https://doi.org/10.17221/11/2023-RAE

Determination of sorghum production energy input-output balance under farmers' practices in Hararghe lowland area of Ethiopia

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Citation: Birhanu A.G., Yetenayet B.T., Abebe F.B., Solomon A.H., Sirawdink F.F. (2023): Determination of sorghum production energy input-output balance under farmers' practices in the Hararghe lowland areas of Ethiopia. Res. Agr. Eng., 69: 189–198.

Abstract: Sorghum production energy input-output balance was studied during the 2020/2021 production year in Hararghe lowland areas of Ethiopia under farming methods practised by the farmers. The study aimed to assess the energy input and output and to analyse the energy use efficiency of sorghum production under farming practices of the farmers using the recently adopted early maturing varieties. Three sorghum varieties were used with Randomized Complete Block Design (RCBD) in 3 replications. Production inputs were uniformly applied to the entire unit plots. The average total production energy input was 12 188.07 MJ·ha^{-1} in which chemical fertiliser and mechanical energy contributed 47.40% (5 771.48 MJ·ha^{-1}) and 43.60% (5 314.10 MJ·ha^{-1}), respectively. The highest energy consumer stage was top-dressing followed by land preparation and sowing stages with values of 33.7, 25.20 and 20.20% of the total input, respectively. The remaining 20.90% of the input was distributed among the rest production operations. The mean energy output of 77 284.59 MJ·ha^{-1} for *Makko* was significantly higher than that of *Qaqaba* and *Malkam* varieties. *Makko* was also superior to *Malkam* and *Qaqaba* in mean energy ratio with values of 6.31, 5.48 and 5.84, respectively.

Keywords: early maturing; energetic depreciation; energy efficiency; energy productivity; sorghum varieties

Sorghum [*Sorghum bicolour* (L. Moench)] is the major cereal crop produced in lowlands areas of Ethiopia in general, and it is the major staple food grain in Hararghe areas, in particular. Ethiopia ranks third in Africa and sixth on the globe in sorghum production (Hari et al. 2017), contributing more than 4.8million metric tons from approximately 1.7 million hectares (Muluken et al. 2021). The Hararghe part of the Oromia national state represents the major sorghum production belt in Ethiopia where almost all the rural peoples engaged in agriculture are investing their scarce resource input of production energy sources. Sorghum is produced for food grain and is also highly valued for its biomass as livestock feed, fuel energy, and building materials in Hararghe areas (Beyene et al. 2016).

However, its production could not match the ever-increasing demand, mainly due to climate

https://doi.org/10.17221/11/2023-RAE

change exasperating the naturally extreme environmental conditions, constrained resources, and the farming systems where these crops are grown (Muluken et al. 2021*).* Much effort has been made to overcome this problem, mainly by introducing improved sorghum varieties. Various types of short maturity period and drought-tolerant varieties released by different research institutions for moisture-stressed lowland areas were introduced in the last decade to increase productivity (Tolesa 2022). Many of those varieties were adopted and in production by most of the farmers using the traditional production practices of the farmers that remained almost as it were. Though such traditional farming practice of the farmers is considered environmentally friendly, it is limited to low-energy inputs and use of the less efficient indigenous hand tools and farm implements (Steenwyk et al. 2022). Efficient use of the production energy source input is vital to increase production, productivity and competitiveness of agriculture (Alipou et al. 2012).

However, the achievement of the endeavours indicated above has not been measured in terms of production energy use efficiency and energy input-output balance that shows the productivity, profitability and sustainability of the inputs used, and the production system. Determination of energy efficiency makes it possible to compare different farming systems for environment-friendly and sustainable of the production (Yuan et al. 2018). Energy efficiency is closely associated with the economic (profitability) and ecological aspects of the chosen farming systems (Shahgholi et al. 2018). Energy use efficiency is among the key indicators for developing sustainable production practices (Muhammad and Orhan 2021) and essential for the analysis of mechanisation status (application level of engineering technology) in the total human work (Emami et al. 2018). Complete determination of production energy is necessary to estimate the operating profit and the fixed costs of production (Voltr et al. 2020). Generally, the knowledge of energy input and output information of a given agricultural production process enables us to analyse the energy efficiency and productivity of that agricultural system, which helps to decide on the future changes and improvement need of the system for sustainability. Nonetheless, sorghum production energy input pattern and use efficiency had been rarely studied in Ethiopia, in general, and not existed particularly. under Hararghe lowland environment.

