Agricultural Research and Energy Security: The Crop Link to Bio-Energy*

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Soaring prices of fossil fuels and environmental pollution associated with their use, has led to worldwide interest in the production and use of bio-fuels. Both developed and developing countries have made a mix of policies, which have triggered public and private investments in bio-fuel crop research and development and bio-fuels production. In this article, we discuss the potential benefits of bio-fuels in reducing environment pollution and contributing to the energy security and the crop options and crop research and development interventions required to generate feedstocks to produce bio-fuels to meet projected demand without compromising food/fodder security in developing countries with special reference to China and India.

Keywords: Agriculture research, energy security, bio-diesel, bio-fuel, ethanol

The United Nations (UN) eight-millennium development goals (MDGs) provide a blueprint for improving livelihoods, and preserving natural resources and the environment with 2015 as target date. The UN member states and the world's leading development institutions agreed upon the MDGs. None of them however, have a specific reference to energy security though energy is the fuel of economic prosperity and hence assist in mitigating poverty. Nonetheless, diversifying crop uses, identifying and introducing bio-fuel crops would lead to farmers' enhanced incomes, thereby contributing to *eradicating extreme poverty* (MDG 1) in rural areas helping 75% of the world's 2.5 billion poor (who live on <US$ 2 per day), and contributing to their energy needs. The energy is required for consumptive uses (cooking, lighting, heating, and entertainment), social needs (education and health care services), public transport (road, rail and air), industries, and agriculture

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and allied sectors. ‘Energizing’ the agriculture production chain has been an essential feature to achieve food security, considering strong correlation between per capita energy consumption and crop yields in both developed and developing countries. For example, in the Philippines, the productivity of rice (5.8 t ha^{-1}) grown using mechanized farming is far greater than that grown using traditional farming (1.2 t ha^{-1}) (www.fao.org). However, agriculture practices in many developing countries including China and India continue to be based to a large extent on animal and human energy. Providing easy access to energy services (such as conventional fossil fuels and renewable sources like solar, wind and bio-fuels) to the agriculture sector is essential to improve farm productivity and hence income of the peasants. However, fossil fuels do not provide equitable economic and environment-friendly benefits. The bio-fuels, produced from agriculture biomass among other renewable sources provide sustainable and eco-friendly energy options that foster *environmental sustainability* (MDG 7) and offer enormous opportunities to improve the income level of developing world’s smallholder subsistence farmers who depend on agriculture for their livelihoods (www.americanprogress.org). The bio-fuel research-for-development will lead to new local, regional and national public-private *partnerships for development* (MDG 8).

The governmental policy support and the availability of efficient biomass (feedstock) energy conversion technologies are the key factors that foster market forces for, and cost-competitiveness of bio-fuels vis-à-vis fossil-fuels. However, the generation of required volume and quality of feedstocks to produce bio-fuel to meet projected demand without compromising food and fodder security, requires massive investments in, and reorientation of agriculture research. In this article, we discuss the opportunities and the role of bio-fuel-based agriculture research and development as a solution for mitigating trade-offs between food/fodder and energy security and the potential benefits of bio-fuels in contributing to alleviating rural poverty and environment sustainability in developing countries with a special reference to China and India.

