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Energy use pattern in production agriculture of a typical village in arid zone, India—part I

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Abstract

The data on energy use patterns and resources present in village ecosystems of the arid region are seldom available. India possesses about 31.71 Mha of hot arid areas of which 61.8% is in Rajasthan State, commonly known as the "Thar Desert", and is characterised by harsh climatic conditions with active dunal activities. Precipitations are far lower (100–420 mm/yr) than evapotranspiration potentials (1500–2000 mm/yr). Soils are sandy, having an undulating topography with poor organic carbon content (0.04–0.3%) against the average value, (0.8%), on an all India basis. Ground water is limited and often brackish. To further add to this grim situation, there is a continuous occurrence of severe drought in the region since the last three years (1997–1998 to 1999–2000). As a result, about 50–60% of the kharif crops (rainfed crops) failed and numbers of animals perished, resulting in shattering of the economy of the region. The data on energy input for cultivating different crops for the 1998–1999 (drought year) were collected, analysed and presented for the representative village "Choukha" district, Jodhpur. Owing to the drought, the farmers of the village have grown kharif crops (rainfed crops) by providing life saving irrigation. Although 50–60% of the crops failed, due to the irrigation, the yield levels were the same or even more during the period compared to the normal rainfall year yield.

Operationwise, the total energy use values (weighted mean) for cultivating the pearl millet crop were found to be 3807.4 MJ/ha compared to 2697.9 for green gram and 8726.3 for wheat. The average value of the energy input–output ratio was found to be 4.8, 6.8 and 3.2, respectively, for pearl millet, green gram and wheat, suggesting that cultivation of green gram is most remunerative to the farmers compared to the pearl millet and wheat crops.

Keywords: Energy analysis; Energy requirements; Energy use in agriculture; Operational energy; Source-wise energy input; Energy ratio

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1. Introduction

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, fertiliser, plant protection, chemicals, irrigation water, machinery etc. Efficient use of these energies helps to achieve increased production and productivity and contributes to economy, profitability and competitiveness of agriculture sustainability to rural living.

India has 31.71 Mha of hot arid areas of which 61.8% is in western Rajasthan, commonly known as the "Thar Desert", characterised by harsh climatic conditions and active dunal activities. Precipitation is far lower (100–420 mm/yr) than evapotranspiration potentials (1500–2000 mm/yr). Soils are sandy, having undulating topography with poor organic carbon content (0.04–0.3%) against an average value (0.8%) on an all India basis. Ground water is limited and often brackish.

A detailed energy census and resource availability surveys have been conducted by Vyas and Singh [1] for the village Hambran, district Ludhiana, Punjab State (northern India), by Maheshwari et al. [2] for the village Islamnagar, district Bhopal, Madhya Pradesh State (central India) and by Swaminathan and Ramanathan [3] for the village Selkkachal, district Coimbatore, Tamil Nadu State (southern India). Attempts have also been made to collect information on one aspect or the other for a number of villages at different locations in India under the All India, ICAR Coordinated Research Project on Energy Requirement in Agricultural Sector [4–6]. The data on energy use patterns in rural areas of the arid region and resources availability in the ecosystems are seldom available. The situation in the arid region (northwest India) is entirely different from other parts of the country. Efforts are needed to document energy use patterns and the availability of resources in the ecosystem in the arid region for planning to meet the energy demand through use of alternate energy and scarce available resources in the region.

The paper deals with energy use patterns in production agriculture for a drought situation for a representative village of zone III (300 mm/yr $\leqslant$ annual rainfall $<$ 400 mm/yr) of the arid region (village "Choukha") district Jodhpur. The paper forms part of a bigger study entitled "Energy Census and Resource Assessment of Arid Zone (Western Rajasthan)".

