Biofuels – Promise / Prospects

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Abstract

The prospects of using agricultural material for biofuel in India for energy purposes are evaluated. A strategy is developed so that from a given piece of land maximum bio-energy and remuneration to the farmers results. For this it is proposed that on a given land area in one year two crops can be grown, viz. sweet sorghum during monsoon followed by a winter oilseed or a monsoon oilseed followed by sweet sorghum in winter.

Thus the values of the product of bio-energy and net returns (BENR) were estimated for the different cropping systems evaluated. The highest values of BENR under rain fed conditions were obtained from a combination of sweet sorghum in monsoon and either groundnut, rapeseed, mustard, sunflower or safflower (in that order) in winter. Under irrigation highest BENR values were obtained for castor in monsoon and sweet sorghum in winter followed by sweet sorghum in monsoon with either mustard or groundnut in winter.

It is shown that with this strategy not only the country can become self-sufficient in edible oil but will also have the potential of taking care indigenously of a substantial proportion of its energy need.

In order that this strategy is followed on a large scale certain policy initiatives are suggested.

1. **Introduction**

The ever rising cost of fossil fuel internationally has forced major world economies, which are also major importers of fossil fuel, to examine renewable and cheaper alternatives to fossil fuel to meet their energy demands. Biodiesel and bioethanol have emerged as the most suitable renewable alternatives to fossil fuel as their quality constituents match diesel and petrol respectively. In addition they are less polluting than their fossil fuel counterparts. Environmental concerns and the desire to be less dependent on imported fossil fuel, have intensified worldwide efforts for production of biodiesel from vegetable oils and ethanol from starch and sugar producing crops.

The use of vegetable oil for energy purposes is not new. It has been used world over as a source of energy for lighting and heating since time immemorial. As early as in 1900, a diesel-cycle engine was demonstrated to run wholly on groundnut oil at the Paris exposition. Even the technology of conversion of vegetable oil into biodiesel is not new and is well established. However the unprecedented rise in fuel prices recently has made it economically attractive. The present availability of vegetable oils in the world is more than enough to meet the edible oil requirements, and surplus quantity available can partially meet requirements of biodiesel production. However, there is a considerable potential to further enhance the oilseeds production in the world to meet the increasing demand for food and biodiesel.

India is a huge importer of crude oil and spends about Rs. 1,200 billion of foreign exchange every year to meet 75% of its oil needs (Anand, 2006). This has affected its balance of payment adversely, especially after the unprecedented rise in crude oil prices. Being an agricultural country endowed with varied climates, nutrient-rich soil and ability to grow many different crops, India offers a great promise as a producer of surplus raw material for biodiesel and bioethanol production. Though presently it meets around 30-40% of its vegetable oil requirements through imports, India has a potential and capability to produce enough vegetable oil not only to meet its edible oil requirements but also for biodiesel production. The present paper discusses the promise and prospects of using vegetable oil as a biofuel with specific reference to Indian situation.

2. World Biofuel Scenario

2.1 Area, production and productivity of oilseeds in the world and in India

Worldwide, oilseed crops occupy an area of 166.36 million hectares with a production of 295.6 million tonnes and productivity of 1777 kg/ha (FAO, 2003). In India, area under oilseeds is 23.7 million hectares with a production of about 25 million tonnes and a productivity of just about one ton/hectare. The oilseed production in the country presently meets only 60-70% of its total edible oil requirements and the rest is met through imports.

India also has a potential of collecting 5 million tonnes of tree-borne oilseeds (TBO) of which only 0.1-1 million tonnes are being collected presently (Kumar, 2003). In addition to the existing potential of TBO, there is about 60 million hectares of wasteland of which 30 million hectares can be suitably utilized for growing plantations of biofuel plants like *Jatropha*. It has been estimated that each hectare can produce about 2000 liters of biodiesel/year after the initial 3-year period of establishment of *Jatropha* in the field (Shukla, 2005; Ghaisas, 2005). This will result in the production of 60 billion liters of biofuel. Thus TBO from the wasteland can make a significant and important contribution to the energy requirement of the country in the days ahead.

2.2 Global biodiesel production scenario

Biodiesel is a fast-developing alternative fuel in the U.S. and Europe. Pilot plants for power generation and encouraging adaptation by fleet operators have established biodiesel as a viable and sustainable alternate fuel. The biodiesel production from vegetable oils during 2004-05 was estimated to be 2.36 million tonnes globally. Of this EU countries accounted for 1.93 million tonnes, U.S. produced 0.14 million tonnes and rest of the world 0.29 million tonnes (Parikh, 2005). The EU usage of vegetable oil for biodiesel has been rising at about 30% annually in the last two years. In EU, rapeseed is the main source of oil for biodiesel, while in the U.S. soybean oil is used for manufacturing biodiesel. Malaysia - the largest producer of palm oil has set up three palm biodiesel plants with a combined annual capacity of 60,000 tonnes.

