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SECTION : REVIEW

Agricultural Crops as Potential Source of Bio-fuel Production

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Abstract

Need for bio-fuel production is gaining momentum due to ever increasing environmental pollution and sky rocketing of prices of fossil fuels. These has led to worldwide interest in the production and use of bio-fuels. Policies have been made in both the developed and developing countries to encourage production of combustible fuels from plants that triggered public and private investments in bio-fuel crop research, development and production. This article emphasizes potential benefits of bio-fuel crops and important role played by them in reducing the environmental pollution and in increasing the farmers' income. This article also gives an insight into various bio-fuel crops being cultivated for production of bio-ethanol or bio-diesel and a brief review of current status of investigations on bio-fuel crops.

1. Introduction

Energy is the fuel of economic prosperity thus assist in mitigating poverty. 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, agriculture and allied sectors (Aziz et al., 2013). The world excessively depends on fossil fuels for its energy requirements which do not provide equitable economic and environment friendly benefits. Bio-ethanol is an alcohol made by fermentation, mostly from carbohydrates produced in sugar or starch crops such as corn, sugarcane or sweet sorghum (Ortiz et al., 2006). Cellulosic biomass derived from non-food sources such as trees and grasses is also being developed as a feedstock for ethanol production. Ethanol can be used as a fuel for vehicles in its pure form, but, it is usually used as a gasoline additive to increase octane and improve vehicle emissions. Bio-ethanol is widely used in Brazil and USA.

A bio-fuel is a fuel that is derived from biological materials, such as plants and animals. Conceptually, bio-fuels offer the opportunity to replace fossil fuels, which when combusted continuously add carbon dioxide to the atmosphere. The CO_2 is recycled between atmosphere and plant material in agriculture and forest systems. CO_2 is emitted when ethanol is used in place of gasoline or, bio-diesel in place of petroleum diesel or biomass in place of coal in electricity generation, but, an equivalent amount of CO_2 is removed from the atmosphere when the next rotation of the feedstock crop is produced. The bio-fuels, produced from selected agricultural biomass provide sustainable and eco-friendly energy options that foster environmental sustainability and offer opportunities to improve the income level of developing world's smallholder subsistence farmers who depend on agriculture for their livelihoods (Reddy et al., 2008). Diversifying crop uses, identifying and introducing bio-fuel crops would lead to enhanced farmers' incomes, thereby contributing to eradicating extreme poverty in rural areas helping 75% of the world's 2.5 billion poor and contributing to the environment protection. However, not all crops offer equal environmental advantages. The crop, cultivar and production system and the processing technology are critical. The bio-fuel research for development will lead to new local, regional and national public-private partnerships for development.

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-a-vis* fossil-fuels (Aziz et al., 2013). However, generation of huge volumes of quality feedstock's to produce bio-fuel to meet the projected demand without compromising food and fodder security requires massive investments and reorientation of research on crops used for bio-fuel production. This article discusses the opportunities and the role of selected bio-fuel crops for mitigating tradeoffs between food or fodder and energy security and the potential benefits of bio-fuels in alleviating poverty and contribution to environment sustainability.

2. Status of Bio-fuels

World bio-fuel production has now surpassed 100 billion liters of annual production (Table 1). After accounting for energy contents, this is displacing 1.15 million barrels of crude oil derived products per day. If all of the bio-fuel were produced in one country, that country would be the world's 24th largest crude oil producer after Qatar but ahead of Indonesia. The United States and the Brazil are the world's top producers of bio-diesel accounting together 90% of global production. As of 2011, mandates for blending bio-fuels exist in 31 countries at the national level and in 29 states or provinces. The International Energy Agency has a goal for bio-fuels to meet more than a quarter of world demand for transportation fuels by 2050 to reduce dependence on petroleum and coal.