Therefore, this study was initiated to assess production energy input and output and to analyse energy use efficiency of sorghum production under farming practices of the farmers using selected improved early maturing sorghum varieties.

MATERIALS AND METHODS

Experimental site. The study was conducted under the lowland conditions of the Eastern Hararghe Zone in the Oromia Regional Sate of Ethiopia. The experiment was conducted on the Erar Research Site of Fadis Agricultural Research Centre (FARC), during the 2021/2022 production season under a rainfed system. The specific study site was Erar Ibada rural Keble area located at about E 42°30" and N 9°12" in Babbile district in Erar valley area within altitude of 1 130 to 1 240 m above sea level (Figure 1).

Experimental materials. Three varieties of sorghum (*Makko*, *Qaqaba* and *Malkam*) were selected and used for the study. The varieties were selected based on their relative adoption, popularity, productivity, similarity of days to maturity and the recommended agronomic management. Consequently, similar inputs of production energy sources were applied with similar production practices used by local farmers. Seed rates (plant spacing) and, rates and time of fertilizer application were uniform across all experimental units based on the available agronomic recommendations.

Experimental design and treatment factors. On-station trial experiment design was used and the experiment was laid in a Randomized Complete Block Design (RCBD). The three sorghum varieties were randomly assigned to the three plots of each 100 m^2

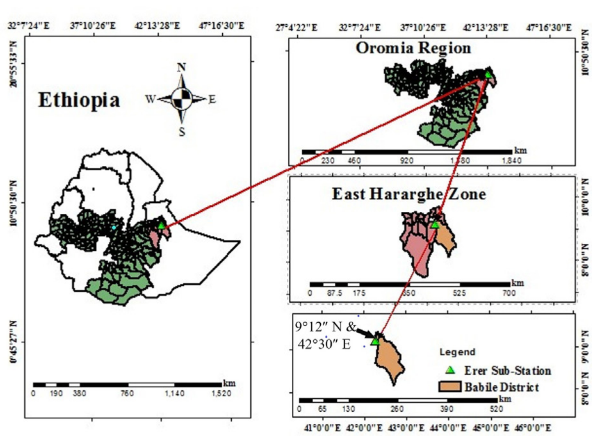

Figure 1. Geographic location of Babbille district within east Hararge Zone of Oromia regional state in Ethiopia

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unit area in a block with 3 blocks of replication. Three working groups of labourers containing equal male and female adult farmers of 10 total members – were formed and randomly assigned to each plot so that activities of the three plots in a block could be accomplished simultaneously. The groups were used throughout the experiment.

Production method details. The conventional sorghum production method practised by the farmers was applied throughout the production processes. The whole production process was divided into 9 stages just for convenience (*i*) pre-sowing (tillage and land preparation) (*ii*) sowing (*iii*) early weeding and cultivation (*iv*) top dressing (*v*) general crop management (*vi*) harvesting (*vii*) threshing (*viii*) winnowing (cleaning) and (*ix*) pre-storage handling (bagging, weighing and transportation to storage place). The entire production activities were made using the conventional traditional methods practised by the farmers which are presented in Figure 2.

Tillage and seed row preparation was done by tractor as tillage by tractor became common practice for most farmers in the area due to the easily accessible tractor rent service provided by tractor owners. All the activities after tillage were performed by traditional methods of farmers' practices. Sowing was done manually by drilling seed and fertilizer in open rows and then covering it using fork recks. Chemical fertiliser consisting of Nitrogen, Phosphorus and Sulphur (NPS) was used with the seed. Early weeding and cultivation were done manually using hoes. Urea was applied (top-dressing) manually when plant height reached knee level, using hoes to cover the fertiliser. Crop management practices like weeding, harvesting, threshing and cleaning were done manually as practised by farmers. Stop-watch was used to control the effective working time of every operation. Data of all inputs involved in the production processes were collected in quantified forms of their participation. Machinery/equipment input was recorded with the type and effective time used. Mechanical energy input data was collected with fuel input measured by tanker toping method whereas number, sex and effective work time were used for labour input per unit plot at all stages. Biological and chemical energy input data were collected in the weight of seeds planted, type and amount of the fertilisers input and chemical biocides applied per plot. Transport energy input data was collected by the quantity transported, the distance travelled or fuel consumed and the time taken with type of transport.

