Development of new sorghum ideotypes to meet the increasing demand of bioethanol

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Fossil fuels reserves are limited and we will reach the peak oil very soon, if not already passed (http://www.oildecline.com). As we consume oil faster than we discover new reserves, the price will inexorably increase in the next years. We also know that in the future we have to reduce GHG emissions, of which large part comes from the transport sector, to mitigate climate change. Thus it is urgent to find alternative and sustainable energies. Biofuels or agrofuels, defined as solid, liquid or gas fuels derived from biomass, are today the only direct substitutes for oil on a significant scale particularly in the transport sector. The development of biofuel production may result in the decrease of the surfaces available for food production and then lead to a great instability of the staple food market and finally to a dramatic increase of the food insecurity. To avoid or minimize such negative impact, we have to identify new crop and define future ideotypes able to meet the energy demand without compromising food security.

Which plant for producing energy?

Considering bioethanol production, the two main sources currently used are maize under temperate area and sugar cane in tropical area. If production from sugar cane in Brazil has a positive energy balance, allows a great GHG saving with a competitive price, production from corn in the USA results in less positive if not sometimes negative balances. Sorghum (*Sorghum bicolor* L. (Moench)) is one of the most efficient crops to convert atmospheric CO2 into sugar with great advantages compared to sugarcane in the tropics and maize in the temperate zone: (i) its growth cycle is short (about four months), (ii) the crop can be established from seed, (iii) its production can be completely mechanized, (iv) it produces sugar in stalk, and starch in grain, (v) it has a high water and nutrient use efficiency, (vi) the bagasse produced from sweet sorghum has high biological value when used as forage and (vii) it has a wide adaptability to environment. Finally, unlike sugarcane and maize, sweet sorghum has little breeding history and the potential of production improvement through genetic enhancement is thus very high. It represents an alternative energy crop.

The FP7 project “SWEETFUEL / Sweet sorghum: an alternative energy crop” was elaborated to develop ethanol production from sweet sorghum in temperate and tropical area through genetic enhancement and improvement of harvest and cultural practices.

Definition of new sorghum ideotypes

The target plant type depends on the environment and also on the type of processing.

- In temperate climate, the sorghum ideotype can be defined as a "biomass" sorghum, sweet or not, with or without grain. Its essential traits are a (i) high biomass production with a good quality and homogeneity (low lignin content + good digestibility) suitable for 2nd generation processing, (ii) a good tolerance to cool temperature at the beginning and end of the season, (iii) high water use efficiency to minimize irrigation requirements, and (iv) a phenology suited to make maximal use of the summer season. The system is highly mechanized and centralized.

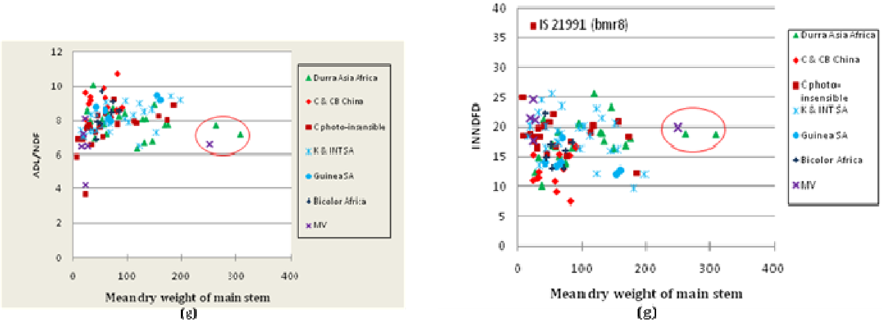
First data showed it was possible to combine interesting traits like high biomass production + low lignin content + good digestibility of fibers (figures 1).

- Under tropical area, situation is a little more complicated as we may find centralized and decentralized systems with different objectives.

In Brazil, the first objective is to complement sugarcane production for maintaining plants/distilleries at full charge all over the year (the issue is to convert 20% of sugarcane area into sweet sorghum = 1.5 millions ha). In that case, the target ideotype includes maximal stem soluble sugars with high biomass production. Stem juicyness, sugar-°Brix% with tolerance to Al toxicity and P deficiency are the main traits, secondary characters are a good production of grains, high feed quality of biomass (low lignin). When considering decentralized systems in Brazil, where the objective is to develop production systems for providing a village or a cooperative with food and fuel, grain production is an essential trait. Some results confirm that it is possible to combine a high sugar concentration in juice with a high quantity of juice as well as a high stalks production, while a gene for tolerance to Al toxicity (Alt_{SB}) is being incorporated to best lines.