Current situation on bio-fuels

Bio-fuels are currently based on the production of ethanol from sugars or starch derived from vegetative biomass and grain, or bio-diesel from the more direct use of edible and non-edible plant oils and animal fats[1]. Brazil is the shining example for using ethanol (produced from sugarcane juice) either in pure form or as a blend with petrol (gasohol) for fuelling the automobiles. Billions of gallons of bio-ethanol are being produced in Brazil using sugarcane. Ethanol (39 billion liters) accounted for about 90% of total bio-fuel production in 2005 in the world (www.commodityIndia.com). Taking a cue from Brazil, several developed and developing countries including China and India are making concerted efforts to reduce their dependence on oil exporting countries, and pollution levels through policies to produce bio-ethanol and bio-diesel for blending with petrol and fossil diesel, respectively. China is now home to the world's largest ethanol plant, with a capacity of eight times that of the average US distillery. In India, molasses from Sugarcane is being used as feedstock to produce ethanol. However, large fluctuations in the production and hence the price of molasses not only result in inadequate supply to produce sufficient ethanol to meet the current and future requirements in India (true in other developing countries) but also makes molasses cost ineffective for use in ethanol production. In China, Cassava, Maize and other cereal grains are being used to produce ethanol. Bio-diesel can be also produced from edible oilseeds from crops such as Soybean, Rapeseed or Sunflower, especially in the developed world. However, developing countries like China and India cannot afford to spare oilseeds for bio-diesel production, considering large gap between demand and supply of edible oil seeds. Fortunately, bio-diesel can also be produced from non-edible oilseeds from shrubs such as Jatropha (*Jatropha curcus),* Pongamia *(Pongamia pinnata)* and Neem (*Azadirachta indica)*. In China and India, these crops are being used to produce bio-diesel only on a pilot scale.

Crop-improvement research to address bio-fuel needs

China and India have plans to double their bio-fuel production within the next 15 years (www.worldwatch.org/node/3893) to achieve energy security. Meeting this target without compromising food and fodder security requires reorientation of agricultural research. This encompasses careful selection among the existing bio-ethanol and bio-diesel feedstock crop species, introducing new crop species, and their genetic and production management to improve their energy value. The most promising crop options and the researchable issues need to be addressed for more efficient bio-ethanol and bio-diesel production are discussed below.

Ethanol

Sweet sorghum. Sweet sorghums, which are similar to grain Sorghums but feature more rapid growth, higher biomass production, and wider adaptation, have great potential for ethanol production[2]. Sweet sorghum, similar to grain Sorghum, can be readily cultivated in China and India as farmers are familiar with grain Sorghum crop cultivation. The dual-purpose nature of Sweet sorghums—they produce both grain and sugar-rich stalks—offers new market opportunities for smallholder farmers and does not threaten food trade for sorghum. Sorghum is being cultivated from time immemorial in India, China and several African countries. Incidentally, most of the landraces that are being grown in India in postrainy season are sweet sorghums that are suitable for ethanol production. In China, specific programs are underway to breed Sweet sorghums for silage production. The emerging bio-fuel needs, therefore offer expanded markets for Sweet sorghum in India, China and several African countries. Because Sweet sorghum requires less water and has a higher fermentable sugar content than sugarcane (which contains more crystallizable sugars), it is better suited for ethanol production than sugarcane or other sources[2]. Also, Sweet sorghum-based ethanol is Sulphur-free and cleaner than sugarcane ethanol, when mixed with gasoline. Pilot studies in India indicated that ethanol production from Sweet sorghum is cost-effective.

The Indian and Chinese national sorghum improvement programs and International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) located at Patancheru in Andhra Pradesh, India, have developed several improved Sweet sorghum cultivars with high stalk sugar content and a few of these are being tested in pilot studies for bio-ethanol production in India and the Philippines. Research experience at ICRISAT and elsewhere, shows that hybrids are known to produce relatively higher biomass, besides being early and photoperiod-insensitive than other cultivar types under normal as well as abiotic stresses including water-limited environments. The requirement of photoperiod- and thermo-insensitivity is essential to facilitate plantings at different dates for timely scheduling the supply of Sweet sorghum stalks to distilleries for ethanol production[2]**.** The development of Sweet sorghum hybrids should therefore receive high priority to produce more feedstock per drop of water and unit of energy invested. Some of the Sweet sorghum hybrids developed at ICRISAT has good potential for ethanol production (Table 1). It is possible to further improve the stalk total sugar yield (and hence, ethanol yield) as there is significant variability for the stalk total sugar content and ICRISAT is poised to increase stalk sugar yield in hybrid parents.

