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Energy assessment of wheat under conventional and drip irrigation systems

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Abstract
In this study, the energy consumption of wheat with different crop geometry and irrigation practices was studied, with data collected from primary and secondary sources. The total energy inputs used in various farm operations during wheat crop, the total energy inputs required respectively for conventional practice, for System of Wheat Intensification (SWI) practice and for SWI with drip irrigation was 87,937 MJ ha^{-1}, 69,817 MJ ha^{-1} and 46,679 MJ ha^{-1}. Average grain yield of wheat in conventional practice was found to be 4.51 t ha^{-1}, 4.85 t ha^{-1} in SWI practice, and 5.61 t ha^{-1} in SWI practice with drip irrigation system. Calculated total energy output from wheat crop production with these respective treatments was 136,658 MJ ha^{-1}, 144,380 MJ ha^{-1} and 158,496 MJ ha^{-1}. The highest net productivity evaluated in terms of energy inputs and outputs was found to be 0.12 kg MJ^{-1} for wheat when using SWI method with drip irrigation treatment.

Keywords: Crop production; energy; energy inputs; energy outputs; energy productivity, wheat, System of Wheat Intensification (SWI).

Introduction
Wheat (*Triticum aestivum* L.) is one of the most important staple food grains of human race. India produced 95.4 million tonnes of wheat during the year 2015-16 and it is the second largest producer of wheat in the world. Wheat contributes substantially to the national food security by providing more than 50% of calories to the people who mainly depend on it (Anonymous, 2015) [4].

In the development process of mankind, energy plays key role, and it is one of the most critical input in production agriculture. In support of crop cultivation practices, it is utilized in various forms, mechanical (farm machinery), chemical fertilizer (pesticides, herbicides), electrical (pumping irrigation water), etc. Efficient use of these energy sources along with human energy helps to achieve increased production and productivity and contributes to the profitability and competitiveness of agriculture sustainability in rural living (Singh, 2002).

Energy use in agriculture has been increasing in response to increasing population, limited supply of arable land, and to reduce the drudgery of field operation. Timely availability of the energy and its effective and efficient use are prerequisites for improved agricultural production, as crop yields and food supplies are directly linked to energy. In the developed countries, increase in crop yields is associated with commercial energy inputs in addition to improved crop varieties. Improvements in crop management practice are another source of increased output which are discussed in this paper.

The suitability and sustainability of any agricultural technology depends on factors like resource availability and productivity, energy costs and environmental constraints (Uphoff, 2012) [22]. Efficient use of energy resources in agriculture provides financial savings, preservation of fossil-fuel resources and reduction in environment pollution. To enhance energy efficiency in agriculture, there must be increased production from a given expenditure of energy or conserving of energy inputs without affecting the level of output (Singh *et al*., 2004; Singh *et al*. 2007) [19, 20].

There is a need to develop more energy-efficient agricultural systems with low energy input compared to their output of resulting food, if possible also reducing the greenhouse gas emissions from agricultural production systems. Assessing improvements in the efficiency of resource use in agriculture requires not only the definition of spatial and temporal uses of current resources, but also the development of tightly defined and broadly applicable indices (Topp *et al*., 2007) [21].

Water supply for irrigated grain production is increasingly becoming a scarce and/or more costly factor in many parts of India. Using irrigation technologies that economize use of water for getting as much or more grain production from a given amount of water, or with less water is important for the sustainability of food supply. But along with considerations of water availability and cost, one needs to reckon also the supply, cost and efficiency of energy used for pumping irrigation water.

Materials and Methods

The present study was carried out at ICAR-Central Institute of Agricultural Engineering, PFDC Bhopal during 2012-13, 2013-14 and 2014-15. Soils of the experimental site are classified as heavy clay soils with clay content varying between 49.7 to 53.7% and with the field capacity ranging from 28.5 to 31%. The site was situated somewhat north of Bhopal at 77º 24' 10" E, 23º 18' 35" N at an elevation of 495 m above mean sea level. During winter, the ambient temperature varies between 10°C and 25°C and in summer between 25°C and 44°C. Annual rainfall in the region is about 1080 mm, with 90% of rainfall received during July and August. Wheat crop was cultivated during November to March every year. The wheat variety *Purna* (HI-1544) was used in the experiment. Three treatments were considered in the study: T1: Conventional practices of Wheat, T2: System of Wheat Intensification (SWI) practices T3: SWI management with drip irrigation emitters spaced at 20 cm.

