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Energy use pattern for rainfed and irrigated sorghum production in the Sudan

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ABSTRACT

This study was conducted to compare the energy productivity of rainfed and irrigated sorghum in Sudan. Input data and yield were collected from the Agricultural Directorate records and The Mechanized rain farming Directorate. Results showed that total energy inputs of rainfed and irrigated sorghum were 1876.32 and 16469.35 MJ/ha, respectively. The total energy outputs were 108820 and 142000 MJ/ha, respectively. Based on these results, the energy use efficiency for rainfed and irrigated sorghum were 58.0 and 8.62, respectively. The energy productivity were 0.32 and 0.17 for rainfed and irrigated sorghum, respectively. The share of renewable energy of rainfed and irrigated sorghum were 15.20% for rainfed and 3.05% of the total input energy. Therefore, rainfed sorghum production is more efficient than irrigated sorghum. The study revealed that although the total energy output is high, only about 8% of it is grain and the rest is straw energy.

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I. Introduction

Agriculture is the cornerstone to Sudan's economy. The country is blessed with a wealth of cultivable area ranges from 84 to 105 million hectares (UNEP, 2007) with reasonably fertile soils and the terrain is generally flat. The agricultural sector employs over 80% of the work force and accounts for nearly 40% of the Gross Domestic Product. Cereals dominate crop production in Sudan and provide about 53% of the population's daily calorie requirements (FAO-SIFSIA, 2010). Sorghum, wheat and millet are the major cereal crops in the country.

Sorghum is one of the main staples for the world's poorest and most food-insecure people (Henry and Kettlewell, 1996). The crop is generally suited to hot and dry areas where it is difficult to grow other food grains. These are also areas subject to frequent drought. In many of these areas, sorghum is truly a dualpurpose crop; both grain and stover are highly valued outputs. In large parts of the developing world, stover represents up to 50 percent of the total value of the crop, especially in drought years. During the agricultural seasons in 2000–2005, about 1.89 million hectares of arable land were under irrigated agriculture, 8.37 million hectares under traditional rain-fed cultivation and 5.44 million hectare under mechanized farming. Despite a few outbreaks of pests and diseases, the 2006–2007 season produced a record cereals harvest of 6.64 million metric tons. These yields were 22% higher than in 2005, and production across all three sectors was considerably improved: 36% higher than the previous year's average and above the long-term average (Ahmed, 2007). Sorghum production fluctuates because 75% of total sorghum production is mainly grown in the rain-fed areas (Abbadi and Ahmed, 2006). Crop production from traditional rainfed farming has grown since the early 1990s; it has surpassed the level of semi-mechanized farming, which shrank during the same period. Semi-mechanized system has ceased to be the dominant source of sorghum for Sudan (Institute for Security Studies, 2005). However, the contribution of the irrigated sector has remained relatively stagnant.

Energy needs for agricultural production are about 3% of the national energy consumption in developed countries and about 3.6% in developing countries (Karkacier et al., 2006; Sauerbeck, 2001; Stout, 1990). However, the energy input per hectare in developing countries for agricultural production is about 7700 MJ and in developed countries, it is about 37,900 MJ. In developing countries, human labor is the major cost item of energy; while, in developed countries, mechanization and fertilizers are major energy inputs (Pimentel and Pimentel, 2008). The entire food system including production, processing, packaging, and transportation could require about 15% to 20% or more of a nation's energy consumption (Pimentel and Pimentel, 2008; Stout, 1990; Ziesemer, 2007). According to various studies done in this field, the process of production between 60% and 90% of consumer energy is non-renewable (Canakci et al., 2005; Ozkan et al., 2004). Many studies have shown the reduction in the productivity and the efficiency of energy consumption in common agriculture in contrast to the agriculture based on natural inputs (Gundogmus, 2006; Guzman and Alonso, 2008; Hoeppner et al., 2005; Pimentel et al., 1983). Chemical fertilizers, pesticides, agricultural machinery, and other farm inputs are used extensively in modern agriculture. Crop specific fertilizer recommendation and input use (Sultana et al. 2015; Hossain and Siddique, 2015) may ensure economic production. Efficient use of energy inputs in agriculture will reduce environmental impacts, prevent damage to natural resources, and improve the sustainability of agriculture as an economical production system (Kizilaslan, 2008). Energy management is an important issue in terms of efficient, sustainable and economic use of energy. Effective energy use in agriculture is one of the conditions for sustainable agricultural production, since it provides financial savings, fossil resources preservation and air pollution reduction (Uhlin, 1998). The aim of this study was to determine the input and output energy used in rainfed and irrigated sorghum production in Sudan, identify operations where energy savings could be realized, for proposes improvements to reduce energy consumption for sorghum production.

