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Energy Input-Output Analysis for Production of Wheat under Different Planting Techniques and Herbicide Treatments

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The assessment of the energy requirements of the different planting techniques and herbicide treatment was carried out at Agronomy farm area, CCS Haryana Agricultural University, Hisar, Haryana, India with five planting techniques i.e. drill sowing at 20 cm, 18 cm and 16 cm, bed planting with three and two rows and five weed management treatments i.e. pinoxaden 50 g/ha, RM of carfentrazone and metsulfuron 25 g/ha, pinoxaden 50 g/ha + RM of carfentrazone and metsulfuron 25 g/ha, weed free and weedy check. Among different planting techniques, drill sowing with 18 cm is most efficient method in respect of energy calculations (NE, EUE, energy profitability, specific energy, energy productivity, energy intensiveness, energy intensity in physical terms, energy intensity in economic terms) followed by three row bed planting and 20 cm row spacing. This may be attributed to total energy output (grain + straw). Tank mix application of pinoxaden (50 g/ha) with RM of carfentrazone and metsulfuron-methyl is very efficient in terms of energy and recorded higher value of different energy calculations (EUE, energy profitability, specific energy, energy productivity, energy intensiveness, energy intensity in physical terms, energy intensity in economic terms).

Introduction

Wheat (*Triticum aestivum* L.) is a main cereal crop cultivated throughout the world along with rice, maize, barley, rye, sorghum, oats and millet. It is grown under irrigated as well as rainfed conditions worldwide. Based on Ministry of Agriculture and Farmers Welfare of India statistics, India produced about 98.38 million tonnes of wheat in 2016-17. Energy is one of the most valuable inputs in agriculture for crop production. Agriculture itself is an energy consumer and energy supplier in the form of bio-energy (Alam *et al.,* 2005). In response to fast growing populations, limited supply of arable land and desire for an increasing standard of living, the concern about energy use in agriculture has been gaining importance.

Agriculture is both a producer and consumer of energy. It uses large quantities of locally available non-commercial energies, such as seed, manure and animate energy and commercial energies directly and indirectly in the form of diesel, electricity, fertilizer, plant protection, chemicals, irrigation water and machinery. Efficient use of energies helps to achieve increased production and productivity and contributes to the economy, profitability and competitiveness of agriculture sustainability. Although energy consumption in agriculture is much lower than the other sectors, energy usage as input and output in the agriculture sector is a very important issue due to its large agricultural potential and the size of rural area in India.

Energy consumption per unit area in agriculture is directly related to the development of farming technology and the production levels. Energy use is one of the key indicators for developing more sustainable agricultural practice. The amount of energy used in agricultural production, processing and distribution is significantly higher. A sufficient supply of the right amount of energy and its effective and efficient use are necessary for an improved agricultural production. The prevalence of high consumption of non-renewable energies is a challenge in relation to agriculture. The available evidence suggests that the excessive consumption of certain agricultural inputs, not only has inhibited the increase in production, but also reduced it in some cases (Omani and Chizari, 2008). The energy agriculture relationship is becoming more and more important with the intensification of the cropping systems, which is considered to be the only means of raising agricultural output in land scarce situations. Timely solving the problems and large scale implementing the approaches of developing the agricultural energy system will contribute to independence of energy supply for overcoming the energy crisis and reviving national farming, which will be a considerable input in ensuring the national food security.

Therefore the present study was undertaken with the objective to analyze the input, output and net return energy of different planting techniques i.e. drill sowing and bed planting with weed management treatments using different herbicide combinations and to identify energy efficient planting technique and herbicide treatment with for satisfactory energy output.