Production energy analysis. Production energy efficiency is a relationship between the energy produced (energy output) and the total energy input used to obtain that output. The energy input of agricultural systems is associated with all inputs involved in the production processes. Each input re-

(A) (B)

(C) (D)

Figure 2. Pictures captured during production field practices of the selected sorghum varieties on the field plots of the experiment: (A) Early weeding and cultivation, (B) top dressing (uria application), (C) after weeding and flowering stage and (D) manual harvesting

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source used has its own specific energy intensities indicated in Table 1 as adopted from various articles of different authors.

Type of production energy inputs can be categorised in different ways as renewable and non-renewable based on the reproducibility of the sources used or as direct and indirect energy input based on the mode of the input energy source participation. It can also be grouped as physical, biological and chemical energy, based on the type of input used. Direct energy input indicates fuel, human and draft animal power used for mechanical operation energy sources. Indirect energy input includes farm machinery and equipment, commercial fertilisers, seeds, biocide chemicals, irrigation and transportation. The direct and/or indirect energy inputs of this study were calculated according to Alipour et al. (2012), Shafique et al. (2015), Rodrigo et al. (2017) and Bazaluk et al. (2021) using Equations (1–4) as indicated below. Human labour is a direct energy input and is computed as:

$$L_E = \frac{T_w(N_L \times L_{EC})}{WA} \qquad (1)$$

where: L_E – labour energy (MJ·ha^{-1}); T_w – effective working time (h); L_{EC} – energy coefficient of an adult labourer (MJ·h^{-1}); N_L – number of labourers.

Fuel energy (F_E) (MJ·ha^{-1}) is a direct mechemical energy input and is computed as:

$$F_E = \frac{(E_{EC} \times V_F)}{W_A} \qquad (2)$$

where: E_{EC} – energy coefficient of fuel (MJ·L^{-1}); V_F – volume of fuel consumed (L); W_A – farm area covered (ha).

Machinery energy of self-propelled automotive machines (E_{AE}) (MJ·ha^{-1}) like tractors and combined or energy of non-automotive machinery/pulled equipment (E_{PE}) (MJ·ha^{-1}) (like disc ploughs, disc harrow, planters, etc.) were calculated using Equations (3) and (4).

$$E_{AE} = \frac{(69.83 \times M)}{U_L} \times T_E \qquad (3)$$

$$E_{PE} = \frac{(57.20 \times M)}{U_L} \times T_E \qquad (4)$$

Table 1. The energy coefficient of various crop production inputs adapted from research report of different authors and used in this study

Input/output		Unit	Energy intensity	Source of information
Disc plough		MJ·h^{-1}	3.762	
Disc harrow		"	7.336	Nassir and Singh (2009)
Cultivator		"	3.135	
Tractor Trailer		"	8.07	
Tractor (≥ 45 hp)		"	16.416	Ortiz-Cañavate and Hernanz (1999)
Transportation		MJ (t·km^{-1})	2.6	
Bullock (3.5–4.5t wt.) pair		MJ·h^{-1}	10.10	
Man-hour		"	1.96	Alipour et al. (2012)
Woman-hour		"	1.57	
Animal plough		"	0.627	
Hand hoe		"	0.502	Jordan et al. (2012)
Serrated sickle		"	0.836	
Diesel fuel		MJ·L^{-1}	56.31	Alipour et al. (2012)
	N	MJ·L^{-1}	60.60	
Fertilisers	P_2O_5	"	12.57	
	S	Kcal·k^{-1}	1 500	Devi et al. (2018)
Liquid chemical		MJ·mL^{-1}	0.102	
Sorghum grain		MJ·kg^{-1}	14.7	
Green fodder		MJ·t^{-1}	26.2	Nassir and Singh (2009)
Dry stover		"	29.3	

