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Energy consumption pattern of wheat production in India

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Abstract

Wheat covers approximately 25% of the total global area devoted to by cereal crops. Wheat production needs to be augmented to meet the growing demand. The amount of wheat produced is a direct function of energy inputs. Wheat is produced using energy sources ranging from human and animal power to power of heavy machinery. The basic purpose of the present study is to optimize energy use patterns of different wheat growing regions (Western Rajasthan, Punjab, Uttar Pradesh (UP) and Madhya Pradesh (MP)) of the Country in order to maximize yield. Villages and farmers were randomly selected for collecting data on energy requirement of wheat in Western Rajasthan and data for other regions were taken from reports. Wheat consumed maximum energy input in Western Rajasthan because light textured soil required frequent irrigation. Punjab and UP recorded maximum output–input energy ratio, 5.2 and 4.2, respectively. Punjab recorded minimum specific energy of 4.6 MJ/kg followed by UP (6.0 MJ/kg). Further, Punjab occupied the first place among all the States with 3334.8 kg/ha average yield, which is about 31% higher than the average productivity (2550.5 kg/ha) of the regions considered under the study. However, use of commercial energy was found maximum in Punjab (91.7%). Therefore, by ensuring optimal energy inputs in different regions wheat production in the Country could be increased.

Keywords: Wheat production; Energy input; Energy ratio; Specific energy; India

1. Introduction

India is a predominantly agricultural country. About 70% of its population depends on agriculture. Wheat and rice are the two major cereal crops that occupy about 50–55% of the total cropped area of India. Wheat alone covers about 25% of the total area covered by cereal crops, which is next only to paddy (40–45%). Wheat flour is mostly used for making *Chapati* and bread. More people eat wheat than any other cereal grain, making it the single most important cereal crop grown in the World [1]. Wheat production is a direct function of high yielding varieties, chemicals, fertilizers, mechanization and other energy inputs. Technology level, energy input and agro-climatic zone constitute the most pertinent set of factors responsible for the higher production of wheat. Wheat is produced using energy sources ranging from human and animal power to power of heavy machinery. Energy input and yield vary with each system, influencing the ultimate output–input ratio. The present study was undertaken to estimate and compare the energy requirements for the production of wheat in different wheat growing areas of India with respect to technology level, energy input and agro-climatic zones. The reason behind selecting the wheat crop was that it is the major cereal crop grown world over. A press release of Consultative Group on International Agricultural Research (CGIAR) termed wheat as the century's miracle crop and gave five main reasons for the growing popularity of wheat in the developing countries increased demand, lower prices and greater convenience, easy to grow, availability of new wheat varieties, and higher yields.

As per FAO Statistics [2], the average annual production of wheat in India comes to about 71.45 million tonnes, over a period 6 years (2000–2005), against World's average of 595.7 million tonnes over the same period. Thus, India contributes about 12% to the World wheat production. Further, according to the FAO data (2005), India is the

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second largest producer of wheat (72 million tonnes) next only to China (97) followed by USA (57.3), France (36.9) and Canada (25.5). India covers the largest area under wheat cultivation (26.5 million ha), which is about 12.2% of the World's wheat area (217 million ha).

Keeping the above points in view, it has become imperative to study the energetics of wheat cultivation as over the years Indian agriculture has shifted from human- and animal-based production system to a mechanized farming in large parts of the Country. It is evident that India with a wheat productivity of 2710 kg/ha is still lagging behind the World's average of 2900 kg/ha. This necessitates the optimal use of available energy inputs to further increase the productivity to a high level in the major wheat growing areas (Fig. 1) for feeding the ever-growing population of the Country.

2. Materials and methods

The energy census and resource assessment of arid zone in regard to different cropping and rainfall patterns was carried out which is summarized below.

The demographic details of the village were collected. The well-laid criterion, presented by Mittal and Dhawan [3] for selection of a representative village was followed. The main factors considered to select a village were cooperation of farmers, easy approach, non-existence of city effect and population being in the neighborhood of 2000 (comprising 100–120 farm families) thus making a reasonable sample.