Table 1: Performance of selected Sweet sorghum hybrids, 2006 rainy season, ICRISAT, Patancheru, India

Hybrid	Days to 50% flowering	Brix	Juice Yield (kl ha^{-1})	Sugar yield (t ha^{-1})	Grain yield (t ha^{-1})	Per day ethanol productivity (l ha^{-1})$
ICSA 749 × SSV 74	85	18.00	27.2	9.2	3.3	18.5
ICSA 502 × SPV 422	88	20.32	19.9	8.1	6.2	14.1
ICSA 511 × SSV 74	88	17.97	22.7	7.8	5.8	15.4
ICSA 474 × SSV 74	82	16.33	25.4	7.6	7.2	17.1
SSV 84 (control)	94	15.65	16.8	5.0	2. 7	10.5
NSSH 104 (control)	91	15.65	16.8	5.0	4.1	10.7

$Ethanol productivity estimated at 40 liters per ton of millable cane yield

Cassava. Cassava, traditionally a staple food crop for millions of people in Africa and Latin America, is widely cultivated in Asia, mainly for industrial uses. It produces an impressive quantity of tuberous root biomass even in low fertility soils. The root tubers contain a very high starch content (about 70–85% by dry weight basis), which can be used as raw material for ethanol production. The harvested roots can be readily transformed into dried chips in order to lengthen the storage time of tubers as well as to reduce the biomass volume to facilitate easy transportation. To produce ethanol, the starch is first converted into glucose by enzymes and glucose is then fermented to alcohol by yeast (www.cassava.org/News/biofuel/2004/poster_ethanol1.pdf).

The International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria and International Center for Tropical Agriculture (CIAT), Cali, Colombia have developed early maturing and high yielding Cassava cultivars with resistance to major diseases and pests. These improved Cassava cultivars need to be introduced and tested to identify most suitable cultivars for different agro-climatic zones of China and India. Also, there is a need to produce cultivars that produce tuberous roots containing simpler starch molecules that would make the production of bio-ethanol more efficient and competitive by eliminating *liquefaction* and *saccharification,* the steps that are additional to those involved in the conversion of ethanol from cereal grains. It has been reported that "*sugary*" clones exists in Brazil**[3]**. Improvement of biomass of these sugary clones will reduce the cost of ethanol conversion through enhanced the efficiency. Currently CIAT is screening the worldwide Cassava germplasm collection in search of useful mutants**[4]**. Efforts should be made to introduce sugary mutants to China and India and their biomass should be improved.

Second-generation ethanol

With the development of bio-catalysts, genetically engineered enzymes, yeasts, and bacteria, it is now possible to produce ethanol (what are called as second-generation bio-ethanol) from any plant or plant part known as ligno-cellulose biomass such as crop residues (stovers) of any cereal. The stover of widely cultivated cereals such as rice, wheat, sorghum, maize, pearl millet etc. serve as excellent feedstocks for ethanol production (Table 2).

Table 2. Potential of ligno-cellulosic biomass for ethanol production

Feedstock	**Liters ethanol ton^{-1}**
Sugarcane bagasse	500
Rice/wheat/maize/sorghum/pearl millet stover	500
Forest thinnings	370
Hardwood sawdust	450
Mixed paper	520

Source: Adapted from Planning commission.nic.in/reports/genrep/cmtt_bio.pdf

Currently, a few countries with higher conventional feedstock-based ethanol and fossil-fuel prices are producing ethanol from lignocellulose feedstocks**[5]**. The stovers contain lignin, hemicellulose, and cellulose. The hemi-cellulose, and cellulose are enclosed by lignin (which contains no sugars), making them difficult to reach and convert them into ethanol and hence energy requirement also escalates. Fortunately, brown mid-rib Maize**[6]** and brown mid-rib Sorghum**[7]** mutants have significantly lower levels of lignin content (by 51% in stems and by 25% in leaves in Sorghum and by 5 to 50% in Maize stems) than those of normal counterparts. Brown mid-rib mutants are also available in Sudan grass and Pearl millet. Research at Purdue University, West Lafayette, Indiana, and USA has indicated 50% higher yield of fermentable sugars from certain Maize and Sorghum brown mid-rib mutants' stover after enzymatic hydrolysis (www.ct.ornl.gov/symposium/index_files/6Babstracts/6B_01.htm). The use of biomass from brown mid-rib crop cultivars as feedstocks would therefore reduce the cost of ethanol production, thereby making the price of ethanol competitive to that of fossil-fuels. Also, considering that brown mid-rib confer increased rumen digestibility, green fodder and stover from brown mid-rib crop cultivars would serve as excellent source of rumen dry matter requirement. Hence, it is worth making research investments on developing high biomass yielding brown mid-rib Sorghum, Sudan grass, Maize and Pearl millet hybrids which besides providing cheaper source for bio-fuel production, meet fodder needs of subsistence farmers. ICRISAT research efforts in breeding brown mid-rib Sorghum hybrid parents are yielding positive results.