Materials and Methods

A field experiment was carried out at Agronomy farm area, CCS Haryana Agricultural University, Hisar, Haryana, India during *Rabi* season of 2012-13. The mean weekly maximum and minimum temperature ranged between 11.6 to 35.7^{0}C and 1.6 to 20.5^{0}C, respectively and about 114.6 mm rainfall was received during crop growing season; while sunshine ranged between 2.0 to 9.5 hrs during crop season. The soil of the field was sandy loam in texture, slightly alkaline in pH (8.3), low in organic carbon (0.33%), poor in available nitrogen (182 kg/ha) and medium in available phosphorus (13 kg/ha) and rich in available potassium (365 kg/ha). The experiment was laid out in a split plot design with five planting techniques [drill sowing at 20 cm (A1), 18 cm (A2) and 16 cm (A3), bed planting with three (A4) and two rows (A5)] in main plot and five weed management treatments [pinoxaden 50 g/ha (Z1), RM of carfentrazone and metsulfuron 25 g/ha (Z2), pinoxaden 50 g/ha + RM of carfentrazone and metsulfuron 25 g/ha (Z3), weed free (Z4) and weedy check (Z5)] in subplots, replicated thrice. The crop was raised with standard package of practices given by CCSHAU, Hisar and details of different cultural operations carried out during pre and post sowing of wheat in the experiment field are presented in Table 1. Energy inputs and outputs of wheat crop were estimated using crop management (machinery operations and amount of input used) and biomass production records. The amount of energy consumption per unit area of different inputs (human labour, machinery, implements, chemical fertilizers, diesel fuel, water, herbicides and wheat seed) and outputs (grain and straw) was estimated by using energy equivalents (Table 2) (Devasenapathy *et al.*, 2009; Tuti *et al.*, 2012; Dhaka *et al.*, 2015; Sorokhaibam *et al.*, 2016; Negi *et al.*, 2016) and formulae used by Chaudhary *et al.*, (2006), Khan and Hussain (2007), Devasenapathy *et al.,* (2009) and given in Table 3. According to energy input and output, cost of cultivation, yield, energy use efficiency, energy productivity, net energy, specific energy, energy profitability, energy intensiveness, energy intensity in physical and economic terms were calculated (Kumar *et al.*, 2017) as following:

$$\text{Energy Use Efficiency (EUE)} = \text{Energy Output (MJ/ha)}/\text{Energy Input (MJ/ha)}$$

$$\text{Energy Productivity (kg/MJ)} = \text{Wheat grain yield (kg/ha)}/\text{Energy Input (MJ/ha)}$$

$$\text{Net Energy (MJ)} = \text{Energy Output (MJ/ha)} - \text{Energy Input(MJ/ha)}$$

$$\text{Specific Energy (MJ/kg)} = \text{Energy Input (MJ/ha)}/\text{ wheat grain yield (kg/ha)}$$

$$\text{Energy Profitability} = \text{Net Energy (MJ/ha)} / \text{Energy Input (MJ/ha)}$$

$$\text{Energy Intensiveness (MJ/Rs.)} = \text{Energy Input (MJ/ha)}/\text{ Cost of cultivation (Rs./ha)}$$

$$\text{Energy intensity in physical terms (MJ/kg)} = \text{Energy Input }/\text{wheat biological yield (kg/ha)}$$

$$\text{Energy intensity in economic terms (MJ/Rs.)} = \text{Total Energy output }/\text{Cost of cultivation}$$

Also the share of direct energy, indirect energy, renewable energy and non-renewable energy was calculated from different sources (Devasenapathy *et al.*, 2009; Beheshti *et al.*, 2010). The direct sources of energy are those that release the energy directly like human labour, animal, fuel (petrol, diesel), electricity etc. The direct energy may be further divided as renewable (natural but can be subsequently replenished in due course of time) and non renewable sources (not renewable at least in near further say next 100 years) of energy depending upon their replenishment (Table 5). Whereas, indirect sources of energy are those which don't release energy directly but release energy by conversion process (Table 6).