2.3 World ethanol production

With the provision of addition of 5-10% of ethanol in petrol and diesel in most of the crude oil importing countries, there has been a substantial rise in ethanol production in last few years. Among the ethanol producing countries, Brazil produces the maximum amount of ethanol (15099 million liters/year) followed by the U.S. (13381 million liters/year), China (3649 million liters/year) and India (1749 million liters/year) (Table 1). Sugar cane is the major source of ethanol in Brazil, while in the U.S. it is produced from corn (Peterson, 2006).

Biofuels in general have often been categorized as first and second generation. The first generation biofuels are the fuels which are produced from conventional agricultural crops by well-established technologies such as biodiesel from oil crops and ethanol from sugar and starch producing crops. The second-generation biofuels on the other hand are produced from the agricultural waste - mainly the lignocellulosic material. However they require advanced production (conversion) technologies. Overall, high energy conversion efficiencies and least cost of production are the key factors for selecting biofuels for the future.

2.4 Ethanol production from crop residues

Enough availability of crop residues as a source of feedstock is obviously mandatory for the production of second-generation biofuels. Annual crop residue availability in the world is estimated to be about four billion tonnes, of which the U.S. and India account for one billion tonnes (Table 2). Lignocellulosic residues of cereal crops like corn, rice, wheat, sorghum and millet are best suited for ethanol production and are estimated to be about 3 billion tonnes/annum in the world and 0.4 billion tonnes/annum each in the U.S. and India respectively (Lal, 2006). These are large quantities and a substantial part of these residues may suitably be used for biofuel production.

The potential of bioethanol production from waste crops and crop residues was estimated by Kim and Dale (2004). According to them there are 74 Tg (Tg = Teragram = 10^{12} g = 1 million metric tonnes) of dry waste crops in the world that have a potential to produce 49 GL (gigaliter or 1 billion liters) of bioethanol/year. It was also estimated that conversion of 1.5 Pg (Pg = Petagram = 10^{15} g = 1 billion metric tonnes) of dry lignocellulosic residues of seven crops viz. corn, barley, oat, rice, wheat, sorghum and sugar cane, could produce an additional quantity of 442 GL of bioethanol per year. This potential bioethanol production of 491 GL could replace 353 GL of petrol or about one-third of the global petrol consumption. The ethanol production potential of residues from lignocellulosic crops ranges from 0.26 to 0.31 L Kg^{-1} (Table 3). The net energy yield of perennial crops ranges from 220-550 GJ/ha/yr, that of grasses 220-260 GJ/ha/yr and that of sugar cane 400-500 GJ/ha/yr (Hamelinck and Faaij, 2006).

Use of lignocellulosic agricultural residues for energy production is thus very favorable and offers good economic prospects for the future of biofuels. EU has set a target of 1 billion liters of second generation bioethanol production to be achieved by 2012 (de Miguel, 2006). The prominent high potential fuels are ethanol produced from agricultural residues rich in lignocellulose, synthetic diesel via Fischer-Tropsch, methanol and hydrogen (Arthur D. Little, 1999; Katofsky, 1993; Turkenburg, 2000; Williams *et al*., 1995). These four fuels are in attractive stages of development.

2.5 **Comparison of biodiesel and ethanol**

Before striving for commercial scale biofuel production from food crops, it would be of paramount importance to determine whether biofuels provide any benefit over the fossil fuels they replace. This needs a thorough analysis of the direct and indirect inputs and outputs for their full production and use life-cycles. To become a successful substitute for a fossil fuel, an alternative fuel in addition to having superior environmental benefits over the fossil fuel should also be produced economically and in sufficient quantities to meet the energy requirements. Hill *et al*. (2006) analyzed the net societal benefits of corn grain (*Zea mays* ssp. *mays*) for ethanol and soybean (*Glycine max*) oil for biodiesel - the two important alternative transportation fuels in U.S.

The study showed that both corn grain ethanol and soybean biodiesel recorded positive Net Energy Balances (NEB). The NEB for corn grain ethanol was recorded as 25% more energy than required to produce it. However, the soybean biodiesel provided 93% more energy than needed in its production.