II. Materials and Methods

Study area: Gedarif agriculture area (representing the rainfed sorghum) is located between 14º.03 N and 35.4º E. It represents parts of the central clay plain of the rainfed agriculture. The area covers about 2.94 million hectares. The climate is semi-arid to high rainfall savanna with hot summer and worm winter. The average rainfall is 400–1000 mm, which falls mainly between May and October (Hamdoun et al., 1991). The soil is heavy dark cracking clays. Cropping is usually undertaken using the wide level disk harrow with attached seeder box drawn by (50-60 kW) tractor. The main crops include sorghum, sesame sunflower and cotton. Gezira and Rahad schemes (representing the irrigated area), with total areas of 0.924 and 0.13 million hectares, respectively, are also located in the central clay plain. The main crops are cotton, groundnut, sorghum and some vegetables. The area under sorghum is about 25% of the irrigated area.

Data collection: Data of irrigated sorghum were collected from the scheme record, Agricultural Directorate, Agricultural engineering Directorate, agricultural field manager and some farmers, since most of the agricultural operations are carried out by these directorates. Data of rainfed sorghum were collected from State Ministry of Agriculture, Mechanized rainfed Directorate, Agricultural Service Companies, Agriculturalists and some farmers. In addition to that some information was collected from scientists in these areas for comparison and verifications.

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Energy conversion factors were obtained from different sources (Yilmaz et al., 2005; Singh and Mittal, 1992; Erdal et al., 2007; Singh et al., 2002; Singh, 2002; Shahan et al., 2008; Esengun et al., 2007; Acaroglu and Aksoy, 2005; Ozkan et al., 2004; Pimentel, 1980; Argiro et al., 2006). Energy demand in agriculture can be divided into direct and indirect, renewable, and non-renewable energies (Alam et al., 2005). Indirect energy included energy embodied in seeds, fertilizers, manure, chemicals, machinery while direct energy covered human labor and diesel used in the crop production. Non-renewable energy includes diesel, chemical, fertilizers and machinery, and renewable energy consists of human labor, seeds and manure. Consumption in each group of inputs was calculated from the multiplication of the amount of the input consumption and its energy equivalent per unit. Then according to energy input and output, energy use efficiency, energy productivity, specific energy, and net energy were calculated.

$$\text{Energy ue efficiency (\%)} = \frac{\text{Energy output (MJ/ha)}}{\text{Energy input (MJ/ha)}} \times 100 \quad \text{......................... (1)}$$

$$\text{Energy productivity (kg/Mj)} = \frac{\text{Grain output (kg/ha)}}{\text{Energy input (MJ/ha)}} \quad \text{......................... (2)}$$

$$\text{specific energy (MJ/kg)} = \frac{\text{Energy input (MJ/ha)}}{\text{Grain ouput (kg/ha)}} \quad \text{........................ (3)}$$

$$\text{Net Energy (MJ/ha)} = \text{Energy output} - \text{Energy input} \quad \text{......................(4)}$$

Also, the share of direct energies (including manpower, fossil fuels, and irrigation water), indirect (including seed, consumer chemicals, and machinery), renewable energies (manpower and seed), non-renewable (fossil fuels, fertilizers and chemicals, water and machinery) was calculated.