2. Materials and methods

Based on annual rainfall, the arid zone is classified into four zones (Fig. 1). The scope of this paper is limited to zone III (300 mm/yr $\leqslant$ annual rainfall $<$ 400 mm/yr) indicated in the map with the exact location of the representative village "Choukha" (Fig. 2). The demographic details of the village were collected. The well laid criteria, presented by Mittal and Dhawan [7] for selection of a representative village were followed. A form was devised in order to collect the required information related to the land possessed by farmers and the utilisation pattern, crops grown in different crop seasons and their yields, operation time, fuel consumption, electricity consumption and seed, fertiliser and chemical inputs etc. The information helpful in estimation/assessment of energy use in production agriculture and post-harvest activities were collected by making personal contacts with the farmers. To check the authenticity of the collected information, the actual

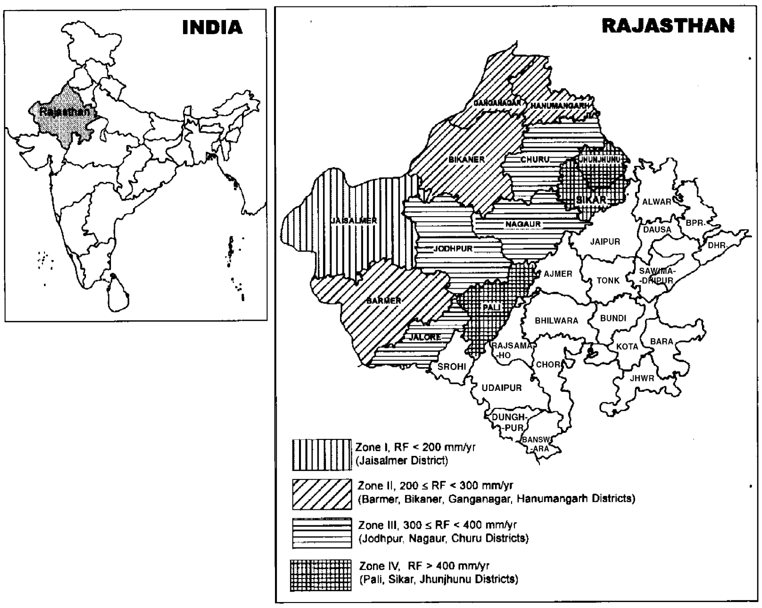

Fig. 1. Zone-wise (annual rainfall being the basis) map of arid region (western Rajasthan).

energy use for a few selected activities were determined experimentally in a few households belonging to different categories of farmers.

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 the different categories of farmers was taken.

The energy use values were determined by multiplying the associated energy equivalents/coefficients presented by Mittal et al. [5]. The cropping pattern and hectarage under the 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 different crops for the various categories of farms to estimate the weighted average energy used for the crop. The procedure for estimating weighted mean values of energy, as suggested by Mittal et al. [6], was followed.

3. Results and discussion

3.1. Village Choukha

The human population of the village is 2337 with a total geographical area of 2412.2 ha out of which only 272.4 ha (11.3%) is cultivable land, 710.8 ha (29.5%) is under pasture, 1196.7 ha (49.6%) is under forest and the rest, 232.3 ha (9.6%), is under settlement. There are 351 households in the village. Pearl millet, green gram, moth beans, cluster beans (kharif) and wheat (rabi) are the main crops grown in the village. Except for wheat, all other crops are grown as rainfed crops, but due to the drought conditions prevailing since the last three years (1997–1998 to 1999–2000) in the