Village Pemasar, district Bikaner (zone II, 200 $\leqslant$ rainfall $<$ 300 mm/yr) was selected out of 43 villages considered in the zone, whereas village Choukha, district Jodhpur (zone

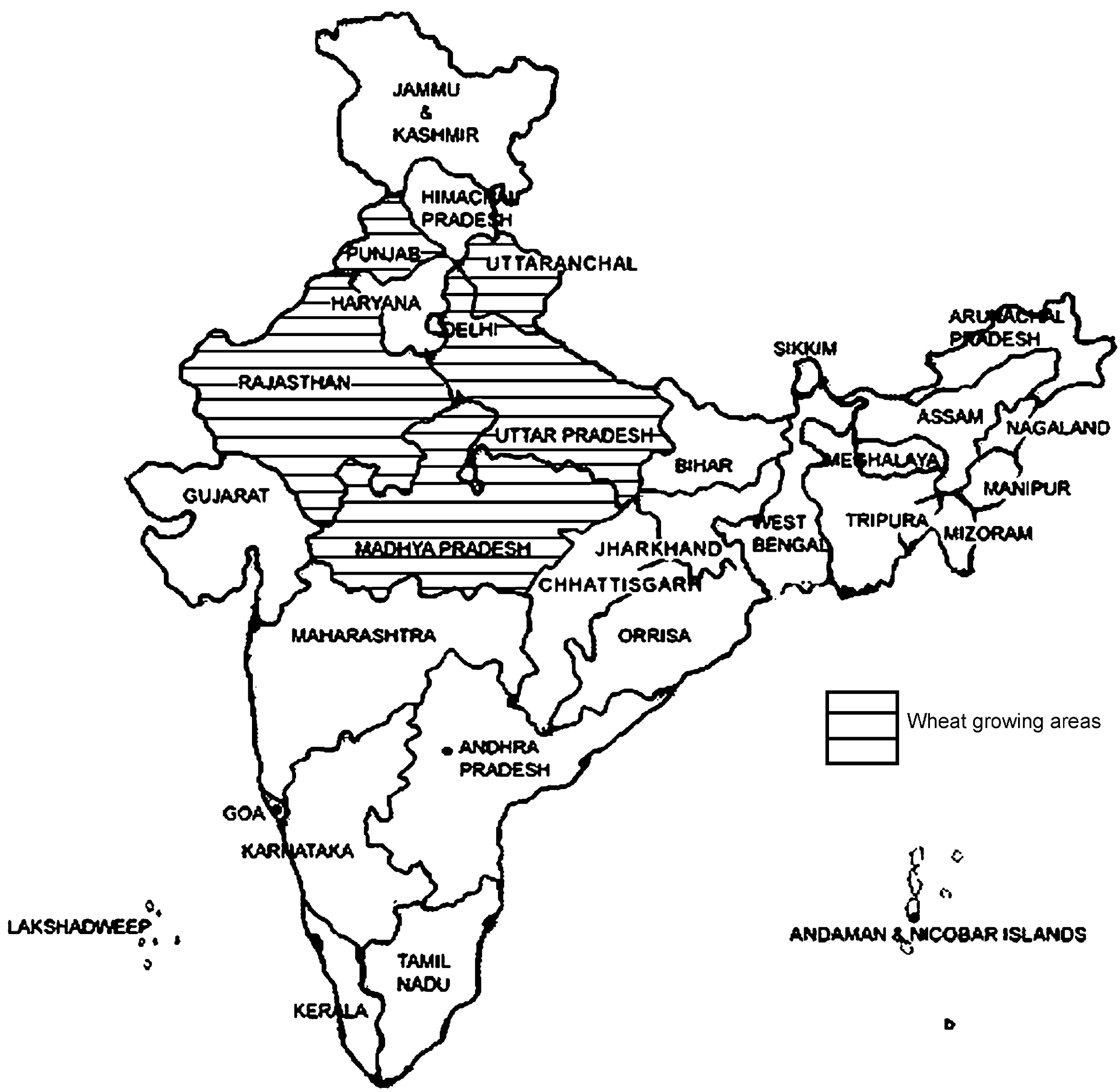

Fig. 1. Map of India indicating major wheat growing areas considered in the study.