Results and Discussion

Analysis of input energy use in wheat production

Total energy used in various farm operations under flat bed sowing (conventional method) during wheat production was 15695.89 MJ/ha and under raised bed sowing was 15586.84 MJ/ha (Table 4). The difference in total energy in these two methods was due to difference in post irrigation water quantity and energy consumed in sowing. There was 25% less water consumption in raised bed planting as compared to flat bed planting; hence a difference in energy of water was recorded. The chemical fertilizer consumed 50.59 and 50.94 % of total energy inputs followed by irrigation 15.12 and 12.7 % under flat and raised bed sowing respectively, during production period. Diesel energy was mainly consumed for land preparation, sowing and threshing. That's why it very important and remarkable to study the energy inputs and their share in production. Similar to the results of this study, the studies of Hosseinpanahi and Kafi (2012) and Giampietro *et al.*, (1992) have also demonstrated that nitrogen fertilizer allocated the largest part of energy consumption among chemicals in crop production. When weed management is included (manual weeding), total energies used during wheat production were 16480.69 MJ/ha and 16371.64 MJ/ha under flat and raised bed sowing, respectively. The manual weeding consumed 2 % of total input energy under both sowing methods in wheat production (Figure 1). Under flat bed sowing (conventional planting), land preparation consumed maximum energy (36 % of total energy) of direct input energy (including renewable and non-renewable sources) followed by threshing (27 %) and manual weeding (20 %) as shown in Table 5. Maximum part of indirect energy came from chemical fertilizer (7938 MJ/ha) followed by sowing (1847.92 MJ/ha) (Table 6) and total energy of tractor *i.e.* 374.85 MJ/ha (Table 3). Maximum part of total input energy of wheat production came from indirect sources like chemical fertilizer, machinery etc. In India, Singh *et al.*, (2007) reported that average grain yield, total energy input and output, in wheat production were 25.51 q/ha, 15572.2 and 63846.02 MJ/ha, respectively.

The results of the main study demonstrated in this experiment are shown in Table 7. Total input energy used for wheat crop production for conventional (flat bed) planting techniques viz. drill sowing with 16, 18, and 20 cm was 15929.49 MJ/ha; whereas for raised bed planting total input energy was 15766.27 MJ/ha (Table 7). The difference in total input energy between this two planting techniques (flat and raised bed sowing) was just one percent (163.22 MJ/ha). Drill sowing with 18 cm row spacing produced maximum total output energy per hectare i.e. 181226 MJ followed by drill sowing with 20 cm (177931.9 MJ) and bed planting with three row (176256.2 MJ) of wheat, whereas, two row bed planting produced lower total output energy i.e. 168739.1 MJ compared to other planting technique.

The increase in net energy was 5.9, 8.1, 0.8 and 4.9 per cent under drill sowing at 20, 18 and 16 cm and bed planting with three rows respectively, with respect to bed planting with two rows. Drill sowing with 18 cm recorded highest value of energy use efficiency (11.38), energy productivity (0.335 kg/MJ), energy profitability (10.38), energy intensity in economic terms (3.50 MJ/Rs) followed by bed planting with three rows and drill sowing with 20 cm. Bed planting with two rows of wheat showed higher value of specific energy (3.25 MJ/kg) followed by drill sowing with 16 cm (3.23 MJ/kg). The value of specific energy was lower under drill sowing with 18 cm which makes it better planting techniques in terms of energy. In spite of consumption of higher input energy, under flat bed planting higher value of energy intensiveness was recorded as compared to raised bed planting which might is due to lower cost of cultivation estimates under conventional planting. Drill sowing with 20 cm and three row bed planting showed higher value of energy intensity in physical terms which can be attributed to higher biological yield and input energy consumption. The higher energy-use efficiency of wheat genotypes was mainly attributed to higher yield production with use of lesser energy utilization (Maurya *et al.*, 2014).

With respect to weed management treatments, energy use efficiency (11.47), energy profitability (10.47), energy productivity (0.339), and energy intensity in terms of economic (3.55 MJ/Rs) were higher with tank mix application of pinoxaden (50 g/ha) with RM of carfentrazone+metsulfuron-methyl (25 g/ha) @ 35 days after sowing (Table 7 and Fig 2). This may attributed to higher production and lower input energy. Whereas, weed free treatment produced significantly higher grain and biological yield over other weed management treatments, but to achieve that 4.58, 4.62, 4.52 and 4.80 percent extra energy was used over Z1, Z2, Z3 and Z5, respectively (Table 7). Weedy check showed higher value of specific energy (3.47 MJ/kg) and energy intensity in physical terms (1.31 MJ/kg), followed by alone application of pinoxaden (50 g/ha) with the values 3.11 and 1.20 MJ/kg (Fig. 2).