As far as the life-cycle environmental effects were concerned, the study showed that both corn and soybean production have negative environmental impacts through movement of agrochemicals especially nitrogen (N), phosphorus (P) and pesticides from farms to other habitats and aquifers. Data on efficiencies of net energy production from agrochemical inputs in corn and soybean reveal (after partitioning these inputs between the energy product and co-products), that biodiesel uses only 1.0% of the N, 8.3% of the P and 13% of the pesticides on weight basis. Although blending ethanol with petrol at low levels as an oxygenate was reported to result in lower emissions of carbon monoxide (CO), total life-cycle emissions of five major air pollutants [CO, VOC, PM10, oxides of sulphur (SO_x) and oxides of nitrogen (NO_x)] are higher with the “E85” (85% corn grain ethanol-petrol blend) than with petrol per unit of energy released upon combustion (Hill *et al*., 2006). The study further revealed that production and use of corn grain ethanol releases 88% of the net green house gas (GHG) emissions of production and combustion of an energetically equivalent amount of petrol. On the other hand life-cycle GHG emissions of soybean biodiesel were recorded to be 59% of those for diesel fuel.

Because fossil fuel energy use imposes environmental costs not considered in market prices, benefits of biofuel to society not only depend on its cost competitiveness compared to fossil fuel but also on its environmental costs and benefits vis-à-vis its fossil fuel alternatives. Subsidies for otherwise economically uncompetitive biofuels are justified if their life-cycle environmental impacts are sufficiently less than for alternatives.

3. **Status of Biofuel Production in India**

3.1 **Biodiesel**

India consumes more than 250 million tonnes of fossil fuels every year. This comprises of approximately 40 million tonnes of diesel. India is ranked fifth in the world after China, Japan, Russia and the U.S. in terms of fossil fuel consumption. Recently in India the Planning Commission, Government of India launched "National Mission on Biodiesel" with a view to find a cheap and renewable liquid fuel based on vegetable oils (Shukla, 2005). The rural development ministry has been appointed as the nodal ministry for implementing the programme. This mission is being carried out in two phases – the first phase involving a demonstration stage for plantation of *Jatropha* on four lakh hectares and associated research activities for establishing the commercial viability of the fuel, and phase two for carrying out a self-sustaining expansion of the biodiesel programme.

Biodiesel production in India has reached a decisive stage and the country is about to make a beginning by introducing a five percent blend of biodiesel with conventional diesel at selected districts in different states (Behl, 2006). In order to attract and secure private participation on larger scale, Government of India has fixed the procurement price of biodiesel as Rs. 25/liter with a provision to revise it after six months. Some biodiesel units using TBO and imported palm oil have already started manufacturing biodiesel on small scale.

Though India is the fourth largest producer of edible oilseeds in the world, it produces only 60% of its total oilseed requirement and the rest is met through imports. Despite the low overall oilseed production presently, the country has a potential not only to become self-sufficient in but to produce surplus oilseeds simply by following the improved low-input technologies of oilseeds production and by a proper delineation of government policies favorable to oilseeds production. These low input technologies have demonstrated 14-100% increase in seed yield over the existing practices under different conditions (DOR, 2005).

3.2 **Ethanol production in India**

In India, the world's second largest sugar producer, ethanol is mainly produced from molasses, a sugar by-product. India's molasses production declined from 8.0 million tonnes in 2002-03 to 5.0 million tonnes in 2004-05 due to poor sugar cane output. However it has started rising again and is expected to achieve record levels this year.

The first phase of the ethanol-blended petrol was to have been launched in January 2003, but it took the industry a good three years to iron out start-up glitches. One issue was that the ethanol imported from Brazil was available at a lower price than domestic ethanol. Even at the 5% blend level being implemented currently there is a shortfall of 225 million liters of ethanol for the oil companies whose current demand is put at 435 million liters (Sify business, 2006).

India produced 1749 million liters of ethanol in 2004 mainly from sugar cane (Peterson, 2006), and has a very high potential to increase it further by using sweet sorghum, sugar beet and sugar cane juice as potential feedstock options. Another potential source of ethanol can be cellulosic energy crops and crop residues as well as other waste products high in cellulose.

4. **Biofuel Strategy for India**

Domestic supply of crude oil meets only about 22% of the demand for surface transportation in India, while the rest is being met from imported crude. Biodiesel and ethanol both are liquid biofuels and are considered as promising alternatives for diesel and petrol, particularly in the transport sector.

A number of developmental activities are being taken up in the country for the production of biofuels which include 5% compulsory blend of ethanol in petrol and 5% biodiesel blend in diesel. These trials are on in various states and the Government of India wants to increase these blends to 10%.

Though ethanol definitely has a role to play in future as a petrol supplement, there are several restraints to its use and small scale on-farm production, the major one being the onerous customs and excise regulations. Nevertheless a strategy to use both fuels (ethanol and biodiesel) as blends will be beneficial to Indian economy. The strategy consists of producing ethanol and biodiesel from crops to be grown on the same piece of land in different seasons. Since sugar cane is a long duration crop, sweet sorghum which is a 4-month crop is more suitable for such rotation.

