storage of agricultural products, sale of agricultural supplies, sale of agricultural products on behalf of the members of the association, retail of agricultural goods, rice packaging and trade.
CULTIVATING SWEET SORGHUM

Introduction

The term ‘sweet sorghum’ is used to describe varieties of sorghum (Sorghum bicolor (L.) Moench) having a high concentration of soluble sugars in the stalks. Sweet sorghum is considered a water-use efficient crop, with high potential as an alternative feed stock for bioethanol production.

Picture 1: Sweet Sorghum, Improved Cultivars & Parents, ICRISAT pilot cultivation.

Sweet sorghum has been widely cultivated in the United States since 1852. Currently sweet sorghum is grown extensively for syrup production and for forage production. Apart from this usage, it can also be used as a feedstock for biofuel.

Sweet sorghum syrup is used in some areas as: table syrup, additive in milk; accompaniment to pancakes and bread, in salad dressing and ice-cream topping, sweetener in cakes and biscuit baking, syrupy base in pharmaceutical formulations and also is used in making alcohol. In China they produce “Maotai”, known Chinese liquor, which is distilled from fermented sweet sorghum and comes in different versions ranging in alcohol content from the standard 53% by volume down to 35%. In Minneapolis a company produces a gluten-free beer, the Bard’s beer, made as well from sweet sorghum.

Sweet sorghum has generated interest as a feedstock for ethanol production since the 1970s. Juice from sweet sorghum can be converted to ethanol using currently available, conventional fermentation technology (similar to ethanol produced from sugarcane juice in Brazil). The bagasse (crushed stalks) that remains after removal of the juice can be burnt to generate electricity or steam as part of a co-generation scheme. Additionally, the bagasse could be utilized as a feedstock if the technology for cellulosic ethanol production becomes viable on a commercial scale.
Typically, sweet sorghum varieties have low grain yield, but recently varieties with more balanced grain/sugar production have been developed in China and India. These varieties can be used as a dual-purpose crop, where the grain is harvested for human or animal consumption and the sugars of the stalks are fermented to ethanol. Alternatively, these varieties can be used as a dedicated bioenergy crop, where both the sugars and the grain are used for ethanol production.

In all varieties, the primary carbohydrate is sucrose, with variable amounts of reducible sugars and starch. Sweet sorghum cultivars are characterized by the accumulation of high levels of fermentable carbohydrates (FC) (15-23%) within the stalk. Total FC are comprised of three main sugars; sucrose (70%), glucose (20%), and fructose (10%), variation in percentages depends on variety and environmental conditions. After harvesting the stalks, most varieties regrow or ratoon.\(^1\)

\(^1\) A Ratoon Crop is the new stalk which grows from the stubble left behind after harvesting (http://www.proserpine.com)
The ability to form a ratoon enables a second harvest per season in certain environments, although yields typically decrease in ratoon crops. Sugar content in the juice increases with maturity and is low prior to seed development.

![Sweet Sorghum Ratoon crop, ICRISAT pilot cultivation.](image)

Currently, there is a limited number of varieties for which seed is commercially available. If sweet sorghum is widely and rapidly adopted as an energy crop, seeds may become difficult to obtain.

The ideal variety for a particular location should have the following desirable characteristics: (1) produce high yields per hectare with minimal inputs, (2) have strong, erect growth so it will not readily lodge, (3) have a high percentage of high quality and easily extractable juice, (4) contain juice with a high total soluble solids (Brix) content, mostly sugars, (5) be disease and insect tolerant, (6) tolerate drought, (7) tolerate excessive water, and (8) produce a high-quality syrup. Varieties will differ greatly in these qualities and in their adaptation to various soil and climatic conditions.

The costs associated with transportation of the crop to the bioethanol plant will be the major limiting factor for the area where sweet sorghum can be grown profitably. Varieties that have higher sugar contents per ton of biomass will be more efficient to process in a plant.

**Botanical Characters of Sweet Sorghum**

Sweet sorghum is an annual herbaceous species and, depending on the varieties, with a high ratoon capacity.

**Stalks**

Sorghum stems are usually solid like in sugarcane; this feature is an exception to the grass family. Stems are made up of a variable number of alternating nodes and internodes. The height ranges from 0.5 to 5.0 m and the width at the stalk base from 1.5 to 5.0 cm of diameter.
Regarding the cross-section structure, the stem consists of an external crown with numerous vascular bundles, densely arranged. Inside this crown there is a soft pith dominated by parenchyma tissue, where some scattered bundles appear. Most of the sugar, mainly sucrose, is accumulated in this pith.

One leaf arises from each node, which has a groove where the leaf grows. In this groove there is an auxiliary bud. All of the auxiliary buds are dormant except some of the lowest nodes of the stem, where tillers may grow from these auxiliary buds.

Either varietal characteristics or some cultivating conditions like plant arrangement and climate conditions (i.e. photoperiod and temperature) have a remarkable influence in sorghum tillering capacity.

Leaves
Sweet sorghum usually develops from 7 to 24 opposite-decussate leaves along the stem, depending on the variety, the latitude and the final degree of development that the stem could reach. There is usually one leaf per node.

Leaves are bright green, parallel-veined, have a long sheath that embraces the stalk and a leaf-blade whose length is 30 to 135 cm and width is 1.5 to 13.0 cm. Leaf-blade is flat, although in water stress conditions can longitudinally roll up, as it happens in maize. Stomata can be found on both sides of the leaf.

Inflorescence
Inflorescences are grouped in a panicle, which is usually apical. Its length is variable and when the inflorescence is well developed can reach 60 cm (peduncle included).
The inflorescence consists of several branches that at the end support some pedicellate and sessile spikelets, which have two sterile florets being only fertile the upper one. Each floret has three stamens and a single ovary with two styles with feathery stigmas.

**Fruit**

It is caryopsis with a roughly rounded shape and differently coloured, depending on the variety. Sweet sorghum fruits are usually smaller than the grain sorghum ones. The weight of one thousand seeds is about 21g, varying between 16-28 g.

**Root system**

Root system is adventitious\(^2\) with fibrous and branched roots and can extend up to 1.5 m while the primary root, as same as other plants from the grass family, has early senescence and is substituted by roots originated in the underground part of the stem. Moreover, sweet sorghum develops brace roots at the lowermost nodes, in a similar way to maize, that help to support the stem.

**Cultural Practices\(^{v,v,vi,vi}i\)**

In order to enable local farmers cultivating sweet sorghum, the required seed, weedicide (herbicide) and fertilizers should be available.

**Land Selection**

Many different soils are used for the production of sweet sorghum, but a soil that has good physical characteristics and good fertility produces the best yield. In general, loam and sandy loam soils are best for the growth of sweet sorghum for syrup production. However, loams will produce excellent sweet sorghum when properly fertilized.

Soils high in organic matter are thought to have a detrimental effect on syrup quality. The field should have good surface drainage and the soil should be deep and moderately to well drained. Shallow soils or soils very low in organic matter may be droughty. Ample moisture during the growing season is important for good yields of stalks and juice. Clayey soils usually produce poor stands, poor yields, and poor syrup. Sweet sorghum usually fits into most common crop rotation systems. You can successfully grow sweet sorghum following a corn or soybean crop. The plant residue should be chopped in the fall and plowed under early in the spring so that it deteriorates before you seed the sweet sorghum. Sweet sorghum should not be grown on land following a tobacco crop.

Sweet sorghum can be produced in a wide variety of soil types, but yields are typically highest in deep, well-drained soils with good fertility. Sorghum grown in shallow soils or soils very low in organic matter may be more prone to drought stress. Although sorghum is more tolerant of drought stress than many other crops, ample moisture during the growing season is important for good yields of stalks and juice.

**Soil preparation**

Adequate seedbed preparation is needed to facilitate the emergence of plantlets and to remove weeds. Soil must be ploughed and finely harrowed for sowing. Compaction should be prevented.

It is also recommended to apply an herbicide (e.g. Glyphosate) to control weeds.

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\(^2\) Adventitious roots arise out-of-sequence from the more usual root formation of branches of a primary root, and instead originate from the stem, branches, leaves, or old woody roots. (Wikipedia)
Soil preparation shall be made taking into account the irrigation system that will be available for the crop. Sorghum has a good response to furrow irrigation, which prevents lodging; in this case ridges would have to be made at the step of soil preparation. In case of sprinkler or drip irrigation, land surface is levelled or maintained flat.

Date of Planting
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In India

Sweet sorghum can be sown during June, coinciding with the south-west monsoon, September October during northeast monsoon with a rainfall of 500-600 mm well distributed across the growing period and also during summer with assured irrigation. The crop does not prefer high rainfall as high soil moisture or continuous heavy rain after flowering may hamper sugar increase. If irrigation is available, sowing can be advanced before June so that the crop does not face heavy rains after flowering and more so during the last half of grain maturing period. Sowing during summer season may result in low biomass and sugar yield. All soils that have medium depth (18" and above) with good drainage are suited. Depending on the soil (red, black, laterite and loamy) and its depth water requirement may vary which in turn influence the suitability of the crop.

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3 A seedling is a young plant sporophyte developing out of a plant embryo from a seed. (Wikipedia)
Water Management

Sweet sorghum is known as a remarkably drought-resistant and resists months of dry weather until rains resume. Nevertheless sweet sorghum needs moisture for uniform seed germination, hence, overhead irrigation is recommended at planting when moisture is insufficient for germination. Furthermore the biomass efficiency depends on the sufficient irrigation of the plant.

Like any other irrigated crop, the irrigation requirements of sweet sorghum depend on the site (i.e. water balance is affected by the temperature and rainfall regimes of the site) and the irrigation system used for the crop. Besides, there is the intrinsic factor of the variety requirements. Generally they may range between 500 and 1,000 mm.

For several varieties of sweet sorghum and within a compatible water availability range, the water use efficiency of the crop decreases at higher water regimes. Values of 3.7-6.1 kg db/m^3 evaporated water have been reported for the water use efficiency of Keller variety grown in the centre of Spain.

Sweet sorghum can grow in conditions of some water stress but yields are affected. In Mediterranean conditions, where water shortage is a fact during summer, a compromise between irrigation dose and expected yield should be reached.

Plant Spacing

The recommended seeding rate is 5-8 kg per hectare to attain a population density of 130,000-150,000 plant/ha. The seeds can be drill-planted by hand or with the aid of a planter.

During the wet season planting, the furrows are set 10 cm deep. The seeds are drill planted at the bottom of the furrow and then spike tooth harrow is passed to cover the seeds to a depth of about 2-3 cm.

For the dry season planting, the furrows should be made at least 15-20 cm deep to be able to make use of more residual soil moisture. The seeds are set at the bottom of the furrows but these are not covered anymore if the soil is dry. The impact of irrigation water running through a flexible hose which is directed at the side of the furrow will cover the seeds. In cases where the soil is moist, the technique used during the wet season planting is followed.

The ideal seeding rate for most sweet sorghum varieties is 3-4 seeds per linear foot of row with a final stand of 2-3 plants per linear foot of row.

Sweet sorghum is commonly grown in rows spaced 90 to 110 cm apart. Wider spacing than 110 cm can result in some yield reduction.

Planting sweet sorghum in hills of two or more plants has been common in the past. Drill planting with plants spaced 20 cm apart in the row has resulted in comparable stalk and syrup yields. Hill plantings may give better emergence in crusted soils.

Planting depths for sweet sorghum seed should be about 2.5 cm, with deeper coverage on light sandy soils and shallower coverage on heavy clay soils.

Sweet sorghum is typically seeded in widely spaced rows (75–100 cm) using a corn planter. The ideal seeding rate for most sweet sorghum varieties is 3–4 seeds per linear ft of row with a final stand of 2–3 plants per linear ft of row. If plant populations are too high, the canes will be spindly and contain less juice than an equal tonnage of larger diameter canes.
Weed Control
Since the earliest stages of the crop, namely from sowing to canopy closure (approximately when the crop is 1m high), sorghum is very sensitive to weed competition. Consequently land must be carefully prepared before sowing with the objective of eliminating weeds. It is also useful to apply a herbicide before land preparation. Anyway, herbicide must be always applied in pre-emergence, immediately after sowing, because sorghum germination is very fast and the crop could be affected if the herbicide is applied late.
Cultivation is widely used for weed control in sweet sorghum. Two or three cultivations may be needed for good weed control in some fields. No herbicides are labeled for use in sweet sorghum. Perennial grasses such as Johnsongrass and Bermudagrass are not easily controlled in sweet sorghum. Fields badly infested with these weeds should be planted with some other crop.

Pest Management & Diseases

Pests and diseases are similar to corn and sugarcane in those areas where both are extensively cultivated, like in the South of the US. In places where those crops are not spread, no problems should arise. For instance, no pests or diseases have been observed in experiences carried out in central Spain, occasionally the presence of borers.

The main abiotic damages that sweet sorghum could suffer are cold and lodging.

1. Cold. Adequate selection of varieties (cycle length) and sowing date are necessary to prevent cold damages.
2. Lodging. Adequate selection of varieties (plant height, stalk diameter, canopy density) is essential as well as the nitrogen fertilisation rate and harvesting date.
3. Setting. In places where damages by wind are possible, shorter varieties with low lodging tendency and low nitrogen rates are recommended. In addition, in order to avoid wind risks during autumn season it is better to harvest as soon as possible.

Sweet sorghum diseases are best controlled by rotating fields with non-grass crops such as soybean and by planting disease-resistant sweet sorghum varieties. The same diseases that affect grain sorghum also attack sweet sorghum. Dale is resistant to most diseases. “Keller” and “M81E” are resistant to red stalk rot (anthracnose) but are susceptible to maize dwarf virus (MDM). “Theis” is resistant to both red stalk rot and MDM. Integrated pest management (IPM) practices should be used to control insects in sweet sorghum. This includes “cultural, mechanical, biological or chemical options” (Bradley et al., 2009). Chinch bugs are usually worse in drought conditions, and worms cause the most damage in late-planted sorghum fields. Several herbicides are labelled for grain and forage sorghum. Consult manufacturers to be sure they can be applied on sweet sorghum. In test plots in Missouri, atrazine and metolachlor gave good grass and broadleaf weed control. Before planting, sweet sorghum seed was treated with fluxofenin herbicide seed safener to minimize crop injury.