Table.1 Schedule of cultural operations carried out in the experimental field

Sr. No.	Nature of operations	Date of operations	Details of operations
A. Pre-sowing operations:			
1.	Pre-sowing irrigation	28.11.2012	Irrigation was done with canal water
2.	Seed bed preparation	06.12.2012	At proper moisture condition the field was ploughed twice by disc harrow and once by cultivator followed by planking with tractor
3.	Layout	09.12.2012	Layout was performed
4.	Sowing and fertilizers application	10.12.2012	Sowing of variety WH711 was done by seed-cum fertilizer drill and bed planter as per treatments at 5-6 cm depth using 125 kg seed/ha and recommended dose of fertilizers was applied (half of the nitrogen (60 kg/ha) as per treatments and recommended dose of phosphorus i.e. 60 kg/ha)
B. Post Sowing operations:			
1.	Final layout	11.12.2012	Final layout, channels and bunds were prepared
2.	Top dressing of remaining half of N	02.01.2013	Remaining half dose of nitrogen (60 kg/ha) was top dressed at 1st irrigation
3.	Weeding	__	The weeds were removed by hand pulling from time to time in all the weed free plots throughout the crop season
4.	Irrigation	02.01.2013 05.03.2013 11.04.2013	Three irrigations with canal water were applied at 23, 85, 122 days after sowing
5.	Harvesting	25.04.2013	Harvesting was done manually with the help of sickles by cutting the plants just above the ground level from the net area of each plot separately. Bundles were made and left in the field for drying in sun
6.	Threshing	06.05.2003	Before threshing the biological yield (grain + straw) was recorded for each net plot. Threshing was done with the help of miniplot thresher. The grains collected from each net plot were weighted

Table.2 Energy coefficient (equivalent) of different inputs and outputs in wheat production

Particulars		Units	Energy coefficient (MJ/unit)	Remarks
Inputs	**1. Human Labour**			1 Adult women is equal to 0.8 adult man
	✓ Adult man	Hour (h)	1.96	
	✓ Woman	h	1.57	
	2. Diesel Fuel	Litre	56.31	It includes the cost of lubricant
	3. Machinery			Distribute the weight of machinery equally over the total life span of the machinery (in hours)
	✓ Tractor	Kilogram (kg)	180.00	
	✓ Farm-machinery	kg	62.70	
	✓ Thresher	kg	17.40	
	✓ Sickle	h	0.031	
	4. Manual implements			These implements were used in many intercultural operations like weeding. Sickle used for manual harvesting of crop
	✓ Sickle	h	0.031	
	✓ Khurpa	h	0.031	
	✓ Kasola	h	0.188	
	✓ Spade	h	0.314	
	5. Chemical Fertilizers			Estimate the quantity of nutrient in the chemical fertilizer. Then compute the amount of energy input from chemical
	✓ Nitrogen	kg	60.60	
	✓ Phosphate(P_2O_5)	kg	11.10	
	✓ Potash(K_2O)	kg	6.70	
	6. Pesticides			
	✓ Herbicides	kg	288	
	✓ Insecticides	kg	237	
	✓ Fungicides	kg	196	
	7. Water	m^3	1.02	
	8. Seed	kg	14.70	
Outputs	**1. Grain wheat**	kg	14.70	
	2. Straw	kg	12.50	

Table.3 Energy consumption and energy input-output relationship in wheat production under different planting techniques and weed management treatments