III, $300 \leqslant \text{rainfall} < 400\,\text{mm/yr}$) was selected out of 40 villages. Similarly, village Siwas, district Pali (zone IV, $\text{rainfall} > 400\,\text{mm/yr}$) was selected out of 45 villages of the zone for the study. Zone-I (Jaiselmer district) is not included in the study as wheat is not grown in the zone due to very low rainfall ($\text{rainfall} < 200\,\text{mm/yr}$) and non-availability of irrigation facilities. A proforma was devised in order to collect required information related to land possessed by farmers and utilization pattern, crops grown in different crop seasons and their yields, operation time, fuel consumption, electricity consumption, seed, fertilizer, chemical inputs, etc. The information helpful in estimation/assessment of energy use in production of wheat was collected by making personal contact with the individual farmer.

The inventory of all the farm machinery in the form of hand tools, tractor and power operated implements and rural transport devices/vehicles available with different categories of farmers were taken.

The energy use values were determined by multiplying the associated energy equivalents/coefficients presented by Mittal et al. [4]. Knowing the energy value associated with the wheat grain (14.7 MJ/kg dry grain) and energy associated with the wheat straw (13.75 MJ/kg dry straw) total output energy was worked out. Further, by knowing the input and output energies, ratio of output–input energy was calculated. The cropping pattern and hectareage under the wheat crop changed from farm to farm, and consequently, the energy use, even for the same crop, varied from farm to farm. Therefore, weights were assigned according to the area under wheat crop for various categories of farms to estimate weighted average values of energy use. The procedure for estimating weighted mean values of energy as suggested by Mittal et al. [5], as given below was followed:

If there are a number of farms having areas $A_1, A_2, A_3, \ldots, A_n$ requiring energy inputs $X_1, X_2, X_3, \ldots, X_n$, then weighted mean of energy input can be determined as

$$X\ (\text{weighted mean}) = \sum A_i X_i / \sum A_i,$$

where $i = 1, 2, 3, \ldots, n$. Similarly, weighted mean of yield, Y with respect to area can be given as

$$Y\ (\text{weighted mean}) = \sum A_i Y_i / \sum A_i.$$

The energy input data for wheat production with yield attributes in respect of the following villages/locations in the country were taken from unpublished Annual Progress Reports of different Centres of All India Co-ordinated ICAR Research Project on Energy Requirements in Agricultural Sector [6–8] and from Final Report on an ICAR Ad-hoc Research Project on Energy Census and Resource Assessment of Western Rajasthan [9]:

Western Rajasthan (1999–2001)	Zone-II (village—Pemasar, district—Bikaner), zone-III (village—Choukha, district—Jodhpur), zone-IV (village—Siwas, district—Pali)
Punjab (1998)	Zone-I (village—Kheewewal, district—Nawasahr), zone-II (village—Pandori phangurian, district—Hosiarpur), zone-III (village—Jaisinghwala), zone-IV (village—Dhanaula khurd, district—Sangrur), zone-V (village—Bhokhra, district—Bhatinda)
Uttar Pradesh (UP) (1998)	Tarai region (village-Khamaria and Phulsangi cluster), Hill region (village–Jaipur Bisha, Jaipur Padli and Tejpur Negi cluster) [10]
Madhya Pradesh (MP) (1996–1998)	Wheat zone (village—Berkheri, district—Sehore and village—Sihoda, district—Jabalpur), Sorghum—wheat zone (village—Sonsa, district—Gwalior).

The basis of study relied on the wheat production and energy consumption pattern of different wheat growing areas of India. Therefore, similar criterion of assigning weights to different zones/areas was adopted while determining average energy input and yield of wheat.

