ICRISAT's experiences on development and application of tools relevant to the sustainable production and use of biofuels

I. Introduction:

To find ways to em**power** the dryland poor to benefit from, rather than be marginalized by the **bio**energy revolution, ICRISAT has launched a global **BioPower** Initiative. The **BioPower** research strategy focuses on feedstock sources and approaches that do not compete with food production but rather produce food as well as fuel, and may even enhance food production by stimulating increased input use and crop management, in a manner that contributes less to greenhouse gas (GHG) production (particularly NO_2) than do other high potential biofuel crops, especially sorghum's inherent capacity for biological nitrification inhibition. Research on the genetic enhancement and the utilization of sweet sorghum as feedstalk in bioethanol production in semi-arid areas with rainfall 750mm and above; and jatropha and pongamia as feedstock for biodiesel production for degraded and marginal lands are the main research areas.

II. Sweet Sorghum

Introduction: ICRISAT considers sweet sorghum as a **SMART** crop as it produces food, feed, fodder and fuel, without significant tradeoffs in any of these uses in the production cycle. A crop of sweet sorghum takes about 4.5 months, and can be followed by a ratoon crop (natural second re-growth from stubbles after the first crop is harvested). Together the main and ratoon crops extract about 8,000 cubic meters (m^3) of water per ha (received through rainfall or irrigation) (Soltani and Almodares 1994). Sweet sorghum requires less fertilizer, labor, and other inputs (Rao et al. 2004; Almodare et al. 1997); cost of production USD 217.5 for sweet sorghum while USD 1079 for sugarcane. Sorghum is planted from seed, which is less laborious than the stem cuttings used to plant sugarcane. Some of the field operations for sorghum can also be readily mechanized. Thus sweet sorghum is more accessible to poor farmers with limited access to capital in areas that receive ≥700 mm annual rainfall. Secondly, sweet sorghum has high net energy balance. Even though the ethanol yield per unit weight of feedstock is lower for sweet sorghum compared to sugarcane, the much lower production costs and water requirement for this crop more than compensates and hence, sweet sorghum still ends up with a competitive cost advantage in the production of ethanol in India (Rao *et al.* 2004). Research at ICRISAT in collaboration with International Livestock Research Institute (ILRI) indicates that sweet sorghum bagasse and the stripped leaves based feed block (BSLFB) was nutritionally equivalent to normal, sorghum stover based commercial feed block. There was no statistical difference in dry matter intake (DMI) and live weight gain (LWG) between animals fed with the bagasse plus stripped leaf based blocks and those fed on original sorghum stover based commercial feed block (Blummel *et al.* 2009). Research also indicates that sweet sorghum stover promotes higher feed intake than normal sorghum when fed to cattle and sheep directly and also its digestibility is higher than normal sorghum stover.

The triple-product potential of sweet sorghum (i) grain for food/feed, (ii) juice for ethanol, and (iii) stripped leaves and bagasse after extraction of ethanol for livestock feed is an added advantage ensuring food and feed security to the farmers, and providing opportunities for additional income both for the farmers. Thus, the concern about the competition between first generation biofuels vs. food and feed crops for land can be addressed by growing sweet sorghum that has multiple uses.

Economic analysis: Preliminary studies of ICRISAT-Rusni Distillery experience involving large-scale sweet sorghum cultivation in 538 ha in 2007 rainy season by 791 farmers sowing NTJ 2 variety indicated that it is commercially feasible to cultivate and use sweet sorghum for ethanol production. The break-even analysis indicated that farmers should harvest 21.8 t ha^{-1} green stalk yields priced at Rs 600 t^{-1} (US$ 14.30). Twenty-six farmers (13%) achieved stalk yields higher than the breakeven yields (Rao 2008). The average yield of sweet sorghum was 19.57 tons per hectare. At this yield, the break-even price worked out to Rs 668 (US$ 16) per ton. By and large, the crop performance was satisfactory where the farmers adopted the recommended crop management practices. The preliminary observations from large scale cultivation of sweet sorghum hybrid CSH22 SS in farmers field in 2008 under ICRISAT-NAIP sweet sorghum ethanol value chain development project in India points to the fact that the farmers are realizing 24 t ha^{-1} of stalks and 1.5 t ha^{-1} of grain by following traditional sowing and recommended management practices in rainfed alfisols. Grain sorghum and maize were the main crops previously grown. However, the rainy season on station stalk yield was about 50 t ha^{-1}, while the postrainy season yield was 35 t ha^{-1} indicating greater scope for increased yields under farmer's conditions, provided they manage crops well and the rainfall is good. The data analysis revealed that the yields were higher on black soils and when intercropped with pigeonpea. Farmers were willing to replace maize, grain sorghum and pigeonpea for sweet sorghum if its profitability is increased by higher yields and higher procurement price. Four important issues raised by the farmers were the need for: i) cultivars with high yield potential, ii) proper guidance on crop management and its harvesting, iii) timely procurement, and iv) higher feedstock prices by the industry. sweet sorghum could be a feasible option in the post-rainy season as farmers can realize higher grain yield and better price for the grain, but the industry needs to plant the crop in more area as the green stalk productivity is less in postrainy season compared to that of rainy season.

