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Energy Use Pattern in Production Agriculture of Arid Western Rajasthan

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Abstract: A detailed study on energy use pattern in production agriculture of arid region for representative villages: Pemasar, district Bikaner; Choukha, district Jodhpur; Siwas, district Pali has been carried out. The data on energy input for cultivating different crops in Choukha village during 1998-99, in Siwas village during 1999-2000 and in Pemasar village during 2000-01 were collected, analyzed and are presented in the paper. For Pemasar village, the average energy output-input ratio for clusterbean (rainfed and irrigated), moth bean (rainfed and irrigated), and groundnut (irrigated) were 2.1, 0.5, 3.4, 3.5 and 3.0, respectively. Similarly, the energy ratio for wheat, gram, mustard and rocket salad were 2.1, 1.6, 3.1, and 3.3, respectively. Thus cultivation of moth bean during kharif season and rocket salad and mustard crops during rabi season is more remunerative to the farmers of Zone II compared to other crops. For Choukha village, the average values of energy output-input ratio were 4.8, 6.8, 3.2 and 2.0, respectively, for pearl millet, green gram, wheat and chilly crop suggesting that cultivation of green gram and pearl millet is most remunerative to the farmers of Zone III compared to other crops. Among the crops grown in village Siwas the energy ratio varied from 3.4 to 7.0. Cotton and mustard crops having energy ratio 7.0 and 4.4, respectively, are found to be the most profitable compared to other crops. The crop yield was correlated with energy input in the form of a second-degree polynomial relationship. Optimum input energy levels of some major crops in all three zones have been determined. Contribution of commercial and non-renewable energy sources are much higher than non-commercial and renewable sources in general and during the rabi season in particular.

Key words: Energy use in agriculture, arid region, energy requirement, energy ratio, operational energy.

The introduction of high yielding varieties of major crops in India in mid sixties brought about many important technological changes that led to unprecedented rise in crop yield and productivity in many parts of the country. These new production technologies require a large quantity of inputs viz. fertilizers, irrigation water, diesel, plant protection chemicals, electricity, etc. Application of these inputs demand more and more use of energy in the form of human, animal and machinery with an improved countryside transportation system. The rural unskilled labor has become more mobile, which makes the agricultural labor supply more elastic. The energy scenario of crop production has changed since the introduction of modern inputs. Therefore, it is imperative to study the energy-use patterns analytically and suggest what is likely to happen on energy front in the future.

India has 31.71 Mha of hot arid area, of which 61.8% is in Western Rajasthan commonly known as "Thar Desert", which is characterized by harsh climatic conditions and active dunal activities. Precipitations are far below (100-450 mm yr^{-1}) the evapo-transpiration potentials (1500-2000 mm yr^{-1}). Soils are sandy having undulating topography with poor organic carbon content ranging from 0.04 to 0.3% compared to national average of 0.8%. Ground water is limited and often brackish.

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Energy census and resource assessment data for representative villages of arid region should give clear picture of energy consumption pattern and resources available in the ecosystem and their utilization status. Availability of such data should also lead to planning for rural development in the arid region.

Detailed energy census and resource availability surveys have been conducted by Vyas and Singh (1984) for village Hambran, district Ludhiana, Punjab State (Northern India), Maheshwari *et al.* (1981) for village Islamnagar, district Bhopal, Madhya Pradesh State (Central India) and Swaminathan and Ramanathan (1984) for 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 All India, ICAR Coordinated Research

Project on Energy Requirement in Agricultural Sector (Anonymous, 1983; Mittal *et al.*, 1987; 1992). The data on energy use pattern in rural areas for representative villages of different zones of arid region and resources availability in ecosystem have already been presented in piecemeal by Singh *et al.* (2002; 2003; 2004).

This paper deals with energy use pattern in production agriculture for arid western Rajasthan. Mathematical relation between crop yield and energy input is presented. Based on the relationship the yields of crops, grown in the arid region, have been maximized to potential with the corresponding optimum energy input.

Theoretical considerations

Yield and energy input relationship: The crop yield (Y) is a function of energy input (X). That is,

$$Y = f(X) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad ...(1)$$

There is a common belief that crop yield must increase with energy input. Beyond maximum yield potential, it should be independent of the energy input. After trying many relations between crop yield and total energy input, it was found that second degree polynomial relation gave the best result with mean maximum value of coefficient of determination. Thus, the crop yield shall be expressed as under;

$$Y = \beta_o + \beta_1 X + \beta_2 X^2. \ldots\ldots\ldots \quad ...(2)$$

Assuming that when the energy input is zero the crop yield is also zero. That is, the constant term β_o (intercept) is zero in Eq. (2) above. Thus, the Eq. (2) may be reduced to,

$$Y = \beta_1 X + \beta_2 X^2 \ldots\ldots\ldots\ldots\ldots \quad ...(3)$$

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

Optimization of energy input

For yield maximum optimum energy input for which the first derivative of Eq. (3) is equated to zero (i.e. $dy/dx = 0$) and second derivative (i.e. d^2y/dx^2) is –ve. Thus the values of optimum energy input to crop and maximum yield can be given as ($\beta_1/2\beta_2$) and ($\beta_12/4\beta_2$), respectively.