The term bio-fuels refers to several different types of fuels, including bio-ethanol and bio-diesel. Bio-ethanol is the most common form of bio-fuel. Bio-diesel can be produced from edible oilseeds from crops such as soybean (*Glycine max* L.), rapeseed (*Brasscia* spp.) or sunflower (*Helianthus annuus* L.). However, considering large gap between the demand and supply of edible oils, several countries cannot afford to spare vegetable oils for bio-diesel production. Fortunately, bio-diesel can also be produced from non-edible oilseeds from shrubs such as castor (*Ricinus communis*), jatropha (*Jatropha curcus*), pongamia (*Pongamia pinnata*) and neem (*Azadirachta indica*). Though higher yields are expected, planting non-edible oilseeds for bio-diesel is not advisable in areas meant for food crops. These crops should be promoted on wastelands and field bunds taking appropriate steps for preventing land or environmental degradation.

On the other hand, bio-ethanol is currently produced in more than 15 countries from a variety of sugar and starch based feedstock's (Table 2). Taking cue from Brazil and the USA, several developed and developing countries are making concerted efforts to reduce their dependence on oil imports and reduce greenhouse gas (GHG) emission levels (Table 3) through policies to produce bio-ethanol and bio-diesel for blending with fossil fuels (Farrell et al., 2006). In 2020, global

Table 1: World fuel ethanol production

Continent	Millions of gallons		
	2011	2012	2013
North and central America	14,401	13,768	13,300
South America	5,772	5,800	5,920
Brazil	5,573	5,577	6,267
Europe	1,168	1,139	1,371
Asia	890	952	545
China	555	555	696
Canada	462	449	523
Rest of World	126	113	727

Source: USDA-FAS

Table 2: World biodiesel production

Region	Million litres	Feed stocks
EU	9848	Rapeseed, soy oil, palm and tallow
USA	1682	Soybean , tallow, canola, palm
Brazil	1386	Soybean, tallow, other vegetable oils
Argentina	1250	Soybean
China	191	Waste vegetable oils
Asia	1687	Palm, soybean, waste vegetable oils
Rest of world	395	Tallow, rapeseed, palm, soybean, waste vegetable oils
World	16436	

Source: http://ethanolrfa.org

Table 3: Fuel ethanol green house gas emission reductions

Country	2009 ml	GHG reduction (kg CO_2 eq l^{-1})
USA	39700	0.85
Brazil	24900	1.7
EU	3935	1.28
China	2050	0.85
Canada	1100	1.13
Other	936	1.7
Thailand	450	1.7
Colombia	315	1.7
Australia	215	1.5
India	150	1.7
Total	73751	

Source: Source: http://ethanolrfa.org

bio-fuel and bio-diesel production was projected to be around 54 billion gallons, increasing to 83 billion gallons by 2030.

3. Potential Benefits of Bio-fuels

Much of the interest in expanding production and use of bio-fuels stems from the view that bio-fuels offer significant opportunities to enhance energy security and independence while reducing green house gas emissions. Bio-fuel crops offer potential benefits interms of biomass they produce in addition to plant economic yield thereby improving the income levels of smallholder farmers. Most of the world's ethanol is currently produced from corn or sugarcane and both. Ethanol from sugar beet and grains is also being produced but most of the world's production of these kinds of ethanol is located in Europe. Ethanol production does not reduce the amount of food available for human consumption. Ethanol is produced from field corn fed to livestock, not sweet corn fed to humans. In the very near future efforts are being made to produce ethanol from agricultural residues such as rice straw, sugar cane bagasse and corn stover, municipal solid waste, and energy crops such as switch grass. Each of the feedstock types are briefly discussed in this paper. Given the bulkiness of most of the feed stocks, it is necessary to locate bio-fuel industries in rural areas where the feedstock crops are grown for ease of transportation. Technologies for reducing the feed stock volume (e.g. decentralized syrup units supplying syrup to the distillery instead of the voluminous stalks) need to be given major thrust.