Food-fuel tradeoff: The food –fuel trade off is one of the widely discussed topics during the second half of 2008 owing to the sharp escalation in food prices for the obvious reasons not required to be discussed in this context. To be truly pro-poor, sweet sorghum should not compromise the grain yield. Trial data over three years (2005, 2006 and 2007) and six seasons (rainy and postrainy) indicated that sweet sorghum hybrids have higher stem sugar yield (by 54%) and lower grain yield (by 9 %) than grain-type hybrids, and sweet sorghum varieties had 11% higher sugar yield and 5% higher grain yield than that of non-sweet stalk (grain type) varieties in the rainy season. On the other hand, both sweet sorghum hybrids and varieties had higher stalk sugar yields (89% and 50%) and lower grain yields (2 and 25%) in the postrainy season respectively. Thus, there is no significant tradeoff between grain and stalk sugar yields in the sweet sorghum hybrids in the rainy season while the tradeoff is limited in these hybrids in the postrainy season.

Preliminary evaluations in ESA (Kenya) have indicated that sweet sorghum hybrids have higher stem sugar yields by 29% than the sweet sorghum varieties. Also, the sweet sorghum hybrids had a grain yield advantage of 20% over the sweet sorghum varieties. It is also worth noting that most of the sweet sorghum varieties were identified amongst the grain sorghum varieties indicating that the sweet stalks is an added advantage and will not compromise the yields. It is also evident that hybrids have potentials for increased grain and sugar contents over varieties. Results from Mozambique indicated varieties such as IESV92021 had high grain yields as well as acceptable sugar contents in the juice. This indicates that there is potential to optimize both grain and sweet stalk traits. As the oil from jatropha and pongamia is non-edible, food-fuel tradeoff will not be an issue.

Crop improvement at ICRISAT- Asia, NARS & Eastern and Southern Africa (ESA): ICRISAT is conducting research on sweet sorghum for use in first generation ethanol technology in all three regions- Asia, Eastern and Southern Africa (ESA) and Western and Central Africa (WCA) by (i) integrating and upscaling the research findings in sweet sorghum ethanol value chain including energy and economic issues following Integrated Genetic and Natural Resource Management (IGNRM) approach (ii) assessing major challenges in sweet sorghum value chain, and identifying key research issues and opportunities and (iii) commercialization of ethanol production technology through Agri-Business Incubator (ABI) with the aim to help the poor farmers in SAT areas.

In Asia, currently available sweet sorghum varieties are more photoperiod-sensitive than available hybrids, and hybrids are earlier maturing and have significant heterosis (30 to 40%) for cane, juice and sugar yields. Hybrids have lower soluble solids concentration (^{0}Bx) than their better parents (by 5 to 8%). National program in India has released sweet sorghum varieties like SSV84, RSSV 9 and hybrids like NSSH 104 (the female parent, ICSA38 is bred at ICRISAT). In ESA, preliminary results for the 2007 and 2008 indicate that most of the sweet sorghum lines that are locally developed had higher brix percentage (15–17%) compared to the Indian check NTJ 2 with 11.6%. Some 20 hybrids also exhibited Brix values between 15% and 21% and the average stalk yield for hybrids were 16 t ha^{-1} (range 9.5 to 25.5 t ha^{-1}). Stalk yields (10.52 t ha^{-1}) of ESA-developed lines were lower than that of materials received from ICRISAT ESA (12.9 t ha^{-1}). A breeding program specifically aimed to increase the sweet stalk yield potential while optimizing both grain and Brix should result in high yielding sweet sorghums that give higher returns to the farmer. G×E interactions are significant for sweet sorghum productivity-related traits; the genotypes that perform well in the rainy season are not necessarily the top-performers in the postrainy season and *vice versa.* In ESA, the evaluation of sweet stalk sorghum varieties across three locations in Mozambique and four environments in Kenya indicate a significant G×E for sugar content, stalk yield, grain weight and biomass yield.