Materials and Methods

Based on annual average rainfall, the arid region may be classified into four zones (Fig. 1) as:

Zone I: Rainfall <200 mm (Jaisalmer district)

Zone II: Rainfall 200-300 mm (Barmer, Bikaner, Ganganagar and Hanumangarh districts)

Zone III: Rainfall 300-400 mm (Jodhpur, Nagaur, Jalore and Churu districts)

Zone IV: Rainfall > 400 mm (Pali, Jhunjhunu and Sikar districts).

The demographic details of the village were collected. The well laid criterion, presented by Mittal and Dhawan *et al.* (1988) for selection of a representative village was followed. Village Pemasar, district Bikaner (Zone II), village Choukha, district Jodhpur (Zone III) and village Siwas, district Pali (Zone IV) were selected for the study. A proforma was devised to collect required information on land possessed by farmers and utilization pattern, crops grown in different seasons and their yields, operation time, fuel consumption, electricity consumption, seed, fertilizer 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.

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 were taken.

The energy use was determined by multiplying the associated energy equivalents/coefficients presented by Mittal *et al.* (1987). The cropping pattern and area under a crop changed from farm to farm, and consequently, the energy use even for the same crop, varied at different farms. Therefore, weights were assigned according to the area under different crop for the various categories of farms to estimate weighted average values of energy used for the selected crop. The procedure for estimating weighted mean values of energy as suggested by Mittal *et al.* (1992) was followed as given below:

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

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

where, $i = 1,2,3\ldots\ldots n$

Similarly, weighted mean of yield, Y with respect to area and energy input can be given as,

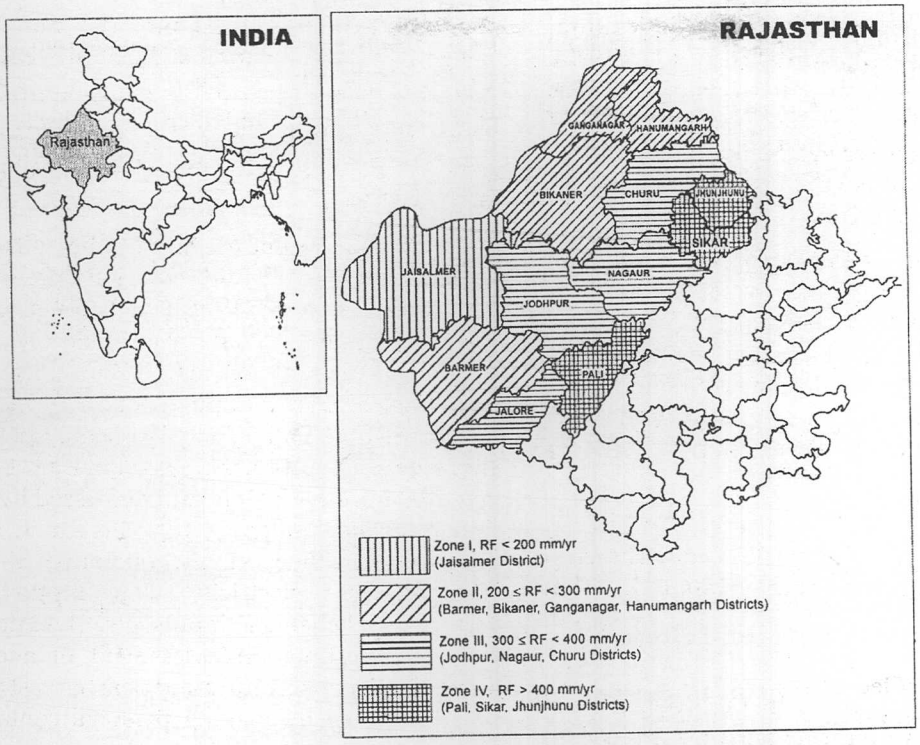

Fig. 1. Zone-wise (annual rainfall being the basis) map of arid region (Western Rajasthan).

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

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

The data showed large variation due to different sources from where these were collected and human error. To overcome this error the sample was randomized. The data in close vicinity were grouped together by considering definite equal intervals of an entity and mean yield and energy use were determined using the relationship presented in Eq. (2, 3). This expression between crop yield and energy input should present the data with better R^2 values, resulting in clear and pronounced relationships.

Results and Discussion

Zone-wise details of resources

The zone-wise details of villages considered, are summarized in Table 1. Zone II has a fairly large area under cultivation (73.3%) as compared to Zone III and Zone IV. The reason for having such a high cultivable area in Zone II is its location in canal command area. Zone III and Zone IV have cultivable lands as low as 11.3% and 33.0%, respectively.

Zone-wise energy use pattern for growing various crops

Zone II: Table 2A gives the details of energy use patterns of main kharif crops of Zone II in the drought year (2000-01). Operation-wise, groundnut consumed maximum energy (12809.6 MJ ha^{-1}) as compared to clusterbean irrigated (5582.6 MJ ha^{-1}), moth bean irrigated (4071.3 MJ ha^{-1}) and clusterbean and moth bean rainfed. Source-wise, electricity contributed only to clusterbean irrigated (3.3%) to the total energy requirement of 5582.6 MJ ha^{-1}. Groundnut consumed maximum diesel 111.4 L ha^{-1}, which accounted for nearly 25.6% of the total energy input.

Moth bean, both rainfed and irrigated, provided maximum energy ratio 3.4 and 3.5 as compared to groundnut (3.0). The specific energy for growing moth bean irrigated is the lowest (7.4 MJ kg^{-1}) followed by clusterbean irrigated (7.5 MJ kg^{-1}).