North American wild grass. Switch grass (*Panicum virgatum*), a perennial grass native to the North American prairies, could provide more than 100 billion gallons of bio-ethanol per year. Switch grass can grow on lands incapable of supporting traditional food crops, with 1/8th the nitrogen runoff and 1/100th the soil erosion of conventional crops[1]. Its deep root system adds organic matter to the soil, rather than depleting it. According to the USA Department of Energy, the switch grass yields biomass of about 40 t ha^{-1} and breeding programs should aim at doubling this yield. Expected ethanol output from switch grass biomass is about 450 liters ton^{-1}. (www.prognog.com/driving/ethanol/switchgrass:__native_american_powerhouse.html).

European grasses. The *Miscanthus* genus (including giant Chinese grass, silver grass, silver banner grass, maiden grass, and eulalia grass) is receiving attention as a potential source of biomass for bio-fuels. Giant *Miscanthus* (*Miscanthus* × *Giganteus*) is a hybrid grass that can grow four meters tall. Given its rapid growth, low mineral content, and high biomass yield, some European farmers use *Miscanthus* to produce energy[1]**.** The biomass from one hectare of *Miscanthus* can produce about 16,650 liters of ethanol.

Considering high biomass potential of North American Switch grass and European grasses, it is worthwhile introducing them to China and India. Research efforts should be made to evaluate these grasses to identify the agro-ecological regions best suited for their cultivation and to develop and standardize region-specific crop production technologies to maximize biomass production. Also, these grasses need to be genetically improved further for biomass yield and alter cellulose and lignin composition for cheaper production of ethanol.

Bio-diesel

The non-edible oilseed crops such as Jatropha, Pongamia, Neem, Kusum, or Pilu are good sources of bio-diesel production. Though Jatropha is an exotic species, it is commonly grown in India as hedge and wild bush whereas Pongamia and Neem are native to India. These crops were once hallmark of village life, and can be grown on lands not suitable for food crops cultivation. For example, Pongamia plants are grown in forests as well as avenue plantations in India. These crops are easy to establish, quick growing and hardy, and are not browsed by cattle and goats, and thus making them the best candidates for rehabilitating degraded common lands without any protection. Pongamia being a nitrogen fixer also helps build the soil fertility[8]**.** The Planning Commission of India has initiated ambitious program of growing Jatropha and Pongamia on wastelands for bio-diesel production. It is estimated that even if 10% of the total wasteland is brought under cultivation of these species, India can produce about 4–5 million metric tons per annum of bio-diesel, which is about 10% of the current diesel demand in India (http://www.renewingindia.org/newsletters/ethanol/current/news_vol1_06.htm). Oilcakes, the byproducts after extraction of oil from Jatropha and Neem are rich sources of macro- and micro-nutrients (Table 3), and thus serve as an excellent organic fertilizer (Table 4).