2.1. Theoretical considerations

The theoretical consideration presented by Singh et al. [11–13] for different crops grown in arid region were adopted for wheat crop also, i.e. the crop yield (Y) is a function of energy input (X) given as

$$Y = f(X). \tag{1}$$

It was found that the following quadratic relationship gave the best fit in case of wheat crop also:

$$Y = \beta_1 X + \beta_2 X^2. \tag{2}$$

The values of coefficients β_1 and β_2 were obtained by the principle of least squares.

In order to obtain optimum value of energy input in national perspective for which wheat yield will be maximum the first derivative of Eq. (2) is equated to zero (i.e. $\mathrm{d}Y/\mathrm{d}X = 0$) and second derivative (i.e. $\mathrm{d}^2Y/\mathrm{d}X^2$) is negative. Thus, the values of optimum energy input to wheat crop and the corresponding maximum yield can be given as ($-\beta_1/2\beta_2$) and ($-\beta_1^2/4\beta_2$), respectively.

2.2. Estimation of energy input in different modes of energy sources

The modewise energy sources used in wheat production were calculated using the following criteria:

Direct energy	Human, animal, petrol, diesel, electricity, canal
Indirect energy	Seeds, fertilizers, farmyard manure, chemicals, machinery

Renewable energy	Human, animal, seeds, farmyard manure, canal
Non-renewable energy	Petrol, diesel, electricity, chemicals, fertilizers, machinery
Commercial energy	Petrol, diesel, electricity, chemicals, fertilizers, seeds, machinery
Non-commercial energy	Human, animal, farmyard manure, canal

3. Results and discussion

3.1. Energy input and yield relationship

Using the relationship between total energy input and yield of wheat crop, i.e. Eq. (2) presented in the preceding section, values of coefficients β_1, β_2 and coefficient of determination (R^2) along with standard error (SE) and 'f' values were calculated using the detailed data available in the reports of mean values are presented in Table 1. The values of the coefficients and R^2 along with SE and f values are presented in Table 2. Based on the relationship (Eq. (2)) wheat yield was predicted for all the wheat growing areas and validated with the observed values. The slope of the line between predicted and observed values of wheat yield was found in the range of 0.97–0.99, in close vicinity of unity indicating predicted values of wheat yield in agreement with the observed values. A sample plot between the observed and the predicted values of wheat yield is presented in Fig. 2 for the case of UP. Optimum energy input and maximum yield for wheat crop grown in different locations of the country were also determined, are presented in Table 2. Figures in parentheses in the table indicate percentage gap between present (1996–2001) and optimum/maximum levels.

It is interesting to note that both energy input and yield are close to optimum level in western Rajasthan. In this

