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Energy budget of *Jatropha*-based cropping systems in Tarai area of Central Himalayas, India

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ABSTRACT

The present investigation was carried out to work out energy budget of *Jatropha curcas* L. sown exclusively and intercropped with three food crops, viz. wheat, mustard and soybean, in Pantnagar University farm at Tarai area of Himalayan foothills during crop season 2017. The results showed that the energy use efficiency expressed as the output-input energy ratio, was highest in case of wheat cultivated as a sole crop (6.76). When the wheat was intercropped with *Jatropha*, the output-input ratio declined to 4.20. Energy productivity (per ha basis) figures brought to the fore the fact that on investing one kJ the highest production was in case of wheat cultivated as a sole crop (18. 88×10^{-5} kg/kJ). The value decreased to 11. 74×10^{-5} kg/kJ in the *Jatropha*-wheat intercropping system. A trend of decrease in energy productivity of food crops in the *Jatropha*-based intercropping system revealed that these cropping systems were not favourable for harvesting more energy of useful production. *Jatropha's* own energy productivity (12. 40×10^{-5} kg/kJ) was comparatively lower than all the food crops raised as sole crops but relatively higher when the crops were raised with *Jatropha*. The figures of specific energy increased with the cultivation practice of *Jatropha*-based intercropping of food crops. The net energy values for wheat raised under both the systems surpassed the values for *Jatropha* and all other food crops. In case of each food crop, the values of net energy decreased on cultivation of the crop with *Jatropha*. We can arrive at the conclusion that the *Jatropha*-based intercropping is not a promising agronomic practice.

Key words: Energy budget, Intercropping system, *Jatropha,* Mustard, Soybean, Wheat

Agro-ecosystems are relatively simple ecosystems comprising only autotrophic crops which store solar energy in the nutrients primarily used for human consumption. In addition to solar energy, agro-ecosystems, unlike natural ecosystems, also use other forms of energy, e. g. that obtainable from fossil fuels (in operating tractors, threshers, etc.), manure, chemical fertilizers, pesticides, etc. After trapping solar energy and using energy from other sources (input energy), an agro-ecosystem produces products (output energy), e. g. fruits, seeds, food grains, straw for livestock consumption, etc.

Output to input (in terms of energy) ratio is indicative of the energy use efficiency of an ecosystem or an agro-ecosystem. This is also indicative of the economic performance of an agro-ecosystem, for energy involved can also be valued in monetary terms.

Functioning of an agro-ecosystem is somewhat different from that of a natural forest ecosystem. In the former case, anthropogenic intervention leads to an alteration in the pattern of energy usage determining the harvestable energy in biomass. While in a natural ecosystem (such as a forest) solar radiation is the sole natural energy input, an agro-ecosystem inevitably uses many other inputs to sustain its productivity.

An analysis of energy flow through an ecosystem, a cropping system, or a society becomes necessary for describing the functioning of that system. *Jatropha* cultivation in the Tarai region of the Central Himalayan Mountains is a recent craze borne out of the idea of replacement of conventional fossil fuel by the so-called biodiesel. The Tarai region lying in the Himalayan foothills is among the most fertile areas of India. *Jatropha* in the Tarai region was earlier cultivated as a pure crop. Looking at the cultivated land as one of the critical factors in India, in recent years food crops are also being cultivated in association with *Jatropha*. Whereas energy budgets of conventional crops have been worked out earlier (Amaducci *et al.* 2017, Graamans 2017, Rastogi *et al.* 2018), energy budget of *Jatropha* cultivation as well as of the crops raised in the *Jatropha*-based inter-cropping systems has not been worked out in detail. This study was thus undertaken to work out energy budget of *Jatropha curcas* L. sown exclusively, and intercropped with three food crops, viz. wheat, mustard and soybean.

MATERIALS AND METHODS

Experimental site: The experimental site is at

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Agroforestry Research Centre of G B Pant University of Agriculture and Technology (29°N latitude 79°E longitudes and an altitude of 243. 8 meters amsl) in the Tarai belt of Shivalik range of the Central Himalayan foothills in the Uttarakhand State of India. It falls in the sub-humid and sub-tropical climate zone. The Himalayan Tarai region is regarded as one of the most fertile cultivated land in India.

