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ENERGY EFFICIENCY ANALYSIS OF WHEAT CROP UNDER DIFFERENT CLIMATE AND SOIL BASED IRRIGATION SCHEDULES

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Abstract: Use of energy in agriculture sector directly or indirectly has been intensified to increase crop production to fulfill the food demand of the growing population. Considering the energy and water scarcity in Pakistan, the present study was carried out to assess wheat production efficiency with regard to energy consumption. For this purpose, a field experiment was conducted at Water Management Research Centre (WMRC), University of Agriculture Faisalabad to compare two irrigation scheduling techniques (climatic and soil moisture based) and farmer's practice. All the inputs except volume of irrigation water were same for all treatments. Energy equivalents (extracted from scientific source) were used to calculate energy balance and indices (Energy use efficiency, Energy Productivity (kg MJ^{-1}), specific energy ($MJ.kg^{-1}$), Net energy (MJ ha^{-1}) and Water productivity (kg m^{-3})). Results shows that soil moisture based treatment (at 30% MAD) gave 7.94% and 27.94% more yield compared to climate based treatment's (20 mm CPE) and farmer's practice respectively. The pumping water for irrigation was the highest energy consumption input for wheat production after chemical fertilizers. T1=30% MAD and T4=20 mm CPE treatments saved 33.71% and 35.72% energy respectively due to water saving over farmer practice. While T1 and T4 treatments increase 11.40% and 6.38% energy output in terms of grain yield and biological yield respectively over farmer practice. The highest net energy (155557.95MJ ha^{-1}), energy use efficiency (7.478), energy productivity (0.181 kg MJ^{-1}) and water productivity (1.875 kg m^{-3}) was achieved with T1 (30% MAD) however highest specific energy (8.148 $MJ.kg^{-1}$) was achieved with farmer practice. The results thus obtained help the farmers, stakeholder agencies and researchers would be helpful for making informed decisions when choosing different alternatives.

Keywords: Energy, Water, Climate, Soil moisture.

1. Introduction

Pakistan is a water and energy scare country and both are important in agricultural production. Agriculture is considered as backbone in economy of country contributing 21% to its GDP, nearly 43.7% of its work force and providing livelihood to more than 67% of its population The water and energy conservation plans are directly related to the poverty reduction and raise livelihood [1].

Wheat is the biggest grain crop grown and chief staple food in Pakistan. Wheat production in the country for the preceding economic year 2013 was 24.21 million tons covering area of 8.66 million hectares (state bank of Pakistan, 2013) and contributes to national GDP was 2.2% and 10.1% to value added agriculture [2]. In 2030 Pakistan will require over 33 million tons of wheat to meet its domestic needs [3].

Use of energy in agriculture sector directly or indirectly has been intensified to increase crop production to fulfill the food demand of the rapidly growing population with limited supply of arable land and improve the living standard. These factors have encouraged to use energy use for getting maximum yield but maximum yield may not bring maximum profit due to higher cost of production. Besides, high production cost, intensive use of energy inputs can cause environmental distortion and result in excessive use of natural resources. Energy is directly used in land preparation, tillage operations, sowing, irrigation, harvesting; and indirectly used in inputs such as seed, pesticides, fertilizers, plant protection agrochemicals. The water for irrigation was the highest energy consumption input for wheat production after chemical fertilizers. The output energy is obtained in the form of feed, fodder, fruits, vegetables, seed and grain.

Energy input and output are two main factors for determining the energy efficiency and environmental impact of crop production. Energy utilization and output differs among crops, production systems and intensity of management practices. Considerable research has been conducted on energy use pattern of field crops under different management practices in the world. Most of the work related to energy use pattern for different crops such as sugarcane [4], Wheat [5, 6, 7], Cotton [8], Garlic [9], Tomatoes [10,11], cucumber [12]. Very little efforts have been made to explore the relationship among water, energy and the yield in Pakistan. Hence, the primary goal of this study to investigate the consumption pattern with regard to energy and water in wheat production under different irrigation schedules and evaluate the differences in different energy and water indices between all irrigation schedules. The second objective of this study, to develop economic analysis to select the optimum irrigation management practices for wheat crop.

2. Materials and Methods

The study was carried out at water management research center (WMRC) Faisalabad, Pakistan (31º38.74 N, 73º01.29 E) and at an elevation of 184 m above mean sea level, during winter season 2014-2015 on wheat crop. Lower Chenab canal, diverted from Chenab River at Khanki headwork, is the main source of irrigation water for Faisalabad region. Faisalabad lies in semi-arid environment and confront by extremes summer with maximum temperature of 50 Cº and minimum temperature of -2 Cº during winter with a mean annual rainfall of 350 mm, most of which falls during monsoon in the form of high intensity rainfall. The topography of the study area is flat and the soil is sandy loam textured throughout the area.