Seed Treatment

Seeds are usually treated with Bavistin or Vitavax to control seed borne fungal diseases including smut. In addition to this, seeds are treated with organic mixture of well decomposed compost, jaggery and cow urine for improving microbial activity in the soil.

Procedure for Seed Treatment

- Grade out bold seeds separately from lots of improved seed.
- Take 10 liter of hot water (60 degree Celsius) in an earthen pot.
- Dip 5 Kg of improved graded seeds in it.
- Remove the seeds which float on the top of water.
- Mix 2 kg well decomposed compost, 3 liter cow urine and 2 kg of jaggery.
- After mixing it properly, keep the mixed material as such for 6-8 hour.
- After this, filter it so that solid materials along with seeds and liquids get separated.
- After that, mix 10 gm of fungicide properly and keep in shade for 10-12 hrs.
- Then wheat gets germinated. The germinated seed is used for sowing in the tilled field.
- Cow urine, well decomposed compost and jaggery in separate vessels

Pre germinates seeds of one day old were sown manually in the T2-System of Wheat Intensification (SWI) practices, T3-SWI management with drip irrigation emitters spaced at 20 cm at 25X25 cm spacing with single seed per hill and a seed rate of 10 kg ha-1.Sowing in T1 was carried out at a spacing of 20 X 10 cm with 2-3 seeds were sowing with a and the seed rate of about 100 kg ha-1 using tractor drawn seed drill. The dates of sowing for all the treatments were the same. Each treatment plot (50 m2) was replicated four times. Inorganic fertilizers were applied in all the plots with the recommended doses of 120 kg N, 60 kg P2O5, and 80 Kg K2O per ha in form of Urea, DAP and MOP, respectively. Half of the recommended dose of nitrogen and all of the phosphorus and potash were applied at the time of sowing, while the remaining N was applied at the time of tillering through broadcasting in the T1 and T2 treatments and through the drip irrigation system in T3. Rates and kinds of soil nutrient supplementation were thus not a variable in this experiment. Under flood irrigation method; five irrigations at critical stages were given to the wheat crop. A total 14.6 cm depth of irrigation water was applied to the treatments under drip irrigation system (T3) by operating the system for 15 min. Whereas a total 41.5 cm & 38.2cm depth of irrigation was applied under conventional irrigation (i.e. T1 & T2 respectively). Weeds were controlled by manual weeding after sowing on the 30th and 60th day. Spraying of plant protection measures (fungicides and insecticide) were applied at 45 and 65 days after sowing for controlling diseases and insects.

Operations

Energy consumption in wheat production, covering tillage machinery, fertilizer broadcasters, sprayers, irrigation, transportation and harvesting was determined according to the respective systems. The number and duration of different operations, seed rate, pesticides, fertilizers and amount of human labour were all investigated. From secondary sources, equivalent energy inputs were determined for all of the input and output parameters for wheat.

Energy Inputs

Human Labour

This is used for almost every task on the farm, from driving machinery, maintenance, repair, irrigation, spraying and fertilizer distribution to management. Currently, the energy output for a labourer is about 1.96 mega joules (MJ) hr-1 (Khan *et al*., 2009) [11] and this is the most expensive form of energy employed in field operations.

Fuel

Diesel fuel is the main source of fuel for agricultural machinery as well as for motor pumps and water pumps. Fuel consumption was determined before and after any operation by filling the tractor fuel tank and recording the difference after the operation was completed. The energy output for analysis was determined (Khan *et al*., 2009) [11] from fuel consumption per operation of one hectare of land times the fuel equivalent energy per liter as shown in equation.