Table 2B presents the details of the energy use patterns of major rabi crops of Zone II in the drought year (2000-01). Operation-wise, wheat consumed maximum energy (7953.1 MJ ha^{-1}) as compared to gram (4845.2 MJ ha^{-1}) and mustard (4779.4 MJ ha^{-1}). Source-wise, rocket salad consumed maximum diesel (30.6%) where as

Table 1. Details of villages considered along with cultivable land and crops grown

Zone	Rainfall (RF) mm yr^{-1}	Village	Population	Total area, ha	Cultivable land, ha	Crops grown in different seasons	
						Kharif	Rabi
II	200-300	Pemasar district Bikaner	1500	945.7	693.6	Clusterbean, moth bean, groundnut and green gram	Wheat, chick pea, mustard and rocketsalad
III	300-400	Choukha district Jodhpur	3337	2412.2	272.2	Pearl millet, clusterbean and green gram	Wheat, mustard, cabbage, onion (green), methi, spinach, chilly and pearl millet (green fodder)
IV	>400	Siwas district Pali	3054	1213.0	410.1	Cotton, maize, green gram, clusterbean, sorghum and sesame	Wheat, mustard, barley and lucerne

Note: Data for Zone I could not be collected.

fertilizer contributed maximum to mustard crop (56.7%). The contribution of electrical energy to wheat was negligible (0.3%) as irrigation was mainly provided through canal.

Zone III: Table 3 presents the energy use patterns of some major crops being grown in Zone III in the drought year (1998-99). Operation-wise, chilly crop, consumed maximum energy (13698.5 MJ ha^{-1}) as compared to wheat (8736.3 MJ ha^{-1}), pearl millet (3807.4 MJ ha^{-1}) and green gram (2697.9 MJ ha^{-1}). Source-wise, electricity contributed maximum (56.4%) to the total energy requirement of chilly crop (17558.1 MJ ha^{-1}) followed by fertilizer (13.7%). Wheat also consumed maximum electrical energy (26% of 15289.8 MJ ha^{-1}) to meet the irrigation requirement. Diesel came next to electricity (23.6%) and performed field preparation and sowing operations. Similarly, both pearl millet and green gram required electricity and diesel as major sources of energy. Green gram provided maximum energy ratio (6.8) as compared to pearl millet (4.8), wheat (3.2) and chilly (2.0). Wheat required maximum diesel (59.0 L ha^{-1}) as compared to chilly (28.4 L ha^{-1}), pearl millet (28.7 L ha^{-1}) and green gram (22.3 L ha^{-1}). Chilly crop needed maximum electricity (885 kWh ha^{-1}), whereas, other crops, such as pearl millet, green gram and wheat consumed only 59.7, 82.7 and 251.2 kWh ha^{-1}, of electrical energy, respectively.

The specific energy for growing chilly crop is the lowest (2.8 MJ kg^{-1}), whereas; wheat and pearl millet needed 7.2 and 7.3 MJ energy, respectively, to produce one kg grains. It consumed only 3.8 MJ energy to produce one kg grains of green gram.

Zone IV: Table 4 presents the energy consumed by some important crops being grown in Zone IV in the drought year (1999-2000). Operation-wise, cotton crop consumed maximum energy (11549.0 MJ ha^{-1}) as compared to wheat (10257.3 MJ ha-1), mustard (7145.1 MJ ha^{-1}), maize (6196.9 MJ ha-1) and clusterbean (2728.2 MJ ha^{-1}). Source-wise, fertilizer contributed maximum (28.5%) to the total energy requirement of cotton crop (19400.6.1 MJ ha^{-1}) followed by electricity (28.0%). Wheat consumed maximum diesel energy (26.0% of 17042.3 MJ ha^{-1}) followed by electricity (24.9%) and chemical fertilizer (24.6%). Both cotton and wheat are irrigated crops in the region, as irrigation alone consumed about 50-60% of total operation-wise energy. Similarly, both mustard and clusterbean required diesel as a major source of energy (33.6 and 48.0%) compared to other crops. In case of maize maximum share came from fertilizer (32.2%).

Cotton provided maximum energy ratio (7.0) followed by mustard (4.4), maize (3.9), clusterbean (3.4) and wheat (3.2). Wheat required maximum diesel (72.3 L ha^{-1}) followed by mustard (54.0 L ha^{-1}), cotton (51.4 L ha^{-1}), maize (42.0 L ha^{-1}) and clusterbean (30.7 L ha^{-1}). Cotton crop needed maximum electricity (399.0 kWh ha^{-1}) followed by wheat 324.5 kWh ha^{-1}.