Six irrigation schedules based on management allowable depletion and cumulative pan evaporation were studied: T1=30% MAD, T2=45% MAD, T3=60% MAD, T4=20mm CPE, T5=30 mm CPE, T6=40 mm CPE and farmer practice. Data collect related to water use, fertilizer, chemicals used for plant protection, and energy consumed in land preparation, pumping water, machinery operations etc. All inputs except volume of irrigation water were same for all treatments. The amount of first irrigation water was same for all treatments to get better emergence. Energy equivalents (extracted from scientific source) were used to calculate energy input and output. The energy equivalents used in this study are shown in Table 1.

Table 1: Energy equivalent of inputs and outputs in agricultural production

Energy	unit	Energy Equivalent ($MJunit^{-1}$)	References
Inputs			
1. Human Labor	h	1.96	[13]
2. Machinery	h	62.7	[13]
3. Diesel Fuel	L	56.31	[13]
4. Chemical Fertilizers	kg		
a) Nitrogen		66.14	[13]
b) Phosphorous		12.44	[13]
c) Potassium		11.15	[13]
5. Herbicides	kg	238	[14]
6. Water	m^3	1.02	[13]
7. Electricity	kWh	11.93	[15]
8. Seeds	kg	14.7	[16]
Outputs			
1. Wheat Grain Yield	kg	14.7	[16]
2. Wheat Straw Yield	kg	12.5	[16]

Based on these energy equivalents given in table 1, energy indices such as energy use efficiency, Energy Productivity (kg MJ^{-1}), specific energy (MJ.kg^{-1}), Net energy (MJ ha^{-1}) and Water productivity (kg m^{-3}) [17].

$$Energy\ \ Efficiency = \frac{Energy\ \ Output(MJha^{-1})}{Energy\ \ Input\ \ (MJha^{-1})} \tag{1}$$

$$Specific\ \ Energy = \frac{Energy\ \ Input\ \ (MJha^{-1})}{Grain\ \ Output\ \ (kgha^{-1})} \tag{2}$$

$$Energy\ \ Productivity = \frac{Grain\ \ Output\ \ (kgha^{-1})}{Energy\ \ Input\ \ (MJha^{-1})} \tag{3}$$

$$Net\ \ Energy = Energy\ \ Output\ \ (MJha^{-1}) - EnergyOutput\ \ (MJha^{-1}) \tag{4}$$

$$Water\ \ Productivity = \frac{Grain\ \ Yield\ \ (kgha^{-1})}{Water\ \ Applied\ \ (m^3ha^{-1})} \tag{5}$$

3. Results and Discussion

3.1. Effect of Irrigation Schedules on wheat grain yield and biological yield

The effects of different irrigation schedules on grain yield and biological yield of wheat crop is investigated as shown in figure 1. The result shows that highest grain yield was observed in T1 treatment whereas minimum grain yield was observed in farmer practice. The T1 treatment gave 7.94% and 27.94% more yield compared to T4 and farmer's practice respectively. The highest biological yield was also obtained with T1 and minimum biological yield was obtained with T6 treatment. The T1 treatment gave 3.1% and 4.1% more biological yield compared to T4 and farmer's practice respectively. The statistical analysis was carried out on water use, grain yield and biological yield using ANOVA with comparison of mean of all treatments using Least Significant Difference (LSD) test at 5% significance level. The significant differences were observed for grain yield and biological yield. However, water use under all schedules vary non-significantly. Treatments based on percentage MAD (T1, T2 and T3) significantly increased wheat grain yields over CPE based treatments (T5 and T6) and non-significantly with T4. The results of this research are similar with the findings of [18].

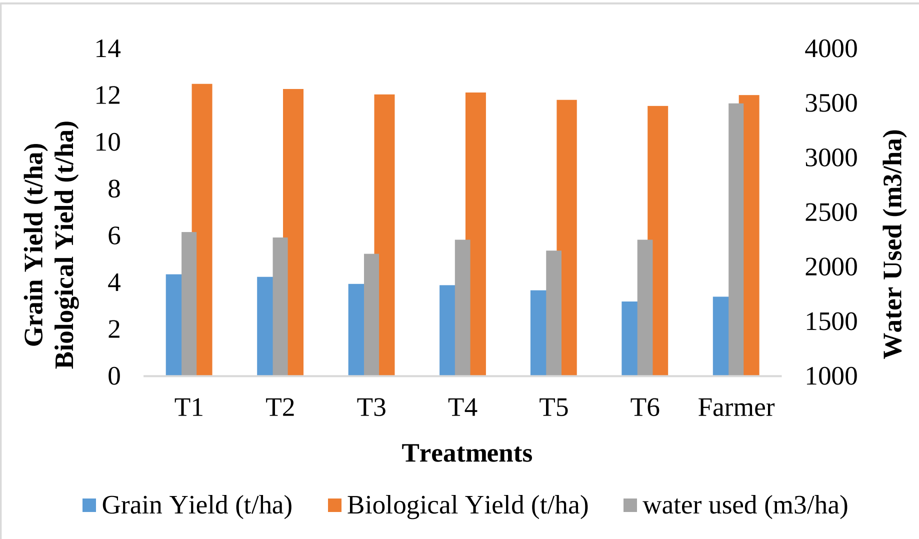

Figure 1: Graphical representation of grain yield, biological yield and water use