Sweet sorghum is susceptible to a number of diseases including anthracnose (red stalk rot), fusarium, and maize dwarf mosaic. Since no fungicides are labelled for sweet sorghum, these diseases must be controlled by using resistant varieties and by crop rotation. Older varieties are now so susceptible to these diseases that they should not be planted for syrup production.

Nutrient Management

Like other crops, sweet sorghum needs adequate nutrients to produce good yields. Soil testing should be used to determine the need for lime, phosphorus, potassium, calcium, and magnesium.

The dose of fertilization depends on soil fertility and wanted productivity. In Mediterranean climates, where soil fertility ranges from low to moderate, the fertilization needs are about: 100-150 kg N, 60-100 kg P$_2$O$_5$ and 60-100 kg K$_2$O per hectare. It is recommended a nitrogen application done in two times: before sowing and 20-30 days after the emergence.

The fertilizer is drilled at the bottom of the furrow before planting.
Side Dressing (21 days after planting).

If “ammonium sulphate” (21-0-0) is used: The rate is 23-24 g/m of row in the 100 cm spacing while 18g/m is applied in the 75 cm spacing. If “urea” is used: 11-12g/m is side dressed in the 100 cm row spacing and 8-9g/m in the 75 cm spacing.

Nitrogen has the greatest impact on yields and will likely be needed on most soils. Fertilization practices may also affect syrup quality. Sweet sorghum is one of the most sensitive crop plants to acid soils. Before planting sweet sorghum, make sure that the soil pH is greater than 6.0. Lime should be applied to soils with a pH below 6.0 to correct soil acidity.

Excessive nitrogen reduces syrup quality. So, recommended amounts of nitrogen should not be exceeded, and all nitrogen should be applied before the crop is 0.8m tall. When sweet sorghum is grown immediately behind a legume crop, the nitrogen application rate can be reduced or eliminated without harming yields. Avoid planting sorghum in fields where poultry litter has recently been applied, because soil nitrogen will be excessive.

Harvesting

The stalks should be harvested at physiological maturity and sun dried for removing excess moisture in the grain. More specifically harvest should be undertaken when biomass and sugar accumulation reaches its peak. The optimum harvest time is usually after panicle development since the highest sugar concentration happens after flowering. Obviously the date depends on the variety and the climate conditions. Whenever possible, frequent determination of sugar concentration in the stems is recommended after flowering, at least the first year of the variety growing, in order to determine its performance.

Sweet sorghum harvest is finalised to the recovery of all sugars which are concentrated most of all in the stalks. Therefore the way in which harvest is performed is by cutting the stems at the ground level; for bioethanol purposes, sorghum leaves are rejected.

The stalks should be sent to the mill for crushing at the earliest as the sugar content decrease in progression with time. In any case it should be crushed within 48 hrs otherwise sugar content will be drastically reduced.

Currently, the only commercially viable harvest method for sweet sorghum is removing the entire crop with a forage harvester and transporting it to a bioethanol plant. Using this method, transportation costs and proximity to the bioethanol plant will play a large role in determining where sweet sorghum production is profitable.

There are a number of studies about the mechanization of sweet sorghum harvest. Some of the machinery used are: sugarcane combines, harvesters that cut and bale the stems, forage choppers and some prototypes. In the US, forage corn harvesters are recommended but the produced crop must be immediately delivered to the bioethanol plant for its processing. This is a convenient method because conventional machinery is used and thus, operation costs are cheaper. The main drawback is the high risk of sugar losses (juice loss and sucrose instability).

The highest-quality syrup is produced when the sorghum is harvested before the mature or ripe seed stage. Sucrose percentage and syrup yields generally increase as the stalk matures to the ripe seed stage.

To obtain high-quality syrup and high yields, most varieties should be harvested when the seed is in the soft dough stage.
Sweet sorghum for syrup production can be harvested by hand using a knife or hoe when acreage is small. Machine harvesting is used on larger acreages.

The seedhead and peduncle (between the base of the seedhead and the top node) should be removed before processing the stalks. Seedheads may be dried and threshed so the seeds can be used for the next year’s crop. A germination test should be made before planting these seed.

Excellent-quality syrup can be made without removing (stripping) the leaves. However, the stalks should not be crushed while the leaves are still wet. Delay milling for 3 to 5 days. This delay will allow the leaves to dry out, the stalks to lose some water, and natural enzymes within the stalk to invert some of the sucrose. These changes will make the syrup easier to cook and less likely to crystallize.

Since juice cannot be held for long periods of time without spoiling, making semisyrup is an attractive alternative in some cases.

Post-Harvesting
In spite of the fact that sweet sorghum is an interesting crop for bioethanol even in temperate climates, little progress has been made on the penetration of this crop. This happens, most of all, because the period of time comprised between harvesting and the processing phase is too short. Moisture content at harvest is very high (70-80%) and temperatures at harvest time are mild. Subsequently to mowing or chopping, juice losses happen. Moreover, sugar degradation (unwanted fermentations) is fast triggered because high biomass moisture is jointed to a high concentration in easily fermentable sugars.

To prevent fermentations sweet sorghum must be harvested quickly and the produced crop must be immediately processed in the plant. In temperate climates (e.g. Mediterranean climates) the harvesting period is reduced by the fact that if the harvest is delayed the climate conditions become bad for this crop and damages by lodging, cold or sugar losses may happen. In other words, the problem is the impact of the high seasonality of this crop in the production and in the industrial process.

To prevent the above mentioned problems several measures have been suggested. One is to grow varieties of different cycle length (short to long cycle varieties) or to combine several sugar crops which help to make longer the harvesting and processing period. Another measure is to extract and preserve the stalk juice or sugars from fermentation. Additionally, it is recommended to use bagasse for further processing as feedstock for bioethanol production.
Picture 11: Sweet sorghum harvesting, TOMMASO GUICCIARDINI/SCIENCE PHOTO LIBRARY

Sweet Sorghum Varieties

The election of the variety is extremely important to obtain good crop yields. Long cycle varieties are usually more productive than the short cycle ones. However, in some locations long cycle varieties are not advisable because temperatures should be warm during the whole cycle to express its potential. In Mediterranean climates this condition means that the temperature must be mild or warm in September.

- **Short cycle varieties**: cycle length of this type of varieties is about 70 to 90 days from emergence to flowering in Mediterranean climates. For instance, the varieties named Mer 60-2, Mer 78-13, Soave, Atlas, Madhura.
- **Long cycle varieties**: they may need about 110 days from emergence to flowering. For instance, the varieties named Keller, Dale, Wray.

Some of the most important sweet sorghum varieties released at international level are **Rio, Dale, Brandes, Theis, Roma, Vani, Ramada** and **Keller**.

**BJ 248, RSSV 9, NSSV 208, NSSV 255** and **RSSV 56** are the sweet sorghum cultures identified by the “All India Coordinated sorghum improvement project at National level”. Hybrid **Madhura** was developed by “Nimkar Agricultural Research Institute, Phaltan, Maharashtra”.

**Dale** is a mid-season variety developed at the U.S. Sugar Crops Field Station. Seeds are small, reddish brown, and germinate well. Dale is resistant to leaf anthracnose and red stalk rot. Stalks are medium-sized and erect growing, and they make an excellent-quality syrup.

**Della**, a mid-season variety with good disease resistance, was developed by Bob Harrison, Virginia Polytechnic Institute, and released in December 1991. Della matures about one week earlier than Dale and about 6 days later than Sugar Drip. Della is a backcross of Dale to an earlier maturing line. It is resistant to anthracnose and maize dwarf mosaic and is moderately susceptible to bacterial stripe. Della does not resist lodging as much as Dale and is more variable in plant height. It is similar to Dale in syrup quality. The biggest advantage of Della is that it matures one week earlier than Dale and thus would let you start cooking a little earlier in the fall.

**Brandes** was released in 1968 from the U.S. Sugar Crops Field Station. It is a late-maturing variety with an excellent root system and stiff stalks that usually remain erect. It is resistant to leaf anthracnose and red stalk rot. It has good syrup quality, but it is more susceptible to drought than some varieties. The seed are small and white and have good germination.

**Georgia** Blue Ribbon, a variety of uncertain origin, lodges badly and is susceptible to major sweet sorghum diseases. Stalks are shorter and juicier than those of Tracy. Syrup quality is excellent. The seed are medium-sized and brown. It matures about the same time as Tracy.

**Honey** is a variety grown by the USDA before 1900; it is also called Honey Drip and Texas Seeded Ribbon. The stalks grow 7 to 10 feet tall and tend to lodge badly. It yields well and makes excellent-quality syrup, but it is susceptible to most major sorghum diseases. It is a few days later than Tracy in maturity.

**M8IE** is a late-maturing variety which matures a few days later than Dale. It was released from the U.S. Sugar Crops Field Station, Meridian, Mississippi. It is similar to Dale in height and lodging resistance. M8IE is resistant to leaf anthracnose and red stalk rot, but it is susceptible to maize dwarf mosaic. The yield of syrup from M8IE is generally superior to Dale. The syrup has a mild sorghum
flavor, amber color, and excellent quality. It appears to be more susceptible to a light frost than the other varieties.

**Simon** is a very early-maturing variety of unknown origin. It matures about 7 days earlier than Sugar Drip. It has a fairly small stalk, low juice yield, and is susceptible to most sorghum diseases. The only advantage for Simon in Kentucky is for very late plantings where Sugar Drip will not mature. Simon is better adapted to areas north of central Indiana and Ohio. It has performed well in Wisconsin, Minnesota, and New York. It does produce a high quality syrup.

**Sugar Drip** is an early mid-season variety of unknown origin. It tends to lodge and is very susceptible to many diseases. Seed are medium-sized and brown. This variety is one of the earliest-maturing varieties for the South, and so it is useful for early syrup production. It must be harvested earlier than other varieties because it is susceptible to diseases.

**Theis** is a variety developed at the U.S. Sugar Crops Field Station, Meridian, Mississippi, and released in 1974. It has late maturity similar to Brandes and Wiley. Theis may grow to 12 to 16 feet tall, but it has good lodging resistance. Theis produces large, brown seed. Syrup quality is usually excellent. It is highly resistant to leaf anthracnose and red stalk rot, has moderate resistance to downy mildew, and is tolerant to maize dwarf mosaic virus.

**Tracy** is a mid-season variety developed by the U.S. Department of Agriculture and released in 1953. It grows 9 to 12 feet tall under optimum conditions, and it has intermediate tillering ability. The stalks are erect and juicy. The syrup quality can be excellent, but under some conditions the juice may contain too much starch for proper boiling. Tracy is susceptible to anthracnose, red rot, zonate leaf spot, and rust. It yields a high tonnage of stalks, but the syrup yield per ton of stalks is low.

**Other Hybrid Profiles**

- **Asgrow A571**: Medium-tall height, semi-open head type, average stalk strength
- **Dyna Gro 751B**: Tall height, good stalk strength, semi-compact head type
- **FFR322**: Medium height, semi-compact head type
- **Garst 5515**: Medium-short height, semi-open head type, average stalk strength
- **Golden Acres 444E**: Medium-short height, good stalk strength, semi-open head type
- **Pioneer 83G66**: Medium height, average stalk strength, semi-compact head type, best suited for light textured soil types, resistant to anthracnose
- **Southern States SS-800**: Short height, semi-compact head type, tolerance to MDMV and greenbug biotype C
- **Terral TV-9421**: Medium height, good stalk strength, semi-open head type, best suited for light textured soil types, susceptible to anthracnose
- **Terral TV-1050**: Medium height, average stalk strength, semi-compact head type, best suited for heavy clay soils and stressful, dryland conditions
- **Terral TV96H81(formerly TVX00981)**: Tall height, average stalk strength, semi-compact head type
- **Triumph 82-G**: Medium-tall height, good stalk strength, well suited for most soil types, compact head type, susceptible to Fusarium head blight

Table 1 gives data on various varieties of sweet sorghum according to their number of days to Maturity.
Table 1: Varieties of sweet sorghum according to their number of days to Maturity

<table>
<thead>
<tr>
<th>SS Variety</th>
<th>Days</th>
<th>Height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simon</td>
<td>100</td>
<td>1.8-2.2</td>
</tr>
<tr>
<td>Sugar Dip</td>
<td>105</td>
<td>2.2-2.4</td>
</tr>
<tr>
<td>Rox Orange</td>
<td>106</td>
<td>2.4-2.7</td>
</tr>
<tr>
<td>Umbrella</td>
<td>112</td>
<td>2.4-3.0</td>
</tr>
<tr>
<td>Della</td>
<td>114</td>
<td>2.7-3.5</td>
</tr>
<tr>
<td>KNMorris</td>
<td>115</td>
<td>3.0-3.7</td>
</tr>
<tr>
<td>Dale</td>
<td>120</td>
<td>2.7-3.5</td>
</tr>
<tr>
<td>Keller</td>
<td>125</td>
<td>2.7-3.5</td>
</tr>
<tr>
<td>Top 76-6</td>
<td>130</td>
<td>2.7-3.5</td>
</tr>
<tr>
<td>Theis</td>
<td>135</td>
<td>2.7-3.5</td>
</tr>
<tr>
<td>M81E</td>
<td>135</td>
<td>2.7-3.5</td>
</tr>
<tr>
<td>Grassl (MN1500)</td>
<td>150</td>
<td>2.7-3.5</td>
</tr>
</tbody>
</table>

Table 2 presents Brix (sugar content) and other agronomic traits values of some sweet sorghum cultivars.