Table 2A. Energy use pattern for cultivating various kharif crops in village Pemasar district Bikaner (Zone II) during 2000-01 (drought year)

Particulars	Weighted mean value for cultivating various crops				
	Clusterbean		Moth bean		Groundnut
	Rainfed	Irrigated	Rainfed	Irrigated	Irrigated
Sample size	59*	24*	46*	23*	22.0*
Total area, ha	181.7*	42.8*	123.9*	24.5*	7.5*
A. Operation, MJ ha^{-1}					
Seedbed preparation and sowing	788.6 (62.5)[a]	943.4 (26.4)	760.1 (64.0)	831.3 (29.2)	2541.6 (19.9)
Weeding	133.6 (10.6)	285.8 (8.0)	154.4 (13.0)	296.3 (10.4)	902.5 (7.0)
Fertilizer application	2.5 (0.2)	21.0 (0.6)	2.1 (0.2)	22.7 (0.8)	43.2 (0.3)
Spraying	0.8 (0.1)	2.0 (0.1)	–	119.9 (4.2)	314.2 (2.5)
Harvesting	120.3 (9.5)	304.5 (8.5)	158.1 (13.3)	406.1 (14.3)	2743.7 (21.4)
Threshing	187.4 (14.8)	820.7 (22.9)	84.9 (7.1)	249.7 (8.8)	1775.3 (13.9)
Bund making	–	108.4 (3.0)	–	119.9 (4.2)	314.2 (2.5)
Irrigation	–	965.0 (27.0)	–	833.1 (29.3)	4192.7 (32.7)
Transportation	28.7 (2.3)	125.6 (3.5)	28.0 (2.4)	87.2 (3.1)	283.9 (2.2)
Total energy	1261.9 (100)	3576.4 (100)	1187.6 (100)	2847.3 (100)	12809.6 (100)
B. Source, MJ ha^{-1}					
Human	282.0 (17.0)	787.4 (14.1)	406.3 (26.1)	1001.3 (24.6)	2142.8 (8.5)
Animal	2.9 (0.2)	14.4 (0.3)	10.6 (0.7)	22.9 (0.6)	389.7 (1.5)
Diesel	896.0 (54.1)	1837.9 (32.9)	692.4 (44.4)	1200.5 (29.5)	6477.0 (25.6)
Electricity		186.9 (3.3)			
Seeds	366.5 (22.1)	490.6 (8.8)	333.7 (21.4)	392.8 (9.6)	3728.2 (14.7)
Farm yard manure	22.6 (1.4)	395.4 (7.1)	25.9 (1.6)	317.9 (7.8)	701.3 (2.8)
Fertilizers		1090.8 (19.5)	12.4 (0.8)	506.9 (12.5)	7812.8 (30.9)
Chemicals	5.0 (0.3)	29.4 (0.5)		6.4 (0.2)	241.5 (1.0)
Machinery	80.9 (4.9)	179.2 (3.2)	78.2 (5.0)	148.3 (3.6)	731.0 (2.9)
Canal		570.6 (10.2)		474.3 (11.6)	3069.3 (12.1)
Total input energy	1656.0 (100)	5582.6 (100)	1559.5 (100)	4071.3 (100)	25593.6 (100)
C. Others					
Yield, kg ha^{-1}	141.4	743.9	202.6	551.8	2253.4
Energy-ratio	2.1	0.5	3.4	3.5	3.0
Specific energy, MJ kg^{-1}	11.7	7.5	7.7	7.4	11.2
Seed rate, kg ha^{-1}	23.9	29.7	19.5	26.6	138.2
Man, h ha^{-1}	68.6	212.9	84.5	263.6	622.0
Woman, h ha^{-1}	44.8	112.4	65.1	227.2	388.4
Animal, h ha^{-1}	0.2	0.7	1.1	1.1	29.8
Diesel, L ha^{-1}	15.2	27.4	9.8	27.1	111.4
Electricity, kWh ha^{-1}	–	64.1	–	–	–
Tractor, h ha^{-1}	3.2	5.6	2.1	–	–
Motor, h ha^{-1}	–	1.9	–	–	–
Engine, h ha^{-1}	0.0	1.9	–	8.3	9.6
Canal, h ha^{-1}		7.2		7.3	63.1
Implements, h h^{-1}	105.0	290.3	84.5	278.5	820.3
Nitrogen, kg ha^{-1}	–	10.4	–	–	–
Phosphorus, kg ha^{-1}	–	3.2	–	–	–
Chemical (sup.), L ha^{-1}	–	0.2	–	0.2	2.5
Farm yard manure, q ha^{-1}	1.1	32.8	1.0	49.8	

* Grand Total; [a] Figures in parentheses indicate percentage of total energy input.

Table 2B. Energy use pattern for cultivating various rabi crops in village Pemasar district Bikaner (zone-II) during 2000-01