Inter-cropping systems: Energy budget of the 4 dominant intercropping systems managed during summer season (2017) was worked out. These were–*Jatropha* (Control), *Jatropha*-wheat, *Jatropha*-mustard, *Jatropha*-soybean.

Energy values: Some of the energy values of the inputs and outputs involved in the *Jatropha*-based cropping system were based on Mitchell (1979) and Ralhan *et al.* (1991) as indicated in Table 1.

Based on the energy equivalents of the inputs and outputs, the energy ratio (energy use efficiency), energy productivity and specific energy were calculated with the help of the following calculations (Sartori *et al.* 2005, Demircan *et al.* 2006):

Energy use efficiency = Energy output (kJ/ha)/ Energy input (kJ/ha)

Energy productivity = Grain output (kg/ha) / Energy input (kJ/ha)

Specific energy = Energy input (kJ/ha) / Grain output (kg/ha)

Net energy = Energy output (kJ/ha) – Energy input (kJ/ha)

RESULTS AND DISCUSSION

Sources of energy: The sources of energy other than solar radiation used invariably in agro-ecosystems are: fossil fuels (used in tractors and other farm machinery for land preparation, threshing, transportation, etc.), manure (for supplying nutrients and energy for soil microbes), seeds (having energy biomolecules, viz. carbohydrates, fats and proteins vital for providing energy for germination and initial growth of the plants), human labour (necessary for all agricultural operations and management) and draught animals (in traditional agriculture, particularly in mountain agriculture, which in the green revolution agriculture, as also in the study area has been replaced by mechanical power).

Chemical fertilizers and pesticides have energy values of their own, but, they also involve very high amounts of energy during their synthesis/manufacturing. The flow of energy and nutrients between environment and plant (*Jatropha* here) is part of a complex physiological phenomenon. Flow of all essential macro- and micro-nutrients in the plant involves different components of the environment. Energy is usually an input in the synthesis of biomolecules (carbohydrates, proteins, lipids, nucleic acids, etc.) as well as in nutrient uptake. In working out energy budget of *Jatropha* cultivation and in raising crops together with *Jatropha* (inter-cropping systems), we considered only the energy component of the plants, both input and output energy, in the cultivation practices.

Inputs for crop cultivation: The various inputs used in the cultivation of a food crop are fossil fuel to be used in tractor tiller and threshing machine. Energy values for various inputs used in the cultivation of *Jatropha*-based cropping patterns are presented in Table 1. Quantitative figures of agricultural inputs, namely diesel (used in tractor), human labour (for accomplishing all agricultural operations), seed rate, fertilizers and pesticides, and those of useful agricultural outputs, namely grains and straws for one hectare land are presented in Table 2. It comes to the fore from these figures that while wheat cultivation required maximum amount of diesel to be used as fuel by tractors. *Jatropha* cultivation used only human labour.

Fertilizer consumption is one of the characteristics of high-yield agriculture. Wheat and *Jatropha*-wheat systems invested maximum amount of chemical fertilizers. The least amount of fertilizer used in raising *Jatropha* in monoculture was attributable to its deep root system compared to other annual crops due to which it can rely on deeper layers of soil for picking up essential nutrients. Application of pesticides can be linked with the vulnerability of individual crop to a variety of pests and diseases (Singh 2019).

Outputs of the crops: Only the outputs of economic value were taken into consideration. Those used as waste were not considered. Seeds were the only economic output of *Jatropha.* The recovery of biodiesel from *Jatropha* seeds was 22%. The other vegetative parts of the *Jatropha* crop were of no use. Wheat straw is a useful product consumed by livestock. Therefore, this by-product of wheat crop was included in energy budget. Crop residues to origin from mustard and soybeans, however, were not taken into consideration as thesewere not utilized in human use system and only ended up as a waste. Raising wheat, mustard and soybean crops with *Jatropha* resulted in decreased food grain yields, which obviously was due to sharing of common resources (nutrients) from a common ecological space by more than one species.