<table>
<thead>
<tr>
<th>Cultivar/Line</th>
<th>Days to anthesis</th>
<th>Plant height (cm)</th>
<th>Brix reading</th>
<th>Wet Stalk (g/stalk)</th>
<th>Dry Stalk (g/stalk)</th>
<th>Stalk Moisture</th>
<th>% germination after 10d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dale</td>
<td>100</td>
<td>288</td>
<td>17.1</td>
<td>831</td>
<td>241</td>
<td>71.0%</td>
<td>80.0%</td>
</tr>
<tr>
<td>Della</td>
<td>78</td>
<td>270</td>
<td>17</td>
<td>878</td>
<td>292</td>
<td>66.7%</td>
<td>80.0%</td>
</tr>
<tr>
<td>Wray</td>
<td>79</td>
<td>216</td>
<td>19</td>
<td>383</td>
<td>132</td>
<td>65.5%</td>
<td>82.0%</td>
</tr>
<tr>
<td>Rio</td>
<td>90</td>
<td>324</td>
<td>17.8</td>
<td>579</td>
<td>193</td>
<td>66.7%</td>
<td>90.0%</td>
</tr>
<tr>
<td>M81E</td>
<td>110</td>
<td>374</td>
<td>14.6</td>
<td>1173</td>
<td>306</td>
<td>73.9%</td>
<td>62.0%</td>
</tr>
<tr>
<td>Theis</td>
<td>111</td>
<td>348</td>
<td>12.9</td>
<td>1026</td>
<td>263</td>
<td>74.4%</td>
<td>31.0%</td>
</tr>
<tr>
<td>Sugar Dip</td>
<td>82</td>
<td>236</td>
<td>17.7</td>
<td>810</td>
<td>241</td>
<td>70.2%</td>
<td>71.0%</td>
</tr>
<tr>
<td>Brandes</td>
<td>110</td>
<td>276</td>
<td>14</td>
<td>695</td>
<td>197</td>
<td>71.7%</td>
<td>43.0%</td>
</tr>
<tr>
<td>N. Sugar Cane</td>
<td>85</td>
<td>218</td>
<td>19.8</td>
<td>562</td>
<td>208</td>
<td>63.0%</td>
<td>21.0%</td>
</tr>
<tr>
<td>Roma</td>
<td>98</td>
<td>280</td>
<td>17.7</td>
<td>813</td>
<td>249</td>
<td>69.4%</td>
<td>92.0%</td>
</tr>
<tr>
<td>Top 76-6</td>
<td>110</td>
<td>302</td>
<td>13.8</td>
<td>840</td>
<td>218</td>
<td>74.0%</td>
<td>36.0%</td>
</tr>
<tr>
<td>Grassl/MN1500</td>
<td>118</td>
<td>288</td>
<td>15.1</td>
<td>936</td>
<td>277</td>
<td>70.4%</td>
<td>60.0%</td>
</tr>
<tr>
<td>Keller</td>
<td>99</td>
<td>304</td>
<td>16</td>
<td>1042</td>
<td>323</td>
<td>69.0%</td>
<td>78.0%</td>
</tr>
<tr>
<td>Norkan</td>
<td>68</td>
<td>172</td>
<td>17.3</td>
<td>348</td>
<td>108</td>
<td>69.0%</td>
<td>96.0%</td>
</tr>
<tr>
<td>N100</td>
<td>79</td>
<td>230</td>
<td>17.2</td>
<td>623</td>
<td>203</td>
<td>67.4%</td>
<td>95.0%</td>
</tr>
<tr>
<td>Rox Orange</td>
<td>67</td>
<td>194</td>
<td>15</td>
<td>390</td>
<td>121</td>
<td>69.0%</td>
<td>75.0%</td>
</tr>
<tr>
<td>G. Blue Ribbon</td>
<td>71</td>
<td>206</td>
<td>14.3</td>
<td>487</td>
<td>149</td>
<td>69.4%</td>
<td>50.0%</td>
</tr>
<tr>
<td>Simon</td>
<td>63</td>
<td>198</td>
<td>17.3</td>
<td>415</td>
<td>135</td>
<td>67.5%</td>
<td>75.0%</td>
</tr>
<tr>
<td>Sumac</td>
<td>72</td>
<td>200</td>
<td>17.6</td>
<td>498</td>
<td>146</td>
<td>70.7%</td>
<td>30.0%</td>
</tr>
<tr>
<td>Rex</td>
<td>85</td>
<td>210</td>
<td>17.3</td>
<td>390</td>
<td>132</td>
<td>66.2%</td>
<td>32.0%</td>
</tr>
<tr>
<td>Honey</td>
<td>78</td>
<td>222</td>
<td>14.6</td>
<td>482</td>
<td>153</td>
<td>68.3%</td>
<td>71.0%</td>
</tr>
<tr>
<td>Minnesota Amber</td>
<td>68</td>
<td>174</td>
<td>14</td>
<td>305</td>
<td>109</td>
<td>64.3%</td>
<td>55.0%</td>
</tr>
</tbody>
</table>

Table 2: Brix (sugar content) and other agronomic traits values of sweet sorghum cultivars/lines, Source: Dr. Ismail Dweikat, University of Nebraska, USA

Potential Yields

To estimate sugar content in juice, a refractometer is used for the Brix (%) measurement. Handheld light refractometers and battery powered digital refractometers can be utilised. A model that automatically compensates for temperature should be used. Brix numbers from 14 to 20% would be
considered acceptable levels for harvesting. Obviously, the higher the sugar content in the stalks, the higher the potential ethanol yield. Table 3 and Table 4 present data on various varieties of sweet sorghum according to their yields.

<table>
<thead>
<tr>
<th>Units</th>
<th>Theis</th>
<th>M-81E</th>
<th>Wray</th>
<th>Keller</th>
<th>Brandes</th>
<th>Rio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh material</td>
<td>mt/ha</td>
<td>125</td>
<td>128</td>
<td>106</td>
<td>107</td>
<td>89</td>
</tr>
<tr>
<td>Stalk</td>
<td>mt/ha</td>
<td>95</td>
<td>89</td>
<td>76</td>
<td>76</td>
<td>62</td>
</tr>
<tr>
<td>Fermentable sugars</td>
<td>mt/ha</td>
<td>10.6</td>
<td>9.6</td>
<td>10.3</td>
<td>10.5</td>
<td>6.4</td>
</tr>
<tr>
<td>Ethanol</td>
<td>l/ha</td>
<td>6,159</td>
<td>5,607</td>
<td>5,981</td>
<td>6,131</td>
<td>3,696</td>
</tr>
<tr>
<td>Seeds</td>
<td>kg/ha</td>
<td>6,674</td>
<td>6,213</td>
<td>1,426</td>
<td>1,960</td>
<td>3,500</td>
</tr>
</tbody>
</table>

**Table 3 Variety - Metric Units**

<table>
<thead>
<tr>
<th>Varieties</th>
<th>Total dry matter (ton/a)</th>
<th>Percent stalk¹%</th>
<th>Stalk moisture %</th>
<th>Brix²</th>
<th>Fermentable carbohydrate yield³ (ton/a)</th>
<th>Calculated ethanol yield⁴ (gal/a)</th>
<th>Stalk lodging⁵ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northrup King 301</td>
<td>9.4</td>
<td>52</td>
<td>68</td>
<td>13.2</td>
<td>1.81</td>
<td>247</td>
<td>47</td>
</tr>
<tr>
<td>Rox Orange</td>
<td>10.6</td>
<td>46</td>
<td>75</td>
<td>10.3</td>
<td>1.84</td>
<td>250</td>
<td>33</td>
</tr>
<tr>
<td>Northrup King 405</td>
<td>11</td>
<td>60</td>
<td>70</td>
<td>7.3</td>
<td>1.25</td>
<td>170</td>
<td>70</td>
</tr>
<tr>
<td>Keller</td>
<td>10.1</td>
<td>70</td>
<td>72</td>
<td>13.4</td>
<td>2.96</td>
<td>403</td>
<td>97</td>
</tr>
<tr>
<td>Dale</td>
<td>10.0</td>
<td>70</td>
<td>74</td>
<td>12.3</td>
<td>3.00</td>
<td>408</td>
<td>98</td>
</tr>
<tr>
<td>Northrup King 8361A</td>
<td>11.7</td>
<td>67</td>
<td>70</td>
<td>8.9</td>
<td>1.85</td>
<td>252</td>
<td>72</td>
</tr>
<tr>
<td>M81E</td>
<td>10</td>
<td>66</td>
<td>73</td>
<td>12.7</td>
<td>2.83</td>
<td>385</td>
<td>96</td>
</tr>
<tr>
<td>Northrup King 8361</td>
<td>13.1</td>
<td>68</td>
<td>73</td>
<td>7.4</td>
<td>1.96</td>
<td>267</td>
<td>93</td>
</tr>
<tr>
<td>LSD (.05)</td>
<td>1.5</td>
<td>3</td>
<td>3</td>
<td>1.7</td>
<td>0.49</td>
<td>66</td>
<td>18</td>
</tr>
</tbody>
</table>

**Table 4: Varietal differences in total dry matter yields, percent stalk, stalk moisture, Brix, fermentable carbohydrate yield, ethanol yield and stalk lodging of sorghum and corn grown at Waseca, MN, 1987.**

1. Dry matter basis.
2. Brix is approximately equivalent to percent sugar.
3. Brix multiplied times stalk sap yield.
4. Assuming 2.5 gal of ethanol/bu of corn grain and 14.7 lb fermentable carbohydrate/gal of ethanol.
5. Stalk lodging: percent of plants lodged at least 450 or more at harvest. Lodging was much more severe in 1987 than 1988 due to two wind storms.

A two-year study was conducted in Northern Greece, the objective of which was to assess the productivity (biomass, juice, total sugar and theoretical ethanol yields) of four sweet sorghum cultivars (Sugar graze, M-81E, Urja and Topper-76-6), one grain sorghum cultivar (KN-300) and one grass sorghum cultivar (Susu) grown under Mediterranean conditions. The results of this study indicated that sweet sorghum provides sufficient yields even when grown under stress of soil salinity and reduced irrigation. Sweet sorghum plants produce sufficient juice, total sugar and ethanol yields in fields with soil sanity up to 3.2 dS m⁻¹ even though the plants receive 50-75% of the water regimes typically applied to sorghum. Therefore, sweet sorghum may be viable as an alternative crop system for bioethanol production under increased salinity and reduced irrigation conditions, especially in semi-saline and semiarid Mediterranean fields where the irrigation water is limited during crop development. The following Table indicates the results.
<table>
<thead>
<tr>
<th>Salinity (dS m(^{-1}))</th>
<th>Irrigation (mm)</th>
<th>Cultivar</th>
<th>Fresh biomass (Mg ha(^{-1}))</th>
<th>Dry biomass (Mg ha(^{-1}))</th>
<th>Juice (Mg ha(^{-1}))</th>
<th>Brix degree (%)</th>
<th>Total sugar (Mg ha(^{-1}))</th>
<th>Theoretic ethanol (L ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2</td>
<td>120</td>
<td>Sugar graze</td>
<td>49.9</td>
<td>16.1</td>
<td>14.3</td>
<td>13.2</td>
<td>1.47</td>
<td>3591</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M-81E</td>
<td>61.2</td>
<td>23.7</td>
<td>22.5</td>
<td>10.2</td>
<td>1.75</td>
<td>3354</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Urja</td>
<td>48.4</td>
<td>15.8</td>
<td>13.9</td>
<td>12.1</td>
<td>1.33</td>
<td>3225</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Topper-76-6</td>
<td>35.5</td>
<td>13.0</td>
<td>14.0</td>
<td>11.1</td>
<td>1.15</td>
<td>2087</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Suzu</td>
<td>23.5</td>
<td>9.3</td>
<td>4.2</td>
<td>11.2</td>
<td>0.37</td>
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Table 5: Fresh & dry biomass yields, juice yields, Brix degree of juice, total sugar yield and theoretical ethanol yields. Source: Sweet sorghum productivity for biofuels under increased soil salinity and reduced irrigation, Ioannis Vasilakogloua, Kico Dhima, Nikitas Karagiannidis, Thomas Gatsis
Breeding programs

Sweet sorghum has been studied as an alternative crop for sugars/ethanol in temperate regions since the end of the nineteenth century. Breeding programs aim at the production of crystallized sugars and syrup, the improvement of the carbohydrate yields and also the prevention of leaf anthracnose and stalk red rot. Several attributes of sweet sorghum as juice extraction percentage, °Brix value, non-reducing sugars, total sugars and inversion enzyme activity are being studied nowadays. Presently sweet sorghum breeding activities are being carried out in the European SWEETFUEL project, supported by the European Commission (7th Framework Programme).

Breeding for temperature environments

Temperature is associated to the emerging and flowering period and it is also related to stalk production and sugar content. Sweet sorghum grows with high radiation and it is adapted to southern European climates but its growth is limited in North and Central Europe because of low temperatures, which affect the biomass yield. The main objective of this project is sweet sorghum adaptation to low temperatures. Biomass yield, tolerance to cold, fast and homogeneous germination, and disease resistance are pursued. Breeding and varietal testing is being carried out in European countries involved in the SWEETFUEL project: Germany, Italy and France.

Breeding for drought prone environments

One of the main limiting factors for this crop is its water requirements, in spite of the fact that they are lower than sugarcane ones. Sweet sorghum may have a double purpose: grain and sugars, with a good drought adaptation, juicy stalks with sugar content and good digestibility. The breeding program objectives, also in the SWEETFUEL project, are the improvement of the juice in the stems, avoiding drought effects even if increasing sugar content. These activities are being carried out in India, Mexico and South Africa.

Breeding for low fertility soil environments

Sorghum is a suitable crop for areas located in semi-arid to semi-humid climate regions of subtropical and tropical latitudes, as moist savannas. Soil acidity and aluminium toxicity are important existing constraints in these areas. Breeding programs are mainly lead to improve genetic tolerance to these restrictions that could allow to obtain higher biomass yields and higher stalks juice and sugar content. These objectives are also included in the SWEETFUEL project; experiences are being performed in countries such as Brazil or South Africa.
CONSERVATION OF SUGARS

A bioethanol plant, processing only sweet sorghum as a primary source, must ensure raw material for a full year operation. A short processing season increases capital costs due to the need for oversized equipment. Thus a sustainable investment for a bioethanol plant depends to a large extent on the development of long-term storage methods of the sweet sorghum raw material.

The sweet stalks of sweet sorghum contain highly fermentable sugars, mainly as sucrose and have high moisture content. After harvest, sugar can deteriorate rapidly, depending on climatic conditions and this deterioration must be prevented.