Thus it is proposed that from a given piece of land two crops can be taken, viz. sweet sorghum during monsoon followed by a winter oilseed or a monsoon oilseed followed by sweet sorghum in winter. In addition to ethanol and oil, they will also yield food grain, meal suitable for animal feed and biomass residues which can also be converted to ethanol. These crops can give a reasonable output even under rain fed conditions with low external input. Though the crops can be grown under a rain fed situation, in most cases just 2-3 irrigations at critical stages can produce a significant increase in both net returns and bio-energy production.

Four of the oilseed crops considered viz. rapeseed, mustard, safflower and linseed can be grown only in winter, while groundnut, sunflower and sesame can be grown in monsoon or winter and castor, niger, soybean and cotton only in monsoon. Sweet sorghum can be grown in either monsoon or winter, but there is considerable decrease in its stalk yield accompanied by an increase in the yield of grain in the winter crop.

4.1 **Energy production from oil**

The assessment of potential biodiesel yield from different oilseed crops has been done and is presented in table 4. The results reveal that under irrigated conditions the maximum bio-energy production of 61.1 X 10^3 MJ/ha/season can be obtained from the oil of castor which is followed by groundnut (45.5 X 10^3 MJ/ha/season), sunflower (27.4 X 10^3 MJ/ha/season) and mustard (23.6 X 10^3 MJ/ha/season). The maximum bio-energy production from oil under rain fed conditions is given by groundnut (31.2 X 10^3 MJ/ha/season), which is followed by castor (25.8 X 10^3 MJ/ha/season) and sunflower (16.7 X 10^3 MJ/ha/season). The agricultural residues - a potential source of second generation biofuels is generally either burnt in the field itself or is used for household purposes like cooking. It does not have any worthwhile use at present. By taking into consideration the possibility of development of suitable technology for bioethanol production from residues in near future, the production of ethanol bio-energy from agricultural residues of the oilseed crops has been estimated (Table 4).

4.2 **Energy production from oil and crop residues**

Calculations of energy production from residues of different oilseed crops revealed that under irrigated conditions castor recorded the maximum energy output of 54.2 X 10^3 MJ/ha/season which was followed by mustard (51.3 X 10^3 MJ/ha/season) and sunflower (32.3 X 10^3 MJ/ha/season). Under rain fed conditions maximum energy production from crop residues is obtained from rapeseed (26.4 X 10^3 MJ/ha/season), which is followed by castor (22.9 X 10^3 MJ/ha/season) and mustard (22.7 X 10^3 MJ/ha/season). The aggregate biofuel production from oil and crop residues of different oilseeds was estimated to range from 7.7 X 10^3 MJ/ha/season obtained from cotton to 49.5 X 10^3 MJ/ha/season obtained from groundnut under rain fed conditions. Under irrigated conditions, aggregate biofuel production ranged from 22.8 X 10^3 MJ/ha/season in sesame to 115.3 X 10^3 MJ/ha/season in castor (Table 4). Thus the value addition to the oilseed crop residues by using them to produce second generation biofuels will help in getting additional monetary returns from oilseeds. This will considerably raise the total remuneration from the crops to the farmer. As a result both area under the oilseed crops and their production in the country will increase. This will not only make India oil-sufficient but surplus in oil which can be used for manufacturing of biodiesel.

4.3 **Bio-energy production from oilseeds and sugar producing crops**

The comparison of bio-energy production from oilseeds and sugar producing crops showed that sugar cane recorded a bio-energy production of 139 X 10^3 MJ/ha/season while sweet sorghum recorded a bio-energy production of 89.7 X 10^3 MJ/ha in monsoon and 35.7 X 10^3 and 42.5 X 10^3 MJ/ha/season under winter rain fed and irrigated conditions respectively (Table 4). Sugar cane was observed to produce higher energy than the highest bio-energy producing oilseed crop viz. irrigated castor. However, the comparison of bio-energy production from sugar cane with that from oilseed crops is not justified, since all the oilseed crops compared are of seasonal (4-5 months duration) nature and are grown under rain fed or limited irrigation conditions often on marginal soils. Contrary to this, sugar cane is a 12-18 month crop grown only under extensive irrigated conditions and usually on good soils with high external input.

To have energy security and to get maximum remuneration from a rainfed cropping system, it would be most desirable to have a combination of crops like sweet sorghum during monsoon and the most promising oilseed crop of the region during winter. In case of an oilseed like castor or soybean, it can be grown in monsoon followed by sweet sorghum in winter. By doing this, aggregate energy production as well as the returns from the rainfed cropping system as a whole can be maximized. Therefore an assessment of aggregate bio-energy production and net returns to farmers from both rain fed and irrigated cropping systems has been done (Tables 5 and 6).