Particulars	Weighted mean value for cultivating various crops			
	Wheat	Gram	Mustard	Rocket salad
Sample size	38*	38*	23*	13*
Total area, ha	14.6*	16.1*	10.9*	5.7*
A. Operation, MJ ha^{-1}				
Seedbed preparation	1921.6 (24.2)[a]	1453.2 (30.0)	1412.5 (29.6)	1118.7 (29.0)
Sowing	1035.4 (13.0)	806.4 (16.6)	715.9 (15.0)	602.5 (15.6)
Weeding	202.1 (2.5)	264.5 (5.5)	269.8 (5.6)	114.8 (3.0)
Fertilizer application	0.3 (0.0)			
Spraying	17.9 (0.2)	63.0 (1.3)	84.2 (1.8)	12.9 (0.3)
Harvesting	506.9 (6.4)	333.0 (6.9)	289.2 (6.1)	225.8 (5.9)
Threshing	1987.6 (25.0)	840.4 (17.3)	1015.0 (21.2)	868.2 (22.5)
Bund making	139.1 (1.7)	122.4 (2.5)	92.9 (1.9)	115.9 (3.0)
Irrigation	1755.4 (22.1)	741.6 (15.3)	726.2 (15.2)	545.5 (14.1)
Transportation	386.9 (4.9)	220.7 (4.6)	173.7 (3.6)	251.3 (6.5)
Total energy	7953.1 (100)	4845.2 (100)	4779.4 (100)	3855.6 (100)
B. Source, MJ ha^{-1}				
Human	1001.2 (4.5)	883.3 (6.8)	824.2 (6.8)	537.1 (6.6)
Animal	47.9 (0.2)	65.9 (0.5)	68.9 (0.6)	78.8 (1.0)
Diesel	4990.1 (22.6)	2929.9 (22.7)	3061.5 (25.4)	2483.0 (30.6)
Electricity	61.7 (0.3)			
Seeds	2845.4 (12.9)	1479.6 (11.5)	154.7 (1.3)	194.5 (2.4)
Fertilizers	11149.6 (50.6)	6378.9 (49.4)	6834.9 (56.7)	4027.2 (49.6)
Chemicals	83.9 (0.4)	206.1 (1.6)	275.3 (2.3)	35.6 (0.4)
Machinery	483.7 (2.2)	337.9 (2.6)	309.9 (2.6)	254.9 (3.1)
Canal	1368.5 (6.2)	628.2 (4.9)	515.1 (4.3)	502.1 (6.2)
Total input energy	22032.0 (100)	12909.8 (100)	12044.5 (100)	8113.2 (100)
C. Others				
Yield, kg ha^{-1}	1668.9	687.3	731.3	474.9
Energy-ratio	2.1	1.6	3.1	3.3
Specific energy, MJ kg^{-1}	11.4	16.5	13.2	13.7
Seed rate, kg ha^{-1}	193.0	98.3	6.3	7.7
Man, h ha^{-1}	240.7	210.8	186.9	141.0
Woman, h ha^{-1}	295.8	266.4	251.5	150.4
Animal, h ha^{-1}	4.9	5.5	8.3	4.4
Diesel, L ha^{-1}	89.5	52.1	52.7	44.6
Electricity, kWh ha^{-1}	6.5	0.0	–	–
Tractor, h ha^{-1}	17.5	11.1	10.9	9.8
Motor, h ha^{-1}	0.5	–	–	–
Engine, h ha^{-1}	7.0	0.5	1.8	–
Canal, h ha^{-1}	24.2	10.8	9.2	6.9
Implements, h h^{-1}	495.7	429.1	402.2	276.4
Nitrogen, kg ha^{-1}	157.7	85.9	101.5	64.6
Phosphorus, kg ha^{-1}	74.6	42.7	43.2	30.0
Chemical (sup.), L ha^{-1}	8.5	1.5	1.6	0.3
Farm yard manure, q ha^{-1}	–	–	–	–

* Grand Total; [a] Figures in parentheses indicate percentage of total energy input.

Table 3. Energy use pattern for cultivating selective crops in village Choukha. district Jodhpur (Zone III) during 1998-99 (drought year)

Particulars	Weighted mean values in cultivating various crops			
	Pearl millet	Green gram	Wheat	Chilly
Sample size	22*	6*	40*	3
Total area (ha)	21.9*	2.7*	34.2*	2.9
A. Operation, MJ ha^{-1}				
Seedbed prep.	652.7 (17.1)[a]	538.6 (20.0)	1222.5 (14.0)	1172.7 (8.6)
Sowing	366.4 (9.6)	289.9 (10.8)	377.7 (4.3)	116.2 (0.9)
Bund making	41.8 (1.1)	18.5 (0.7)	81.7 (0.9)	112.4 (0.8)
Irrigation	1264.6 (33.2)	1088.6 (40.4)	4241.0 (48.6)	10325.9 (75.4)
Weeding	101.5 (2.7)	98.5 (3.7)	85.5 (1.0)	110.5 (0.8)
Fertilizer applic.	53.5 (1.4)	47.6 (1.8)	103.3 (1.2)	96 (0.7)
Harvesting	167.0 (4.4)	91.7 (3.4)	166.4 (1.9)	714.2 (5.2)
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)	725.9 (5.3)
Post-harvest activities	35.7 (0.9)	33.2 (1.2)	61.1 (0.7)	263.9 (1.9)
Total energy	3807.4 (100)	2697.9 (100)	8726.3 (100)	13698.5 (100)
B. Source (MJ ha^{-1})				
Human	521.8 (10.5)	398.3 (11.6)	775.4 (5.1)	1736.9 (9.9)
Diesel	1933.0 (38.8)	1161.4 (33.8)	3608.0 (23.6)	1717.2 (9.8)
Electricity	1161.3 (23.3)	1020.1(29.7)	3981.8 (26.0)	9896 (56.4)
Seeds	101.1 (2.0)	103.4 (3.0)	1766.1 (11.6)	8.2 (0.1)
FYM	944.2 (19.0)	631.1 (0.0)	1319.1 (8.6)	749.5 (4.3)
Fertilizers	128.5 (2.6)	0.0 (0.0)	3433.8 (22.5)	2401.8 (13.7)
Chemicals	0.0 (0.0)	0.0 (3.4)	44.4 (0.3)	700.1 (4.0)
Machinery	191.4 (3.8)	118.0 (100)	361.2 (2.4)	348.4 (2.0)
Total energy	4981.3 (100)	3432.4	15289.8 (100)	17558.1 (100)
C. Others				
Yield, kg ha^{-1}	684.9	909.5	2118.3	6328.4
Energy-ratio	4.8	6.8	3.2	2
Specific energy, MJ kg^{-1}	7.3	3.8	7.2	2.77
Seed rate, kg ha^{-1}	6.5	7.1	109.8	1.4
Man, h ha^{-1}	133.0	128.8	218.2	–
Diesel, L ha^{-1}	28.7	22.3	59.0	28.4
Electricity, kWh ha^{-1}	59.7	82.7	251.2	885.8
Tractor, h ha^{-1}	7.7	6.0	15.1	8.3
Motor, h ha^{-1}	11.6	27.7	51.9	127
Engine, h ha^{-1}	3.3	0.0	0.0	–
Nitrogen, kg ha^{-1}	1.3	0.0	38.7	32.1
Farmyard manure, q ha^{-1}	58.5	44.9	79.0	58.3
Woman, h ha^{-1}	66.4	76.0	96.2	417.7
Thresher, h ha^{-1}	1.0	0.0	0.0	–
Implements, h ha^{-1}	0.0	178.8	248.2	493.8
P_2O_5, h ha^{-1}	0.0	0.0	14.1	17.4