Researcher: Eiland, Clayton, and Bryan\textsuperscript{xvi} found that sweet sorghum (variety: Wray) lost about half of its sugar content in 8 days, with about 14% of the total sugar lost in the first day; while researcher: Daeschel, Mundt and McCarty\textsuperscript{xvii} found that freshly squeezed sweet sorghum juice spoiled within 5 to 12 h at ambient temperatures.

The best solution to preserve the sugars in the juice is to boil the juice and produce syrup from sweet sorghum juice (concentration process). The concentration is the strategy chosen for the EU model of “Sweethanol” project, to preserve sugars and to supply the plant in the months after the harvesting of the sweet sorghum biomass. This section may apply in both cases: sweet sorghum as sole feedstock or as a complementary raw material for the bioethanol production.

The percentage of juice extracted is an important factor in mill operation. The juice extraction rate depends upon the mill speed, the moisture content of the cane, the mill adjustment, and the feeding rate. Sweet sorghum juice apart from sugars contains soluble solids (anthocyanins and chlorophyll) and insoluble solids (starch granules). The extracted juice should be strained in order to become clean. Let the juice settle a minimum of 2 hours before evaporating. Holding the juice more than 3 to 4 hours without refrigeration or without heating may cause it to ferment and spoil. In some
operations, settling tanks are heated to a point just below boiling and held for about 2 hours. The temperature should not be allowed to go below 70 degrees C as it is held overnight. This holding temperature allows for much of the skimmings to rise to the top and the settlings to precipitate to the bottom.

When heat is applied to the juice, much of the starch becomes soluble, but certain proteins and other nonsugar substances begin to coagulate. If allowed to settle, some of this coagulated material rises to the surface of the juice and some sinks to the bottom. The best practice is to remove this material as quickly as possible by skimming as soon as it appears on the surface of the juice.

Good quality syrup can be made after carrying out evaporation with continuous skimming of coagulated materials, which have risen to the surface. Evaporation should be done with uniform heating. Initially coagulation starts when juice temperature increases. This scum should be removed during slow heating. Evaporation should not be done fast as scum gathered on the top of the juice may get dissolved during rapid boiling and then floating or settled mass problems may be seen in the syrup made.

Continuous evaporators have significant factor of superiority. They are constructed in such a way as to produce a quick concentration of the juice to syrup, and, with proper operation, to facilitate efficient skimming. If the pan is operated so the skimmings are properly concentrated and removed, the major function of the operation is to ensure that the syrup is drawn from the pan when the proper density is reached.

Once the juice is clarified, the evaporation process is carried out. The evaporation process will be done in a falling film evaporator working under vacuum to ensure the minimum energetic consumption and the best quality of the sugar juice. The previous clarification is needed to ensure the reduction of incrustations and soiling on the pipes and on the concentration unit. The aim of this stage is the concentration of the sugar juice from 12-16º Brix to 45-85º Brix, depending on the
storage period for the concentrated juice. This process increases the osmotic pressure in the liquid and avoids any bacterial or yeast development.

The falling film evaporator concentrates the sugar juice in several steps (between 2 and 4, depending on the final concentration), working under vacuum to ensure a low temperature process, lower steam consumption, and lower sugar degradation. At each concentration step, the diameter of the tubes of the falling film evaporator is increased to reduce fouling and to maintain the performance of concentration. From this step, the water condensed after the concentration could be used on the sugar extraction unit, minimizing the water consumption on the total process.

Research has shown that sweet sorghum syrup of at:

- 45 degrees Brix can be held for 21-30 days.
- 60-65 degrees Brix can be held for 90 days.
- 85 degrees Brix can be held for 270-360 days.

The syrup is diluted before it undergoes fermentation.
SUPPLY CHAIN

An assured supply of raw materials is critical for the success of any industry. Sweet sorghum stalks are available for crushing only for a limited period during the harvesting season. To ensure a viable ethanol industry, assured and continuous supply of raw material is essential for at least 9 months of the year. Therefore, to extend the period of raw material availability, the operation of both centralized (farmers supplying stalks directly to distilleries) and decentralized (farmers supplying stalks to crushing units located in a cluster centre- a crushed and syrup production unit) models, is needed.

Scenario A

FARMERS SUPPLY WITH SWEET SORGHUM (FRESH BIOMASS) A CRUSHING AND SYRUP PRODUCTION (CSP) UNIT.

The purpose of setting up a crushing and syrup production unit is to crush sweet sorghum stalks extract and boil the juice to produce syrup. By this process the volume of feedstock to be transported to the bioethanol unit is reduced while the life period of the feedstock is increased.

All of the following conditions may apply

- The fields of sweet sorghum are far from the bioethanol plant.
- The farmers are able to cooperate.
- There is a potential to create a Crushing and Syrup Production Unit in the area.

The distance from the bioethanol plant may cause delays in the supply of the fresh biomass and consequently sugar degradation (unwanted fermentations) may happen. Thus the farmers may create synergies and develop a Unit which would buy the raw material from the farmers and produce syrup of sweet sorghum in order to safely transport it to the bioethanol plant without facing sugar losses problems.

An example of such a unit is already successfully operating in India. Sweet sorghum supply chain in India involves centralized and decentralized models. Under the centralized model, farmers supply the sweet sorghum stalks directly to the distillery whereas in decentralized model farmers supply stalks to decentralized crushing and syrup making unit located in their area which act as a cluster centre.

In the CSP units stalks are crushed and the sweet juice is boiled to produce concentrated syrup that can be stored for more than 9 months and can be used in ethanol production, particularly in off-season. The CSP unit also helps in reducing the volume of raw material for transportation, and in preventing the losses from delay in crushing.

The main disadvantage of the CSP unit is that the bagasse (crushed stalk) is left in the unit to serve its energy needs. This fact may affect the sustainability of the bioethanol unit if the plant is to cover its energy thermal needs by conventional fuels.

Establishment of Crushing and Syrup Production Unit

A survey should be conducted in order to establish a CSP unit for syrup production. The area to be located should be selected on the basis of farmers’ response to the idea, and their willingness to participate in the project activities.
Example of a “Crushing and Syrup Production Unit” In India.

- **The CSP of ICRISAT organization.**

The CSP unit of ICRISAT organization in Hyderabad India processes the sweet sorghum crops of 70 farmers, a yield of about 30 hectares. The unit has 3 crusher machines two of which have a capacity of crushing 2tn of sweet sorghum stalks per hour while the other has a capacity of 1tn per hour. In the 2009 rainy season, a total of 560 tons of fresh stalks were crushed to produce 29 tons of syrup (approx. 65% Brix). All the syrup was transported to Rusni Distilleries through established marketing linkages between the CSP and industry for ethanol production.

**Plant and machinery**

The following equipment and machinery were required for the CSP unit

- **Crusher**
- **Weigh bridge**
- **Generator**
- **Chulhas (stoves)**
- **Juice boiling pans**
- **Juice boiling accessories (stirrer, dragger, sieves and scum storing drum)**
- **Electric motors and pumps**
- **Supply pipelines**
- **Juice storage tank**
- **Steel baskets**
- **Motors**

**Crushing:** The crusher is an important component of the CSP unit. It is required to crush the sweet sorghum stalks to extract the juice. In the CSP unit of ICRISAT, a popular sugarcane crusher model with three rollers was used, 2tn per hour crushing capacity was chosen after consultations with local dealers, jaggery making farmers and a couple of crusher manufacturers. It has a high crushing efficiency, entails less maintenance cost and fewer mechanical problems. Its spare parts and
repairing facilities are easily available. During crushing, the juice flows through a preliminary juice collection and filtration pit beside the juice outlet channel. From this outlet, the filtered juice flows into a juice collecting drum placed beneath the soil surface for convenience. The juice in the drum is pumped by a motor into boiling pans through an industrial hosepipe.

**Syrup making**: The syrup making process involves collection of juice from the crushing point and boiling it to evaporate the water and concentrate the sugars in the juice. The juice from the crushing point is pumped to the boiling pans for making syrup with constant boiling and stirring. Chemicals are added to the boiling juice in different concentrations to avoid froth formation and coagulation of unwanted materials float on the surface of the boiling juice. The juice in the pan is constantly stirred. During the boiling, some undesirable contents coagulate. These materials (skimming) are removed frequently. The skimming are generally rich in protein and starch as well as some sugar and can be used in preparing animal feed.

As the syrup density increases, the boiling temperature is increased gradually. The boiling pans are removed from the burners when the temperatures reaches 108°C to 110°C or when the syrup attains a density of 70° Brix when tested with a syrup hydrometer or sugar refractometer. The final syrup is allowed to cool to 67-76°C and stored in plastic containers. The finished syrup is strained with a mesh to remove any crushed plant materials or other inert foreign materials. The syrup is stored in clean, air-tight plastic wide-mouth containers at room temperature. The shelf life of the syrup at 70° Brix stored at room temperature is around 9-12 months. In the CSP at Ibrahimbad, a total of 557 tn of sweet sorghum stalks were crushed and 23 tn of syrup produced during the 2008 rain season.

![Picture 17: Sweet Sorghum Crushing and Syrup making unit in India](image)
Scenario B

FARMERS SUPPLY WITH SWEET SORGHUM (FRESH BIOMASS) A BIOETHANOL PRODUCTION UNIT.

All the following may apply

- The fields of sweet sorghum are near the bioethanol plant.
- There is a potential to create a Bioethanol Unit in the area.

The Bioethanol production unit may obtain freshly harvested sweet sorghum stalks from the farmers or sweet sorghum syrup from the “crushing and syrup production units”. Bioethanol plants for the reasons described above, apply the concentration process in order to ensure the continuous feeding of the plant.

As farmers supply stalks directly to the distillery, it requires mobilization of farmers in the nearly area, according to the EU Sweethanol model, so that the time and cost of transportation of stalks is reduced. However, this option has some limitations:

I. Farmers located more than 20 km from the distillery will be endorsed by higher transportation costs.
II. Delay in stalks crushing will cause reduction in juice yield.
III. Delay in harvesting and transportation of stalks to distilleries will lead to reduction in stalk weight, causing financial loss to the grower.

Examples of “bioethanol plants” processing sweet sorghum as a sole feedstock in India.

- Rusni Distillery is the World's first Sweet sorghum based Ethanol plant.

Running at full capacity, Rusni Distillery produces 40,000 liters of ethanol per day (the yield of about 40 hectares of crop at 20 tons stalk/ha). According to Mr AR Palaniswamy, a mid-sized plant such as Rusni costs about 7 million €.

Rusni apart from the sweet sorghum syrup supplied by the cluster center (DCU) buys sweet sorghum stalk for Rs 600 (9-10€) per ton from other farmers near the area. To avoid food-fuel competition; Rusni does not buy grain unless it is diseased. Grain spoiled for human or livestock consumption is still suitable for making ethanol.

Rusni has 30 crushing units of 1tn/hour capacity each and 6 tanks for the fermentation phase and the ss syrup production.

To enable farmers who are located away from the distilleries to participate in the sweet sorghum to ethanol value chain, a decentralized crushing and syrup making unit is proposed involving farmers from a cluster of three to four villages.
ICRISAT’s strategy is to examine the feasibility of applying any one or more of these measures to mitigate the yield losses and help supply raw materials (stalks or syrup) to the distillery over an extended period in a year.

- Twenty-four hectare sweet sorghum stalks (870 t) needed per day for 40000 litres of ethanol per day for the unit
- US$ 10.8 paid per ton of sweet stalks
- Stalks passed in series of two rollers, so crushed twice
- Juice yield to an extent of 40% of stalk yield on weight basis
- Juice pasteurized at 100°C for 30 minutes batch type
- Enzymes added to breakdown starch to glucose
- Yeast is added and allowed to ferment for 34 to 45 hours
- 40 to 45 l ethanol per ton of stalks obtained
- Sweet sorghum stillage – 2200 Kcal/kg at 50% moisture
- CO₂ produced: 30 tn/day and sold at US$0.1/m3
- Methane collected from spent wash (vinasse), used as fuel in boiler (3300 m³/day)
- Dehydration with Molecular Sieve Process for ethanol production up to 99.8%
- Plant operates 270 days as per law (potential of 300 days with sweet sorghum)
- Production cost: US$ 0.39/litre
- Public outlet pays US$ 0.51/litre while private outlet pays US$ 0.60/litre of ethanol

- **TATA Chemical Ltd**

The bioethanol plant in Nanded, Maharashtra, TATA Chemical Ltd, is a 30,000 L/day facility using sweet sorghum as feedstock for bioethanol, and sweet sorghum bagasse as fuel for generating power.
The bio-ethanol production phases of TATA Chemical Ltd

Sweet sorghum stalks are transported to TATA bio-ethanol plant, unloaded on the feeder table and discharged on to the carrier with the help of electrically operated stalk unloader. Through a Kicker which is fitted on the Carrier stalks are discharged to the fibrizer. This special equipment designed to chop the sweet sorghum stalks and feed the millers with the bagasse blanket. Automatic stalk feeding device is fitted on the carrier to control the feed. Sweet sorghum stalks are passed through 4 power operated hammer mills (Toothed Roller Pressure Feeder milling system) to collect the juice. The bagasse blanket goes through the 4 mills while during the 3rd press; hot water at a temperature around 65°C is added to increase the juice extraction efficiency. The juice derived from the 4 mills is collected and carried to the furnace for syrup production. The extracted juice is strained so as to become clean. For the production of good quality syrup the ss juice is evaporated with continuous skimming of coagulated materials, which is raised to the surface. When the temperature reaches 100-107°C with a Brix of 85%, heating is completely stopped. If the syrup is to be carried directly for fermentation, sugar has a lower Brix of around 40-50% (semi-syrup). The syrup is diluted before it undergoes fermentation. Freshly activated dry yeast and sweet sorghum juice are loaded together into the fermentation tank with proper handling and cleanliness by observing sanitary measures to avoid contamination with unwanted bacteria or other undesirable microorganisms. The juice is inoculated with yeast and run in fermenter for a period of 72 hours more or less at 30-32 °C and 750 rpm for ethanol production (pH ~3.5). If yeasts are yet vital, they are reused in the fermentation process. The bioethanol concentration in the fermented medium is 9-14% v/v and the objective of this unit is to obtain the azeotropic bioethanol (i.e. 95-96% v/v).