Operations		Quantity per unit (ha)	Total energy Equivalent (MJ)
A. Inputs			
1.Human Labours (h/ha)			
✓ **Land Preparation**	-Harrowing+Cultivator	2+1.67 (M-h)	7.19
	-On flat bed	1.67 (M-h)	3.27
✓ **Sowing**	-On raised bed	2.50 (M-h)	4.90
		1 (M-h)	1.96
✓ **Fertilizer Application**	-Pre-sowing	10 (M-h)	19.60
	-Post sowing (on flat bed)	30 (M-h)	58.80
✓ **Irrigation Application**	-Post sowing (on raised bed)	24 (M-h)	47.04
	-(a)Pinoxaden	11 (M-h)	21.56
	-(b)Carfentrazone+Metsulfuron(RM)	11 (M-h)	21.56
✓ **Herbicide Spraying and manual hand weeding**	-(a)+(b)	11.5 (M-h)	22.54
	-Hand Weeding	80 (M-h)	156.80
		400 (W-h)	628.00
	-Sickle		
		40 (M-h)	78.40
		120 (W-h)	188.40
✓ **Harvesting**			
		15 (M-h)	29.40
		15 (W-h)	23.55
✓ **Threshing**			
2. Machinery (h)			
✓ **Tractor**	-In case of flat bed (including all operation)	8.33	374.85
	- In case of raised bed (including all operation)	9.17	412.65
✓ **Cultivator**			
✓ **Harrowing**		1.67	6.51
✓ **Seed Drill**		2	12.54
✓ **Bed Planter**		1.67	10.42
✓ **Thresher**		2.50	21.55
✓ **Sickle**		3	31.32
✓ **Khurpi &**		160	1.24
Kasola		480	3.72
3. Diesel fuel (l)	-Land Preparation	25.50	1435.91
	-Sowing (on flat bed)	5.83	328.46
	-Sowing (on raised bed)	10	563.10
	-Threshing	18	1031.58
4.Water (m^3)	-Pre-sowing	750	765
	-Post sowing(on flat bed)	1500	1530
	-Post sowing (on raised bed)	1125	1147.5
	-(a)Pinoxaden	0.2	0.204
	-(b)Carfentrazone+Metsulfuron(RM)	0.2	0.204
	-(a)+(b)	0.2	0.204
5.Chemical Fertilizers	-Nitrogen	120	7272
	-Phosphorus	60	666
6. Herbicide (kg a.i.)	-(a)Pinoxaden	0.050	14.4
	(b)Carfentrazone+Metsulfuron(RM)	0.025	7.20
7. Seeds (kg)		125	1837.5

Table.4 Operation wise energy values of wheat crop excluding weed management

Operations	Energy (MJ/ha)	Percentage of total energy input (%)
	Flat Bed Sowing	
1. Land Preparation	1462.15	9.32
2. Seed	1837.50	11.71
3. Sowing	0716.99	4.57
4. Fertilizer	7939.96	50.59
5. Irrigation	2373.40	15.12
6. Harvesting	0268.04	1.71
7. Threshing	1097.85	6.99
Total Energy	15695.89	100
	Raised Bed Sowing	
1. Land Preparation	1462.15	9.38
2. Seed	1837.50	11.79
3. Sowing	1002.20	6.43
4. Fertilizer	7939.96	50.94
5. Irrigation	1979.14	12.7
6. Harvesting	0268.04	1.72
7. Threshing	1097.85	7.04
Total Energy	15586.84	100

Table.5 Sources of direct energy in weed free condition

Field Operation	Direct Energy (MJ/ha)							Grand Total
	Renewable		**Total**	**Non-renewable**			**Total**	
	Man	**Woman**		**Petrol**	**Diesel**	**Electricity**		
Land Preparation	7.19	-	7.19	-	1435.91	-	1435.91	1443.10
Sowing	3.27	-	3.27	-	328.46	-	328.46	331.73
Fertilizer Application	1.96	-	1.96	-	-	-	-	1.96
Irrigation Application	78.40	-	78.40	-	-	-	-	78.40
Manual weeding	156.80	628.00	784.80	-	-	-	-	784.80
Harvesting	78.40	188.40	266.8	-	-	-	-	266.8
Threshing	29.40	23.55	52.95	-	1031.58	-	1031.58	1084.53
Total	**355.42**	**839.95**	**1195.37**	**-**	**2795.95**	**-**	**2795.95**	**3991.32**

Fig.1 Energy Fraction of different operations including hand weeding in flat bed and raised bed sowing