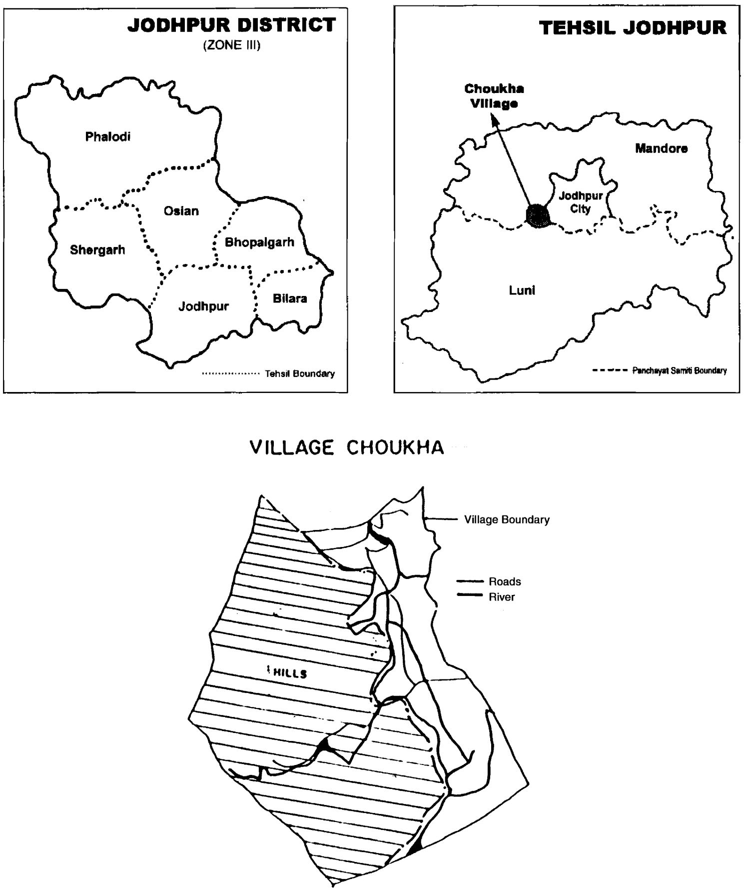

Fig. 2. Map showing location of geographical area surveyed (village Choukha, district Jodhpur, zone III).

arid region, even kharif crops were grown by a few resourceful farmers by providing life saving irrigation. The wheat crop is grown by farmers having assured irrigation facilities. Since irrigation was the limiting factor, only a few selective crops (pearl millet and green gram in kharif and wheat in rabi) were grown by the farmers.

3.2. Energy consumed in cultivating various selective crops of village Choukha

Operationwise, the energy consumed (weighted mean) and contribution of different energy sources for cultivating selective crops in the village Choukha, district Jodhpur, is presented in Table 1. The figures in parentheses indicate the percentage-wise distribution of energy. Crop-wise mean yield is also presented in the table for pearl millet, green gram and wheat.

(a) Pearl millet crop: Out of 57 farmers, only 16 have provided supplemental irrigation owing to drought conditions, which was essential to save the crop. About 60% of the crop failed due to the occurrence of the severe drought during 1998–1999.

Table 1
Energy use pattern for cultivating selective crops in village "Choukha", district Jodhpur, zone III of arid region, during drought period 1998–1999

Particulars	Weighted mean values in cultivating various crops		
	Pearl millet	Green gram	Wheat
Sample size	22[a]	6[a]	40[a]
Total area (ha)	21.9[a]	2.7[a]	34.2[a]
A. Operations (MJ/ha)			
Seedbed preparation	652.7 (17.1)[b]	538.6 (20.0)	1222.5 (14.0)
Sowing	366.4 (9.6)	289.9 (10.8)	377.7 (4.3)
Bund making	41.8 (1.1)	18.5 (0.7)	81.7 (0.9)
Irrigation	1264.6 (33.2)	1088.6 (40.4)	4241.0 (48.6)
Weeding	101.5 (2.7)	98.5 (3.7)	85.5 (1.0)
Fertiliser application	53.5 (1.4)	47.6 (1.8)	103.3 (1.2)
Harvesting	167.0 (4.4)	91.7 (3.4)	166.4 (1.9)
Threshing	452.6 (11.9)	280.6 (10.4)	1359.4 (15.6)
Transportation	671.7 (17.6)	210.7 (7.8)	1020.2 (11.7)
Post-harvest activity	35.7 (0.9)	33.2 (1.2)	61.1 (0.7)
Total	3807.4 (100)	2697.9 (100)	8726.3 (100)
B. Source (MJ/ha)			
Human	521.8 (10.5)	398.3 (11.6)	775.4 (5.1)
Diesel	1933.0 (38.8)	1161.4 (33.8)	3608.0 (23.6)
Electricity	1161.3 (23.3)	1020.1 (29.7)	3981.8 (26.0)
Seeds	101.1 (2.0)	103.4 (3.0)	1766.1 (11.6)
Farmyard manure	944.2 (19.0)	631.1 (18.4)	1319.1 (8.6)
Fertilisers	128.5 (2.6)	0.0 (0.0)	3433.8 (22.5)
Chemicals	0.0 (0.0)	0.0 (0.0)	44.4 (0.3)
Machinery	191.4 (3.8)	118.0 (3.4)	361.2 (2.4)
Total input energy	4981.3 (100)	3432.4 (100)	15289.8 (100)
C. Others			
Yield (kg/ha)	684.9	909.5	2118.3
Energy ratio	4.8	6.8	3.2
Specific energy (MJ/kg)	7.3	3.8	7.2
Seeds rate (kg/ha)	6.5	7.1	109.8
Man (h/ha)	133.0	128.8	218.2
Diesel (l/ha)	28.7	22.3	59.0
Electricity (kW/ha)	59.7	82.7	251.2
Tractor (h/ha)	7.7	6.0	15.1
Motor (h/ha)	11.6	27.7	51.9
Engine (h/ha)	3.3	0.0	0.0
Nitrogen (kg/ha)	1.3	0.0	38.7
Farmyard manure (q/ha)	58.5	44.9	79.0
Woman (h/ha)	66.4	76.0	96.2
Thresher (h/ha)	1.0	0.0	0.0
Implements (h/ha)	0.0	178.8	248.2
Phosphorous (h/ha)	0.0	0.0	14.1