III. Jatropha and pongamia

Background :

Current increase in demand of knowledge for alternative sources to fossil fuel has triggered lot of interest in use of non-edible oils as green knowledge source in developed and developing countries. ICRISAT is adopting pro-poor bio-fuel strategy to benefit vulnerable sections of the society through development of degraded common property resources and individual lands which are not suitable for food production by adopting consortium approach. Research and development options for harnessing the potential of *Jatropha* and *Pongamia* are undertaken to increase productivity of *Jatropha* and *Pongamia* plantations without sacrificing food security.

Research for Development :

Government of India has initiated a targeted strategic research through the institutions network in the country under the leadership of National Oilseeds and Vegetable Oils Development Board (NOVOD). In Andhra Pradesh, state government has initiated a research program in 2005 on *Jatropha curcas* by adopting the consortium approach of different institutions such as International Crops Research Institute for the semi Arid Tropics (ICRISAT), Central Research Institute for Dryland Agriculture (CRIDA), Acharya N G Ranga Agricultural University (ANGRAU), National Bureau of Plant Genetic Resources (NBPGR), and Indian Institute of Chemical Technology (IICT). In addition, there are public-private partnership (PPP) project supported by Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) and research projects supported by International Fund for Agricultural Development (IFAD), Rome and other corporates.

Diversity in *Jatropha and Pongamia*

The NBPGR along with the consortium partners of the Government of Andhra Pradesh (GoAP) project have collected 124 accessions of *Jatropha* and 10 accessions of *Pongamia.* To harness the potential through crop improvement, effort is made to understand the existing variability for different characters amongst the seed samples of *Jatropha* and *Pongamia.* Large variability amongst the samples for seed oil content ranging from 27.4 to 40.6 per cent amongst different accessions with a mean oil content of 34.3 per cent and hundred seeds weight (44 to 72.6) were recorded in *Jatropha.* Most importantly large variation for female to male flower ratios (3.5 to 16.5) was also observed amongst different samples with a mean of 1:10 during the first flowering season after planting. Many plants yielded fruits and variation for the yield determining characters such as number of female flowers (2 to 45), pod bunches per plant (1 to 7), number of pods per plant (3 to 90), and seed yield (28 to 270 g) was observed.

Similar evaluation of *Pongamia pinnata* accessions reveled large variation in seed oil yield with 21 to 41 %. Variation for plant growth parameters expressed that height varied from 135 to 380 cm with a mean of 243 cm, number of branches varied from 3 to 25 with a mean of 13, stem girth varied from 10 to 40 cm with a mean of 54 cm. During the fourth year although sparse flowering was recorded with no significant fruit yield.

Application of molecular technique for characterization of diversity among Forty-eight accessions of *Jatropha curcas* collected from six different states of India, using Amplified fragment length polymorphism (AFLP) primer combinations generated a total of 770 fragments with an average of 110 fragments per primer combination. A total of 680 (88%) fragments showed polymorphism in the germplasm analyzed, of which 59 (8.7%) fragments were unique (accession specific) and 108 (15.9%) fragments were rare (present in less than 10% accessions). In general, accessions coming from Andhra Pradesh were found diverse as these were scattered in different groups, showed occurrence of higher number of unique/rare fragments and had greater variation in percentage oil content.

Further, these samples were grown in fields at ICRISAT to assess the variability for other agronomic characters as well as to confirm the genetic variability for oil content and seed weight when grown under uniform environment. Wide range of variability for different plant characteristics amongst 124 lines of *Jatropha* was recorded.