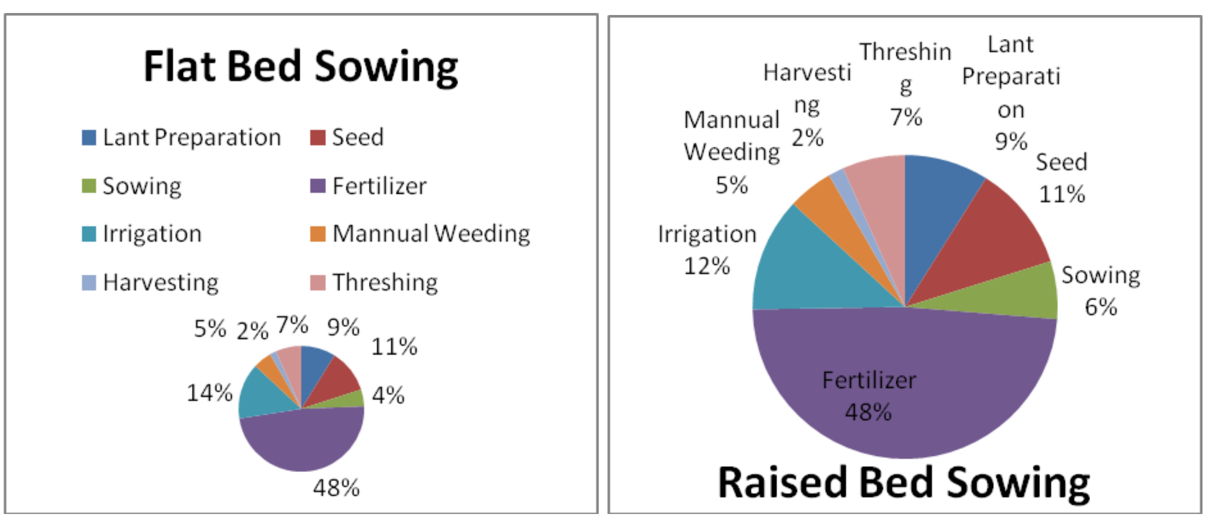


Table.6 Sources of indirect energy in weed free condition

Field Operation	Indirect Energy (MJ/ha)							Grand Total
	Renewable		**Total**	**Non-renewable**			**Total**	
	Seed	**FYM**		**Chemical**	**Fertilizer**	**Machinery**		
Land Preparation	-	-	-	-	-	19.05	19.05	**19.05**
Sowing	1837.50	-	1837.50	-	-	10.42	10.42	**1847.92**
Fertilizer	-	-	-	-	7938	-	7938	**7938**
Irrigation Application	-	-	-	-	-	-	-	**-**
Manual weeding	-	-	-	-	-	3.72	3.72	**3.72**
Harvesting	-	-	-	-	-	1.24	1.24	**1.24**
Threshing	-	-	-	-	-	31.32	31.32	**31.32**
Total	**1837.50**	**-**	**1837.50**	**-**	**7938**	**(65.75+ 374.85*) 440.60**	**8378.60**	**10216.10**

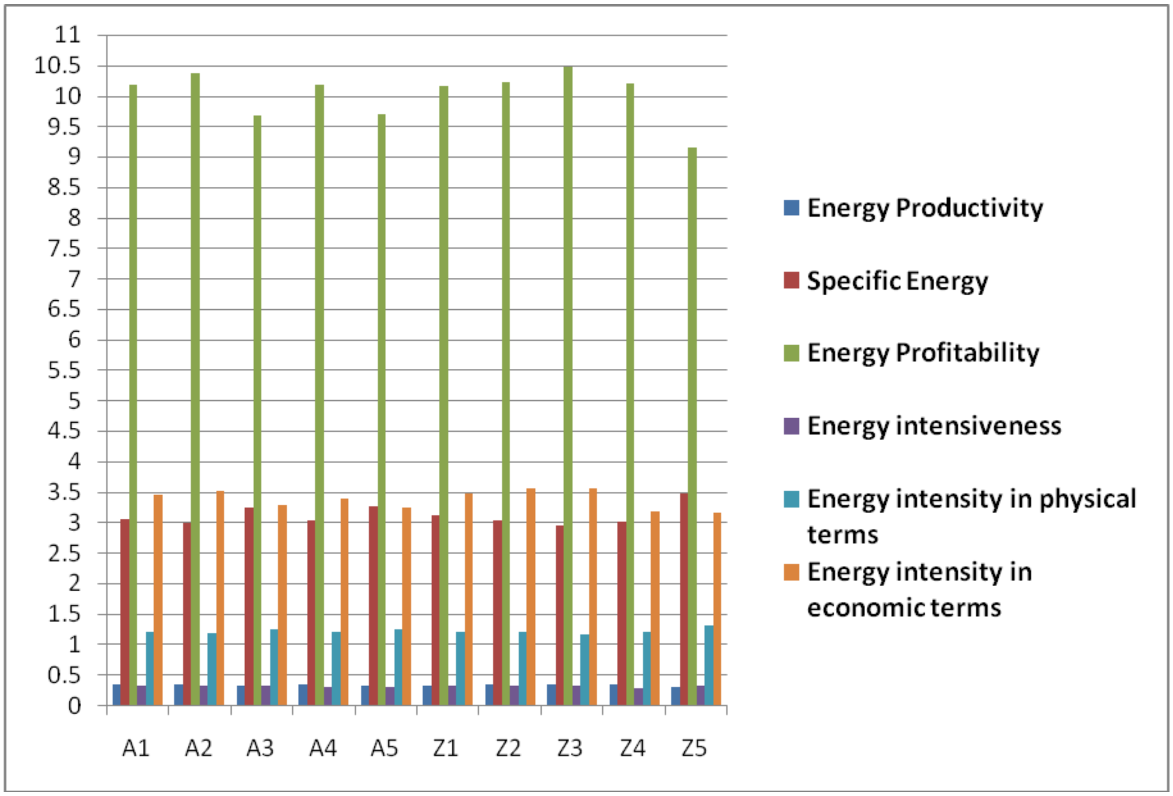
*Tractor energy (see in Table 3)