[a] Grand total.
[b] Figures in parentheses indicate percentage of total energy input.

Out of all the farm operations, irrigation consumed the maximum energy (33.2%), followed by transportation (17.6%) and seedbed preparation (17.1%). Harvesting and threshing operations consumed 4.4% and 11.9% of the total energy input, respectively (Table 1). Harvesting of pearl millet is done manually, whereas threshing is performed mechanically. The transportation energy is more due to the fact that farm yard manure is applied in large quantities by the farmers. Bund making and post-harvest activities consumed only about 2.0% of the total energy input. The bund making operation is done by farmers having irrigation facilities.

For source-wise energy input, diesel contributes 38.8% of the total energy input (Table 1), followed by electricity (23.3%) and farm yard manure (19.0%). The share of farm yard manure is relatively more as the number of animals are more in the region (human:animal ratio, 1:4 or above compared to about 1:1 on an all India basis). A total of 133 man-h/ha are required for performing various farm activities as compared to 66.4 woman-h/ha, (i.e. 49.9% of the total man-h/ha required in cultivating pearl millet crop). Generally, smaller farms were effectively managed compared to larger size farms. The intensiveness of farm operations was more on smaller farms than on larger farms. In the case of the large size farms, with the land holding being relatively more, the intensiveness of operations may not be possible with the available resources.

The yield of pearl millet was in the range of 179.5–914.1 kg/ha (mean 684.9 kg/ha), being significantly high on marginal farms as compared to medium farms. This may be due to timely irrigation of the crop as well as better management of available resources by the marginal farmer. The energy input–output ratio varied from 3.4 to 5.8 with weighted mean of 4.8. On an average, 7.3 MJ/kg specific energy was required for cultivating pearl millet.

The data on pearl millet yield and energy input were analysed. An exponential relationship between energy input and yield with R^2 66% was obtained (Eq. (1)) as:

$$Y = 1.5 \times 10^3 \exp(0.247 \times 10^{-3} X) \tag{1}$$

where Y is yield of pearl millet, kg/ha and X is energy input, MJ/ha.

The plot of the observed and predicted values of yield is presented in Fig. 3.

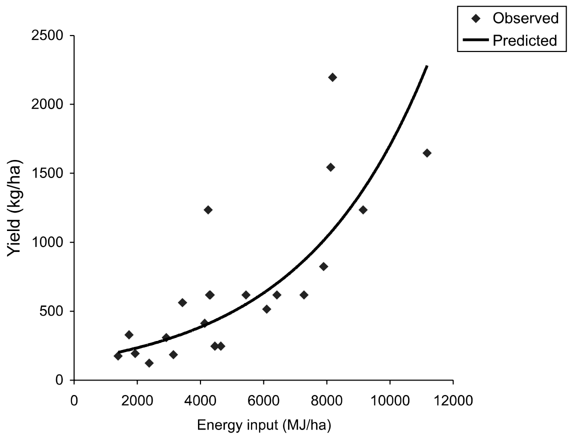

Fig. 3. Relation between yield and energy input for cultivating pearl millet crop.

(b) Green gram crop: It may be inferred from Table 1 that out of all farm operations in raising the green gram crop, irrigation consumed the maximum energy (40.4%), followed by seedbed preparation (20.0%), sowing (10.8%) and threshing (10.5%). Similar to pearl millet, green gram is a rainfed crop in the region, but the farmers have raised it as an irrigated crop under the drought situation.

For source-wise energy input, diesel alone contributed 33.8% of the total energy input, followed by electricity 29.7%, farm yard manure 18.4% and human 11.6%. Human energy was mainly required for harvesting and weeding, as these activities were mainly performed manually. The contributions of machinery and seeds were 3.4% and 3.0%, respectively. Except farm yard manure, no chemical fertiliser was applied in green gram compared to pearl millet, where the contribution of chemical fertilisers was 2.6%.