At this aim the fermented medium flows through some distillation columns (i.e. multiple effect distillation) made of bubbling dishes, where water and alcohol are separated basing on their own specific boiling points as they run up the tower. The multiple effect technology allows reducing the heat consumption of this unit, because the pressure on the column head is lower than the
atmospheric value and the boiling point of the components to separate is inferior. In the end the dehydration process is necessary to produce anhydrous bioethanol (i.e. 99.7-99.8% w/w).

Concerning the distance between the plant and the fields, different evaluations must be integrated. The main elements are the impact of the transport on the energy balance of the chain, the logistics coherent with the requirements of the farms (e.g. the necessary number of agricultural machinery, number of driven kilometres) and the plants (e.g. timing of supply during the harvesting) and with the impact of the consequent traffic in the considered area.

![Picture 20: TATA Chemical Ltd, Nanded, Maharashtra](image)

**Range of supply according to the EU model of “Sweethanol project”**

In order to give some indications for the range of supply and its repercussions, in Table 6 the details for two simulations are reported.

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<tr>
<td>15 km</td>
<td>4 parallel yards</td>
<td>4 mower-shredder-charger machines</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>24 farm tractors</td>
<td></td>
</tr>
<tr>
<td>20 km</td>
<td>6 parallel yards</td>
<td>6 mower-shredder-charger machines</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>24 farms tractors</td>
<td></td>
</tr>
</tbody>
</table>

Table 6: results of two simulations for the supply of a plant with capacity 10,000 t/y as anhydrous bioethanol

In the model creation the dimensioning of the units for the by-products exploitation is based on the amounts of obtained bagasse and vinasse, which are linked to the cultivated agricultural land and then to the assumed capacity as anhydrous bioethanol.

The main elements to dimension the related units are reported in the specific paragraph (7.4 Exploitation of by-products).
PROCESSING THE SYRUP OF SWEET SORGUM

The technological sections for the production line of 1st generation bioethanol are: the sugar extraction unit, the concentration unit for the storage of the sugar juice, the fermentation unit, the distillation and rectification units and finally the dehydration unit.

Crushing unit

The extraction of free sugars from the chopped biomass can be carried out through direct pressing using the rolling mills or through a lixiviation system.

In both processes the extraction is carried out using hot water (75-85 °C) in the ratio between feedstock and hot water of 1:0.1-1:1. The extraction yield is in the range of 93-98%, considering a range of 85-93% of extraction yield using a rolling mills series (from 3 to 5 rolling mills) and a range of 93-98% of extraction yield using a continuous diffuser.

In case of crushing into horizontal or vertical power mills, the working principle is the application of high pressure, which is exercised by some couples of rollers (TRPF milling system): 3 couples in the small vertical crushers, up to 9 couples in the big horizontal ones. The speed of the top roller is usually 10-12 rpm in small mills, 6-8 rpm in large mills. In order to improve the extraction efficiency, the optimal addition of hot water is 10% w/w.

The working scheme of the crushing unit is reported in the following figure.

Alternatively, the operation of the diffuser is based on systematic counter that puts the raw material under current washing by means of imbibition water. In practice, this is achieved by forming a bed of shredded stalk or first mill bagasse on a conveyor. Water is added at the discharge end of the conveyor and percolates through the bed of bagasse and the perforated slats of the conveyor. The water dissolves the sugar in the bagasse and the thin juice thus formed is collected in a hopper. This juice is moved forward one stage by pumping and the process is repeated until the juice reaches
maximum concentration at the feed end of the diffuser. The diffuser may be conditioned either for single-flow or for parallel-flows juice circulation.
Usually the diffusers are designed from 35 m to 52 m long; the cross section is rectangular and diffusers of different capacities are made in different widths. The conveyor grids and screens are supported by 2 outboard type roller chains with a pitch of about 3 feet. These chains are supported at the extreme ends by sprockets. At the driven end, the sprockets are coupled through a gearwheel and pinion to a variable speed hydraulic drive or electric gear-motor drive.

The conveyor itself is made of articulated frames to which the screens are fixed. The screens and frames are rigidly attached to corresponding links of the 2 chains. These chains are fitted with self-lubricating bushings. The rollers ride on parallel rails. The return rails are completely exposed underneath the housing, giving full visibility and accessibility to the screens. The thickness of the bed varies from 1.5 m to 2 m. The space between the 2 conveyor spans is occupied by a large tank with a sloping bottom split into individual hoppers by means of vertical plates. These vertical plates have horizontal slots, at specified levels, through which the juice overflows to the next hopper. At the end of the conveyor, there is a revolving scraper to even out the flow of bagasse which falls in an outlet.
hopper. This hopper is provided with a conveyor for removing the bagasse. The diffuser is equipped with lifting screws in the press-water feedback area.

During the whole duration of its passage through the diffuser, the bed of stalks is submitted to intensive sprays of juice of progressively decreasing concentration. The juice is evenly sprayed above the bed by a series of overflowing troughs extending on the whole width of the housing. One of these troughs is fitted above each juice-collecting hopper and designed to distribute uniformly the juice across the bed, with an accuracy of 2%. The curve showing the decreasing concentration of the juice in the successive hoppers that is very steady.

![Picture 27: degree Brix curves: (1) sweet sorghum stalks diffuser, (2) bagasse diffuser](image)

The last trough is fed with pure water. All the juice hoppers have the same width. They collect the juice percolating from each juice distributor through the bed of stalks. Each hopper is piped to an individual high capacity centrifugal pump. Each pump is piped to take juice from one hopper and to spray it above the preceding hopper (in opposite direction to the movement of the bed). A last single pump feeds the richest juice to the rich juice tank. Another pump of great capacity continuously circulates rich juice on the fresh prepared stalks of sweet sorghum. The intensive flow of stalks or first mill bagasse is fed into the diffuser by a drag type cross conveyor so designed as to spread the feed evenly on the diffuser conveyor. Juice from the rich juice tank is pumped to the factory. The diffuser is operated and controlled from a central panel on which all instruments are grouped.

The main advantages of the continuous diffusion are:

- high extraction achieved in combination with existing milling equipment or in completely new extraction plants;
- low initial cost of the overall extraction plant because diffusers are designed to work with conventional sweet sorghum stalks preparation and milling equipment. The diffusers can be installed outdoors;
- low maintenance costs because of massive design and extremely slow movement of the main conveyor;
- low operational costs: diffusers are completely automated and can be operated by 1 man per shift. Lubrication costs are negligible;
- low power requirements: live steam is not needed. Steam of low-pressure is used for juice heating in the diffuser. All moving parts are driven by electric motors;

- very wide capacity range: diffusers can operate without modifications and without loss of efficiency from 30% to 10% over nominal capacity. By varying the bed height and conveyor speed, the capacity range may be extended even more. The design of the diffuser is such that unforeseen increases in capacity can, to a certain extent, be met by the addition of washing stages to existing diffusers;

- absence of fermentation: the diffusers are designed to eliminate all static zones where fermentation could develop. The return span of the diffuser conveyor is washed at every cycle to prevent contamination of the feed by pieces of bagasse sticking to the screen. The diffuser is fitted for pH control and for operation at optimum temperature;

- bagasse discharge is by gravity at the tail end of the diffuser: a special scraper is provided to even out the flow of bagasse and provide a continuous feed to the dewatering mills. The diffuser can be completely discharged for long stops and must not be cleaned manually;

- juice quality is good: systematic clarification of last mill juice enables removal of impurities early in the process and contributes towards the production of juices which are easy to clarify and which present no problems in the boiling house;

- heat economy: all heaters are of the type used for mixed juice heating in sugar factories. The diffuser is completely enclosed and insulated.

The continuous diffuser gives high yield on the extraction and low power consumption, and also the juice has low amount of interfering and contaminants that must be removed before the concentration step.

If sweet sorghum juice contains soluble solids (e.g. anthocyanins and chlorophyll) and insoluble solids (e.g. starch granules), these components have to be separated to process the sugar juice to bioethanol.

Good quality juice can be made after carrying out evaporation with continuous skimming of coagulated materials, which have risen to the surface. Evaporation should be done with uniform heating. Initially coagulation starts when juice temperature increases. This scum should be removed during slow heating. Evaporation should not be done fast as scum gathered on the top of the juice may get dissolved during rapid boiling and then floating or settled mass problems may be seen in the syrup.

The evaporation of the sugar juice must be done with a good quality product, eliminating the solids content and other interfering. This purification can be done with the addition of lime and CO$_2$ for flocculating these compounds and eliminating them by filtration.

Once the juice is clarified, the evaporation process carries out. The evaporation process will be done in a falling film evaporator working under vacuum to ensure the minimum energetic consumption and the best quality of the sugar juice. The previously clarification is needed to ensure the reduction of incrustations and soiling on the pipes and on the concentration unit.
Falling film evaporator

The concentration is the strategy chosen to preserve sugars and to supply the plant in the months after the harvesting of the sweet sorghum biomass. This section is required in both cases: sweet sorghum as sole feedstock and sweet sorghum and another raw material as feedstock.

The aim of this stage is the concentration of the sugar juice from 12-16 °Brix to 45-85 °Brix, depending on the storage period for the concentrated juice. This process increases the osmotic pressure in the liquid and avoids any bacterial or yeast development.

The falling film evaporator concentrates the sugar juice in several steps (between 2 and 4, depending on the final concentration), working under vacuum to ensure a low temperature process, lower steam consumption, and lower sugar degradation. At each concentration step, the diameter of the tubes of the falling film evaporator is increased to reduce fouling and to maintain the performance of concentration. From this step, the water condensed after the concentration could be used on the sugar extraction unit, minimizing the water consumption on the total process.
Fermentation unit

The fermentation is carried out by yeasts (*Saccharomyces cerevisiae*) at the conditions which favour firstly their quick cell growth and division and afterwards their anaerobic metabolism.

Especially the following conditions are required:

- glucose concentration > 9 g/l (in order to benefit from the Crabtree effect and to ensure the alcoholic fermentation instead of the oxidative metabolism);
- pH 4-5;
- temperature in the range 30-35 °C;
- nitrogen concentration 150-180 mg/l (as ammonium).

The fermentation unit has five sections.

1. **Pasteurisation of sugar juice**: in order to avoid unchecked fermentations by bacteria, sugar juice is sterilised through the pasteurisation (Table 7).

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Time</th>
<th>Pasteurisation type</th>
</tr>
</thead>
<tbody>
<tr>
<td>63 °C (145 °F)</td>
<td>30 minutes</td>
<td>Vat Pasteurisation</td>
</tr>
<tr>
<td>72 °C (161 °F)</td>
<td>15 seconds</td>
<td>HTST</td>
</tr>
<tr>
<td>89 °C (191 °F)</td>
<td>1.0 seconds</td>
<td>HHST</td>
</tr>
<tr>
<td>90 °C (194 °F)</td>
<td>0.5 seconds</td>
<td>HHST</td>
</tr>
<tr>
<td>94 °C (201 °F)</td>
<td>0.1 seconds</td>
<td>HHST</td>
</tr>
<tr>
<td>96 °C (204 °F)</td>
<td>0.05 seconds</td>
<td>HHST</td>
</tr>
<tr>
<td>100 °C (212 °F)</td>
<td>0.01 seconds</td>
<td>HHST</td>
</tr>
<tr>
<td>138 °C (280 °F)</td>
<td>2.0 seconds</td>
<td>UP</td>
</tr>
</tbody>
</table>

**Table 7**: conditions for the pasteurisation of sugar juice

2. **Preparation of yeasts**: yeasts are re-hydrated and stabilized in order to obtain the suspension in the mother tank. This step is carried out with a solution rich in glucose, fructose or sucrose, an average temperature of 35 °C and with the addition of bactericide, oxygen and eventually ergosterol. At the beginning of each fermentation reaction, an amount of the mother suspension is flowed as inoculum in the fermentation tank.

3. **Fermentation**: it can be applied in a in batch process or in continuous one.
   - **In batch fermentation**: the fermentation reactions are performed in independent reactors without direct communications among them. The bioethanol yield of this process depends
on the tolerance of yeast to the alcoholic concentration in the medium (maximum tolerance 19% v/v for selected strains). Although in this process the yield is lower than the yield of the continuous one, the control of contaminations is better and consequently the security is higher because this system allows an easy isolation of the contaminated tank, preventing that it can extend throughout all the unit.

- **Continuous fermentation.** The continuous process is set up flowing the pasteurised sugar juice only to the first tank where yeasts is inoculated. From the first tank the partially fermented juice flows to the following ones; in this transit bioethanol is removed and its concentration in the medium maintains inferior to the inhibition level of yeasts. Then the fermentation by degrees continues until the last tank, where all the free sugars are converted in bioethanol. The yield of this process is higher than the yield of the batch one, because yeasts are not inhibited. Furthermore, the necessary capacity is less than the volume required by the other one. The main criticism is the contamination risk: in fact if one of the continuous tanks is contaminated with bacteria, the total system can be contaminated and the decontamination is more difficult.

4. **Recovery of yeasts.** The recovery of yeasts at the end of the fermentation process is a measure to increase the economic viability of the plant. Yeasts are recovered from the fermented medium through centrifugation. If yeasts are yet vital, they are reused in the fermentation process. If yeasts have finished their own lifetime, they are a source of proteins for the preparation of human and/or animal feed.

**Distillation and rectification unit**

The bioethanol concentration in the fermented medium is 9-14% v/v and the objective of this unit is to obtain the azeotropic bioethanol (i.e. 95-96% v/v).

At this aim the fermented medium flows through some distillation columns (i.e. multiple effect distillation) made of bubbling dishes, where water and alcohol are separated basing on their own specific boiling points as they run up the tower. The multiple effect technology allows to reduce the heat consumption of this unit, because the pressure on the column head is lower than the atmospheric value and the boiling point of the components to separate is inferior.

**Dehydration unit**

The dehydration process is necessary to produce anhydrous bioethanol (i.e. 99.7-99.8% w/w). This value of purity is required to produce bio-ETBE or to blend bioethanol directly with petrol.

The dehydration unit is based on the molecular sieve technology: zeolite, which is the component of the sieves, retains selectively the residual water molecules, increasing gradually the percentage of bioethanol in the flowing blending.