3.2. Energy Balance Analysis

The quantity of inputs used and output obtained in wheat production, their energy equivalents and energy indices (energy ratio, energy productivity, specific energy and net energy) are described in Tables 2, 3 and 4, respectively. Table 2 indicated that about 85 h human labor, 20 h machinery power and 50-liter diesel fuel per hectare is required for wheat production in the experimental area. The amount of total fertilizers and herbicides were used 445 kg (including 104 kg nitrogen, 212 kg phosphorus and 129 kg potassium) and 1.5 kg per hectare respectively. The total amount of water and electricity used for pumping were different for all treatments.

Table 2: Quantity of inputs and outputs per unit hectare in wheat production

Energy	unit	Energy Equivalent (MJunit^{-1})	Quantity per unit hectare						
			Farmer	T1	T2	T3	T4	T5	T6
Inputs									
1. Human Labor	h	1.96	85	85	85	85	85	85	85
2. Machinery	h	62.7	20	20	20	20	20	20	20
3. Diesel Fuel	L	56.31	50	50	50	50	50	50	50
4. Chemical Fertilizers	kg								
a) Nitrogen		66.14	104	104	104	104	104	104	104
b) Phosphorous		12.44	212	212	212	212	212	212	212
c) Potassium		11.15	129	129	129	129	129	129	129
5. Herbicides	kg	238	1.5	1.5	1.5	1.5	1.5	1.5	1.5
6. Water	m^3	1.02	3500	2320	2270	2120	2250	2150	2250
7. Electricity	kWh	11.93	618.136	409.712	400.882	374.392	397.35	379.69	397.35
8. Seeds	kg	14.7	125	125	125	125	125	125	125
Outputs									
1. Wheat Grain Yield	kg	14.7	3400	4350	4240	3940	4030	3670	3320
2. Wheat Straw Yield	kg	9.25	12010	12500	12280	12050	12120	11810	11550

As it can be seen in Table 3, the total amount of energy consumed directly or indirectly in wheat production was in the range of 21224.29 MJ/ha - 24132.15 MJ/ha. The pumping water for irrigation was the highest energy consumption input for wheat production after chemical fertilizers. T1 (30% MAD) and T4 (20 mm CPE) treatments saved 33.72% and 35.72% energy respectively due to water saving over farmer practice. While T1 and T4 treatments increase 11.40% and 6.38% energy output in terms of grain yield and biological yield respectively over farmer practice.

The energy indices such as net energy, energy use efficiency, energy productivity, specific energy and water productivity for wheat production in study area are shown in Table 4. The highest net energy (155557.95MJ ha^{-1}), energy use efficiency (7.478), energy productivity (0.181 kg MJ^{-1}) and water productivity (1.875 kg m^{-3}) was achieved with T1 (30% MAD) however highest specific energy (8.148 MJ.kg^{-1}) was achieved with farmer practice. The highest energy use efficiency (energy output to input ratio) was obtained with T1 treatment (7.478) while the lowest energy use efficiency was obtained with farmer practice, showing thee affective use of inputs. In Turkey, [19] reported wheat output/input ratio as 2.8. [20] calculated energy output/input ratio 2.9, 4.0, 4.2 and 5.2 at different locations in India. The highest specific energy (8.148 MJ.kg^{-1}) was achieved with farmer practice, showing the amount of energy used to produce a unit of marketable product. [19] and [17] calculate specific energy for wheat production as 5.24 MJ.kg^{-1} and 6.36 MJ.kg^{-1} respectively.