An average yield of 909.5 kg/ha (range 797.9–1003.8 kg/ha) was obtained for green gram with an energy input–output ratio of 6.8 (range 6.1–7.7) and specific energy consumption of 3.8 MJ/kg (range 3.3–4.2 MJ/kg). In the case of green gram, the energy ratio was observed to be high (6.8) compared to pearl millet (4.8), suggesting that cultivation of green gram is more remunerating to the farmers of the arid region (zone III, $300 \leqslant$ rainfall < 400 mm/yr) compared to pearl millet, particularly during drought conditions.

(c) Wheat crop: The wheat crop is raised only by those farmers having irrigation facilities. Hence, no adverse affect of drought was observed in the case of the wheat crop. From Table 1, it may be inferred that the total energy input in the various farm operations varied between 6091.3 and 10190.8 MJ/ha (weighted mean 8726.3 MJ/ha), being maximum on small farms and minimum on medium farms. The farmers having relatively low land holding (marginal and small farmers) have provided more irrigation to the wheat crop compared to medium farmers. The command area for a tube well is less in the case of marginal and small farmers compared to medium farmers. The energy use per unit area through irrigation was more in the case of marginal and small farmers compared to medium farmers. Based on weighted mean energy values, the percentage-wise energy used in performing various farm operations, was a maximum for irrigation (48.6%), followed by threshing (15.5%) and seed bed preparation (14.0%). 11.7% of the total energy is consumed in transportation of farm yard manure and farm produce. Sowing of wheat is done with the help of a tractor drawn seed drill whereas harvesting is generally done manually in the region. The farmers use more farm yard manure and apply a small quantity of chemical fertilisers to the crop in the region.

The source-wise total energy input for cultivating the wheat crop varied from 10047.1 to 16202.3 MJ/ha with a weighted mean of 15289.8 MJ/ha. The major share of this source-wise energy input is contributed through electricity (26.0%) followed by Diesel (23.6%) and fertilisers (22.5%). The electricity and diesel contributes about 50% of the total energy consumed. The shares of seeds, farm yard manure, human and machinery energy of the total energy are 11.6%, 8.6%, 5.1% and 2.4%, respectively.

The yield of wheat was in the range of 1539.5–2440.9 kg/ha with a weighted mean of 2118.3 kg/ha. The yield of wheat was high 2440.9 and 2163.5 kg/ha, respectively, on small and marginal farms compared to 1698.8 kg/ha on medium farms and 1539.5 kg/ha on semi-medium farms. The energy ratio was observed to be 3.2 (mean value), a relatively low value compared to pearl millet (4.8) and green gram (6.8). It is because of the high energy input through irrigation in wheat. The specific energy required for cultivation of wheat was 7.2 MJ/ha (range 5.9–8.9 MJ/kg).

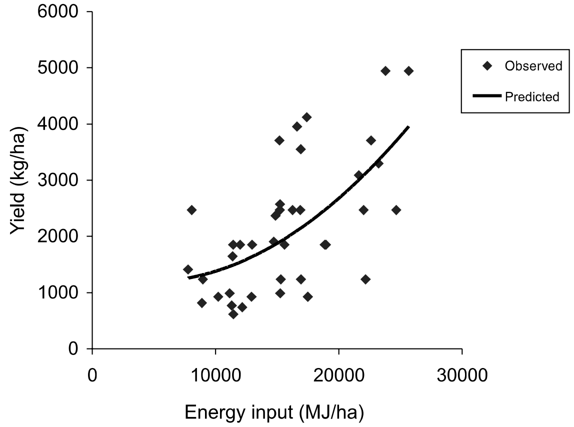

Fig. 4. Relation between yield and energy input for cultivating wheat crop.

Similar to pearl millet, the data on the yield of wheat and total energy input were analysed. The following relationship with R^2 37% was obtained as:

$$Y = 1.30 \times 10^3 - 0.0537X + 0.611 \times 10^{-5}X^2 \tag{2}$$

The notations have already been explained above. A plot of the observed and predicted values of the yield of wheat is presented in Fig. 4. The heterogeneity of data sources and human error involved justify the low value of R^2 obtained for wheat as well as that for pearl millet.