Anhydrous bioethanol has to be stored in tanks with controlled atmosphere (free of air, usually with $\text{N}_2$ or $\text{CO}_2$), in order to avoid the solubilization of water vapour.

The same conditions have to be applied in the transport phase.
EU POTENTIAL MODELS TO PROCESS SWEET SORGHUM AS AN ENERGY CROP

Introduction

Sorghum is a multipurpose crop because it supplies high yields in biomass, sugar and grain depending on the chosen varieties.

At the current time the sweet sorghum varieties provide mainly biomass and sugar, whereas its potentiality as grain crop is not yet expressed. Many agricultural researches are aimed to overcome this limit, selecting hybrids with high yields in biomass, sugar and grain at the same time. Actually, in order to express all the potentialities of the crop, other agricultural researches are directed to optimize the harvesting operations, separating all the products: biomass and sugar on one side, grain on the other side.

Since these researches are not yet finished, the model to process sweet sorghum foresees the exploitation of sugars and lignocellulosic biomass.

![Diagram of the plant to process sweet sorghum in bioethanol and energy commodities]

In accordance with the scheme in Picture 31 the sweet sorghum biomass is crushed and sugar juice is processed in bioethanol.

Bagasse, which is the lignocellulosic residue of the crushing unit, is dried and burnt in CHP plant to get electricity and heat.

Vinasse, which is the residue of the distillation and rectification unit, is a feedstock for the anaerobic digestion, to use in co-digestion eventually with other substrates like for example manure as microbial inoculum. The obtained biogas is purified and burnt in CHP plant to get electricity and heat.

This approach for processing sweet sorghum allows different variations that can be applied in the planning of a specific chain model to supply decentralised small-medium plants in the EU.
In fact, the conversion of the sugar juice in bioethanol and the energetic exploitation of bagasse and vinasse can be the sole production line or can be one of the production lines implemented in the plant.

These different strategies are explained in detail in the specific chapters. In particular, the use of sweet sorghum as sole feedstock is deepened in three case studies (i.e. in Italy, in Greece and in Spain) and the feasibility for processing sweet sorghum plus another raw material (i.e. sugar beet) in the same plant is reported in the Spanish conditions.

All these applications have some common elements regarding the dimensioning of the chain supply, the technological contents of the processing and the by-products exploitation. Consequently, the following paragraphs are aimed to give the main guidelines, which are common to the different applications. They are the indicative input data to perform a feasibility study and at this aim they require a contextualisation to each specific situation.

Dimensioning of the chain supplying
In the creation of the EU model the capacity as anhydrous bioethanol obtained from the processing of sweet sorghum is assumed as criterion for the dimensioning of the chain supplying.

As appropriate this dimensioning regards the whole plant (if sweet sorghum is the sole feedstock) or the specific production line to obtain 1st generation bioethanol from this crop (if the plant processes different raw materials).

Two elements are required in the assessment: the agricultural surface cultivated with sweet sorghum and the range of supplying.

Agricultural land requirement
The required agricultural land depends on the yields of biomass and sugars, which are consequent for example of the kind of soil, the water availability, the climate, the grown variety.

The main specificities have been traced to some reference scenarios, in order to give an indicative value to the stakeholders (Table 8).

<table>
<thead>
<tr>
<th>Macro scenarios to plan the chain supply</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type MEDITERRANEAN</strong></td>
</tr>
<tr>
<td>Low fertility soils</td>
</tr>
<tr>
<td>Dry climate</td>
</tr>
<tr>
<td>Irrigation</td>
</tr>
<tr>
<td>Biomass yield</td>
</tr>
<tr>
<td>10.3-35.0 t/ha db</td>
</tr>
<tr>
<td>Bioethanol yield</td>
</tr>
<tr>
<td>1.5-6.0 t/ha</td>
</tr>
<tr>
<td>1.9-7.6 m³/ha</td>
</tr>
<tr>
<td>40.5-162.0 GJ/ha</td>
</tr>
<tr>
<td><strong>Type TEMPERATE</strong></td>
</tr>
<tr>
<td>Medium fertility soils</td>
</tr>
<tr>
<td>Temperate oceanic climate</td>
</tr>
<tr>
<td>No irrigation</td>
</tr>
<tr>
<td>Biomass yield</td>
</tr>
<tr>
<td>14.3-19.0 t/ha db</td>
</tr>
<tr>
<td>Bioethanol yield</td>
</tr>
<tr>
<td>2.1-3.4 t/ha</td>
</tr>
<tr>
<td>2.8-4.4 m³/ha</td>
</tr>
<tr>
<td>56.7-91.8 GJ/ha</td>
</tr>
<tr>
<td>Irrigation (emergency)</td>
</tr>
<tr>
<td>Biomass yield</td>
</tr>
<tr>
<td>30.0-40.0 t/ha db</td>
</tr>
<tr>
<td>Bioethanol yield</td>
</tr>
<tr>
<td>4.3-6.1 t/ha</td>
</tr>
<tr>
<td>5.9-7.9 m³/ha</td>
</tr>
<tr>
<td>116.1-164.7 GJ/ha</td>
</tr>
</tbody>
</table>

Table 8: yields in biomass and bioethanol obtainable from sweet sorghum in some reference type of environments xl,xli
The reported ranges for the yields concern some different sweet sorghum varieties, currently available in the EU market.

Two different types of environment are analysed and in each one the conditions to ensure the economic viability are considered.

The cultivation of sweet sorghum in marginal lands is taken into consideration for contexts where the economic viability is guaranteed and the related yields correspond to the lowest values in the reported range for each type of environment.

Especially in the Mediterranean environments (i.e. South Italy, Spain, Greece) the cultivation of sweet sorghum without irrigation is excluded because the biomass yields are too low. In the temperate environments (i.e. North Italy) only the eventual emergency irrigation is considered because the rainfall during the growing period is usually sufficient (e.g. 670 mm in May-Sept 2010).

These data are the input to calculate the hectares which must be cultivated with sweet sorghum in order to supply the plant, basing on its capacity. Nevertheless, for each specific situation the calculated surface could require a wider area, for example if rotations with other crops are proposed in the considered region in order to protect the soil fertility.

These values of macro scenario, of course, require a following careful contextualisation to calculate the actual dimensioning of the chain supply.

Range of supplying
Concerning the distance between the plant and the fields, different evaluations have to be integrated. The main elements are the impact of the transport on the energy balance of the chain, the respect of specific limits to access to eventual national aids (e.g. short chain recognised for a maximum range of supplying), the logistics consistent with the requirements of the farms (e.g. the necessary number of agricultural machinery, number of driven kilometres) and the plants (e.g.
timing of supplying during the harvesting) and with the impact of the consequent traffic in the considered area.

In order to give some indications for the range of supplying and its repercussions, in Table 9 the details for two simulations are reported.

<table>
<thead>
<tr>
<th>3,700-3,800 hectares cultivated with sweet sorghum</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maximum range</strong></td>
</tr>
</tbody>
</table>
| 15 km \(^{51}\) | 4 parallel yards | 4 mower-shredder-charger machines  
24 farm tractors |
| 20 km \(^{52}\) | 6 parallel yards | 6 mower-shredder-charger machines  
24 farms tractors |

Table 9: results of two simulations for the supplying of a plant with capacity 10,000 t/y as anhydrous bioethanol \(^{xlii,xliv}\)

In the model creation the dimensioning of the units for the by-products exploitation is based on the amounts of obtained bagasse and vinasse, which are linked to the cultivated agricultural land and then to the assumed capacity as anhydrous bioethanol.

The EU model 1: sweet sorghum as sole feedstock of the plant

This model is aimed to develop a chain in the EU based only on sweet sorghum as feedstock.

The main advantage of this model is the utilisation of a crop which is characterised by low agricultural inputs (i.e. water and fertilisers).

The main disadvantage of this model is the dependence of the plant from a single type of raw material.

In order to explain this model for the EU, the guidelines described in the previous chapter are applied to an exemplifying plant with capacity as anhydrous bioethanol of 10,000 t/year.

The main details of this application are summarised in Table 10.

<table>
<thead>
<tr>
<th>Capacity 10,000 t/year (as anhydrous bioethanol)</th>
</tr>
</thead>
</table>
| **Dimensioning of chain supply** | **Agricultural land** | **Type Mediterranean**  
2,200-6,700 ha |
|  | **Type Temperate**  
3,000-4,800 ha (no irrigation)  
1,700-2,300 ha (emergency irrigation) |
| **Range of supply** | It depends on the specific region, for example in terms of crop diversification, farm structure, limits for the incentives to short agro-energy chains |
| **Processing of sugar juice** | **Operational details** | 330 working days per year  
68,000-69,000 t db of sweet sorghum biomass crushed in 40 days  
Crushing, fermentation, distillation, rectification and dehydration in accordance with the guidelines |
|  | **Concentration unit** | Storage  
Syrup at 45% storable up to 3 months |
Concerning the agricultural land requirement, in the temperate climate characterised by medium fertility soils and rainfall of about 600-700 mm during the growth period, 3,000-4,800 hectares are required. If the emergency irrigation is foreseen, the higher yield allows to reduce the cultivated surface to 1,700-2,300 hectares, but in this situation the agricultural costs increase significantly and usually maize or other crops becomes more competitive. Consequently, this important variable has to be taken into consideration in choosing the fields to cultivate and in the related feasibility study.

On the contrary in the Mediterranean conditions the irrigation is necessary to obtain viable yields. A surface of 2,200-6,600 hectares is required; the high width of the range is due to the very different values in the yields, which depend on the inputs of water and fertilisers.

The decision about the range of supply is correlated to different factors, such as technical, logistical, energetic, economic ones. Firstly, the competitiveness of sweet sorghum compared to other crops depends by its economic viability which is the prerequisite, but also by the agricultural tradition of the specific area and by the propensity to innovation of the farmers. Some indicators can be utilised in this evaluation, for example the crop diversification and the farm structure. If the crop...
diversification in the considered area is high, it is plausible that the range of supply increases, because this suggests that numerous crops are competitive and the market repays all of them. On the contrary, the low age of farmers, the big size of farms and the application of innovative solutions in the agricultural practices usually indicate a possible decrease in the range of supply. Secondly, the decision must be subjected to the LCA and to the analysis of the logistics, evaluating the energetic and environmental impacts of each hypothesized value for the range of supply. Finally, the assumed range of supply must allow to benefit from eventual national incentives that the different countries make available for the RES.

As regards with the logistics, the harvesting operations are carried out in yards; each one of them is fitted out with 1 mower-shredder-loader machine and 4-6 farm tractors fitted out with dumper (i.e. capacity about 50 m³) for the transport of the chopped biomass to the plant.

Regardless the number of hectares and the range of supplying, every year 68,000-69,000 tons of biomass are processed in the plant to obtain 1st generation bioethanol from the sugar juice and electricity and heat from the by-products.

The biomass supply to the plant occurs only during the harvesting period: 40 days at maximum between August and September in the South EU climate conditions. On the contrary, the working period of the plant is 330 days per year; in fact one plant shutdown is foreseen approximately in July for the planned maintenance.

To preserve sugars during the entire working period of the plant, the chopped biomass is immediately crushed at the moment of the delivery and the obtained sugar juice is concentrated for the storage and processing in the period after the harvest. The final sugar concentrations of the syrup are 45% for the storage up to 3 months and 80% for the storage up to 11 months. The concentrated syrups are stored in adequate tanks at the plant.

The syrup is diluted before the inoculum with the mother suspension of yeasts; afterwards the fermentation is started up with an in batch process and the duration is set up in 22 hours.

As regards with the other technical aspects of the processing, the fermentation, distillation, rectification and dehydration phases are carried out in accordance with the guidelines described in the chapter 7.

A special explanation is necessary in this model for the water management, because a relevant amount of water is evaporated and then condensed and afterwards an important amount of water is required for the dilution of the syrup.

In the considered model this potential criticism is solved assuming that waste water of the concentration unit is discharged into surface water body (in accordance with the limits foreseen by the national and eventual local laws in terms of COD, nitrate, pH, phosphate, temperature and other chemical and physical parameters), whereas the potable water for the dilution is bought. This assumption appears preferable from technical and economic points of view if compared to the choice of storing waste water and using it the next dilution, because in this second case too high storage volumes are required.

Concerning the energetic exploitation of the by-products, bagasse is dried and then burnt in CHP plant fitted out with steam turbine (electric power 4.20 MWe), and biogas, obtained from vinasse through the anaerobic digestion, is burnt in a CHP plant based on a gas turbine (electric power 0.75
MWe). Electricity and heat, produced in these units, can be used for the self-consumption and the surplus of both of them is sold to the electric grid and distributed through a district heating network.

When the concentration unit stops working (i.e. at the end of harvesting period), a relevant thermal consumption lacks in the plant and consequently the correspondent energy can be converted in electricity with a small steam turbine (electric power 0.43 MWe), increasing the total production.

The EU model 2: sweet sorghum and sugar beet as feedstock of the plant

This model is aimed to develop in the EU a chain based on sweet sorghum and another bioethanol crop as feedstock for the same decentralised small-medium plant.

This model has been studied as alternative to the first one, because the model 1 is penalised by the dependence from just one feedstock. Furthermore, the model 2 has the advantage to allow to process mainly fresh raw material and consequently to minimize the concentration of the sugar juice. In fact the short number of days of the harvesting period obliges to make a high concentration of the sugar juice to maintain the production process of the bioethanol plant (fermentation, distillation and dehydration) during almost all the year (11 months per year). On the contrary using also another fresh biomass the required concentration level can be significantly reduced.

The disadvantage of the model 2 is due to the necessity that in one area two bioethanol crops must be cultivated in different period of the year. This condition can be satisfied or not in different regions.

The production of sugar beet can vary between 80,000 – 120,000 kg/ha with irrigation. Considering the percentage of sugar per kilogram of sugar beet, the variation can be between 13% and 16% of the fresh samples. Usually, the amount of sugar can be fixed on 14%. This amount of sugar per kilogram and the productivity of sugar beet per hectare is indicating a variation of 6,600 – 10,000 litres per hectare of bioethanol.