Table 3: Chemical composition of Neem and Jatropha seed oil cakes

Chemical	**Neem[1]**	**Jatropha[2]**
Azadirachtin	800–900 ppm	--
Nitrogen	4.0% minimum	5.7–6.5%
Phosphorus	3.0%	2.6–3,1%
Potassium	1.67%	0.9–1.0%
Carbon	1.2%	--
Sulfur	1.2%	--
Calcium	0.77%	0.6–0.7%
Magnesium	0.75%	--

Source: Planning commission.nic.in/reports/genrep/cmtt_bio.pdf: Wani et al. 2006;[1]Adilabad, Andhra Pradesh, India; [2] Tumkur, Karnataka, India

Table 4. Grain yield response of soybean to the application of Pongamia press cake and inorganic fertilizers.

Treatment	**N applied (kg** ha^{-1}**)**	**Grain yield (kg ha^{-1})**	**% increase over farmers' practice**	**Net benefit over farmers' practice (Rs. ha^{-1})**
Farmers' practice (DAP – 100 kg)	16	900	--	--
Pongamia press cake (300 kg)	12	1340	49	4230
Fertilizer (urea – 50 kg)	23	1450	61	6800
½ pongamia cake (150 kg) + ½ urea (25 kg)	17	1650	83	7950

Pongamia oil cake in addition is also a proven nitrification inhibitor in fields enhancing nitrogen-use efficiency by reducing nitrate losses. Jatropha oilcake contains about 61% protein compared to about 45% in soybean oilcake[9]. However, the presence of toxins/anti-nutrient factors such as phorbol esters, trypsin inhibitors, lectins, phytates[10], renders Jatropha oil cake unfit for animal feed. After detoxification, oil cakes could be good sources of feed for milch and drought animals, which are indispensable components of mixed crop-livestock system that prevails in China and India[9]. The Neem oil cake besides providing nutrients to plants has proven insecticidal property and thus its use not only empowers farmers to improve soil health but also provide them an eco-friendly means of protecting their crops that support their livelihoods. Developing technologies to make these oilcakes amenable for multiple uses is a key to attract bio-fuel industries and hence to create large demand for biomass sources.

As Jatropha and Pongamia are still wild species, research is necessary to develop improved cultivars and crop management technologies to maximize seed and oil yields per unit of water and land area. Altering fatty acid composition of the seed oils of these species is a key to improve bio-diesel productivity. At present a large number of Jatropha and

Pongamia accessions are being collected by various research organizations in India under bio-diesel network programs funded by the Department of Biotechnology and National Oilseeds and Vegetable Oils Development Board. The collections are being characterized for their oil content and fatty acid composition by ICRISAT, Tata Energy Research Institute (TERI), and other institutions in India. Seed oil content ranges from 28-40% in Jatropha and Pongamia accessions that are being maintained and characterized at ICRISAT. In view of their out-breeding mode of reproduction, large variability in seed yield and oil content between individual plants is observed. For example, per plant seed yield of Jatropha ranges between 200 g to more than 2 kg[10]**.** The appropriate kind of planting material (vegetative propagation/tissue culture seedlings) need to be therefore standardized, to ensure the true breeding nature of the best clone to be identified or developed through concerted research efforts.