wt – weight; N – nitrogen; P_2O_5 – phosporus; S – sulphur

https://doi.org/10.17221/11/2023-RAE

where: T_E – effective time of the equipment use in hour per unit area (hha^{-1}); M – total mass of the machinery/equipment (kg); U_L – useful service life of the machinery/equipment (h); 69.83 = specific energy of automotive machinery/equipment (MJ·kg^{-1}); 57.20 = specific energy of pulled equipment (MJ·kg^{-1})

Equivalent fertiliser energy was computed from the quantity of each component of N, P and S fertiliser in the chemical compound used per unit area, based on their percentage (P_C) in the compound using Equations (5–9) depicted below (Shafique et al. 2015; Ogunlade et al. 2020).

$$\text{Mass of (N, P or S) input} = \frac{\text{Compound used} \times P_C\,(\text{N, P, S})}{100} \quad (5)$$

where: Mass of (N, P or S) input and compund used have (Kg·ha^{-1}) unit.

The equivalent energy input of each component (N, P, S) was then calculated from the quantity of the ingredients per unit area (ha) using their respective energy coefficients as:

$$\text{Energy of N} = \frac{\text{N} \times \text{energy coefficient of N}}{\text{planted area}} \quad (6)$$

$$\text{Energy of } P_2O_5 = \frac{P_2O_5 \times \text{energy coefficient of } P_2O_5}{\text{planted area}} \quad (7)$$

where: energy coefficient of N and P_2O_5 have (MJ·ha^{-1}); N and P_2O_5 are in kg.

Sorghum seeds energy (S_E) (MJ·ha^{-1}) was calculated using sorghum grain energy intensity (S_{EC}) as:

$$S_E = \frac{\text{seed weight} \times S_{EC}}{\text{cultivated area}} \quad (8)$$

The total energy input (EI) (MJ·ha^{-1}) per plot was obtained by the addition of the partial energies of each input to the unit production as:

$$EI = DE + IDE \quad (9)$$

where: DE – total direct energy input (MJ·ha^{-1}); IDE – total indirect energy input (MJ·ha^{-1}).

The energy output (EO) (MJ·ha^{-1}) of crop production is the energy value of the products obtained at the end of production processes. It includes partial energy of the main product (grain) and dry biomass (by-products). The total EO was calculated using the total mass of each product component and their respective energy coefficients using Equation (10) as used in Rodrigo et al. (2017) and Muhammad et al. (2020).

$$EO = (M_g \times E_g) + (M_B \times E_B) \quad (10)$$

where: M_g – weight of sorghum grain (kg·ha^{-1}); E_g – energy coefficient of sorghum grain (MJ·kg^{-1}); M_B – weight of dry biomass (kg·ha^{-1}); E_B – energy coefficient of dry biomass stover (MJ·kg^{-1}).

Production energy efficiency. Crop production energy use efficiency is the relationship between the energy of the crop produced and the energy of the inputs participated in the processes and the efficiency parameters (energy indices) are termed as energy ratio (ER), net energy gain (NE) (MJ·ha^{-1}), energy productivity (EP) and specific energy (SE) (Ortiz-Cañavate and Hernanz 1999). These energy indices can be calculated using Equations (11–14) (Elfadil 2018; Muhammad et al. 2020).

NE is the difference between the gross energy output produced and the total energy input to produce it and it is expressed as:

$$NE = EO - EI \quad (11)$$

where: EO – The energy output (MJ·ha^{-1}); EI – the total energy input (MJ·ha^{-1}).

ER is defined as the ratio between the energy of the output products and the total energy input applied to the production. ER was calculated as:

$$ER = \frac{EO}{EI} \quad (12)$$

Energy productivity (EP) (kg·MJ^{-1}) is the ratio of the product to the energy input that measures the amount of a product obtained per unit of energy input. It was computed as:

$$EP = \frac{M_g}{EI} \quad (13)$$

where: M_g – weight of sorghum grain (kg·ha^{-1}); EI – the total energy input (MJ·ha^{-1}).