As bio-fuels are renewable, non-toxic and bio-degradable, they contribute to energy security and reducing environment pollution. The production and use of crude oil and the fuels produced from it creates about 215 mt of GHG emissions annually. The uses of even 10% ethanol blends reduce GHG emissions by 12 to 19% compared with conventional fossil fuels. Burning E 85 (85% ethanol) reduces the Nitrogen oxide emissions by 10% compared to conventional gasoline. Ethanol can be blended in low proportions up to 25%, with petrol for use in normal internal combustion engines without modification. Similarly, 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 (Francis, 2005). 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. The forecast of world bio-diesel production of 16.4 billion liters was calculated to result in a reduction of GHG emissions of 35.9 mt. Most of this reduction is experienced in Brazil and the United States due to their high levels of ethanol production and use.

4. Bio-ethanol Feed Stocks

Most of the world's ethanol is currently produced from corn or sugarcane whose potential is limited to irrigated (or high rain fall) and well endowed environments. Further, their use for ethanol production compromise with the food security in developing countries.

4.1. Sugarcane

Many a countries use molasses from sugarcane (*Saccharum officinarum*) to produce ethanol. Brazil is the world's largest producer of sugar cane ethanol. A significant number of studies have been undertaken on Brazilian ethanol. The emissions from some of these are summarized in the following table. It can be seen that there is a relatively small range for the emissions.

4.2. Sweet sorghum

Sweet sorghum [*Sorghum bicolor* (L.) Moench] has been the object of sustained research and development programmes in China, India and the USA (Aziz et al., 2013). Sweet sorghums, which are similar to grain sorghum's have good potential for ethanol production (Reddy et al., 2005). 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 (Reddy et al., 2005). Also, sweet sorghum-based ethanol is sulphur-free and cleaner than molasses-based ethanol, when mixed with gasoline. Research studies in India indicated that ethanol production from sweet sorghum is cost-effective (Table 3).

4.3. Cassava

Cassava (*Manihot esculenta* Crantz), 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 adequate quantity of tuberous root biomass even in low fertility soils. The tuberous roots contain high starch (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. Ethanol yields from cassava vary from 137 to 190 l t^{-1} fresh cassava or 3 705 to 6 313 l ha^{-1} (Aziz et al., 2013).

4.4. Second-generation ethanol

Potential feedstocks: The perennial grasses switch grass and *Miscanthus* spp. are tipped to be potential sources for second generation (lignocellulosic) ethanol production.

4.5. Switch grass

Switch grass (*Panicum virgatum* L.), a perennial grass native to the North American prairies, is one of the most sought after grasses for cellulosic bio-energy production can grow on lands incapable of supporting traditional food crops, with ⅛th the nitrogen runoff and 10^{-2th} the soil erosion of conventional crops (Ortiz et al., 2006). Its deep root system adds organic matter to the soil, rather than depleting it. According to the USA Department of Energy, switch grass yields biomass of about 40 t ha^{-1} and ethanol output of about 450 l t ha^{-1}.

4.6. European grasses

The *Miscanthus* genus (including giant Chinese grass, silver grass, silver banner grass, maiden grass, and eulalia grass) is a hybrid grass that can grow four meters tall offer an abundant and inexpensive source of fermentable sugars (Stampfl et al., 2007). Given its rapid growth, low mineral content, and high biomass yield, some European farmers use Miscanthus to produce energy (Ortiz et al., 2006).

4.7. Bio-diesel

The non-edible oilseed crops such as castor (*Ricinus communis*), jatropha (*Jatropha curcus*), pongamia (*Pongamia pinnata*) and neem (*Azadirachta indica*) are attractive sources of bio-diesel production. Though jatropha is an exotic species (Latin American origin), it is commonly grown in India and other developing countries as hedge and wild bush, whereas pongamia and neem are native to India. These crops were once hallmark of village life, 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.