*Energy values of inputs:*The amounts of inputs presented in Table 2 were converted into energy values of the inputs based on already ascertained energy values for individual inputs as presented in Table 1. On the basis of the interaction between the data of Tables 1 and 2, Table 3 was drawn. Solar energy as a fixed input of *Jatropha* and food crops under study would inevitably be received as a function of the climate and latitude of the area. According to Pandey and Singh (1984), the amount of sunlight received as an

Table 1 Energy values for different inputs and outputs

Item	kJ/kg
Grains	16233.00
Straw	13986.00
Fertilizer	30340.80
Pesticide (Insecticide)	148000.00

Source: Based on Mitchell (1979); value for pesticides (insecticides) based on Ralhan *et al.* (1991)

Table 2 Amount of different inputs and outputs of *Jatropha* and crops cultivated under two systems (per ha per year)

Inter-cropping system	Inputs					Outputs	
	Fossil fuel (l)	Human labour (mandays)	Seed (kg)	Fertilizer (NPK+Sulphur) (kg)	Pesticides (kg)	Grains (kg)	Crop residue (kg)
Jatropha	-	365	-	100	30.00	5500* (1210)	-
Wheat	300	225	100	250 (150+60+40)	14.50	5600	7840
Jatropha-wheat	300	275	90	250 (150+60+40)	14.50	3500	4900
Mustard	150	116	4	120 (60+30+30)	8.50	2000	-
Jatropha-mustard	150	166	4	120 (60+30+30)	8.50	1600	-
Soybeans	220	200	80	170 (20+80+40+30)	18.5	3000	-
Jatropha-soybeans	220	250	70	170 (20+80+40+30)	18.5	2200	-

* Jatropha seeds (oil in kg, based on 22% oil recovery).

input in the Central Himalayas is equivalent to 6×10^{10} kJ/ha/yr. The same would be considered to be received in the study area in the proximity of the Indian Central Himalayas. However, since the solar energy is the common factor, it won't appear in discussing the overall energy budget.

Fossil fuel energy, particularly the energy value of diesel, utilized in land preparation and in threshing, is expended in maximum amount in wheat raised as a sole crop and along with *Jatropha* during a crop season each in the two systems of cultivation. The fossil fuel values have been calculated by multiplying total diesel quantity by 56310 kJ, the energy value of 1 litre diesel, according to Tamta (2010). A crop season, of course, denotes length of time (i.e. total number of days) between its sowing and harvesting, but it can be treated equal to one year as the crop is cultivated only once during a year. For *Jatropha* the calculations were based on 365 days of the year.

Energy invested through human labour,measured in terms of mandays, came up with highest value in the production of *Jatropha* during a year which was greater than that invested in the cultivation of food crops. The food crops were also foundexpending more human energy when cultivated with *Jatropha*. Seed is the basic source of energy required in germination of the seed till the plant is capable to prepare its own food following development of photosynthetic machinery. The energy value of seed was not considered in working out the energetics for *Jatropha*, for it depended on its own for capturing solar energy five years after the crop was raised utilizing the initial energy in the vegetative parts of the plants. Food crops raised as pure crops invested more energy in terms of seeds than when cultivated with *Jatropha*. Wheat as a sole crop invested maximum energy through seed while mustard as the sole crop invested the minimum (Table 3). Energy input in the form of seed mainly depends on the seed rate for individual crop cultivation. This is the key reason of differences in the seed energy content employed in individual crop cultivation.

Chemical fertilizers applied in different crops make major differences in the energy budget of crop cultivation. Amounts of fertilizers vary according to the type (genetic makeup) of crop and chemical compositionof the soil. Most of the energy in the form of fertilizers was absorbed in the cultivation of wheat, followed by soybeans and mustard. In its fifth year, *Jatropha* fields did not require much expenditure of energy. Again, there was no variation in the amount of energy input. Pesticides employed in crop cultivation consumed large amounts of energy. A kg of pesticide provides as many as 148000 kJ (Mitchell 1979). Maximum energy input in the form of pesticides was employed in *Jatropha*. Amongst the food crops studied, soybeans expended maximum energy in the form of pesticides, followed by wheat and mustard (Table 3). The reason of varying pesticide applications was obvious: the more vulnerable a crop to pest infestation, the greater the

Table 3 Energy equivalents (kJ×10^5) of various inputs and outputs used in the cultivation of *Jatropha* and food crops per ha per year