Agronomy and management practices :

Application of nitrogen and phosphorus at different levels indicated that during 4th year harvest index (pod to seed ratio) varied from 53-56% with different fertilizer treatment. The plant yield of *Jatropha* within a accession with 3x2 spacing varied upto 1.4 to 1.6 kg ha per plant (2.3 to 2.7 t ha^{-1} under rainfed conditions). Water use efficiency of 3 years old *Jatropha* plantations indicated that evapo-transpiration demand under no moisture stress for *Jatropha* varied from 1150–1350 mm per year. Under the semi-arid tropical conditions *Jatropha* is able to use water relatively 40-57% of non-stress situation. It is found that, during July to October, soil moisture status is sufficient to satisfy much of the ET requirements; this period coincides with flowering and fruit set stage. The pruning of *Jatropha* plants significantly ($p < 0.05$) increased 15 % of plant height, 50 % of branches, 26 % of stem girth, and 10 % of crown area compared to non-pruned treatment plants.

The feasibility of growing different agricultural crops as intercrops with *Jatropha* and *Pongamia* has reveled that crops like sorghum, pearl millet, pigeonpea, soybean, mungbean, chickpea, sunflower, and safflower can be successfully cultivated during rainy season and post-rainy season. Productivity of these crops in terms of grain yield varied from 0.29 t ha^{-1} in case of green gram to 1.5 t ha^{-1} in case of sorghum. Total economic value from additional income through grains and fodder from these crops varied from Rs 5355/- to Rs 20430/- per ha in case of *Jatropha.* Intercrops with *Pongamia* plantations peralmillet and pigeonpea have been successfully grown achieving productivity of 0.5 t ha^{-1} in case of pigeonpea and 1.1 t ha^{-1} in case of peralmillet grains. Total economic value from the additional income of intercrops in case of *Pongamia* intercrops systems is around Rs. 10700/- per ha. Nutrient budgeting approach is used successfully to work out nutrients requirement needed to achieve targeted yields in crop like *Jatropha*.

Nutrient recycling and budgeting

Fallen leaves quantity and nutrient content of *Jatropha* varied with plant age and fertility treatment and contained 9500 mg N kg^{-1} which is lowest amongst different plant parts such as shoots and seeds as well as deoiled seed cake. One-year plantation with 3x2 m spacing with 1666 plants per ha returned 15.7 kg N, 0.8 kg P, and 15.2 kg K per ha. Three-years old plantation recycled 20.8 kg N, 2 kg P, and 23 kg K per ha through fallen leaves. One year plantation returned 16 kg N ha^{-1} and three-years plantation returned 21 kg N ha^{-1} through fallen leaves. The fallen leaves also added 1000 kg ha^{-1} organic C to soil in addition to carbon fixed in seeds which will replace fossil fuel C.

Our Nutrient budget results showed that one ton seeds of *Jatropha* remove 22 kg N, 5 kg P and 8 kg K per ha. Average productivity of 3 t seeds ha^{-1} will remove 66 kg N, 15 kg P and 24 kg K per year per ha. For achieving target yield of 3 t ha^{-1} seeds, one will need to meet the demand of additional 60 kg plant available N per ha and applying the basis of even 50% recovery from the chemical fertilizers one will need to apply about 120 kg N per ha. Similar will be the case for phosphorus which will need application of 14 kg P i.e. 38 kg P_2O_5 per ha. These studies clearly indicate that for sustainable *Jatropha* production at any level will definitely need application of plant nutrients in sufficient quantities. The agronomic trials have revealed that for achieving targeted yields using nutrient budgetary approach 3 t ha^{-1} seeds 120 kg N and 38 kg P_2O_5 per ha are required.

Pongamia seed cake (a by-product after extracting oil) was found to be rich in all plant nutrients in general and nitrogen (4.28%) and sulphur (0.19%) in particular. Both nitrogen and sulphur were found to be deficient in 100% and 80% soil samples from farmers' fields in Powerguda village of Adilabad district, respectively. Use of Pongmia seed cake as a source of plant nutrients for maize, soybean and cotton was found beneficial in participatory research and development (PR&D) trials on farmers' fields. Further, application of critically deficient micronutrients such as zinc and boron and secondary nutrient sulphur increased crop yields by 16.7% and 19% in soybean and cotton, respectively. Additional B:C ratios of 5.03, 1.81 and 2.04 were obtained for soybean, maize and cotton, respectively with use of cake as a source of N, however it needed higher initial investment.