* Grand Total; [a] Figures in parentheses indicate percentage of total energy input.

The specific energy for growing clusterbean was 7.8 MJ kg^{-1}, whereas; maize needed highest specific energy (12.5 MJ kg^{-1}). Wheat consumed 8.0 MJ energy to produce one kg grains.

Table 4. Energy use pattern for cultivating selective crops in village Siwas, district Pali (Zone IV) during 1999-2000 (drought year)

Particulars	Weighted mean value for cultivating various crops				
	Clusterbean	Cotton	Maize	Wheat	Mustard
Sample size	58*	56*	55*	95*	92*
Total area, ha	46.6*	39.5*	22.9*	70.6*	59.7*
A. Operation, MJ ha^{-1}					
Seedbed preparation	998.5 (36.6)[a]	2090.8 (18.1)	1530.1 (24.7)	1484.6 (14.5)	1477.3 (20.7)
Sowing	444.2 (16.3)	274.2 (2.4)	390.7 (6.3)	626.0 (6.1)	550.0 (7.7)
Bund making	48.0 (1.8)	253.8 (2.2)	149.6 (2.4)	269.2 (2.6)	298.1 (4.2)
Irrigation	392.5 (14.4)	6432.4 (55.7)	2785.4 (44.9)	6003.2 (58.5)	3405.4 (47.7)
Weeding	163.3 (6.0)	1103.7 (9.6)	501.8 (8.1)	263.8 (2.6)	225.9 (3.2)
Fertilizer application	18.5 (0.7)	52.5 (0.5)	41.3 (0.7)	37.0 (0.4)	34.9 (0.5)
Spraying	0.4 (0.0)	346.5 (3.0)	2.2 (0.0)	0.0 (0.0)	4.4 (0.1)
Harvesting	221.7 (8.1)	674.1 (5.8)	224.4 (3.6)	304.6 (3.0)	262.3 (3.7)
Threshing	363.1 (13.3)	0.0 (0.0)	457.4 (7.4)	1129.6 (11.0)	805.8 (11.3)
Transportation	78.6 (2.9)	320.9 (2.8)	93.9 (1.5)	139.2 (1.4)	81.0 (1.1)
Post harvest activity	0.0 (0.0)	0.0 (0.0)	20.1 (0.3)	1484.6 (14.5)	7145.1 (100)
Total energy	2728.9 (100)	11549.0 (100)	6196.9 (100)	10257.3 (100)	1477.3 (20.7)
B. Source, MJ ha^{-1}					
Human	479.5 (12.6)	2287.1 (11 8)	973.5 (9.1)	1048.8 (6.2)	829.2 (7.5)
Animal	49.2 (1.3)	420.7 (2.2)	309.7 (2.9)	189.7 (1.1)	116.7 (1.1)
Diesel	1828.1 (48.0)	2988.4 (15.4)	2548.3 (23.8)	4431.7 (26.0)	3690.2 (33.6)
Electricity	214.5 (5.6)	5433.0 (28.0)	2108.3 (19.7)	4236.6 (24.9)	2233.6 (20.3)
Seeds	322.8 (8.5)	156.7 (0.8)	457.8 (4.3)	1694.1 (9.9)	187.8 (1.7)
Farm yard manure	324.0 (8.5)	742.7 (3.8)	594.7 (5.6)	551.8 (3.2)	392.4 (3.6)
Fertilizers	435.0 (11.4)	5527.5 (28.5)	3450.4 (32.2)	4196.1 (24.6)	2984.5 (27.2)
Chemicals	1.3 (0.0)	1424.7 (7.3)	6.7 (0.1)	343.0 (2.0)	282.0 (2.6)
Machinery	157.6 (4.2)	419.7 (2.2)	257.1 (2.4)	350.5 (2.1)	275.3 (2.5)
Total input energy	3812.0 (100)	19400.6 (100)	10706.5 (100)	17042.3 (100)	10991.8 (100)
C. Others					
Yield, kg ha^{-1}	487.5	1553.5/233.0	831.8	2133.8	1102.7
Energy-ratio	3.4	7.0	3.9	3.2	4.4
Specific energy, MJ kg^{-1}	7.8	12.5/83.3	12.9	8.0	10.0
Man, h ha^{-1}	93.3	422.4	240.2	227.4	133.7
Animal, h ha^{-1}	4.1	24.4	26.1	14.5	9.3
Diesel, L ha^{-1}	30.7	51.4	42.0	72.3	54.0
Electricity, kWh ha^{-1}	14.6	399.0	153.8	324.5	142.1
Tractor, h ha^{-1}	7.2	12.1	8.7	12.5	9.9
Motor, h ha^{-1}	5.0	110.1	44.7	88.9	39.5
Engine, h ha^{-1}	2.5	5.3	7.3	20.6	12.2
Implements, kg ha^{-1}	218.5	574.0	449.8	448.7	292.3
Seeds, kg ha^{-1}	21.1	5.9	29.9	105.2	7.2
Nitrogen, kg ha^{-1}	7.1	64.2	43.7	52.8	36.7
Phosphorus, kg ha^{-1}	6.6	48.7	36.2	41.8	27.8
Chemical, L ha^{-1}	0.0	10.1	0.0	34.0	25.1
FYM, q ha^{-1}	26.0	45.9	46.8	40.8	29.8
Woman, h ha^{-1}	136.3	521.5	236.2	276.7	189.7