Inter-cropping system	Input					Output	
	Fossil fuel	Human labour (mandays)	Seed	Fertilizer	Pesticides	Grains	Crop residue
Jatropha	-	22.84	-	30.34	44.40	476.01	-
Wheat	168.93	14.08	16.23	75.85	21.46	909.05	1096.50
Jatropha-wheat	168.93	17.21	14.61	75.85	21.46	568.16	685.31
Mustard	84.47	7.26	0.65	36.41	12.58	324.66	-
Jatropha-mustard	84.47	10.39	0.65	36.41	12.58	259.73	-
Soybeans	123.88	12.52	12.99	51.58	27.38	486.99	-
Jatropha-soybean	123.88	15.65	11.36	51.58	27.38	357.13	-

1.0 litre diesel = 56310 kJ; 1.0 kg Jatropha biodiesel = 39340 kJ

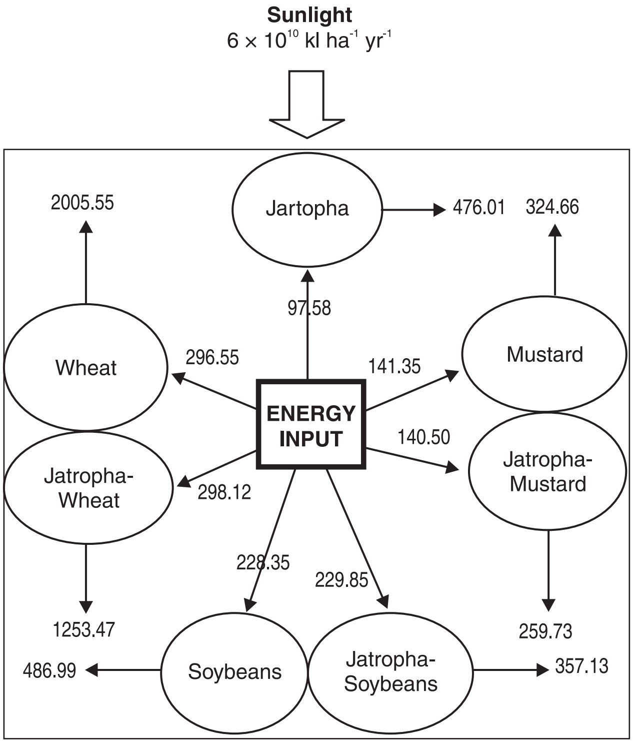

Fig 1 Energy budget of *Jatropha curcas* and food crops cultivated with and without *Jatropha* (all values, except for sunlight, are in kJ×10^5/ha/yr).

amount of the pesticide sprinkled for crop protection. Apart from the recommended doses crop-wise, the amount of the sprinkled pesticides is also determined on the basis of close observations of plant protection needs.

Energy values of outputs: The only product of economic value coming out of *Jatropha* cultivation is the oil, or the so-called biodiesel. One kg of biodiesel provides energy equal to 39340 kJ (http://www. greencarcongress. com/2006/11/comparing_the_e. html); thus the total energy provided by total production of *Jatropha* diesel oil from one ha area over a period of one year was 476.01 × 10^5 kJ (Table 3).

Wheat crop has emerged as one of the most important food crops the world over. The two outputs of vital economic value obtainable from wheat are grains usable for human consumption and straw usable as fodder for livestock. Areduction of 37.5% energy in each product (food grains and straw) was recorded when wheat was cultivated with *Jatropha*. Mustard and soybean registered 20% and soybean of 27% reduction in yields when they were raised in *Jatropha*-based intercropping system (Table 3). On the whole, it is the wheat crop cultivated with *Jatropha* which expended the highest amount of energy (298.12 × 10^5 kJ/ha) during a crop season (Fig 1).

The least amount of energy was expended in the production of *Jatropha curcus* over a period of one year, which was because of the fact that during the fifth year of production the *Jatropha* plants did not need much input for increasing production.

It would also be interesting to note the pattern of animate and inanimate energy involved in crop cultivation. Animate energy includes human labour and seed, while inanimate energy includes fossil fuel, fertilizers and pesticides (Singh and Partap 2002). In *Jatropha* cultivation the animate energy comprised only 23.34%. Wheat cultivated in exclusive form expended only 16.97% animate energy. When cultivated along with *Jatropha*, the wheat crop expended reduced proportion of animate energy (10.66%). Out of a total (animate and inanimate) energy, the mustard crop consumed only 5.6% and 4.25% animate energy when cultivated without and with *Jatropha*, respectively. Soybeans expended 11.17 and 11.36% animate energy of the total energy input when cultivated without and with *Jatropha*, respectively. Thus, in every food crop, except for soybeans, the proportion of the animate energy was reduced when the crop was raised with *Jatropha*. Reduced rate of seed in the *Jatropha* based intercropping system was the reason of this decrease.