The results indicate that bio-energy production from sweet sorghum (juice + crop residues) and oilseed crop (oil + crop residues) under rain fed conditions ranged from 139.2 X 10^3 MJ/ha/year in sweet sorghum + groundnut to 43.4 X 10^3 MJ/ha/year in the combination of cotton + sweet sorghum. Sweet sorghum not only gives a very high yield of crop residues but also juice from stalk and grain for human consumption. Under irrigated conditions the bio-energy production ranged from 164.6 X 10^3 MJ/ha/year in sweet sorghum + mustard to 76.5 X 10^3 MJ/ha/year in cotton + sweet sorghum.

Just the introduction of sweet sorghum in the oilseeds area during monsoon or winter for production of bio-energy from sweet sorghum juice alone, for which technology is already in place, can achieve significant biofuel production. Even if only 50% of the 8.5 million ha of winter oilseeds area is planted with sweet sorghum in monsoon, it can produce 4165 million liters of ethanol which is equivalent to 2546 million liters of petrol energy wise. This assumes a conservative estimate of 35 tonnes/ha of fresh stalk, juice extraction of 40% and production of 7 liters ethanol/100 liters of juice in monsoon. This much ethanol is nearly 3.27% of total transport fuel consumed in the country and is nearly 6% of the total crude oil produced in the country (Planning Commission, 2003). Such a system would enhance the area under sweet sorghum and oilseeds in the country to a substantial level to produce enough ethanol and surplus oilseeds to be utilized for bio-energy production.

4.4 Economics of the sweet sorghum-oilseed cropping system

In addition to the bio-energy production, it is important to consider the net returns a farmer is able to get from a given cropping system. As far as a farmer is concerned the end utilization of his crop is irrelevant. He is only interested in the total remuneration that he can get from a given piece of land in a year.

Net returns under rain fed conditions ranged from Rs. 32680/ha/year in soybean + sweet sorghum to Rs. 19617/ha/year for sweet sorghum + sesame (Table 5, Fig. 2). Under irrigated conditions the net returns ranged from Rs. 94743/ha/year for castor + sweet sorghum to Rs. 21741/ha/year for sweet sorghum + sesame (Table 6, Fig. 2).

Thus ultimately the promise of a given cropping system can be determined from the product of its bio-energy output and net returns it can give to a farmer (BENR).

Under rain fed conditions the highest values of BENR are given by a combination of sweet sorghum in monsoon followed by either groundnut, rapeseed, mustard, sunflower or safflower (in that order) during winter (Table 5, Fig. 3).

As far as the values of BENR under irrigated conditions were considered, castor-sweet sorghum was the only crop combination which was better than sugarcane. It was followed by combinations of sweet sorghum in monsoon with either mustard or groundnut in winter. Cotton in monsoon followed by sweet sorghum in winter was ranked fourth (Table 6, Fig. 3).

4.5 **Tree-borne oilseeds (TBO)**

Tree-borne minor oilseeds have been accorded very high priority as a source material for biodiesel production in the country. India is endowed with a vast potential for oilseeds of tree origin, the important of them being sal, mahua, neem, rubber, karanja, kusum, khakan (pilu), undi, dhupa, etc. (Table 7). These oilseed-bearing trees are found widely and distributed throughout the country. The present availability of oilseeds from them is estimated to be about 5 million tonnes annually. However, only 20% of the total availability is utilized for commercial applications (Kumar, 2003).

The availability of TBO can be enhanced considerably without any extra land and inputs if proper network for procurement from seed collectors is established. There is a considerable scope to enhance the collection of seeds from the existing trees by developing infrastructure facilities such as seed/produce procurement centers equipped with facilities for drying, decorticating, cleaning/grading, depulping, storing and oil extraction near the areas of collection of TBO. Establishment of biodiesel processing units near the procurement centers will further help in reducing the cost of transportation of the raw oil to the biodiesel processing plant. This should result in reasonable remuneration to the primary seed collector and also help in getting a quality product by reducing losses caused due to delayed and improper handling of the material at different stages in the existing trade of TBO in India.

Apart from the existing trees in the country, there is 60 million hectares of wasteland, of which 50% can be suitably used for growing TBO plantations like those of *Jatropha* and karanja. With the recent central government drive to produce biodiesel from TBO, many state governments have given very high priority to plantations of *Jatropha* for biodiesel production. Information from various sources indicates that area under *Jatropha* plantations in the country has gone up to 20,000-30,000 hectares. Governments of states like Chhattisgarh, Gujarat and Madhya Pradesh have drawn up plans to take up *Jatropha* plantations on massive scale.

In order for the above strategy to become operational, the following policy issues have to be addressed :

Policy issues :

1. Make long term policy on utilization of edible and non-edible oils by deciding their allocation for different uses.
2. Delineate taluka-wise liquid fuel requirements to decide the cropping pattern to be adopted in them.