Role of biotechnology

The advances in biotechnology provide opportunities to significantly reduce cost of bio-fuel production by genetic manipulation of feedstocks in a way that improves bio-fuel yields. The development of genetically engineered Sweet sorghums with enriched stalk juice and sugar yields and altered proportion of reducing and non-reducing sugars (in favor of reducing sugars) and efficient microbial fermenters of sugars into ethanol would significantly reduce cost of ethanol production. Similarly, the development of genetically engineered enzymes that can perform both starch hydrolysis and saccharification of Cassava root tuber starch, will greatly reduce the cost of conversion of starch into ethanol. Reducing lignin in crop biomass without reduction in biomass yield will substatially improve bio-refinery efficiency. Genomics, proteomics, and metabolomics are being used to improve our understanding of and ability to manipulate the lignin biosynthesis pathway[1]. For example, before processing, Maize and Sorghum stover is currently pretreated to convert ligno-cellulose into sugars but transgenic technologies may provide alternatives to pretreatment such as genetically engineered microbes that convert ligno-cellulose into sugars. In this regard, the potential of Maize and Sorghum brown mid-rib mutants that have altered lignin composition and ultra structure of secondary cell walls are being explored at Purdue University, West Lafayette, Indiana, USA. A considerably higher (50%) yield of fermentable sugars after enzymatic hydrolysis of stover from certain maize and Sorghum brown mid-rib mutants has been achieved (www.ct.ornl.gov/symposium/index_files/6Babstracts/6B_01.htm). Care must be however taken, as changes in lignin properties may reduce biomass yield and resistance to pest, disease and lodging and/or alter stover nutritional value[1]. Biotechnological tools hold promise for altering fatty acid composition (intractable trait for manipulation through conventional tools), one of the key traits for improving productivity of bio-diesel from Jatropha and Pongamia seed oils. Also, addressing more complex traits such as reducing toxins/anti-nutrients in Jatropha oilseed cake for making it more valuable as animal feed, requires the use of biotechnological tools. The success stories on the use of molecular marker-assisted selection to improve the equally complex characteristic of oil concentration in maize kernels or fatty acid composition of Soybean oils provide optimism for potential of biotechnological tools to improve the traits important for bio-fuel production from the biomass crops.

Potential benefits of bio-fuels

As bio-fuels are produced from biomass of crop plants, they offer enormous opportunities to improve the income levels of smallholder farmers in predominantly agrarian countries such as China and India. At community level, farmers can cultivate energy crops that fetch more income while meeting their food needs. Given the bulkiness of most of the feedstocks, it is necessary to locate bio-fuel industries in rural areas where the feedstock crops are grown for ease of transportation. Local production of bio-fuels is projected to have a broad range of positive economic, social and environmental implications. At a national level, producing more bio-fuels will generate new industries, new technologies, new jobs and new markets assisting economic growth in rural areas. Of the 1.7 million jobs in 2004 related to the renewable energy industry, almost a million of them were related to bio-fuels. For example, in Brazil, the ratio of jobs created from bio-fuel industry to those created from fossil fuel industry is 22:1 at 100% ethanol use and 6:1 at 25% ethanol use in transport vehicles (www.americanprogress.org).

As bio-fuels are renewable, non-toxic and biodegradable, they contribute to energy security and reducing environment pollution. The use of even 10% ethanol blends reduce green house gas emissions (GHG) by 12-19% compared with conventional fossil petrol. Ethanol can be blended in low proportions–up to 25%, with petrol for direct use in normal internal combustion engines without modification. Similarly, the use of diesel blended with fossil-diesel up to 20% (B 20) results in substantial reduction of un-burnt hydrocarbons (by 30%), carbon monoxide (by 20%) and particulate matters (by 25%) and negligible sulfur content in the emissions and requires very little or no modification of engine[9]. Bio-diesel can be directly used to run power-drawn implements, tractors, pump sets for lift irrigation, and vehicles to transport agriculture produce to the markets. Tribal communities in Andhra Pradesh are using straight Pongamia oil for running diesel generator sets to produce electricity in villages. The Indian Railways has started to use the Jatropha seed oil (blended with fossil-diesel fuel in various proportions) to power its diesel engines with great success. Currently, the diesel locomotives that run from Thanjavur to Nagore section and Tiruchirapalli to Lalgudi, Dindigul and Karur sections in Tamil Nadu state run on a blend of Jatropha and diesel oil (http://en.wikipedia.org/wiki/Jatropha_In_India).

Energy balance of bio-fuels

The impact of bio-fuels on the global atmosphere and human and animal wild lives has been relatively small to date, particularly when compared with the environment and health costs of extracting, processing and burning of fossil fuels. However, as the production and use of bio-fuels increase, their impact on environment in relation to fossil fuels can be assessed. The climate impact of bio-fuels depends on their net energy balance (NEB) ratio (the energy contained in the bio-fuels to the fossil energy required to produce bio-fuel). This in turn depended on the energy intensity of feedstock production including the type of farming system and inputs used, processing, and transport. Though NEB ratio of sugarcane compared to other crops is high (Table 5), its use as a feedstock may not be favored politically in India as it viewed largely as a food-related crop.