* Grand Total; [a] Figures in parentheses indicate percentage of total energy input.

Table 5. Values of constants ß1, ß2, and coefficient of determination (R^2) in eq. (3) and maximum yield in relation to optimum energy input for selective crops of various identified villages of arid region

Crop	ß1	ß2	R^2 (%)	Optimum input energy	Corresponding maximum yield (kg ha^{-1})
Village Pemasar, district Bikaner (Zone II)					
Clusterbean (rainfed)	0.1560	$-9x10^{-6}$	98.9	8666.7	676.0
Clusterbean (irrigated)	0.1641	$-4x10^{-6}$	94.0	20512.5	1683.1
Moth bean (rainfed)	0.2185	$-4x10^{-5}$	61.0	2731.3	298.4
Moth bean (irrigated)	0.1606	$-6x10^{-6}$	73.3	13383.3	1074.7
Groundnut (irrigated)	0.1090	$-8x10^{-7}$	82.9	68125.0	3712.8
Wheat	0.1276	$-2x10^{-6}$	63.4	31900.0	2035.2
Gram	0.1047	$-3x10^{-6}$	65.9	17450.0	913.5
Mustard	0.1081	$-2x10^{-6}$	73.2	27025.0	1460.7
Rocket salad	0.1261	$-4x10^{-6}$	92.3	15762.5	993.8
Village Choukha, district Jodhpur (Zone III)					
Pearl millet	0.2196	-1x10-5	94.5	10980.0	1205.6
Wheat	0.1827	-2X10-6	93.9	47136.6	4305.9
Green gram	0.5351	-7x10-5	97.5	3822.1	1022.6
Village Siwas, district Pali, (Zone V)					
Cotton	0.1000	-1x10-6	52.1	50000	2500
Maize	0.0924	-2x10-6	71.8	23100	1067.2
Clusterbean	0.1762	-1x10-5	68.2	8810	776.2
Wheat	0.1780	-3x10-6	58.0	29666.67	2640.3
Mustard	0.1357	-2x10-6	80.3	33925	3019.3

Optimization of energy inputs

It is obvious from the Table 5 that groundnut required optimum energy (68125.0 MJ ha^{-1}) to obtain maximum yield (3712.8 kg ha^{-1}) followed by wheat, mustard and clusterbean (irrigated) in Zone II. Similarly, in Zone III wheat required optimum energy (47136.6 MJ ha^{-1}) for maximum yield (4305.9 kg ha^{-1}) followed by pearl millet (10980.0 MJ ha^{-1}) and green gram (3822.1 MJ ha-1) and in Zone IV cotton crop required optimum energy (50000 MJ ha^{-1}) for maximum yield (2500 kg ha^{-1}) followed by mustard, wheat, maize and clusterbean crop.

Source-wise energy use pattern for cultivating various crops

In Zone III maximum energy is required for raising chilly crop followed by, wheat, pearl millet and green gram (Table 6). Maximum direct energy is used for raising chilly crop as it is irrigated crop and minimum in case of wheat crop. The direct energy input is higher in all the crops compared to indirect form of energy. On an average the direct energy input remained at 69.6% of the total energy input compared to 30.4% indirect energy. In Zone IV, maximum energy is required for raising green gram followed by clusterbean, mustard, wheat, cotton and maize. The direct energy input is higher in all the crops compared to indirect form of energy and varies from crop to crop. On an average the direct energy input remained at 62.4% of the total energy input compared to 37.6% indirect energy.

Similarly, for Zone II, it is evident from the Table 6 that maximum energy is required for raising groundnut crop followed by wheat, mustard, rocket salad, clusterbean (irrigated) moth bean (irrigated), clusterbean (rainfed) and moth bean (rainfed). Maximum direct energy is used in raising clusterbean (rainfed) and minimum in wheat crop.