3.3. Effect of drought on crop yield and energy input

The month-wise rainfall and number of rainy days for the last 10 years (1991–2000) received at Jodhpur are presented in Table 2. From this table, an average of 382.9 mm rainfall is received in the monsoon season, i.e. from June to September, the period in which rainfed crops, viz pearl millet and green gram were raised (Table 3). Further, 56.7 mm rainfall was received in July 1998 in four days as against an average value, 133.7 mm in six days. Similarly, in the month of August, only 105.3 mm rainfall has occurred just in three days as against an average value of 130.0 mm in 5.5 days. Therefore, pearl millet and green gram crops were raised only by those farmers who have provided irrigation during the no rain period. The rest of the farmers could not raise the crop.

The average grain yield and corresponding rainfall (June to September for the kharif season and November to March for the rabi season) for the last eight years is shown in Table 3. From the table, it is clear that the average production of pearl millet was about 500 kg/ha in the normal years of rainfall, whereas the average yield recorded at the farmers field in Choukha village was 684 kg/ha under irrigated conditions, which is in agreement with the average yield of pearl millet in a normal rainfall year. Therefore, the only difference in drought and normal rainfall years is that the farmers will not have to provide any irrigation in the normal rainfall year, and as a result, the energy component associated with irrigation will be zero. The other input components will remain more or less the same. Similarly, in the case of green gram, the average yield in the normal rainfall year is 500 kg/ha, while applying a little life saving irrigation, the farmers at Choukha

Table 2
Month-wise rainfall and number of rainy days during 1991–2000 for district Jodhpur (zone III of arid region)

Year	Rainfall (mm) during different months of year												
	January	February	March	April	May	June	July	August	September	October	November	December	Total rainfall (mm/yr)
1991	0.0 (0)	0.0 (0)	0.0 (0)	11.1 (1)	0.0 (0)	10.2 (2)	74.7 (7)	96.4 (6)	11.0 (2)	0.0 (0)	0.0 (0)	0.6 (0)	204.0 (18)
1992	26.6 (2)	12.8 (1)	3.7 (1)	0.0 (0)	5.0 (1)	4.2 (1)	82.1 (5)	104.7 (6)	196.3 (6)	0.0 (0)	0.0 (0)	0.0 (0)	435.4 (23)
1993	3.2 (1)	0.7 (0)	0.0 (0)	28.6 (1)	0.0 (0)	92.0 (4)	136.9 (6)	4.1 (1)	47.4 (3)	11.7 (1)	1.6 (0)	0.0 (0)	326.2 (17)
1994	23.6 (1)	0.0 (0)	0.0 (0)	27.0 (2)	0.8 (0)	11.2 (3)	191.2 (10)	254.3 (12)	87.8 (8)	0.0 (0)	0.0 (0)	0.0 (0)	595.9 (36)
1995	1.8 (0)	0.0 (0)	0.7 (0)	0.0 (0)	0.0 (0)	26.7 (2)	229.6 (8)	75.5 (6)	0.8 (0)	4.5 (1)	0.0 (0)	0.0 (0)	339.6 (17)
1996	1.4 (0)	3.4 (1)	0.0 (0)	4.8 (1)	30.8 (3)	164.0 (7)	145.6 (5)	273.5 (9)	4.7 (1)	0.0 (0)	0.0 (0)	0.0 (0)	628.2 (27)
1997	0.0 (0)	0.0 (0)	1.5 (0)	0.4 (0)	20.1 (3)	66.4 (4)	50.2 (5)	201.1 (9)	42.8 (3)	47.7 (4)	9.8 (1)	0.0 (0)	440.0 (29)
1998	0.0 (0)	3.8 (1)	14.0 (2)	36.0 (2)	0.0 (0)	163.0 (4)	56.7 (4)	105.3 (3)	52.4 (4)	47.3 (3)	0.0 (0)	0.0 (0)	478.5 (23)
1999	6.0 (1)	14.2 (1)	0.0 (0)	0.0 (0)	11.7 (1)	48.5 (2)	58.6 (4)	138.6 (2)	7.8 (2)	10.7 (1)	0.0 (0)	0.0 (0)	296.1 (14)
2000	0.0 (0)	0.5 (0)	0.0 (0)	2.5 (1)	5.0 (1)	19.3 (1)	214.1 (8)	46.4 (1)	3.0 (1)	1.5 (0)	0.5 (0)	0.0 (0)	292.8 (13)
Average	6.3 (0.5)	3.5 (0.8)	2.0 (0.3)	11.0 (0.8)	7.3 (1.2)	60.6 (3.0)	124.0 (6.7)	130.0 (5.5)	45.4 (3.6)	12.3 (1.0)	1.2 (0.1)	0.1 (0)	403.7 (21.7)
Average for 1963–2000	3.0 (0.3)	3.7 (0.4)	3.7 (0.4)	8. (0.5)	15.1 (1.1)	34.9 (2.0)	133.7 (5.7)	125.9 (6.0)	48.5 (2.8)	6.6 (0.6)	3.0 (0.2)	2.7 (0.1)	389.3 (20.1)