$\textbf{Energy Inputs/hectare} =$ Operation fuel consumption (L ha^{-1}) X Fuel energy (MJ L^{-1})

Fertilizer

The use of inorganic fertilizers is the fastest-growing form of energy consumption in agricultural production. Nitrogen fertilizer is the most widely-used fertilizer in world agriculture, both in the amount of plant nutrients used and in energy requirements. The respective energy requirements for one kilogram of nitrogen, phosphate and potassium are 66.14, 12.44 and 11.15 MJ kg-1 (Rafiee *et al*., 2010) [17].

Agrichemicals

Different methods of pest control, i.e., chemical and mechanical are usually applied to control or eliminate insects, weeds and diseases. Chemical methods are mostly used for the control insects, diseases and weeds.

Seed

Clean and proper seeds were provided in packages from seed industry and private institutes. Different factors, such as the planting system, variety of seed and germination rate influence the amount of seed used for wheat.

The different agronomical practices of the wheat crop considered in the present study are shown in table 1.0.

(Plate 1 and Table 1 about here)

Methods of Energy Calculation

Evaluation of manual energy input

Manual energy (Em) expended as an input was determined in MJ by using coefficients from Khan *et al*. (2009) [11] according to the following formula,

Em = 1.96 X Nm X Tm

Where, Nm = Number of labourers engaged in a specific farm activity

Tm = Useful time spent by a labourer on that farm activity, in hours

The total number of manual labourers was recorded for each operation together with working hours which were then converted in man-hours. All other factors affecting manual energy were neglected. Table 2 shows the energy coefficients used in the calculations.

Evaluation of mechanical energy use

Mechanical energy input was evaluated by quantifying the amount of diesel fuel consumed during the tillage, sowing, and threshing and winnowing operations. The total time spent was also recorded. Diesel consumption for pumping was also recorded during irrigation. For every farm operation, the diesel fuel energy input was determined in MJ (Khan *et al*., 2009) [11] by the equation,

Ef = 56.31 X D

Where, 56.31 = unit energy value of diesel, MJ L-1

D= amount of diesel consumed, L

Data recorded for energy determination

Energy demand in agriculture can be divided into direct and indirect energy forms (Alam *et al*., 2005) [3]. The energetic efficiency of the agricultural system has been evaluated by the energy ratio between output and input. The inputs are human labour, machinery, diesel oil, fertilizer, pesticides, seed, electricity and irrigation, and output yield values of rice and wheat crops have been used to estimate the energy ratio. The different field operations performed for completion of each activity in the experiment were measured in terms of time taken for human/machinery use and fuel consumption and were then expressed as energy input in mega joules using corresponding constants (Lal *et al*., 2003; Binning *et al*., 1983; Alam, 1986) [13, 5, 2] as detailed in Table 2.

(Table 2 about here)

Energy indices

Based on the energy equivalents of the inputs and outputs (Table 2), the energy ratio (energy use efficiency), the energy productivity, and the specific energy were calculated (Demircan *et al*., 2006).

$$\text{Energy use efficiency} = \frac{\text{Total Energy Output (MJ ha}^{-1})}{\text{Total Energy Input (MJ ha}^{-1})} \quad (1)$$

$$\text{Energy productivity (kg MJ -1)} = \frac{\text{Grain Output (kg ha}^{-1})}{\text{Total Energy Input (MJ ha}^{-1})} \quad (2)$$

$$\text{Specific energy (MJ kg -1)} = \frac{\text{Total Energy Input (MJ ha}^{-1})}{\text{Grain Output (kg ha}^{-1})} \quad (3)$$

Net Energy (MJ ha-1) = (Energy Output (MJ ha-1)-Energy Input (MJ ha-1) (4)

Energy output to input ratio and specific energy are integrative indices indicating the potential environmental impacts associated with the production of crops (Khan *et al*., 2009) [11]. These parameters can be used to determine the optimum intensity of land and crop management from an environmental point of view. Specific energy is the reversal of energy productivity hence its lower values indicates that lesser energy is used for production of each yield unit. Higher Net energy values indicates relative gain in energy from direct and indirect inputs utilized in crop production system (Ziaei *et al*., 2015) [24].

Results and Discussion

Energy utilization in wheat

The total input energy used in various farm operations during wheat production was 87,937 MJ ha-1 for conventional practice, 69,816 MJ ha-1 for system of wheat intensification practices and 46,679 MJ ha-1 for system of wheat intensification with drip irrigation practice.