As the form of energy is important for the quality of the environment, proportion of the animate energy involved in energy input is of crucial importance. Animate energy is renewable energy and therefore environmentally safer than the inanimate energy which is a non-renewable form of energy often hazardous to the environment (Singh 1998, Singh and Partap 2002). From this perspective, *Jatropha* is environmentally sounder than the food crops. Amongst the food crops, wheat is environmentally safer than mustard and soybeans. However, it is not the only proportion of the animate energy that is used, the overall amount of the inanimate energy would be the key input to affect quality of the environment.

Energetics of cultivation: Energy use efficiency or output-input ratio was the widest in case of wheat cultivated as a sole crop, which means that on investing unit energy in cultivation as many as 6.76 units were harvested. When wheat was intercropped with *Jatropha*, the output-input ratio declined to 4.20. The ratio also declined from 2.29 to 1.80 when mustard was sown with *Jatropha*. There was no change in the energy use efficiency of soybeans (2.13) when the crop was taken with *Jatropha*. *Jatropha* produced 4.88 units of energy in the form of biodiesel against investing a unit of energy (Table 4).

Usage of energy depends not only on the supply and availability of energy in various forms but also on certain edaphic factors responsible for stimulating or inhibiting bioavailability of certain nutrients to plants. *Jatropha*, owing to its shade (due to which it could alter microclimatic factors) and allelopathic effects, is likely to affect a crop cultivated along with *Jatropha*.

Energy productivity figures revealed that on investing one kJ the highest production was in case of wheat cultivated as a sole crop (18.88 × 10^{-5} kg/kJ). The value decreased to 11.74 × 10^{-5} kg/kJ when wheat was cultivated with *Jatropha*. The trend of decrease in productivity in the cultivation of food crops along with *Jatropha* persisted in all the crops. *Jatropha*'s own productivity measured in energy value was comparatively lower than all the food crops cultivated as sole crops but comparatively higher when the crops were

Table 4 Comparative performance of different cropping systems in terms of energy input, output and production

Cropping system	Energy use efficiency (Output Input ratio)	Energy productivity (kg/kJ × 10^{-5})	Specific energy (kJ/kg)	Net energy (kJ/ha× 10^{-5})
*Jatropha**	4.88	12.40	8064.46	378.43
Wheat	6.76	18.88	5295.54	1709.00
Jatropha-wheat	4.20	11.74	8517.71	955.35
Mustard	2.29	14.14	7067.50	183.31
Jatropha-mustard	1.80	11.07	10447.72	115.23
Soybean	2.13	13.14	7611.67	258.64
Jatropha-soybean	2.12	9.57	10447.72	127.28

* In Jatropha oil production (the only product of economic value) per ha was taken in place of the grains produced by food crops.

raised with it (Table 4).

Energy productivity of food crops raised along with *Jatropha* is affected adversely perhaps due to *Jatropha's* allelopathic effects on the food crops. However, the allellopathic effects were limited by increased spacing between the rows of *Jatropha* plants.

Specific energy was recorded to be the highest in case of soybeans when cultivated with *Jatropha* followed by that of mustard also cultivated with *Jatropha*. The figures of specific energy increased with the cultivation practice of *Jatropha*-based intercropping of food crops (Table 4).

Net energy value, which is a very useful indicator of productive performance of a crop or of an ecosystem, revealed that it was the highest for wheat sown without *Jatropha*. However, this value decreased when wheat was cultivated with *Jatropha*. The net energy values for wheat raised under both the systems surpassed the values for *Jatropha* and all other food crops. In case of each food crop the values of net energy were found decreased with the cultivation of the crop with *Jatropha*.

In the light of the data obtained during the working out of energy budget of *Jatropha*, we can arrive at the conclusion that the agrofuel crop being propagated rapidly these days creates adverse conditions for the productive performance of food crops to a certain extent and that the *Jatropha*-based intercropping is not a promising agronomic practice.

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