Table 1
Comparative energy use status of wheat crop in different states of India

Particulars	Various zones/regions												
	Western Rajasthan (1999–2001)			Punjab (1998)					Uttar Pradesh (1998)		Madhya Pradesh (1996–1998)		
	II	III	IV	I	II	III	IV	V	Tarai	Hill	Berkheri	Sihoda	Sonsa
Sample size	38	40	95	135	231	164	108	643	99	460	29	33	36
Total area (ha)	14.6	34.2	70.6	93.0	419.0	362.0	653.0	3629.0	218.7	126.3	50.0	52.2	42.8
A. Operations (MJ/ha)													
Seedbed preparation	1921.6	1222.5	1484.6	1095.0	1398.0	1245.0	1793.0	921.0	2924.0	2019.0	1070.4	1109.0	2188.0
Sowing	1035.4	377.7	626.0	216.0	380.0	295.0	542.0	611.0	400.0	510.0	628.2	334.0	548.2
Bund making	139.1	81.7	269.2	25.0	69.0	51.0	58.0	69.0	—	—	0.0	85.1	52.0
Irrigation	1755.4	4241.0	6003.2	4090.0	1660.0	3031.0	2575.0	1610.0	2133.0	890.0	2450,0	3582.1	5185.0
Weeding	202.1	85.5	263.8	161.0	150.0	40.0	0.0	44.0	42.0	4.0	0.0	0.0	9.0
Fertilizer application	0.3	103.3	37.0	5.0	8.0	16.0	6.0	7.0	42.2	28.0	11.8	5.8	9.2
Spraying	17.9	7.7		0.0	5.0	15.0	24.0	30.0	3.0	4.0	0.0	0.0	0.0
Harvesting and threshing	2434.5	1525.8	1434.2	1470.0	2809.0	2930.0	2420.0	1469.0	1504.0	1463.0	929.9	1128.3	2000.0
Transportation	386.9	1020.2	139.2	129.0	215.0	171.0	396.0	313.0	—	—	495.5	218.2	1153.0
Post—harvest activity	—	61.1		84.0	52.0	117.0	0.0	60.0	—	—	134.0	0.0	88.0
Total	7953.1	8726.3	10257.3	7275.0	6746.0	7911.0	7814.0	4834.0	7048.0	4918.0	5719.8	6464.2	12235.4
B. Source (MJ/ha)													
Human	1001.2	775.4	1048.8	684.0	802.0	936.0	358.0	454.0	468.0	853.0	780.2	895.7	1106.6
Animal	47.9		189.7	654.0	432.0	544.0	12.0	27.0	7.0	1733.0	443.7	150.8	218.0
Diesel	4990.1	3608.0	4431.7	1713.0	4298.0	3800.0	4541.0	2961.0	5262.0	1892.0	1536.9	1306.8	3891.9
Electricity	61.7	3981.8	4236.6	3973.0	833.0	1786.0	2304.0	146.0	1311.0	439.0	2250.4	3852.3	5469.3
Seeds	1845.4	1766.1	1694.1	1455.0	1500.0	1433.0	1544.0	1437.0	1619.0	2007.0	1783.8	1559.7	2541.2
Farmyard manure	—	1319.1	551.8	0.0	0.0	0.0	0.0	10.0	8686.0	5875.0	8.7	0.0	1138.7
Fertilizers	11149.6	3433.8	4196.1	3963.0	5343.0	8431.0	8411.0	7600.0			3639.7	4676.8	4215.6
Chemicals	83.9	44.4	343.0	0.0	2.0	108.0	194.0	119.0			18.9	0.0	0.0
Machinery	483.7	361.2	350.5	258.0	376.0	414.0	568.0	309.0	—	—	315.4	258.5	548.6
Canal	1368.5	—	—	—	—	—	—	1368.5[a]	—	—	—	—	—
Total energy input	21032.1	15289.8	17042.3	12700.0	13591.0	17452.0	17932.0	14431.5	17353.0	12799.0	10777.7	12700.6	19131.2
C. Others													
Yield (kg/ha)	1668.9	2118.3	2133.8	1895.0	2952.0	3947.0	4341.0	3539.0	2919.0	2125.0	1241.7	3015.6	2857.0
Energy-ratio	2.2	3.2	3.2	3.6	5.2	5.4	5.7	5.9	4.7	3.6	2.8	5.7	3.6
Specific energy (MJ/kg)	12.1	7.2	8.0	6.7	4.6	4.4	4.1	4.1	5.9	6.0	8.6	4.2	6.7

[a]Canal energy, 1368.5 MJ/ha is added as irrigation is provided in the zone through canal.

Table 2
Relevant statistical parameters and maximum yield in relation to optimum energy input for cultivating wheat crop at various locations in India

Item	Western Rajasthan	Punjab	Uttar Pradesh	Madhya Pradesh
Coefficients of Eq. (2) with other output parameters				
$\beta_1 \times 10^{-4}$	2297.0	3297.0	2134.0	2294.0
$\beta_2 \times 10^{-6}$	−6.0	−6.3	−3.6	−4.2
R^2, %	98.8	99.3	99.2	97.5
SE	236.1	300.7	227.4	402.8
'*f*' value	604.4	1678.0	544.8	257.0
Energy values				
Average energy input (MJ/ha) at 1996–2001 level	17,788.1	15,221.3	15,076.0	14,203.2
Optimum energy input required (MJ/ha) $(-\beta_1/2\beta_2)$	19141.7	26166.6	29638.9	27309.5
Additional energy input required (MJ/ha) over and above (1996–2001) level	1353.6 (7.6)	10995.3 (71.9)	14562.9 (96.6)	13106.3 (92.3)
Yield values				
Average yield at 1996–2001 level (kg/ha)	1973.7	3334.8	2522.0	2371.4
Maximum possible wheat yield (kg/ha) $(-\beta_1^2/4\beta_2)$	2198.4	4313.6	3162.5	3132.4
Possible gain of yield over and above the 1996–2001 level (kg/ha)	224.7 (11.4)	978.8 (29.4)	640.5 (25.4)	761.0 (32.1)