Table.7 Effect of different planting techniques and weed management treatments on different energy indices

Treat-ments	Input Energy (MJ/ha)	Output Energy of Grain (MJ/ha)	Output Energy of Straw (MJ/ha)	Total Output Energy (MJ/ha)	NE (MJ/ha)	EUE	Cost of Cultiva tion	GY	BY
Planting Techniques									
A1	15929.49	76469.40	101462.50	177931.90	162002.41	11.17	51708	20.81	53.28
A2	15929.49	78351.00	102875.00	181226.00	165296.51	11.38	51708	21.32	54.24
A3	15929.49	72573.90	097587.50	170161.40	154231.91	10.68	51708	19.75	50.98
A4	15766.27	76381.20	099875.00	176256.20	160489.93	11.18	52091	20.78	52.74
A5	15766.27	71339.10	097400.00	168739.10	152972.83	10.70	52091	19.42	50.58
SEm±	-	-	-	-	-	-	-	0.30	0.48
CD at 5%	-	-	-	-	-	-	-	0.97	1.55
Weed Management Treatments									
Z1	15688.43	74073.30	101012.50	175085.80	159397.37	11.16	50587	20.16	52.48
Z2	15681.23	76307.70	099662.50	175970.20	160288.97	11.22	49547	20.77	52.66
Z3	15696.61	78145.20	101950.00	180095.20	164398.59	11.47	50801	21.26	53.89
Z4	16440.79	80350.20	103912.50	184262.70	167821.91	11.21	57973	21.86	55.12
Z5	15652.27	66238.20	092662.50	158900.70	143248.43	10.15	50396	18.02	47.68
SEm±	-	-	-	-	-	-	-	0.27	0.44
CD at 5%	-	-	-	-	-	-	-	0.77	1.26

NE- net energy, EUE- energy use efficiency, CC- Cost of cultivation (Rs./ha), GY- Grain Yield (q/acre), BY- Biological yield (q/acre)

Fig.2 Effect of planting techniques and weed management methods on different energy indices



In case of alone application of herbicides, RM of carfentrazone and metsulfuron-methyl was more efficient in terms of energy calculations (input energy, total output energy, NE, EUE, energy productivity, energy intensity in economic terms etc.); this may be attributed to higher biological yield due better control of broad leaved weeds.

In conclusion among different planting techniques, drill sowing with 18 cm is most efficient method in respect of energy calculations (NE, EUE, energy profitability, specific energy, energy productivity, energy intensiveness, energy intensity in physical terms, energy intensity in economic terms) followed by three row bed planting and 20 cm row spacing. This may be attributed to total energy output (grain + straw). Tank mix application of pinoxaden (50 g/ha) with RM of carfentrazone and metsulfuron-methyl is very efficient in terms of energy and recorded higher value of different energy calculations (EUE, energy profitability, specific energy, energy productivity, energy intensiveness, energy intensity in physical terms, energy intensity in economic terms). Weed free condition consumed higher input energy due to manual weeding compared to weed control by herbicide application.

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