The figures showed revealed that 324.0 h of human power and 32.0 h of machine power were required per hectare for wheat production under conventional practice, whereas in system of wheat intensification practices with and without drip irrigation, slightly higher human power and slightly lower machine power was needed (Table 4). The use of diesel fuel for operating tractors, combine harvester, water pumping systems and transportation was calculated as 112 L in conventional practice of wheat which was more as compared to SWI and SWI with drip practices.

The total distribution of fertilizers in terms of energy input was estimated 71.5% nitrogen, 7.1% phosphorus and 2.4% potassium and farmyard manure 19.0%. Similar studies have also reported that diesel fuel and fertilizer were the most energy-intensive inputs. The total chemical (fungicide, insecticide and weedicide) energy input for wheat was estimated as 252 MJ ha-1 under all the practices. The total energy input for irrigation, electricity and seeds for wheat production was more in conventional practices as compared to other practices (Fig. 2).

(Table 3 about here)

Energy input-output ratio in wheat production

Average annual grain yield of wheat obtained was 4515 kg ha-1 in conventional practices, 4849 kg ha-1 in system of wheat intensification practice and 5612 kg ha-1 in system of wheat intensification practice with drip. Total energy output was calculated as 136,658 MJ ha-1 for conventional wheat production, 144,380 MJ ha-1 for SWI and 158,496 MJ ha-1 for SWI with drip irrigation. The energy input and output, yield, energy use efficiency, specific energy, energy productivity, and net energy of wheat production are

presented in Table 4. Energy use efficiency (energy ratio) was calculated as 1.55 for conventional practice, 2.06 for SWI and 3.39 for SWI with drip.
The highest average energy productivity of farms was 0.12 kg MJ-1 for wheat under SWI with drip. The highest specific energy was obtained 19.5 with conventional practice as compared to the other two practices, while highest net energy for wheat (111,817 MJ ha-1) was obtained through SWI with drip practices.

(Table 4 about here)

Direct and indirect energy for wheat production (MJ ha^{-1})

The distribution of total energy input in direct and indirect forms is presented in Table 7.The total energy input for the three alternative production methods for wheat could be classified as direct (63.4%, 62.7% and 44.2%) and indirect energy (30.6%, 37.3% and 55.8%), respectively (Table 5). The SWI with drip irrigation method had the lowest proportion of direct energy and highest proportion of direct energy.
This indicates that in the conventional cultivation practice of wheat, the share of direct energy components viz., labour, fuel and irrigation water is more. The availability of labour in time and their cost, increasing fuel cost and depleting water resources would suggest for alternate practices to the conventional cultivation.

(Table 5 about here)

Conclusions

Energy analysis has been carried out to evaluate the energy requirements in wheat crop cultivated with different cultural practices. The results showed energy inputs for wheat production to be higher with conventional practices as compared to SWI with or without drip irrigation. The energy inputs related to water, electricity/fuel and labour contributed the biggest share of the total energy inputs in conventional cultivation practices.
The results indicated that net energy for conventional wheat production systems had low values, indicating inefficient utilization of energy in conventional wheat cultivation. The study concludes that the quantity of irrigation water and electricity used in wheat crop is considerably higher than necessary for successful crop production, which was evident from the higher grain yield of wheat under SWI management with drip irrigation. The highest total energy output was 158,496 MJ ha^{-1} for wheat with SWI management using drip irrigation. The highest average energy productivity as 0.12 kg MJ^{-1} for wheat was the same, SWI management with drip irrigation systems.