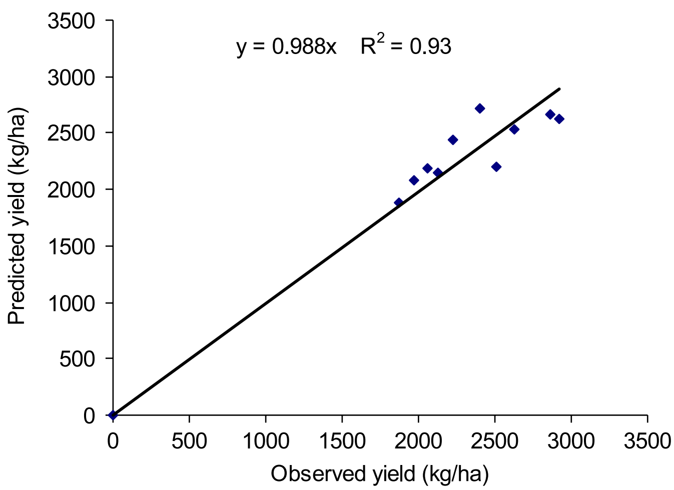

Fig. 2. Comparison of observed and predicted values of wheat yield.

part of India meager amount of additional energy (i.e. 7.6% over and above, 1999–2001 level, 17,788.1 MJ/ha) can be applied to obtain enhanced yield by 11.4%. It is worth mentioning here that the soils in Western Rajasthan are invariably sandy with low carbon content, 0.3% against all India average of 0.8%. Further, due to low annual average precipitation, 100–450 mm, the conditions are arid.

Maximum possibility of increasing the productivity of wheat is in the state of Punjab from its present level (year 1998) of 3334.8–4313.6 kg/ha (i.e. 978.8 kg/ha increase corresponding to 10,945.3 MJ/ha additional energy input over and above 15,221.3 MJ/ha) followed by MP from 2371.4 (year 1996–1998) to 3132.4 kg/ha (i.e. 761.0 kg/ha increase corresponding to 13,106.3 MJ/ha additional energy input over and above 14,203.2 MJ/ha) and UP from its present level (year 1998) of 2522.0 to 3162.5 kg/ha (i.e. 640.5 kg/ha increase corresponding to 14,562.9 MJ/ha additional energy input over and above 15,076.0 MJ/ha).

3.2. Energy use pattern

Table 1 gives the comparative energy use status and yield of wheat crop in different states of India. These states; namely, Punjab, UP, MP and Rajasthan are the major wheat growing areas of the Country. Sample size and total area corresponding to various states are given in the table. The table also includes operationwise and sourcewise energy consumed for growing wheat crop at different locations of India in addition to the other information such as, crop yield, energy output–input ratio and specific energy required to produce 1 kg of wheat. From the table, it is clear that operationwise UP consumed minimum energy (5983.0 MJ/ha) followed by Punjab (6916.0 MJ/ha), MP (8139.8 MJ/ha) and Rajasthan (8978.9 MJ/ha).

Average share of energy consumed in different forms (MJ/ha) for wheat production in different states along with average values of total energy input (MJ/ha), grain yield (kg/ha), energy output–input ratio and specific energy required (MJ/kg) are presented in Table 3. Further, figures in parentheses indicate corresponding values in percentage of the total energy input. It is evident from the table that Western Rajasthan occupied first place with an energy requirement of 17,788.1 MJ/ha followed by Punjab (15,221.3 MJ/ha) and UP (15,076.0 MJ/ha). The least energy input is required for the state of MP with only 14,203.2 MJ/ha, where as the average energy consumption of the regions under study comes to 15,572.2 MJ/ha (Fig. 3). Rajasthan required maximum energy input because of light textured soil with low carbon content, 0.3% against all India average of 0.8% and arid conditions, which led to frequent irrigations thereby resulting in very high input energy.