Specific energy (SE) is the reciprocal of energy productivity indicating the amount of energy input required to obtain a unit of product and indicated as:

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$$SE = \frac{EI}{Mg} \tag{14}$$

where: EI – the total energy input (MJ·ha^{-1}); M_g – weight of sorghum grain (kg·ha^{-1}).

Data analysis. All the data collected were converted into their equivalent energy quantity and the resulting values were organised in a suitable format for statistical entry based on the experimental design used for the study. The data was finally subjected to statistical analysis using GenStat 18th edition computer software. Descriptive statistics were used for energy input and analysis of variance was applied for efficiency analysis. Ryan/Einot-Gabriel/Welsch multiple test method was selected for means separation and determination of the significance mean differences using Least Significant Difference (LSD) at 5% probability.

RESULTS AND DISCUSSION

The total energy input recorded from the field trial experiment indicated an average value of 12 188.00 MJ·ha^{-1} as can be seen from Table 2 indicating the detail of all energy inputs. There is no variation in energy input at the same operation stage among the experimental units as every input was applied uniformly.

Energy input by category and stage of production. The result of energy input obtained has been summarized by category and percentage of the

Table 2. Means of the energy inputs at each production stage with items of the energy sources used and percentage share of the stages from the total input

Stages of production operations	Source of the *EI*	Unit of intensity	S_{EC}	Energy (MJ·ha^{-1})	Sub-total (MJ·ha^{-1})	Share (%)
Tillage and land preparation	nachinery	MJ·h^{-1}	7.39*	183.49		
	diesel fuel	MJ·L^{-1}	56.31	2 852.95		
	labour power	MJ·h^{-1}	1.97	30.73	3 067.17	25.19
Seed and fertilizer drilling (sowing)	seed	MJ·Kg^{-1}	14.70	153.41		
	nitrogen	"	60.60	1 465.03		
	phosphorus	"	12.57	614.24		
Seed and fertilizer drilling (sowing)	sulphur	"	6.280	56.52		
	labour power	MJ·h^{-1}	1.570	154.95		
	hand tools	"	0.502	29.98	2 474.13	20.24
Early weeding cultivation	labour		1.570	463.09		
	hand hoe	"	0.502	166.54	629.63	5.17
Top dressing (urea application)	nitrogen	MJ·Kg^{-1}	60.600	3 645.44		
	hand hoe	MJ·h^{-1}	0.502	76.03		
	labour	"	1.570	386.23	4 107.70	33.73
Crop management after top dressing	labour	"	1.570	315.85		
	equipment	"	0.613	99.57		
	chemical	MJ·mL^{-1}	0.102	258.51		
	other inputs			81.99	755.92	6.21
Harvesting	labour	MJ·h^{-1}	1.570	326.48		
	sickle	"	0.836	115.90	442.37	3.63
Threshing	labour	"	1.570	236.85	236.85	1.94
Cleaning	labour	"	1.570	288.52	288.52	2.37
Bagging and transporting	labour	"	1.970	107.51		
	trailer	MJ·h^{-1}t^{-1}	8.070	19.01		
	diesel fuel	MJ·L^{-1}	56.310	59.19	185.71	1.52
Grand total input				12 188.00	12 188.00	100.00

*average intensity of all the equipment used; *EI* – energy inpout; S_{EC}– energy intensity

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categories with total input at each production stage as presented in Table 3. The total energy input comprises 5 314.2 MJ·ha^{-1} (43.60%) direct energy, 6 873.90 MJ·ha^{-1} (56.40%) indirect energy in which biochemical (seed and fertilizers) and machinery energetic depreciation contributed 6 183.40 MJ·ha^{-1} (89.95%) and 690.50 MJ·ha^{-1} (10.05%), respectively. The total energy input obtained indicated similarity with sorghum production energy input reported by different authors. For instance, Abdalla and Mohamed (2013), and Bazaluk et al. (2021) reported similar total energy input of 1 2600 and 12 280 MJ·ha^{-1} for sorghum production, respectively. Similarly, Shafique et al. (2015) reported a 12 390 MJ·ha^{-1} for maize production. However, high energy inputs of 15 110 and 16 500 MJ·ha^{-1} were reported from rain-fed and irrigated production systems respectively by Rodrigo et al. (2017) and Elfadil (2018). This variability might arise from variation of agricultural practices among different societies and production locations that may require different type and quantity of inputs used. Manju et al. (2006) described that farm size was among the major reason for variation of the energy inputs per unit area reporting 8 788.00 and 99 380.00 MJ·ha^{-1} for marginally small and large farm sizes, respectively and indicated higher energy productivity for the small farm size.