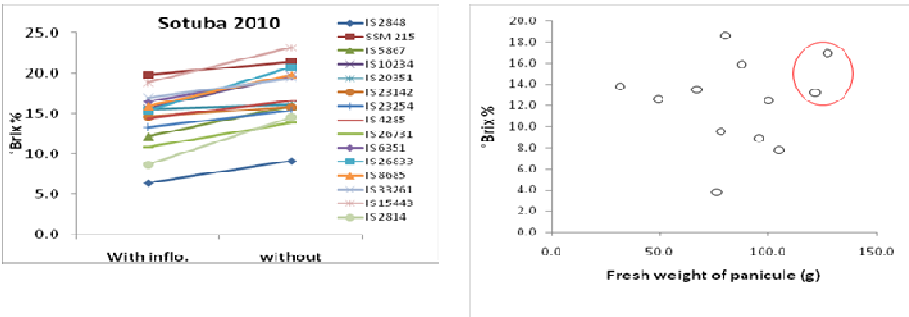
In India, where both centralized and decentralized systems exist, the target ideotype is a triple f plant, producing food (grain), feed (bagass) and fuel (ethanol from sugar in stalks). The main traits are stem juiciness, grain yield, sugar-°Brix%, adaptation to rainy and post rainy seasons, stay green, low lignin content, and biomass. First data on competition between grain production and sugar accumulation in stalks showed there is a competition between the 2 sinks, but if we explore the diversity in sorghum, we can find some genotypes combining good production of grain with high accumulation of sugars in stalks (figures 2). Two sources of stay green with a high °Brix% were identified and will be used in breeding programs.

a. b.



Figures 1: lignin content (a) and digestibility of fibers (b) according to the biomass of stalk for 206 accessions (source: 2009 Grassbiofuel report)

a. b.



Figures 2 : °Brix% value in 15 lines with or without inflorescence (a) and according to fresh weight panicles among 12 accessions (b)

In the case of Haïti, where we can find some very contrasted situations in terms of rainfall distribution and where we target a triple purpose crop (grain, ethanol, fodder), an adapted phenology is essential as the favorable season around Port au Prince (from April to August) is quite different from those near Cap Haïtien (from October to February).
From the first observations conducted in different environments, the new target ideotypes of sorghum are achievable giving this plant a good opportunity to be a promising alternative energy crop in many environments.

Development of a new sorghum model

For the conception of new ideotypes, for the identification of their Target Populations of Environment (TPE) as well as the study of their adaptation to climat change or climat variation, we needed a new model able to simulate particularly accumulation of reserves (sugars) in stalks.

Based on ECOTROP software and on water balance and phenology modules from SARRAH, the new model, SAMARA was developed (figure 3). As calibration for sorghum is possible in many different environments, the model seems quite robust. The first sensitivity analysis was performed by modifying varietal parameters (plant height, cycle duration…) or agronomic practices (irrigation, plant density…) or a combination of 2 parameters (height + density…) before analyzing evolution of output values (panicle and grain yield, total biomass, sugar yield, LAI…). On a qualitative basis, results of the sensitivity analysis matches field observations. We need now to conduct specific field experimentations to validate SAMARA for sorghum.

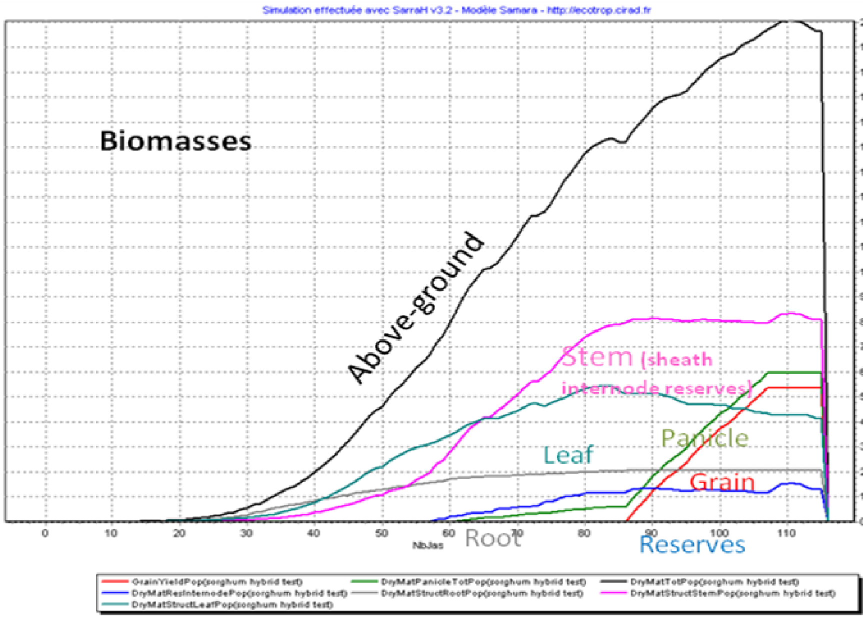


Figure 3: Example of the biomass outputs of SAMARA model for sorghum

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