III. Results and Discussion

For rainfed sorghum production, land preparation is usually carried out using the standard disk plow (wide level disk) and sowing is carried out by the same implement, while in the irrigated sorghum, land preparation is usually carried out using disk plow and ridging using a 56kw tractor. Sowing is usually carried out manually using a digging hoe. Fertilizer is mainly applied through broadcasting. Irrigation water is applied at 12-15 days interval during the whole crop growing period by gravity irrigation. No pesticides application is done except for seed coating. Harvesting is partially mechanized that is, the crop is manually cut with the use of a cutting knife, followed by threshing using power operated thresher having an average capacity of 2 ton/hr (Tables 01 and Table 02). It can be noticed that rainfed agriculture depends mainly on wide level disk for land preparation and sowing which has many problems. These are in case of seedbed preparation, the resulting seedbed is usually shallow restricting root and shoot growth; for seeding, the implement broadcasts the seeds with no depth control, resulting in patchy, poor plant population and poor crop establishment; and broadcasting the seeds makes manual weeding difficult and mechanical inter-row cultivation impossible.

Despite the availability of modern technology for sowing, large areas in the irrigated sorghum is sown manually using the digging hoe that results in uncontrolled within row spacing and consequently poor plant population.

Table 03 shows the energy input and output for rainfed and irrigated sorghum. Diesel and fertilizers contribute more than 53% of the total energy input in irrigated sorghum while it is 46.42% in rainfed sorghum. Water contributes about 41.29% of the total input in the irrigated sorghum and only 21.75% in the rainfed.

Table 01. Management practices for rainfed sorghum

Operations	Duration	Methods
Land preparation	20/6-20/7	wide level disk
Sowing	10/7-20/8	Wide level disk
Weeding	1/8-10/9	No
Irrigation	-	Rain
Fertilizer	Not applied	-
Spraying	1/7- 20/7	12-14 m width boom sprayer
Harvesting	25/11-1/1	Manual Labor cutting
Threshing	-	Stationary combine, stationary thresher

Table 02. Management practices for irrigated sorghum

Operations	Duration	Methods
Land preparation	1/3-31/5	Disk harrow, ridger
Sowing	10/6-10/7	Planter, manual
Fertilizer application	45 days after sowing	Band, broadcasting
Irrigation	Every 12-15 days	Surface irrigation (gravity)
Spraying	Not applied	-
Harvesting	4 months after sowing	Manual cutting.
Threshing	-	Stationary thresher

Table 03. Inputs and outputs in relation to sorghum production

Energy form	Rainfed		Irrigated
	Direct combine	Stationary thresher	
Labor	5.23	8.37	436.68
Machinery	129.14,	145.46	104.71
Tractor	88.24	88.24	342.36
Fuel	1182.51	844.65	1447.17
Fertilizer	0	0	7272
Pesticides	25.08	25.08	0.28
Water	408	408	6800
Seed	110.25	110.25	66.15
Grain	8820	8820	2857
Straw	100000	100000	100000

Table 04. Amount and percentage of different inputs and output energy equivalent

A. Inputs	Farming systems					
	Rainfed			Irrigated		
	Quantity per unit area	Total energy Equivalent (MJ/ha)	% of total energy Input	Quantity per unit area	Total energy Equivalent (MJ/ha)	% of total energy Input
1.Labor	89.26	174.95	9.32	222.80	436.68	2.65
land preparation	1.51	2.96	0.16	1.4	2.74	
Sowing	1.63	3.19	017	1.4	2.74	
Irrigation	0	0	0	16	31.36	
Weeding	0	0	0	96	188.16	
Fertilizer application	0	0	0	8	15.68	
Spraying	0.33	0.65	0.03	96	188.16	
Harvesting	80	156.8	8.36	96	188.16	