Table 5. The net energy balance of gasoline and ethanol by feedstock.

Feedstock	**Energy output/fossil energy input**
Sugarcane	8.3
Switch grass	4.4
Sugar Beet (European Union)	1.9
Corn (United States)	1.3-1.8
Wheat (Canada)	1.20
Fossil fuel (Gasoline)	0.8

Source: www.americanprogress.org

There is a need to assess the NEB ratio of Sweet sorghum, Cassava, Jatropha and Pongamia, to justify research investments on improving and use of these potential feedstock crops in bio-fuel production.

Bio-fuels and Kyoto Protocol

Under the Kyoto Protocol, Food and Agricultural Organization (FAO) supports the use of bio-fuels in agricultural practices and reforestation (rehabilitating waste lands and degraded lands with bio-fuel crops) so that developing countries may gain additional income from selling carbon credits, while improving the livelihoods of farmers through enhanced soil fertility and higher crop production. The Clean Development Mechanisms (CDM) under Kyoto Protocol provides opportunity to direct financing the projects that reduce GHG in developing countries. To date, however, no CDM projects related to liquid bio-fuels have been approved, likely because of overall lack of capacity for CDM project development in many developing countries including China and India, and limited availability of CDM baseline and monitoring methodology specifically developed for bio-fuels projects[11]. The development and successful financing of CDM projects in future, requires establishing approved baseline and monitoring methodologies and building developing countries' capacity to develop and deal with bio-fuel projects.

Institutional arrangements for bio-fuel research

Bio-fuel production poses a major new challenge to crop improvement and management research. For farmers to respond to market changes, they need multipurpose crops combining food, feed, fodder, fiber, and bio-fuel traits. Basic research on bio-fuel crops may best be undertaken by upstream academic organizations and the private sector. On the other hand, trait-based mining of genetic resources may be the most appropriate niche for public research organizations, particularly those of international agricultural research centers (IARC) supported by the Consultative Group on International Agricultural Research (CGIAR)[1]. Clearly there are substantial financial incentives for private investment in developing new crop cultivars for bio-fuel production. Private investment, however, also threatens to result in the locking up of a large proportion of enabling technologies under various intellectual property protection mechanisms, as is already happening with, for example, critical enzymes in the bio-fuel production process. Therefore, the breeding of new crop cultivars for the bio-fuel market and development of new microbial/enzyme technologies provide an opportunity for a whole new paradigm in public-private partnerships for bio-fuel research and development. IARCs such as ICRISAT, IITA, CIAT, and CIMMYT may focus on genetic enhancement of plant genetic resources and feed into national public and private research and extension programs worldwide. The may also serve as conduits of new knowledge and technology to small-scale farmers, particularly in resource-poor farming areas of the developing world[1]. These IARCs together with national research programs have clear roles in finding suitable mechanisms to ensure that smallholder farmers (particularly those in resource-poor areas) can have sustainable benefits from this potentially lucrative bio-fuel market.

Summary

Investments in research and development and use of bio-fuels besides providing sustainable energy for increased agricultural production, offers enormous opportunities to developing world’s smallholder farmers to diversify their livelihood options to augment their income levels. From an environmental standpoint, it offers an alternative lower carbon intensive development path, by offering ways to reduce GHG, while pursuing energy development goals and by taking advantage of the financial incentive embodied in the flexible mechanisms of Kyoto Protocol. Improving the energy value traits of widely cultivated food crops and identifying and genetic enhancement of water-saving non-food/new bio-fuel crops through research is necessary to mitigate trade-offs between food/fodder and energy security. Innovations in existing conversion technologies and/or development of new conversion technologies for efficient production of bio-fuels and the development of technologies that enable broadened use of byproducts of bio-fuel production chain are keys to attract investment in bio-fuel production. These along with building-up databases on NEB ratio of bio-fuel crops are essential to justify increased investments on research, development and the use of bio-fuels that have great potential in contributing to energy security of China and India.

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