Table 1: Management practices and timing for wheat trials

Practices/operations	Wheat
Name of varieties	HI-1544 (Purna)
Land preparation tractor used	Cultivator, rotavator, land leveler, and puddler
Land preparation period	Oct-Nov
Planting period	Nov
Fertilization period	Nov-Jan
Average number of fertilizations	3
Period of manual weed control	Nov-Jan
Average number of weedings	2
Irrigation period	Nov-Jan
Spraying period	Dec-Jan
Average number of sprayings	2
Harvesting time	March

Table 2: Energy conversion factors used in agricultural production

S.No	Power source	Equivalent energy (MJ)	Reference
A.	**Inputs**		
1.	Human labour (h)	1.96	(Rafiee *et al*., 2010)
2.	Machinery (h)	62.7	(Canakci *et al*., 2005)
3.	Diesel fuel (L)	56.31	(Canakci *et al*., 2005)
4.	Chemicals (kg)	120	(Erdal *et al*., 2007)
5.	Fertilizer (kg)		
a.	Nitrogen	66.14	(Rafiee *et al*., 2010)
b.	Phosphate (P_2O_5)	12.44	(Rafiee *et al*., 2010)
C.	Potassium (K_2O)	11.15	(Rafiee *et al*., 2010)
d.	Zinc (Zn)	8.40	(Pimentel,1980; Argiro *et al*., 2006)
e.	Farmyard manure	0.30	(Demircan *et al*., 2006; Ozkan *et al*., 2004)
6.	Water for irrigation (m^3)	1.02	(Rafiee *et al*.,2010)
7.	Seed (kg)	3.60	(Beheshti Tabar *et al*., 2010)
8.	Electricity (kWh)	11.93	(Mobtaker *et al.*, 2010)
B.	**Output (kg)**		
a.	Wheat grain	14.70	(Ozkan *et al*., 2004)
b.	Wheat straw	12.50	

Table 3: Amounts of inputs and outputs in wheat production

Quantity (inputs and outputs)	Conventional practices		SWI		SWI with Drip	
	Quantity per unit area (ha)	Total energy equivalent (MJ/ha)	Quantity per unit area (ha)	Total energy equivalent (MJ/ha)	Quantity per unit area (ha)	Total energy equivalent (MJ/ha)
A. Input						
1.Human labour (h)	324	635	426	835	402	788
2. Machinery (h)	32	2,006	26	1,630	26	1,630
3.Diesel fuel (L)	112	6,307	91	5,124	91	5,124
4.Chemical fertilizers (kg)						
a. Nitrogen	260	17,223	260	17,223	260.	17,223
b. Phosphate	137	1,709	137	1,709	137	1,709
c. Potassium	52	575	52	575	52	575
5. Farmyard manure (kg)	15,245	4,574	15,245	4,574	15,245	4,574
6. Chemicals (kg)	2.1	252	2.1	252	2.1	252.0
7. Water for irrigation (m^3)	4,545	4,636	3,125	3,188	1,315	1,341
8. Electricity (kWh)	4,148	49,480	2,903	34,636	1,122	13,390
9. Seeds (kg)	150	540	20	72	20.0	72
Total energy input (MJ)		87,936		69,815		46,679
B. Output						
1. Grain (kg)	4,515	66,371	4849	71,280	5612	82,496
2. Straw (kg)	5,623	70,288	5848	73,100	6080	76,000
Total energy output (MJ)		136,658		144,380		158,496

Table 4: Energy input-output ratio in wheat production

Items	Conventional practices	SWI	SWI with drip
Energy input (MJ ha^{-1})	87,937	69,816	46,679
Energy output(MJ ha^{-1})	136,658	144,380	158,496
Grain yield (kg ha^{-1})	4,515	4,849	5,612
Energy use efficiency	1.55	2.06	3.39
Specific energy (MJ kg^{-1})	19.6	14.4	8.3
Energy productivity (kg MJ^{-1})	0.05	0.07	0.12
Net energy (MJ ha^{-1})	48,721	74,565	111,817

Table 5: Total energy input in the form of direct and indirect for wheat production (MJ/ha)

Form of energy (MJ/ha)	Conventional practices	%[a]	SWI practices	%[a]	SWI with drip	%[a]
Direct energy [b]	61,057	63.4	43,783	62.7	20,644	44.2
Indirect energy [c]	26,879	30.6	26,033	37.3	26,036	55.8
Total energy input	87,936	100	69,816	100	46,680	100

[a] Indicates percentage of total energy input
[b] Includes human labour, diesel, electricity, irrigation
[c] Includes seeds, fertilizers, manure, chemicals, machinery

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