Renewable and non-renewable form of energy input

There is more of non-renewable form of energy input (on an average 74.0%) than renewable form (26.0%) in all the crops of Zone III. More non-renewable energy is required for cultivating rabi crops compared to kharif crops (Table 6). Both renewable and non-renewable forms of energy vary from crop to crop. The reduction in consumption

Table 6. Total energy input in the form of direct & indirect, renewable and non-renewable and commercial and non-commercial for raising various crops in different zones of arid region

Crop	Total mean energy input, MJ ha^{-1}	% - wise energy input in its various forms					
		Direct	Indirect	Renewable	Non-renewable	Commercial	Non-commercial
Zone II (Village: Pemasar, district Bikaner)							
Clusterbean (rainfed)	1656.0	71.3	28.7	40.7	59.3	81.4	18.6
Clusterbean (irrigated)	5582.6	60.9	39.1	40.5	59.5	68.3	31.7
Moth bean (rainfed)	1559.5	71.1	28.9	49.8	50.2	71.6	28.4
Moth bean (irrigated)	4071.3	66.3	33.7	54.3	45.7	44.6	55.4
Groundnut (irrigated)	25293.5	47.8	52.2	39.7	60.3	24.9	75.1
Wheat	22032.1	37.1	62.9	13.0	87.0	88.3	11.7
Mustard	12044.4	44.4	55.6	16.2	83.8	86.2	13.8
Rocket salad	8113.2	34.9	65.1	23.7	76.3	87.8	12.2
Mean value		54.2	45.8	34.7	65.3	69.1	30.9
Zone III (Village: Choukha, district Jodhpur)							
Pearl millet	4981.3	72.6	27.4	31.5	68.5	70.6	29.4
Wheat	15289.8	54.7	45.3	25.2	74.8	86.3	13.7
Green gram	3432.4	75.2	24.8	33.0	67.0	70.0	30.0
Chilly	17558.1	76.0	24.0	14.2	85.8	85.8	14.2
Mean value		69.6	30.4	26.0	74.0	78.2	21.8
Zone IV (Village: Siwas, district Pali)							
Clusterbean	3812.0	67.5	32.5	30.8	69.2	77.6	22.4
Maize	10706.5	55.5	44.5	21.8	78.2	82.5	17.5
Cotton	19400.6	57.4	42.6	18.6	81.4	82.2	17.8
Green gram	4006.5	73.1	26.9	39.0	61.0	33.2	66.8
Wheat	17042.3	58.1	41.9	18.1	81.9	89.5	10.5
Mustard	10990.8	62.5	37.5	13.9	86.1	87.8	12.2
Mean value		62.4	37.6	23.7	76.3	75.5	24.5

Direct energy: Human, Animal, Petrol, Diesel, Electricity, Canal, etc.; Indirect energy: Seeds, Fertilizers, FYM, Chemicals, Machinery, etc.; Renewable energy: Human, Animal, Seeds, FYM, Canal, etc.; Non-renewable energy: Petrol, Diesel, Electricity, Chemical, Fertilizers, Machinery, Canal, etc.; Commercial energy: Petrol, Diesel, Electricity, Chemicals, Fertilizers, Seeds, Machinery, etc.; Non-commercial energy: Human, Animal, FYM, etc.

of non-renewable energy has a direct bearing on the cost of cultivation. Being a drought year even the kharif crops were irrigated by the farmers, as a result the component of non-renewable energy is higher even in the case of kharif crops.

Similarly, in Zone IV, there is more of non-renewable form of energy input (on an average 76.3%) than renewable form (23.7%) in all the crops. Similar to Zone III, more non-renewable energy is required for cultivating rabi crops compared to kharif crops. Both these renewable and non-renewable forms of energy vary from crop to crop. In Zone II also the percentage of non-renewable form of energy is more (on an average 65.3%) than the renewable form (34.7%) in all the crops. Further, similar to Zone III and Zone IV more non-renewable energy is required for cultivating rabi crops compared to kharif crops.

Commercial and non-commercial forms of energy - As may be seen from the Table 6, by and large, the commercial energy input is higher than non-commercial energy input in all the crops irrespective of zone. Since data was collected during drought period the commercial and non-commercial energy input ratio was adversely affected. However, green gram is the only crop to have used non-commercial energy 30% in Zone III and as high as 66.8% in Zone IV followed

by pearl millet (non-commercial energy 29.4%) in Zone III. As far as non-commercial energy in Zone II is concerned, groundnut (75.1%) and moth bean (55.4) did exceedingly well followed by clusterbean irrigated (31.7).

Conclusions

Energy ratio being high, it is most profitable to grow moth bean in kharif season and rocket salad and mustard crops in rabi season in Zone II (Bikaner region), green gram and pearl millet crops in Zone III (Jodhpur region) and cotton and mustard crops in Zone IV (Pali region). Source-wise, diesel and electricity combined together are major contributors to total energy input in production agriculture (on an average 55.4%) in the arid region. On an average the share of human energy to total energy was 13% (range 5.1 to 26.1%). The contribution of farm women to human energy varied from 50 to 60%, thus, a farm woman plays an important role in arid agriculture. Irrespective of zone, the direct energy input is higher (range, 35-76%) compared to indirect energy (range, 24-65%) and varies from crop to crop. Similarly, there is more of non-renewable form of energy input (range, 45-87%) compared to renewable energy (range, 13-54%). By and large, the commercial energy input is also higher than non-commercial energy input. The crops like chilly, wheat, etc. are highly irrigated crops, and therefore, it is recommended that farmers should change the cropping pattern to accommodate horticultural crops requiring low water and should use drip and sprinkler irrigation systems so as to command more area and adopt moisture-conserving techniques/methods, such as, runoff harvesting in tanks, inter row rain water harvesting method, sowing on furrow slants, etc.

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