As far as the yield of wheat is concerned, Punjab tops the list of all the States with 3334.8 kg/ha, which is about 31% higher than the average productivity, 2550.5 kg/ha of the region under study. The possible reason for Punjab recording the maximum yield may be fertile soil, adequate

Table 3
Energy consumption for wheat production under different modes of energy sources

Item	Western Rajasthan	Punjab	Uttar Pradesh	Madhya Pradesh	Average values
A. Different modes of energy (MJ/ha)					
Direct	8813.0 (49.5)	6526.3 (42.9)	5982.5 (39.7)	7300.9 (50.4)	7155.7 (45.6)
Indirect	8975.1 (50.5)	8695.0 (57.1)	9093.5 (60.3)	8901.9 (49.6)	8916.4 (54.4)
Commercial	15967.4 (89.8)	13964.0 (91.7)	13545.5 (89.8)	12621.9 (89.3)	14024.7 (90.2)
Non-commercial	1820.6 (10.2)	1257.3 (8.3)	1530.5 (10.2)	1580.8 (10.8)	1547.3 (9.9)
Renewable	3400.5 (19.1)	2731.0 (17.9)	3340.0 (22.1)	3542.4 (24.9)	3253.5 (21.0)
Non-renewable	14,387.5 (80.9)	12,489.8 (82.1)	11,736.0 (77.9)	10,660.4 (75.1)	12,318.4 (79.0)
B. Average total energy input (MJ/ha)	17,788.1	15,221.3	15,076.0	14,203.2	15,572.2
C. Average total grain yield (kg/ha)	1973.7	3334.8	2522.0	2371.4	2550.5
D. Output–input energy ratio	2.9	5.2	4.2	4.0	4.1
E. Specific energy (MJ/kg)	9.0	4.6	6.0	6.5	6.5

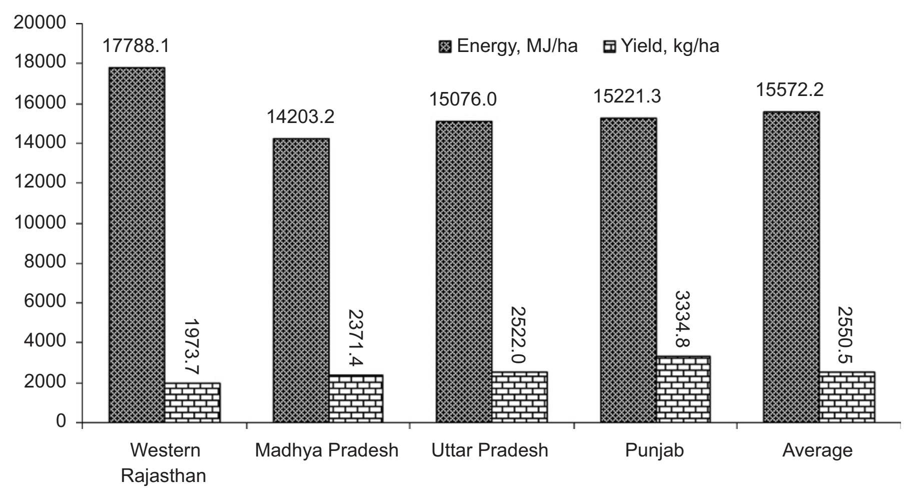

Fig. 3. Energy input and yield level of wheat crop at different locations in India.

irrigation facilities, conducive climate and above all high level of awareness among the farmers about emerging technologies and their adoption. The states immediately following Punjab are UP, 2522.0 kg/ha and MP, 2371.4 kg/ha. The productivity level of Rajasthan (1973.7 kg/ha) is far less than the average productivity of the region under study.