Soil micro-flora studies indicated numbers of fungi in the rhizosphere soil samples were more by two folds than the non-rhizosphere soil samples. Similar results were observed for higher number of bacteria, fungi and actinomycetes in rhizosphere soil samples of *Pongamia* than the non-rhizosphere soil samples. High microbial population in rhizosphere soil indicates increase soil biological activity, which was also observed with increased microbial biomass C and N. Number of bacteria and actinomycetes in the rhizosphere soils of *Jatropha* were more by 40 and 50% respectively than from the non rhizosphere soil samples. Although *Jatropha* and *Pongamia* plants are non edible for human beings as well as animals, microbes were not adversely affected but were stimulated due to rhizosphere effect of *Jatropha* and *Pongamia.*

Model to rehabilitate degraded lands

In order to improve livelihoods of rural poor with opportunities for additional income from *Jatropha* and *Pongamia* plantations through collective action, ICRISAT in partnership with Civil Society Organization (CSOs) and Community Based Organization (CBOs) have developed a model to rehabilitate degraded common lands in a village. This project on integrated development of bio-fuel promotion in Andhra Pradesh was initiated in July 2005 as ICRISAT-NOVOD (National Oilseeds and Vegetable Oils Development Board) model demonstration project to rehabilitate the wastelands. The project was implemented as a model plantation on 300 ha common property resources (revenue land) of two villages namely Velchal village in Mominpet mandal and Kothlapur village in Marpally mandal of Ranga Reddy District and 200 ha of *Pongamia* and *Jatropha* plantations in private degraded lands in Rollapadu, Cherakucherla and Sunkesula villages in Midthur Mandal of Kurnool District. Eight self-help groups were formed with a total of 80 laborers in Velchal village and bank accounts were opened in Deccan Grameena Bank, Velchal branch for group savings. Seven self-help groups with a total of 78 laborers were formed in Kothlapur village and bank accounts were opened in Andhra Bank, Marpally branch to save the amount and carry out the plantation activities.

The grain yield from third year onwards was 100 kg per ha and expected to reach to 1000 kg per ha by sixth year. Growing intercrops on areas where good soil existed additional income provided for the farmers from intercrops. The *Jatropha* and *Pongamia* plantations on waste lands have not only created employment in the rural areas but also provided additional sources of income through usufruct rights by selling *Jatropha* seeds. Other impacts in terms of social capital development, building of institutions in the villages, improving soil health through recycling of organic matter and enhanced soil water conservation measures, reduced soil erosion and land degradation were also recorded. The unique institutional mechanisms adopted in this model for development of CPRs through collective action, landless people were organized into self help groups and took up labour work in development of degraded common property resources such as soil and water conservation measures supported by the project. District administration of Government of Andhra Pradesh gave them usu-fruct rights over the plantation for harvesting the produce. Farmers are growing good quality grass supporting their livestock and feed requirements from grass grown in between the rows of plantation. Now with the support of GTZ and Kirlosker Engineering Pvt Ltd., we are operationalizing a value-chain model for extracting oil through decentralized electricity generation in the village. This model plantation of 300 ha in two villages has set a live example as how degraded lands can successfully be used for producing *Jatropha* and *Pongamia* without sacrificing good quality land and food security, which is very critical.

Similarly public private partnerships in the area of biodiesel through GTZ-support with Southern On-line Biotechnology (a private enterprenuer) with German technology from Lurgi is proving technical backstopping to the farmers for undertaking plantation with *Jatropha* and Pongamia.

IV. Sustainability issues

The impact of expanded biofuel production on land and water resources and on bio-diversity is the focus of increasing attention, as is the question of how to ensure its environmental sustainability. In-depth studies are necessary to ensure that production and use of biofuels is sustainable in accordance with the three pillars of sustainable development (economic, social, and environmental) and take into account the need to achieve and maintain global food, feed and fuel security. As of now, not much information related to sweet sorghum is available on the said sustainability criteria. ICRISAT is taking initiatives to augment the currently on-going research and development efforts directed towards social and economic welfare of the poor farmers in SAT areas to prioritize research issues related to

(i) resource utilization efficiency, particularly water and fertilizers of biofuel feedstocks (Sweet sorghum, Jatropa and Pongamia)
(ii) life cycle assessment in terms of GHG emissions, energy and economics for the three biofuel crops
(iii) carbon trading opportunities for maximizing the economic yields as a potential avenue to plough back the benefits to the society with a bearing on social and ecological sustenance.

V. References

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