The calculations of the model have been done considering a bioethanol plant with a capacity of 12,500 m³/year (i.e. 10,000 t/year). Thus, if the sugar beet is the raw material for three months per year, the amount of bioethanol from sugar beet must be approximately 3,500 m³/year. This production requires from 350 to 525 hectares of sugar beet, depending on their productivity.

Logistics

The logistic system of this model is similar for both raw materials as regard with the transport from the fields to the production plant.

An important difference between the 2 crops is the time needed from the harvest to the process.

Apart from the density of the crops, the type of machinery to make the harvest and so on, the main difference is that the storage of the sweet sorghum is not possible due to the sugar loss and the beginning of fermentation after 7-8 hours, but, on the other hand, in the case of sugar beet, the storage can be done in the field or in the production plant during one month. Apart from this, the maintenance of the sugar beet in the fields without harvesting it is possible without losing the sugars.
Thus, sugar beet can be used as feedstock increasing the time between the harvest and the process. This allows making a better structuring of the transport from the fields to the production plant and reducing the transport cost using bigger trucks and trailers.

Processing
The production process must be adapted to the use of sugar beet and sweet sorghum as feedstock. This is not an important problem, due to the fact that the types of sugar stored in the sugar beet and in the stalks of sweet sorghum are sucrose, glucose and fructose. Thus, the fermentation, distillation and dehydration are similar.

The main difference between the use of sugar beet or sweet sorghum is on the first step of the process, during the cleaning of the raw material, cutting and sugar extraction.

In this model the incorporation of a cleaning line is necessary to eliminate sludge and stones from the sugar beet before the cutting step. In the case of sweet sorghum, there is not a cleaning step, and after the reception of the stalks, these are shredded before the extraction.

The extraction process must be done with a continuous diffuser to ensure the best yield on the extraction process and the use of the same equipment for extracting from sweet sorghum and sugar beet. On the contrary the rolling mill can not be used in the extraction of sugar from sugar beet.

After the extraction, the other steps of the process are similar regardless the type of raw material.
ENERGY EXPLOITATION OF THE SWEET SORGHUM BY-PRODUCTS

Bagasse

Basing on its own characteristics (Table 11), the dried bagasse, residue of the extraction unit, can be burnt in CHP plant to produce electricity and heat.

<table>
<thead>
<tr>
<th>Bagasse characterisation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture after crushing</td>
<td>30-50%</td>
</tr>
<tr>
<td>Residual sugars</td>
<td>6-7% db</td>
</tr>
<tr>
<td>Cellulose</td>
<td>16-18% db</td>
</tr>
<tr>
<td>Hemicellulose</td>
<td>11-13% db</td>
</tr>
<tr>
<td>Lignin</td>
<td>7-9% db</td>
</tr>
</tbody>
</table>
| LHV                      | 17-18 MJ/kg db  
|                          | 4.7-5.0 kWh/kg db |

Table 11: main characteristics of bagasse, obtained in a TRPF milling system, to plan its energetic exploitation

The size of the CHP plant is correlated to the bagasse availability and then to the agricultural land cultivated with sweet sorghum and to its biomass yield.

Considering the biomass yields reported in Table 7 and the LHV of Table 11, the reference values in order to design the unit for the combustion of bagasse in CHP plant are reported in Table 12

<table>
<thead>
<tr>
<th>Energy exploitation of bagasse</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of environment</td>
<td>Yield</td>
</tr>
<tr>
<td>Type MEDITERRANEAN</td>
<td></td>
</tr>
<tr>
<td>Low fertility soils</td>
<td></td>
</tr>
<tr>
<td>Dry climate</td>
<td></td>
</tr>
</tbody>
</table>
| Irrigation                     | Bagasse yield 6-20 t/ha db  
|                                | Available energy 100-340 GJ/ha  
|                                | 28-94 MWh/ha |
| Type TEMPERATE                 |  |
| Medium fertility soils         |  |
| Temperate oceanic climate      |  |
| No irrigation                  | Bagasse yield 10-12 t/ha db  
|                                | Available energy 190-200 GJ/ha  
|                                | 53-56 MWh/ha |
| Irrigation (emergency)         | Bagasse yield 18-25 t/ha db  
|                                | Available energy 312-442 GJ/ha  
|                                | 87-123 MWh/ha |

Table 12: Main elements for the dimensioning of the unit of bagasses exploitation in some reference type of environments

As regards with the technical details of the CHP plant, it is kitted out with a biomass burner, suitable to the combustion of herbaceous feedstock, and a turbine, which could be for example a steam turbine based on the Rankine-Hirn cycle, a gas turbine based on the Brayton cycle, or a turbogenerator based on the ORC cycle.
The choice of the technology for the CHP plant depends, most of all, on the electric power. The summarises some situations for the power values in the range interesting for the EU model (0.1-10 MWe) with the related energy efficiency.

The main criticism of the combustion of sorghum bagasse is the high content in ashes (3-5% db) that are characterised by a low melting point. Consequently, the technology applied in the biomass burner requires an adequate ash removal system and the special extended warranty has been issued by the manufacturer. The management of ashes depends on the law of the specific country.

Vinasse

Vinasse, residue of the distillation and rectification units, has a chemical composition which is suitable to the production of biogas through the anaerobic digestion (Table 13).

<table>
<thead>
<tr>
<th>Vinasse characterisation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry matter</td>
<td>6-7%</td>
</tr>
<tr>
<td>Volatile matter</td>
<td>85-90%</td>
</tr>
<tr>
<td>BOD&lt;sub&gt;5&lt;/sub&gt;</td>
<td>40-50 gO&lt;sub&gt;2&lt;/sub&gt;/l</td>
</tr>
<tr>
<td>COD</td>
<td>70-90 gO&lt;sub&gt;2&lt;/sub&gt;/l</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>750-850 mg/l</td>
</tr>
<tr>
<td>Phosphorous</td>
<td>1.5-2.5 g/l</td>
</tr>
<tr>
<td>pH</td>
<td>4.4-4.6</td>
</tr>
</tbody>
</table>

Table 13: main characteristics of vinasse to plan the anaerobic digestion

The dimensioning of the anaerobic digester is correlated to the vinasse availability and then to the capacity as anhydrous bioethanol and to the HRT.

Concerning the vinasse yield, the theoretical correlation coefficient is 7-8 litre of vinasse per litre of bioethanol.
As regards with the HRT to complete the biomethanation, it depends on the chemical composition of the feedstock: as a principle, lignin, cellulose, protein show a slower degradation than fats, starch and sugars. The methanogenesis of vinasse is carried out using also other substrates to start up and/or stabilise the process: for example manure is utilised as microbial inoculum at the beginning of the process and lignocellulosic feedstock can be mixed to vinasse to improve the ratio between carbon and nitrogen, if necessary. In this hypothesis the HRT for vinasse is 60 days approximately.

The typical chemical composition of biogas is reported in the Table 14.

<table>
<thead>
<tr>
<th>Biogas characterisation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CH₄</td>
<td>50-70%</td>
</tr>
<tr>
<td>CO₂</td>
<td>25-45%</td>
</tr>
<tr>
<td>H₂</td>
<td>1-10%</td>
</tr>
<tr>
<td>N₂</td>
<td>0.5-3.0%</td>
</tr>
<tr>
<td>CO</td>
<td>0.08-0.10</td>
</tr>
<tr>
<td>H₂S</td>
<td>0.02-0.20</td>
</tr>
<tr>
<td>O₂</td>
<td>traces</td>
</tr>
<tr>
<td>LHV</td>
<td>21-22 MJ/Nm³</td>
</tr>
<tr>
<td></td>
<td>5.8-6.1 kWh/Nm³</td>
</tr>
</tbody>
</table>

Table 14: main characteristics of biogas

The theoretical methane yield is 0.395 Nm³ per kilogram of COD, if the content of methane in biogas is 60%.

Assuming the yields in vinasse and methane and the values of Table 13 and Table 14 for COD and LHV respectively, the elements to dimension this unit are summarised in Table 15.

<table>
<thead>
<tr>
<th>Energy exploitation of vinasse</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of environment</td>
<td>Yield *</td>
</tr>
<tr>
<td>Type MEDITERRANEAN</td>
<td>Methane</td>
</tr>
<tr>
<td>Low fertility soils</td>
<td>340-1,030 Nm³/ha</td>
</tr>
<tr>
<td>Dry climate</td>
<td>Available energy</td>
</tr>
<tr>
<td></td>
<td>7.9-23.7 GJ/ha</td>
</tr>
<tr>
<td></td>
<td>2.2-6.6 MWh/ha</td>
</tr>
<tr>
<td>Type TEMPERATE</td>
<td>Methane</td>
</tr>
<tr>
<td>Medium fertility soils</td>
<td>500-790 Nm³/ha</td>
</tr>
<tr>
<td>Temperate oceanic climate</td>
<td>Available energy</td>
</tr>
<tr>
<td></td>
<td>11.6-18.4 GJ/ha</td>
</tr>
<tr>
<td></td>
<td>3.2-5.1 MWh/ha</td>
</tr>
<tr>
<td></td>
<td>Methane</td>
</tr>
<tr>
<td>Irrigation (emergency)</td>
<td>1,070-1,420 Nm³/ha</td>
</tr>
<tr>
<td></td>
<td>Available energy</td>
</tr>
<tr>
<td></td>
<td>24.9-32.7 GJ/ha</td>
</tr>
<tr>
<td></td>
<td>6.9-9.1 MWh/ha</td>
</tr>
</tbody>
</table>

* calculations with the application of the actual methane yield

Table 15: main elements to the dimensioning of the unit of vinasse exploitation in some reference type of environments

The obtained biogas is burnt in a CHP plant which can be based on Diesel engine or gas micro-turbine.

The utilised Diesel engine requires some modifications in order to work with the Otto cycle in the combustion of methane: especially it is fitted out with a carburettor and the spark plugs. At the current time these modified engines are already available on the market. Heat is recovered through a exchanger from the flue gases and/or from the engine cooling.
The energy efficiency is correlated with the electric power of the CHP plant: in the range considered for the EU model (0.1-5.0 MWe) the electrical efficiency is 30-42%, the thermal efficiency is 45-50%. The highest powers are characterised by the most efficiency, above all in the electric conversion.

The digested matter, residue of the biomethanation, is a good fertiliser (nitrogen 800 g/t, mainly as ammonium) and it is applied in the fields in order to compensate the nitrogen removal carried out by sweet sorghum growth.
CONTRACT FARMING AMONG SWEET SORGHUM & BIOETHANOL PRODUCERS

Commercial-scale production of sweet sorghum, as well as that of all energy crops, has significant obstacles to overcome. In particular, an efficient supply chain that can procure biomass in an economically cost effective manner is crucial for producing advanced biofuels (Yoder 2010).

A bioethanol plant is estimated to require more than 3700 ha of biomass annually to operate at capacity (Sweethanol EU model). Besides obvious issues such as creating an efficient transportation system and adapting equipment to suit the characteristics of sweet sorghum and bioethanol, farmers and plant owners requires assurances to produce large volumes of the crop and of bioethanol respectively. Consequently, finding ways to assure farmers and plant owners’ investment will be crucial to the development of an efficient supply chain. The most effective way securing both parts is through a “Contract Farming”.

Contract Farming could be used to provide farmers with the assured sale of their energy crops and biofuel plants with a steady supply of biofuels into the market.

Contract farming - Definition

Contract farming can be defined as agricultural production carried out according to an agreement between a buyer (plant owner) and farmers, which establishes conditions for the production and marketing of a farm product. Typically, the farmer agrees to provide agreed quantities of a specific agricultural product on agreed quality. The farm product should be supplied at the time determined by both involved parties. The buyer commits to purchase the product and, in some cases, to support production through, for example, the supply of farm inputs and the provision of technical advice.

The use of farming contracts has become attractive to many agricultural producers worldwide because of the given benefits. It is a means for buyers who are looking for assured supplies of produce for sale or for processing. Processors are among the most important users of contracts, as they wish to assure full utilization of their plant processing capacity. The key benefit of contract farming for farmers is higher returns through the assured markets and prices (lower risks).

Governments have to play an important role if contract farming is to be successful. A relevant legal framework and an efficient legal system are preconditions. Moreover, governments can do much to foster success by developing linkages between investors and farmers and can play an important role in protecting farmers by ensuring the financial and managerial reliability of potential sponsors.

One of the main challenges to successful contract farming is the absence of strong legal systems that guarantee an adequate protection to the parties in their contractual relations.

Contract farming – Main principles

The main principles to be considered during farming contracts are presented below.

Force majeure and hardship

After the conclusion of a contract, unforeseeable events beyond the control of farmer and buyer may arise. Such an exceptional situation is called force majeure and may constitute a production risk caused by climatic or human factors, among others. Because of this unforeseeable and exceptional
situation, both farmer and buyer shall be considered exempted from liability for non-performance of their contractual duties and shall not be held in breach of contract.

A similar circumstance to force majeure is hardship, which is another exceptional situation beyond the control of farmers and buyers, which may arise after the conclusion of the contract, when the duty of the performing party (for instance, the farmer) becomes extremely expensive or too difficult to fulfill, so that the latter is prevented from meeting his or her obligations. Such a situation may be due, for instance, to a substantial increase in the cost for the farmer of performing its obligation, because of a dramatic rise in the price of the raw materials necessary for the production of the goods, or also to a decrease or total loss of any value of the performance received by the farmer due to the drastic change in market conditions, such as the effect of a dramatic increase in inflation on a contractually agreed price. In such cases, the farmer or the buyer should be entitled to request the contracting partner to enter into renegotiation of the original terms of the contract, with the view to adapting them to the changed circumstances.

Performance

Farmers and buyers are bound to fulfill commitments according to the stipulated terms. The performance of a farming contract is the execution of its terms, by which farmers and buyers are automatically discharged of their contractual obligations. It is advisable that they provide in the contract terms regarding the quality specifications and standards of the goods that should be supplied.

Non-performance

The non-performance of a contract is the failure to meet the obligations under contract. It includes complete failure to perform, as well as defective and late performance in cases where time of performance is considered essential. Sometimes parties may include in the contract the so called exemption clauses, i.e. terms which directly limit or exclude the nonperforming party from liability in the event of non-performance. Exemption clauses are normally suggested by the strongest party (such as the buyer) who in this process may take advantage of the weaker bargaining power of the other party (e.g. the farmer).