Bio-diesel, an alternative diesel fuel from vegetable oils and animal fats is bio-degradable, non-toxic with low emission profiles thus proven to be an environmentally friendly fuel compared to petroleum diesel (Meher et al., 2006). Demand for bio-diesel has been increasing due to rise in the petroleum prices during the last few years. Support policies by governments in different countries like Europe, Brazil, Namibia and India gave a fillip to the use of bio-diesel fuels for transport like the EU Directive 2003/30/EC in Europe (Vicente et al., 2007). The National Mission on Bio-fuels in India targeted to achieve 20% blending of bio-diesel (B20) by 2012 with an aim of bringing 4,00,000 ha of marginal land under cultivation of non-edible oilseed crops mainly Jatropha. However, castor is a viable alternative to Jatropha due to its shorter growing period, availability of standard agronomic practices for assuring good yields, good yield potential of 1500 to 1800 kg ha^{-1} in rainfed conditions and 2500 to 3000 kg ha^{-1} under irrigated dry conditions and 3500 to 4000 kg ha^{-1} under drip irrigation and early maturity within 150 to 210 days after sowing (Hanumantha Rao et al., 2003; Lavanya et al., 2006; Lavanya and Mukta, 2008; Pathak, 2009). Further, after the reproductive phase begins, the castor plant is able to continually initiate new racemes and produce seeds (Severino and Auld, 2013). The non-edible seed and hardiness of the crop with high oil yield potential make it suitable for bio-fuel programmes in waste lands (Sudhakar Babu, 2010).

Currently, a few countries with higher biomass availability are producing ethanol from lignocellulosic feedstocks. Biomass is seen as an interesting energy source for several reasons for the reason that bio-energy can contribute to sustainable development (Yan and Shuzo, 2006). 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 in this process. Brown midrib mutants of maize (Marita et al., 2003; Barriere et al., 2004; Vermerris et al., 2007) and sorghum (Reddy et al., 2008) 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. The use of biomass from brown midrib crop cultivars as feed stocks would reduce the cost of ethanol production, thereby making the price of ethanol competitive to that of fossil-fuels as indicated by the research at Purdue University which revealed 50% higher yield of fermentable sugars from certain maize and sorghum brown midrib mutants' stover after enzymatic hydrolysis (Vermerris et al., 2007). Also, considering that brown midrib confers increased rumen digestibility, green fodder and stover from brown midrib crop cultivars would serve as excellent source of animal feed.

5. Competition With Food

Food security may conflict with energy security as bio-fuel production certainly competes with food production for same resources such as land, water and labour. The introduction of bio-fuels increases the price of staple crops, especially corn and soybeans consumed by livestock, people and bio-fuel producers. At the same time, bio-fuels increase fuel supplies, reducing fuel prices and increasing fuel consumption. The issue of competition between bio-fuels and food is a potentially significant concern which has not been resolved. However, recent studies show that food and fuel prices are affected by changes in fossil fuel prices (Ejimakor and Kyei, 2011). On an average, the introduction of bio-fuels was responsible for one-quarter of food price inflation in 2007 and 2008 (Deepak et al., 2009).

6. Research and Development in Bio-fuel

The growth of bio-fuels is likely to be constrained by competition for limited land resources, so technology will be critical in widening the role of bio-fuels. If the energy from abundant cellulosic materials could be economically harnessed and ethanol per acre of feedstock increased, land requirements would be significantly reduced. But this will require innovation and diffusion of new conversion technologies and genetic advances. Research options consistent with the analysis include increasing yields for existing feed stocks, developing new feed stocks that can be sustainably produced out of crop land and enhancing the sustainable use of bye products.

Most of the developing nations, including China and India, have plans to double their bio-fuel production within the next 15 years. 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.

As Jatropha and Pongamia are still under crop domestication, research is necessary to develop improved cultivars and crop management technologies to maximize seed and oil yields unit^{-1} 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, The Energy Research Institute (TERI), and other institutions in India. Seed oil content ranges from 28 to 40% in jatropha and pongamia accessions that are being maintained and characterized at ICRISAT (Wani et al., 2006). In view of their out-crossing, 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 (Sharma et al., 1997). The appropriate kind of planting material (vegetative propagation or 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.

7. Conclusion

Much research is undoubtedly necessary to better understand the capabilities and downfalls of bio-fuels. A huge number of questions remain and more are still surfacing like; whether *Jatropha* will be economically viable, whether indirect and environmental costs of bio-fuels will outweigh the direct benefits, or whether impoverished farmers will significantly benefit. Firm recommendation based on research are needed before investing major sums into bio-fuel development policy particularly those policies based around *Jatropha*.

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