Punjab recorded maximum output–input energy ratio (5.2) followed by UP (4.2) and MP (4.0). However, western Rajasthan recorded the lowest output–input energy ratio (2.9), which is comparable with Turkey (2.8) as presented by Canakci et al. [14]. The specific energy, also defined as energy required to produce one kg of wheat, was recorded maximum in respect of Rajasthan (9.0). Next to Rajasthan came MP (6.5), UP (6.0) and Punjab (4.6). Punjab recorded the minimum specific energy (4.6) because of high grain yield and relatively low energy input given to the wheat crop. The values of specific energy of wheat are reported, 5.2 and 3.9 for Turkey and United States, respectively [14,15].

3.3. Energy consumption under different modes of energy sources for cultivating wheat crop

3.3.1. Direct and indirect form of energy input

The total mean energy input along with its direct and indirect, renewable and non-renewable and commercial and non-commercial forms for raising wheat crop is presented in Table 3. The direct energy input is slightly higher in wheat crop compared to indirect form of energy in respect of MP (50.4%). On an average the direct energy input remained at 45.6% of the total energy input compared to 54.4% indirect energy. However, UP recorded the maximum indirect energy (60.3%) which indicated enhanced use of seeds, farmyard manure, fertilizers, chemicals and machinery. The energy use is more in fertilizer than irrigation which is in conformity with the results of Singh and Singh [16]. MP spent only 49.6% indirect energy because of negligible input given in the form of farmyard manure and chemicals.

3.3.2. Renewable and non-renewable form of energy input

There is more of non-renewable form of energy input (on an average 79.0%) than renewable form (21.0%). Both renewable and non-renewable forms of energy vary from state to state. The reduction in consumption of non-renewable energy has a direct bearing on the cost of cultivation. The component of non-renewable energy is high in all the states. Punjab recorded the maximum non-renewable form of energy input (82.1%), which indicates more use of diesel, electricity, fertilizer, machineries, etc.

3.3.3. Commercial and non-commercial form of energy

There is more of commercial form of energy input (on an average 90.2%) than non-commercial form (9.9%). Similar to renewable and non-renewable energy inputs, the commercial and non-commercial forms of energy inputs also vary from state to state. The reduction in consumption of commercial energy has a direct bearing on the cost of cultivation. The component of commercial energy is high in all the states. Punjab recorded the maximum commercial energy input (91.7%), which contributed to enhanced use of diesel, electricity, fertilizers and machineries, etc. as compared to human, animal and farmyard manure.

4. Conclusions

(i) Maximum energy input (17,788.1 MJ/ha) was required for the cultivation of wheat crop in the state of Rajasthan (western part) compared to the other states of the Country.
(ii) Punjab recorded maximum output–input energy ratio, 5.2 followed by Uttar Pradesh (UP), 4.2, and Madhya Pradesh (MP), 4.0, whereas lowest energy ratio, 2.9, was recorded in case of western Rajasthan.
(iii) Punjab recorded specific energy as low as 4.6 MJ/kg, whereas western Rajasthan recorded the highest specific energy, 9.0 MJ/kg.
(iv) Punjab state occupied first place in the productivity of wheat (3334.8 kg/ha), which is about 31% higher than the average productivity, 2550.5 kg/ha of the region under study.
(v) Maximum possibility of increasing the productivity of wheat is in the state of Punjab from its present level (year 1998) of 3334.8–4313.6 kg/ha followed by MP, from 2371.4 (year 1996–1998) to 3132.4 kg/ha, and UP, from 2522.0 (year 1998) to 3162.5 kg/ha.
(vi) The direct energy input is slightly higher in wheat crop compared to indirect form of energy in respect of MP (50.4%). However, UP recorded the maximum indirect energy (60.3%).
(vii) Punjab recorded the maximum use of non-renewable energy (82.1%) as well as commercial energy (91.7%).
(viii) By raising the energy input level in the vicinity of optimum values wheat production in the Country can be increased provided energy input is made available in required quantity.

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