Damages

Any non-performance of contract farming obligations gives the aggrieved party the right to compensation for damages, except where the non-performance may be excused (for instance in case of force majeure or hardship). The parties may provide in the contract a so-called penalty clause, i.e. a term that establishes to pay a specified penalty sum to the aggrieved party in case of non-performance.

Termination

Termination of a farming contract takes place when farmer and buyer are released from their contractual obligations. A farming contract may be terminated by performance of farmer and buyer’s obligations. Discharge of the contract in this way takes place when performance of the contract is complete and exact, with reference to the terms of the contract. A farming contract may also be terminated by agreement where farmer and buyer provide for the event. In addition, termination may occur in case of force majeure and hardship, where farmer and buyer may be excused from their obligations to perform as a result of exceptional and unforeseen events arising after the contract has been entered. Finally, termination may arise in case of breach of contract.
Breach of contract takes place when a party does not perform its obligations or where its performance is defective or late. The aggrieved party may terminate the contract only if the non-performance of the other party is material and not merely of minor importance and it must give notice of termination to the other party within a reasonable time.

Dispute settlement methods

Farmers and buyers should include in the contract a reference to the dispute settlement methods in case of contractual disputes (court, arbitration, mediation). It is advisable that, before resorting to court, parties agree on mediation, whereby they request a third party to assist them in their attempt to reach an amicable settlement of their dispute. It is also important that, in the dispute settlement clause, parties provide for the place to settle their dispute as well as the language to be used in the agreed proceedings. Finally, the law applicable to the contract envisaged by the parties may give some responses such as what to do in case of contingency, breach of contract or new elements that obstacle or modify the conditions on which a contract was conclude.

The following are key points which must be considered for any agreement to withstand scrutiny:

- Farmer must be capable of being seen to be actively in business, for example the business has a bank account, is VAT registered, has a proper recordkeeping system, prepares full annual accounts showing sales and purchases, completes forms and collects the Single Payment.
- Arable farming is a seasonal business, the cashflows attached to the contract farming arrangements must correlate with those of a working farmer – capital must be employed and be at risk to the farmer, cashflow cannot be positive before crops are harvested unless there is a legitimate commercial argument for this.
- Invoicing from contractor to farmer must be regular, at least quarterly, and invoices must be paid on the normal commercial terms operated by the contractors.
- Inputs should ideally be invoiced by the merchant direct to the farmer.
- The contractor carries out operations of husbandry as agent for the landowner. The farmer must make all key decisions about cropping and strategy, obviously the contractor can advise and be involved in this process. The farmer must be involved in the day to day management of the operation and must be able to evidence this by means of minutes of meetings, diaries etc.
- All regulatory documents must be completed by the farmer and retained by the farmer on his premises.
- The farmer cannot have a guaranteed return, he must take risk – the contractors bonus or penalty must be defensible. No risk equals rent.
- Any written agreement must be adhered to and the farmers and contractors accounts must reflect this.
- The harvested crop must be sold after due commercial consideration. The crop can be sold standing or “off the combine”, particularly if storage facilities are in short supply, but evidence should be available of the reasons behind any decision.
- Any arrangements with third parties such as agronomists, consultants etc. should be direct with the farmer.

Contract Farming in Italy-legal issues

The farming contract in Italy is governed by Legislative Decree No. 102 of 27/05/2005, about the regulation of the food farming market. The decree regulates the economic relationship between...
agricultural associations and producer associations, and it defines the minimum content of contract frameworks.

The content of the contract framework includes the following points:
1) Role of farmer and producer associations;
2) Identification of the contract parties;
3) Quality and quantity of the raw material;
4) Point of delivery of raw materials;
5) Duration of the contract;
6) Recognition to force majeure, for breach of contract;
7) Court for disputes.

At the moment there has not been any contract farming signed for the production of bioethanol. A contract was signed only regarding 40.000t of biodiesel with a reduction of excise tax in 2006.

**Contract Farming in Spain - legal issues**

In Spain, the contract farming is governed by Law 2/2000 (Published in B.O.E. number 8 of 10/1/2000, pages 881 to 885. Reference: B.O.E.-A-2000-413), about the contracts of agrifood products. As explained in the law, its application is directed to the system of economic relations of the agrifood system and its primary objective is to promote the market transparency and improve the competition through agrifood contracts approved. The law provides a model contract that can be adjusted to the operators of the agrifood system and regulates voluntarily the contract.

The agrifood contracts should include at least the following provisions to be approved:

a) Identification of the contracting parties.
b) Duration of the contract.
c) Object of the contract, clearly defining the product, quantity, quality, presentation and timing and place of delivery and any other aspect related to the trading position.
d) Pricing and payment terms, being the price to be received freely set by the parties to the contract.
e) How to resolve disputes in the interpretation or execution of the contract.
f) Faculty of the monitoring committee and reference to financial contributions that can collect it.

Further references to the Law are:

- RESOLUTION of November 6, 2001, about conversion into euro of the amounts indicated.

**Contract Farming in Greece - legal issues**

On September 21, 2011, Greek Law 4015/2011 on agricultural associations (including cooperatives) was published in the Official Journal of the Greek Republic. The new legal framework changes profoundly the conditions of action for agricultural associations and in this sense, has a significant importance for the implementation of the Single Common Organization of Market. Among the most important elements, that should be underlined is the obligation of cooperatives to work more as businesses in a market economy, as a prerequisite in order to participate to new interprofessional organizations. In the same law also the preconditions on the contract farming are agreed as following.
With written private contracts, on certain date, is adjusted the future sale of agricultural products. The Collective Agricultural Organizations of law 4015/2011 may sign contracts on behalf of their members. Relevant contracts must at least include the following data:

a) The type and the total amount of the agricultural products to be sold.
b) The minimum time frame of the contract, which cannot be less than one year.
c) The method of collection, storage and conservation of agricultural products, the quality or related certifications.
d) The price of the product.
e) The manner and time of payment.
f) The reasons and the way of complaint.
g) The Activity Code Number (K.A.D.) and the Special Registration Number (UAE) registered commodities trading.
h) The certificate of authenticity of signature

The Minister of Agriculture may determine the type and content of the minimum legal contracts for each commodity, which supersedes any contrary intention of the parties.

If contracts of farm products do not meet the minimum legal content, as determined in the preceding paragraph incur to the buyers a penalty of ten thousands euro (10,000€) for each year up to 80,000 euro in total with the decision of the Head of the Agriculture sub-sector of the Region after termination of each party producer.

The buyer who fails to pay the agreed money on the agreed day shall be punished with imprisonment of at least six months. For the purpose of prosecution is required indictment.

Expressly prohibited the resale or otherwise transfer in auction areas, stock markets or commodity in Greece or abroad. Violation of this provision is punishable by imprisonment of at least two (2) years and a fine of at least fifty thousand (50,000) euro. The criminal prosecutions against the responsible and concerned parties are carried out automatically.

Cost-Income for farmers

The adequate reward of farmers as biomass suppliers is the prerequisite for the development of the chain. Consequently, the quantification of the biomass price requires a very precautionary approach.

Sweet sorghum syrup production offers farmers an excellent opportunity to improve farm income and productivity.

In USA, ideally suited for the small landowner with limited capital, this crop requires only 0.4 to 1.2 ha. Sweet sorghum yields 1800 to 2800 litres of syrup per ha, and sorghum syrup sells for $4 to $5 per litre as a pastry additive. A recent budget estimated that total fixed and variable costs are approximately $2000 per ha. So, net profits of over $6000 per ha are possible.

Assuming that in Europe and more specifically in Italy, Spain and Greece, the agricultural costs correspond to 16-18 €/t wb (equivalent to 1,040-1,170 €/ha, including the transport to the plant with an average distance of 10 km), the affordability threshold is estimated at 30 €/t. In fact, in worse conditions other crops become more competitive than sweet sorghum and then the security of supply becomes critical.

The price of bioethanol depends on the energy market, especially on the oil price, and the considered range is believed precautionary.
ALTERNATIVES USES OF SORGHUM IN ASIA

Sweet sorghum has a long history of cultivation in Asia, Europe and America. Because of the rapid increase in crude oil prices that occurred during the 1970s, sweet sorghum has been investigated as a potential source of fermentable sugars for ethanol fuel production. This is because of the crop’s high sugar content and biomass production, wide geographic and climatic adaptation, and relatively low water and fertilizer requirements (Nathan 1978). It has been grown for making sweet syrup in the United States. It is also suitable for feeding to animals as forage, silage and hay.

Alternative uses of sorghum encompass utilization of grain and sweet stalk in food and non-food sectors for fourth production of commercially valued 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).

In India

In India, sorghum is traditionally consumed in the form of unleavened flat bread (roti). In southern India, it is consumed in the form of sankati, annam and ganji (thin porridge). Popped sorghum and sorghum noodles are eaten as breakfast or snack foods. The possible promising alternative food products from sorghum are bakery products, maltodextrins as fat replacers in cookies, liquid or powder glucose, high fructose syrup and sorbitol. Malted sorghum can be a good alternative for baby weaning foods.

The industrial products made from sorghum grain include alcohol (potable grade) and lager beer. Commercialization of alcohol production from grain is already in practice. Other technologies such as production of glucose, maltodextrins, high fructose syrup and cakes from sorghum are yet to be scaled up. The sweet sorghum with its juicy sweet stalk is used as a bio-energy crop. Sweet sorghum products like syrup and jaggery have received good attention from dry land farmers. Attempts for scaling up the technology for alcohol production from sweet sorghum were successful, but more work is needed to integrate the current production with potential market.

In China

Since ancient times sorghum grain has been used in China as food and as raw material for Chinese liquor, starch, vinegar and caramel. There are many traditional sorghum foods in China, with various processing methods. According to Zhao Shukun (1987), it was found that there were a round 40 traditional sorghum foods, which could be sorted in to three groups based on raw materials and processing methods: polished grain foods, flour foods and popped foods. Chinese sorghum beer was first made with sorghum as main raw material in the Institute of Sorghum, Shanxi Academy of Agricultural Sciences in early 1980s based on traditional technology for barley beer. Popped sorghum is a newly developed food in recent years. Crisp and popped sorghum made with special popping machine is popular. Sorghum pigment (red) is chemically a derivative of flavones – like compound, which is a natural pigment with no toxicity or flavour. Usually it is a red powder or lumpy solid, and can also be processed in to liquid or paste as needed. It can be dissolved in water. Sorghum pigment can be widely used for colouring processed meat at and fish, soy bean products, cake, drinks, candy, medical capsules, etc.

Because sorghum is not as popular as rice and wheat, and seed companies are reluctant to manage sorghum seed, it is not easy for farmers to get new sorghum varieties or relevant technologies that
are desired. Sometimes research results cannot meet requirements of winery. So it is necessary to establish a coalition of research institutes, producers and processing companies.

**In Pakistan**

Sorghum is mainly consumed as a food grain (87%) while only 5% of it goes into feed. Sorghum is the most important summer fodder crop with increasing importance in the irrigated areas near towns. Like many developing countries, the available data on production and utilization of sorghum in Pakistan are less accurate because these are primarily grown in outlying areas as subsistence crops. Also, in the hot and dry agro-eco regions, they are grown as dual-purpose crops, where both grain and stover are highly valued outputs. Currently sorghum and millet, each contribute about 3% of the cereal area and slightly less than 1% of cereal production. Before the development of commercial poultry feed industry, the grains of these crops were basically used to feed livestock and rural poultry.

**In Thailand**

Methods and feasibility on alternative uses of sorghum in Thailand are discussed. The use of sweet sorghum for ethanol production is proposed. Sorghum (Sorghum bicolor) is an important cereal crop grown in Thailand and ranks third following rice (Oryza sativa) and maize (Zea mays). It is cultivated for its grain and primarily used for animal feeding. There are four classes of sorghum commonly grown in Thailand: grain sorghum, fodder sorghum, sweet sorghum and broomcorn. Major emphasis is on grain sorghum production. In Thailand, sorghum grain is primarily utilized for the livestock feed industry. However, high tannin sorghum grains are not efficiently utilized by monogastric animals. Recently, the Thai government promoted the use of gasohol (gasoline +10% of 99.5% ethanol) and also tried to promote the use of diesohol (diesel+10% ethanol) in the future.

Of the raw materials, ie, rice, cassava (Manihot esculenta), sugarcane, molasses and sweet sorghum for producing ethanol in Thailand, only cassava and molasses were cost effective Use of cassava and molasses as raw materials for producing ethanol can generate more income than selling as cassava chips, cassava pellets and raw molasses. Production of ethanol from rice and sugarcane will decrease the value of the crops. Many experiments on sweet sorghum production have been done at Khon Kaen University, Thailand. It is already proved that sweet sorghum is one of the suitable crops for use as an energy resource.
LIBRARY AND SOURCES

i Gene Stevens, Division of Plant Sciences, University of Missouri, Morris Bitzer, Professor Emeritus, University of Kentucky, Klein Ileleji, College of Engineering, Purdue University, Farm Energy community “Sweet Sorghum for Biofuel Production”


iv [http://www.bardsbeer.com](http://www.bardsbeer.com)

v Paul L. Mask, Extension Agronomist, and William C. Morris, Associate Professor, University of Tennessee., ANR-625, New Nov 1991 “Sweet Sorghum Culture and Syrup Production”

vi Morris J. Bitzer, Grain Crops Extension Specialist, University Of Kentucky., “Production Of Sweet Sorghum For Syrup In Kentucky”

vii Wilfred Vermerris, John Erickson, David Wright, Yoana Newman, and Curtis Rainbolt., “ Production of Biofuel Crops in Florida: Sweet Sorghum”

viii Department of Millets Centre for Plant Breeding and Genetics Tamil Nadu Agricultural University

ix Dr. Heraldo Layaoen, National Team Leader for Sweet Sorghum Mariano Marcos State University, Batac, Ilocos Norte, Dr. Ernesto del Rosario, College of Arts and Sciences, University of the Philippines Los Baños, Los Baños, Laguna

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