Fertiliser energy input of 61.43% of the total production input reported by Bazaluk et al. (2021) in their sorghum cultivation energy assessment result was closer to our finding. A field study of 11 years productivity and energy balance of sweet sorghum production indicated minimum fertilizer energy input of 70.70% (Jankowski et al. 2020) which was much higher than our finding. This difference could arise from variation in the study area, production environment and variety of the crop used. The energy consumed at different production stages can vary depending on the type of the activity performed and quantity of the input required at each of the stage.

Top-dressing ranked first with 33.70% of the total input, mainly from fertiliser, followed by tillage taking 25.17% of the input and sowing stage being the third with 20.30% of the total input. Energy consumption of the remaining operation stages together consumed the rest 20.83% of the total with each stage sharing a range of 1.53% to 6.20% of the total input.

Labour energy input at different production stages. Labour energy input was high as all production activities after tillage and land preparation were based on human power. Labour energy input of 2 402.08 MJ·ha^{-1} was recorded on an average across the experimental units. A summary of the labour energy input across the chain of production stages has been presented in Table 4. From the total labour energy input required for sorghum production, 58.92% was used for preharvest production activities while the remaining 41.08% was consumed during harvesting and on-field postharvest activities. About one-third of the labour energy consumed during preharvest was expended for urea top-dressing application, while about 60.89% of the labour energy of the harvest and postharvest was consumed during threshing and cleaning. Alipour et al. (2012) indicated low labour input of 419.65 man-days per hectare (822.53 MJ·ha^{-1}), whereas Devi et al. (2018) reported total labour in put 1 312.97 MJ·ha^{-1} that

Table 3. Means of the total energy input (MJ·ha^{-1}) at each of the operation stages by category and, percent share of the stages and categories from the total input

Farming activity	Machinery energy (depreciation)	Mechanical energy	Biochemical energy	Sub-total for stages	Share of the stages (%)
Tillage	183.50	2 883.70	0	3 067.20	25.17
Sowing	30.00	165.00	2 279.50	2 474.50	20.30
Early stage cultivation	166.50	463.10	0	629.60	5.17
Top dressing	76.00	386.20	3 645.40	4 107.60	33.70
Crop management	99.60	397.80	258.50	755.90	6.20
Harvesting	115.90	326.50	0	442.40	3.63
Threshing	0	236.40	0	236.40	1.94
Cleaning	0	288.50	0	288.50	2.37
Pre-storage handling	19.00	166.90	0	185.90	1.53
Grand Total	690.50	5 314.10	6 183.40	12 188.07	100.00
Category (%)	5.67	43.60	50.73	100.00	100.00

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is about half of this study findings. This difference could be due to differences in farming methods and/or mechanization status of the farms studied.

Early weeding and crop establishment cultivation ranked first with 463.09 MJ·ha^{-1} (19.28%) of the total labour input followed by Urea top-dressing, where 386.23 MJ·ha^{-1} (16.08%) labour energy was expended. This was due to labour and time-consuming nature of the operation as it required care not damage emerged plants during early cultivation and not to injure plant roots during hoeing to open the soil. Top dressing was labour intensive for it consisted of hoeing, scooping and putting fertilizer in the soil, and covering the fertilizer. Labour energy input at cultivation and crop management stage was the third by 370.51 MJ·ha^{-1} (15.42%) of the total labour energy input due to repetition of at least twice weeding, after top-dressing. The high labour input during pre-harvest was further increased during guarding form birds. More labour consumed in sorghum, especially during the birds scaring operation period of three-to-four weeks, up 8 to 10 hours per day could be spent by number of labourers in a small farm (Steenwyk et al. 2022). We could not make further discussion on this issue due to lack of references with such detail description on labour energy input under the farmers traditional practices. Though there are various articles published on the study of sorghum production energy analysis, I couldn't find literatures specifically concerned with varieties of short maturity period to compare the results with this study findings.