3. Encourage public-private partnerships for successful large scale implementation of oilseeds program.
4. In addition to transport sector, investigate use of vegetable oils or biodiesel for irrigation pumps, diesel generators, farm equipment, cook stoves, lanterns etc.
5. Liberalize excise law.

5. Conclusions

The prospects of using agricultural material for biofuel in India for energy purpose appear to be promising.

In the final analysis, the cropping systems with sweet sorghum in monsoon and an oilseed like groundnut, rapeseed or sunflower in winter appear to be the best as they have a potential to give high bio-energy production coupled with good net returns to the farmer under both rain fed and irrigated conditions.

Cropping system with castor in monsoon and sweet sorghum in winter was also found to be promising mainly under irrigated conditions, though it gave very high returns even under rain fed situation. It is even more attractive as it produces a non-edible oil. India is the world's leading producer of castor and the first in the world to exploit hybrid vigor in the crop on commercial scale.

Extent of bio-energy outputs and net returns obtainable from *Jatropha* is still a question mark and till the results of trials currently underway are in, it may not be a good idea to plant large tracts of cultivable land under this genus. It will be better in the long run to attempt to increase the area under conventional oilseeds. This in addition to giving higher remuneration to farmers can potentially alleviate the twin problems of shortage of edible oils and energy in the country. As a result there will be tremendous savings to the country's foreign exchange reserve.

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Table 1 : World ethanol production in 2004 and major feedstock

Country	Feedstock	Million Liters
Brazil	Sugarcane	15,099
United States	Corn	13,381
China	Corn, wheat	3,649
India	Sugarcane	1,749
France	Sugarbeet, wheat, corn	829

Source : F.O. Licht, cited in Renewable Fuels Association, Homegrown for the Homeland : Industry Outlook 2005 (Washington, DC), p. 14.

Table 2 : Crop residue production in India, U.S. and the world in 2001

Crop	India	U.S.	World
------------------------ 10^6 tonnes -------------------------			
Cereals	396	367	2802
Legumes	24	82	305
Oil crops	22	20	108
Sugar crops	-	14	170
Tubers	-	5	-
Total	**442**	**488**	**3385**

Source : Adapted from Lal, 2004a, b; 2005a, b.

Table 3 : Ethanol production from residues of some crops

Crop	Ethanol yield (L Kg^{-1})
Barley straw	0.31
Corn stover	0.29
Oat straw	0.26
Rice straw	0.28
Sorghum straw	0.27
Wheat straw	0.29
Sugarcane bagasse	0.28

Source : Adapted from Kim and Dale, 2004.

Table 4 : Biofuel potential of different oilseed crops in comparison with sweet sorghum and sugarcane

Sr. No.	Crops	Seasons	Potential seed* yield/ season (kg/ha)	Average oil yield/ season (kg/ha)	Average dry crop residue yield/ season** (kg/ha)	Energy production from oil/ season (MJ/ha) X 10^3	Energy from crop residues/ season (MJ/ha) X 10^3	Total energy production/ season (MJ/ha) X 10^3	References
1.	**Castor** Rain fed	Monsoon	1267	621	3801	25.8	22.9	48.7	12, 38
	Irrigated		3000	1470	9000	61.1	54.2	115.3	
2.	**Groundnut** Rain fed	Monsoon/ Winter	1500	750	3045	31.2	18.3	49.5	3, 12,
	Irrigated		2186	1093	4438	45.5	26.7	72.2	
3.	**Mustard** Rain fed	Winter	613	251	3766	10.4	22.7	33.1	7, 12
	Irrigated		1385	568	8508	23.6	51.3	74.9	
4.	**Sunflower** Rain fed	Monsoon/ Winter	1028	401	3255	16.7	19.6	36.3	12, 37
	Irrigated		1691	659	5355	27.4	32.3	59.7	
5.	**Safflower** Rain fed	Winter	1034	310	3102	12.9	18.7	31.6	12, 13
	Irrigated		1688	506	5064	21.0	30.5	51.5	
6.	**Rapeseed** Rain fed	Winter	898	368	4384	15.3	26.4	41.7	7, 12
	Irrigated		1027	421	5014	17.5	30.2	47.7	