Table 3: Energy Consumption and Production in wheat production

Energy	Total Energy equivalent (MJ/ha)						
	Farmer	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**
Input							
1. Human Labor	166.6	166.6	166.6	166.6	166.6	166.6	166.6
2. Machinery	627	627	627	627	627	627	627
3. Diesel Fuel	2815.5	2815.5	2815.5	2815.5	2815.5	2815.5	2815.5
4. Chemical Fertilizers							
a) Nitrogen	6878.56	6878.56	6878.56	6878.56	6878.56	6878.56	6878.56
b) Phosphorous	2637.28	2637.28	2637.28	2637.28	2637.28	2637.28	2637.28
c) Potassium	1438.35	1438.35	1438.35	1438.35	1438.35	1438.35	1438.35
5. Herbicides	357	357	357	357	357	357	357
6. Water	3570	2366.4	2315.4	2162.4	2295	2193	2295
7. Electricity	7374.362	4887.864	4782.522	4466.497	4740.386	4529.702	4740.386
8. Seeds	1837.5	1837.5	1837.5	1837.5	1837.5	1837.5	1837.5
Total energy input (MJ ha^{-1})	27702.15	24012.05	23855.71	23386.69	23793.17	23480.49	23793.17
Output							
1. Grain Yield	49980	63945	62328	57918	59241	53949	48804
2. Straw Yield	111092.5	115625	113590	111462.5	112110	109242.5	106837.5
Total energy output (MJ ha^{-1})	161072.5	179570	175918	169380.5	171351	163191.5	155641.5

Table 4: Analysis of energy indices in wheat production

Indices	**Farmer**	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**
Net Energy (MJ ha^{-1})	133370.35	155557.95	152062.29	145993.81	147557.82	139711.01	131848.32
Energy Use Efficiency	5.814	7.478	7.374	7.243	7.202	6.950	6.541
Energy Productivity (kg MJ^{-1})	0.123	0.181	0.178	0.168	0.169	0.156	0.139
Specific Energy (MJ.kg^{-1})	8.148	5.520	5.626	5.936	5.904	6.398	7.167
Water productivity (kg m^{-3})	0.971	1.875	1.868	1.858	1.791	1.707	1.475

3.3. Economic Analysis

The energy analysis helps in planning to conserve as well as increase energy productivity. Energy savings are essential but not satisfactory for an economic benefit. An energy saving production practices system may not necessarily bring more economic benefits. A combination of economic and energy analysis of the production system may be more comprehensive for the best management strategies. The economic analysis for wheat production under different irrigation schedules are shown in table 5. The maximum benefit to cost ratio was obtained with T1treatment. Results depicts that just irrigation timing and amount create a lot of difference in net returns. Therefore, decisions on when and how much to irrigate are critical especially under water scarcity conditions.

Table5: Cost analysis (PKR) for wheat crop (per hectare) for Faisalabad-Pakistan, 2014-15

Treatments	**Farmer**	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**
INPUT:							
1. Seed (a)	2335	2335	2335	2335	2335	2335	2335
2. Fertilizers							
- Urea (b)	4150	4150	4150	4150	4150	4150	4150
- DAP (c)	9880	9880	9880	9880	9880	9880	9880
- MOP (c)	17000	17000	17000	17000	17000	17000	17000
3. Spray							
- Topic	250	250	250	250	250	250	250
- Bacterial Super	1350	1350	1350	1350	1350	1350	1350
4. Irrigation (Energy cost) (d)	3300	2186	2152	1996	2120	2026	2120
5. Fuel (Bed preparation + Sowing +Threshing) (e)	18500	18500	18500	18500	18500	18500	18500
6. Labor	15000	15000	15000	15000	15000	15000	15000
Total Cost of Production	71765	70651	70617	70461	70585	70491	70585
OUTPUT:							
1. Grain Yield (f)	110500	141375	137800	128050	126425	119275	103675
2. Straw Yield (g)	60050	62500	61400	60250	60600	59050	57750
Total Value of Production	170550	203875	199200	188300	187025	178325	161425
Net Return	98785	133224	128583	117839	116440	107834	90840
Benefit to Cost Ratio (--)	1.38	1.88	1.82	1.67	1.65	1.53	1.29

(a) @ PKR 33 per kg
(b) @ PKR 40 per kg
(c) @ PKR 80 per kg
(d) @ PKR 8 per kWh
(e) @ PKR 86 per liter
(f) @ PKR 1300 per mond
(g) @ PKR 200 per mond

4. Conclusion:

The study illustrates trends investigate the consumption pattern with regard to energy and water in wheat production under different irrigation schedules based on percent MAD and CPE in Faisalabad, Punjab, Pakistan. Results shows that the soil moisture based treatment (at 30% MAD) gave 7.94% and 27.94% more yield compared to climate based treatment's (20 mm CPE) and farmer's practice respectively. The pumping water for irrigation was the highest energy consumption input for wheat production after chemical fertilizers. T1 (30% MAD) and T4 (20 mm CPE) treatments saved 33.72% and 35.72% energy respectively due to water saving over farmer practice. While T1 and T4 treatments increase 11.40% and 6.38% energy output in terms of grain yield respectively over farmer practice. Economic analysis also shows that maximum benefit to cost ratio was attained with T1 treatment (30% MAD). Energy input in terms of irrigation water is the most important energy input in arid and semi-arid regions. Overuse and mismanagement of limited water resources may raise a huge concern on agricultural production quantity and quality. Hence, the precise application of irrigation water at proper time can be considered as an effecting and simple approach to conserve water with minimal environmental effect and less cost.

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