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Direct	1.76	3.45	0.18	0	0	
Stationary	4	7.84	0.42	4	7.84	
2.Machinery (hr/ha)	2.93	183.72	9.79	1.67	104.71	0.64
land preparation	0.77	48.28		0.7	43.89	
Sowing	0.83	52.04		0.47	29.47	
Irrigation	0	0		0	0	
Fertilizer application	0	0		0	0	
Spraying	0.46	28.84		0	0	
Harvesting	0.45	28.22		0	0	
Direct	0.72	45.14		0	0	
Stationary	0.42	26.33		0.5	31.35	
3.Tractor (hr/ha)	2.05	128.54	6.85	5.40	342.36	2.08
4.Fuel (l/ha)	15.02	845.78	45.08	25.71	1447.17	8.79
land preparation	5	281.55		12.40	698.24	
Sowing	6	337.86		3.81	213.98	
Irrigation	0	0		0	0	
Fertilizer application	0	0		0	0	
Spraying	0.02	1.12		0	0	
Harvesting				0	0	
Direct combine	10	563.1		0	0	
Stationary	4	225.24		9.5	534.95	
5.Fertilizer (kg/ha)	0	0	0	120	7272	44.15
Nitrogen	-	0		120	7272	
Phosphorous	-	0		0	0	
Potassium	-	0		0	0	
6. Pesticide (kg/ha)	1.20	25.08	1.33	0.003	0.28	
7.Water	400	408	21.75	6666	6800	41.29
8.Seeds (kg/ha)	7.5	110.25	5.88	4.50	66.15	0.40
B. Outputs		108820				
1.Seed (kg/ha)	600	8820	8.11	2857	42000	29.58
2.Straw (kg/ha)	8000	100000	91.89	8000	100000	70.42

Table 05. Various Energy performance parameters in sorghum production

Parameter	Units	Energy amount		
		Rainfed sorghum		Irrigated sorghum
		Direct combine	Stationary thresher	
Total Input Energy	MJ/ha	2209.79	1876.32	16469.35
Total Output Energy	MJ/ha	108820	108820	142000.00
Energy use efficiency	-	49.24	58.00	8.62
Grain	kg/ha	600	600	2857
Specific energy	MJ/kg	3.68	3.12	5.76
Energy Productivity	kg/MJ	0.27	0.32	0.17
Net energy (MJ/ha)	MJ/ha	106610.21	106943.68	125530.65

Table 05 shows the energy performance parameters for rainfed and irrigated sorghum. It reveals that the energy use efficiency for irrigated sorghum production is very low compared to rainfed sorghum. The energy ratio for rainfed sorghum is about 6-7 folds of that of irrigated sorghum. The average energy input in the rainfed sorghum is about 11.39% of that of the irrigated sorghum while the output is 21% of that of irrigated sorghum (excluding straw energy). Including the straw energy, the rainfed sorghum produces 84.94% of the energy produced by irrigated sorghum.

Table 06. Total energy input in the form of direct, indirect, renewable and nonrenewable for sorghum production (MJ/ha)

Form of energy	Amount (MJ/ha)		%	
	Rainfed	Irrigated	Rainfed	Irrigated
Direct Energy	1428.73	7579.04	76.15	46.00
Indirect Energy	447.59	8890.28	23.85	54.00
Renewable Energy	285.20	502.83	15.20	03.05
Non-Renewable	1591.12	15966.42	84.80	96.95
Total energy inputs	1876.32	**16469.32**	-	-

Referring to Table 06, the irrigated sorghum uses 46% of its energy input in the form of direct energy and 54% in the form of indirect energy while the rainfed sorghum uses about 76.15% direct energy and 23.85 as indirect energy. Sorghum production in Sudan uses a large amount of non-renewable energy, 84.80% for rainfed and 96.95% for irrigated sorghum. This represents an environmental threat to Sudan agriculture. Therefore, the country should go to produce sorghum in the rainfed areas and replacing the irrigated sorghum with other cash crop. Bearing in mind the low productivity can be increased by development of improved genotype. This could be achieved by breeding for higher yielding varieties suitable for the different environments and improved cultural practices to improve crop establishment and yield for the diverse farming systems. Of special interest will be seedbed preparation and suitable seeding methods.

IV. Conclusion

Energy use in sorghum production can be detrimental to the environment due to mainly excess input use. Although the total energy output is high, only about 8% of it is grain and the rest are straw. Reducing fuel consumption in tractor and equipment in field operations along with optimum nutrient application method and efficient irrigation system, in addition, breeding for high yielding varieties can help to improve the energy efficiency of sorghum.

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