Table 4 contd….2

Sr. No.	Crops	Seasons	Potential seed* yield/ season (kg/ha)	Average oil yield/ season (kg/ha)	Average dry crop residue yield/ season** (kg/ha)	Energy production from oil/ season (MJ/ha) X 10^3	Energy from crop residues/ season (MJ/ha) X 10^3	Total energy production/ season (MJ/ha) X 10^3	References
7.	**Soybean**	Monsoon	1705	307	3166	12.8	19.1	31.9	5, 12, 17
8.	**Linseed** Rain fed	Winter	861	319	1599	13.3	9.6	22.9	8, 12
	Irrigated		1097	406	2037	16.9	12.3	29.2	
9.	**Niger**	Monsoon	304	122	3593	5.1	21.6	26.7	12, 42
10.	**Sesame** Rain fed	Monsoon/ Winter/ Summer	516	258	1395	10.7	8.4	19.1	12, 41
	Irrigated		616	308	1665	12.8	10.0	22.8	
11.	**Cotton** Rain fed	Monsoon	463 (268)	35	1030	1.5	6.2	7.7	9, 15, 18, 31
	Irrigated		2060 (1195)	155	4585	6.4	27.6	34	
12.	**Jatropha**	Perennial	3750	1200	-	49.9	-	49.9	1

Table 4 contd….3

Sr. No.	Crops	Seasons	Potential seed* yield/ Season (kg/ha)	Average oil yield/ season (kg/ha)	Average dry crop residue yield/ season** (kg/ha)	Energy production from oil/ season (MJ/ha) X 10^3	Energy from crop residues/ season (MJ/ha) X 10^3	Total energy production/ season (MJ/ha) X 10^3	References
13.	**Sweet sorghum** Monsoon		1000	980 (ethanol)	8750	26.4 (ethanol from juice)	63.3	89.7	6, 32
	Winter	Rain fed	2900	236 (ethanol)	5250	6.3 (ethanol from juice)	29.4	35.7	
		Irrigated	7400	351 (ethanol)	6000	9.4 (ethanol from juice)	33.1	42.5	
14.	**Sugarcane**	July-Aug. to Oct.-Nov. 15 months	-	4400 (ethanol)	34268	118.4 (ethanol from juice)	20.6 (bagasse)	139	30, 35

* Potential seed yield of each crop has been taken from the sources cited. Cotton seed yield given in paranthesis is 58% of seed cotton yield [45].

** Average crop residue yield for different crops has been estimated from the potential seed yield (average) furnished in the present table and the harvest indices in the articles cited.

Table 5 : Estimated bio-energy production and net returns from sweet sorghum and oilseed-based cropping system (Rain fed)

Sr. No.	Season and crop		Bio-energy Production (MJ/ha X 10^3)			Net Returns (Rs/ha)			Bio-energy X Net returns X 10^4
	Monsoon	Winter	Monsoon	Winter	Total/year	Monsoon	Winter	Total/year	
1.	Sweet sorghum	Groundnut	89.7	49.5	139.2	12500	18773	31273	435.3
2.	Sweet sorghum	Rapeseed	89.7	41.7	131.4	12500	11599	24099	316.7
3.	Sweet sorghum	Mustard	89.7	33.1	122.8	12500	12806	25306	310.8
4.	Sweet sorghum	Sunflower	89.7	36.3	126	12500	11839	24339	306.7
5.	Sweet sorghum	Safflower	89.7	31.6	121.3	12500	11365	23865	289.5
6.	Castor	Sweet sorghum	48.7	35.7	84.4	16810	15800	32610	275.2
7.	Sweet sorghum	Linseed	89.7	22.9	112.6	12500	10997	23497	264.6
8.	Soybean	Sweet sorghum	31.9	35.7	67.6	16880	15800	32680	220.9
9.	Sweet sorghum	Sesame	89.7	19.1	108.8	12500	7117	19617	213.4
10.	Niger	Sweet sorghum	26.7	35.7	62.4	5563	15800	21363	133.3
11.	Cotton	Sweet sorghum	7.7	35.7	43.4	7715	15800	23515	102.0
12.	Jatropha	Jatropha	-	-	49.9	-	-	15000	74.8

Table 6 : Estimated bio-energy production and net returns from sweet sorghum and oilseed-based cropping system (Irrigated)

Sr. No.	Season and crop		Bio-energy Production (MJ/ha X 10^3)			Net Returns (Rs/ha)			Bio-energy X Net returns X 10^4
	Monsoon	Winter	Monsoon	Winter	Total/year	Monsoon	Winter	Total/year	
1.	Sweet sorghum	Groundnut	89.7	72.2	161.9	12500	26905	39405	638
2.	Sweet sorghum	Rapeseed	89.7	47.7	137.4	12500	15133	27633	380
3.	Sweet sorghum	Mustard	89.7	74.9	164.6	12500	30729	43229	711.5
4.	Sweet sorghum	Sunflower	89.7	59.7	149.4	12500	21855	34355	513.3
5.	Sweet sorghum	Safflower	89.7	51.5	141.2	12500	18614	31114	439.3
6.	Castor	Sweet sorghum	115.3	42.5	157.8	47943	46800	94743	1495
7.	Sweet sorghum	Linseed	89.7	29.2	118.9	12500	13188	25688	305.4
8.	Sweet sorghum	Sesame	89.7	22.8	112.5	12500	9241	21741	244.6
9.	Cotton	Sweet sorghum	34	42.5	76.5	29223	46800	76023	581.6
10.	Jatropha	Jatropha	-	-	49.9	-	-	15000	74.8
11.	Sugarcane	Sugarcane	-	-	139	-	-	85000	1181.5