Figures in parentheses indicate number of rainy days.
Note: 2.5 mm or more rainfall occurring on a particular day was considered as one rainy day.

Table 3
Average yield of various selective crops of Jodhpur district (zone III) for the period 1991–1998

Year	Area (ha)	Production (q)	Productivity (kg/ha)	Rainfall (June–September) (mm)
(i) Pearl Millet				
1991	573,947	831,900	145	192.3
1992	684,810	3,287,360	480	387.3
1993	591,135	399,820	68	280.4
1994	705,793	3,771,760	534	544.5
1995	614,756	894,630	146	332.6
1996	626,124	2,301,030	368	587.8
1997	616,177	2,394,030	405	360.5
1998	511,288	320,790	63	377.4
Average	547,114	1,577,924	238	382.9
(ii) Green Gram				
1991	28,438	5260	18	192.3
1992	33,737	167,410	496	387.3
1993	40515	39,690	98	280.4
1994	NA	NA	NA	544.5
1995	49,393	37,420	76	332.6
1996	64,587	181,740	281	587.8
1997	69,118	224,630	325	360.5
1998	NA	NA	NA	377.4
Average	47,631	109,358	216	382.9
(iii) Wheat[a]				
1991	19,527	322,890	1654	43.7
1992	27,395	521,860	1905	3.9
1993	26,210	324,030	1236	25.2
1994	26,314	577,640	2195	2.5
1995	25,995	552,700	2126	4.8
1996	27,073	616,380	2277	1.5
1997	34,857	590,100	1693	27.6
1998	36,017	648,970	1802	20.2
Average	27,924	519,321	1861	16.2

[a] The rainfall data for wheat are for November–March.

could obtain an average yield of 900 kg/ha. Wheat, being a rabi crop, is totally irrigated in the region. Therefore, drought did not show a significant adverse effect on the yield in village Choukha.

4. Conclusions

The following conclusions are drawn:

(i) Out of the total geographical area (2412.2 ha) of the village, only 272.4 ha is cultivable land (i.e. only 11.3%).

(ii) Pearl millet, green gram (kharif crops) and wheat (rabi crop) are selective crops of the village. The kharif crop is normally taken under rainfed conditions, whereas the rabi crop is grown under irrigated conditions. During the year 1998–1999, being drought years, even kharif crops were raised under irrigated conditions by providing life saving irrigation. Further, 50–60% of the kharif crops failed due to drought.
(iii) Operationwise, the total energy use value (weighted mean) for cultivating pearl millet was found to be 3807.4 MJ/ha compared to 2697.9 MJ/ha in the case of green gram and 8726.3 MJ/ha for the wheat crop. Thus, cultivation of green gram is less energy intensive compared to the pearl millet and wheat crops.
(iv) The average specific energies for cultivating pearl millet, green gram and wheat crop were observed to be 7.3, 3.8 and 7.2 MJ/ha, respectively.
(v) The average values of the energy ratio were estimated to be 4.8, 6.8 and 3.2, respectively, for the pearl millet, green gram and wheat crops, suggesting that cultivation of the green gram crop is more remunerating to the farmers compared to the pearl millet and wheat crops under zone III of the arid region.
(vi) A definite non-linear relationship exists between crop yield and total energy input as inscribed in the manuscript. The crop yield increases with an increase in total energy input.
(vii) During a drought period, additional energy is required for irrigating kharif crops in the arid region (zone III) for maintaining yield levels commensurate with normal rainfall years yields. However, in the case of rabi crops, the drought did not show a significant adverse effect on the yield, as these are totally irrigated crops.

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