Table 7 : Available potential of tree-borne oilseeds in India

Sr. No.	TBOs	Seed yield [10] (lakh tonnes)	Oil content [36, 43] (%)	Oil yield (lakh tonnes)
1.	Sal (*Shorea robusta*)	62.0	12	7.44
2.	Mahua (*Madhuca indica*)	5.2	35	1.82
3.	Neem (*Azadirachta indica*)	5.0	20	1.0
4.	Rubber (*Hevea brasiliensis*)	0.79	45	0.35
5.	Karanja (*Pongamia pinnata*)	1.11	27	0.30
6.	Kusum (S*chleichera oleosa*)	0.45	33	0.15
7.	Khakan (*Salvadora oleoides*)	0.44	33	0.14
8.	Undi (*Calophyllam inophyllum*)	0.11	60	0.07
9.	Dhupa (*Vateria indica*)	0.13	19	0.02
10.	Other*	2.0		
	Total	77.34		

Source : Adapted from Damodaram and Hegde (2005).

* **Other** : Maroti (*Hydnocarpus wightiana*), Palash (*Butea monosperma*), Pisa (*Actinodaphne angustifolia*), Ratanjyot (*Jatropha curcas*), Tumba (*Citrullus colocynthis*), Teak (*Tectona grandis*)

Fig. 1. Bio-energy from sweet sorghum and oilseed-based cropping system under rainfed and irrigated conditions

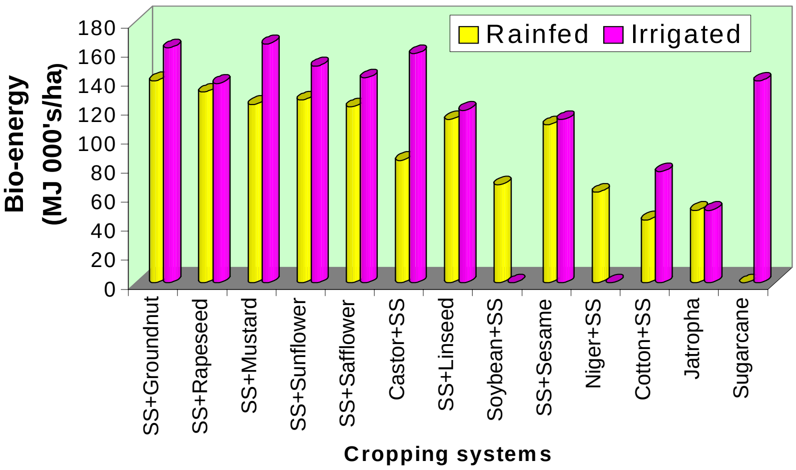

Fig. 2. Net returns from sweet sorghum and oilseed-based cropping system under rainfed and irrigated conditions

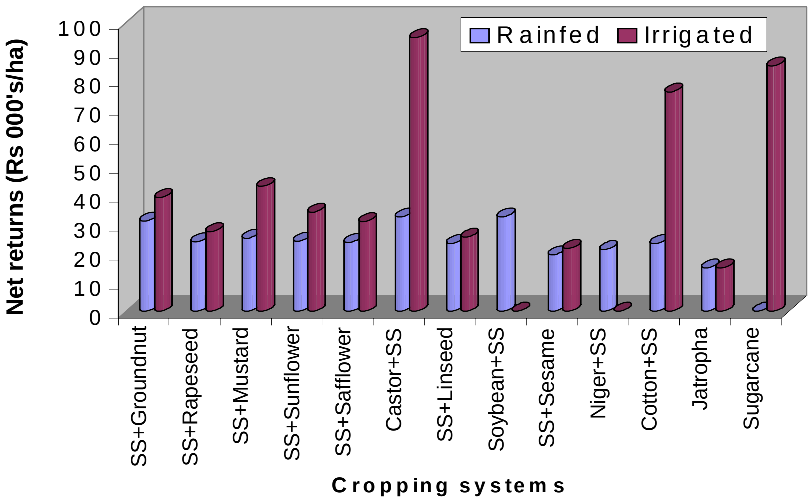

Fig. 3. Bio-energy X net returns from sweet sorghum and oilseed-based cropping system under rainfed and irrigated conditions