Energy output-input balance and efficiency. The total production energy input (energy requirement) indicated non-significant mean differences between the varieties. This is because of the uniform application of the inputs as the varieties were selected for similarities in their days to maturity and recommended production inputs that has been already in use by the farmers in the area.

The production energy output and efficiency analysis indicated significant (P < 0.01) differences among the involved sorghum varieties. Means of energy outputs were significantly varied from the maximum of 77 284.59 MJ·ha^{-1} for *Makko* to the minimum of 66 667.39 MJ·ha^{-1} for *Malkam* as indicated in Table 5. Similarly, significant (P < 0.05) net-energy output of 65 039.13, 54 497.40, 58 834.23 MJ·ha^{-1} were observed for *Makko, Malkam* and *Qaqaba*, respectively. The maximum energy output of *Makko* variety resulted in higher energy ratio and energy productivity of 6.31 and 0.374 kg·MJ^{-1}, respectively, and in significantly lower specific energy of 2.67 MJ·kg^{-1}. *Qaqaba* and *Malkam* varieties were the second and the third, respectively in all energy efficiency, in line with their energy output ranks. This difference of the energy output could be due to variations in inherent (genetic) properties existing between the varieties.

Energy output of 108 820 and 142 000 MJ·ha^{-1} reported from rain-fed and irrigated sorghum production, respectively (Elfadil 2018) higher than our findings. Muhammad and Orhan (2021) reported energy input and output of 21 070 MJ·ha^{-1} and 50 990 MJ·ha^{-1}, were respectively and this indicated higher energy input with lower output and efficiency than this study result. Energy productivity varies

Table 4. Labour energy input at each operation stage under farmers traditional sorghum production practices

No.	Stages of production operation	Labour energy input at each stage	
		MJ·ha^{-1}	(%)
1	tillage and land preparation (tractor)	30.73	1.28
2	sowing (drill seed and fertilizer)	164.83	6.86
3	early stage weeding and cultivation	463.09	19.28
4	urea top dressing labour	386.23	16.08
5	cultivation and crop management	370.51	15.42
	pre-harvest labour sub-total (1 to 5)	1 415.39	58.92
6	harvesting and collection labour	326.48	13.59
7	threshing andseparation labour	236.85	9.86
8	winnow and cleaning labour	288.52	12.01
9	pre-storage handling	134.84	5.61
	total labour after harvesting (7, 8 and 9)	660.21	27.48
	total post-production labour (6 and 10)	986.69	41.08
	grand total labour energy input	2 402.08	100.00

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Table 5. Comparison of the production mean energy inputs, outputs and mean energy efficiency indices of the sorghum varieties involved in the study

Variables parameters	Compared varieties and their means		
	Makko	*Malkam*	*Qaqaba*
Total energy input (MJ·ha^{-1})	12 245.46^{a}	12 169.94^{a}	12 148.81^{a}
Grain sorghum produced (kg·ha^{-1})	4 582.13^{a}	3 994.53^{c}	4 256.25^{b}
Dry stalk or by-product (kg·ha^{-1})	3 388.15^{a}	2 712.56^{b}	2 842.41^{b}
Total energy output (MJ·ha^{-1})	77 284.59^{a}	66 667.39^{c}	70 983.04^{b}
Net-energy output (MJ·ha^{-1})	65 039.13^{a}	54 497.45^{c}	58 834.23^{b}
Energy ratio (efficiency)	6.31^{a}	5.48^{c}	5.84^{b}
Energy productivity (kg·MJ^{-1})	0.374^{a}	0.328^{c}	0.350^{b}
Specific energy (MJ·kg^{-1})	2.67^{c}	3.05^{a}	2.85^{b}

[a]Means with the same superscript in a row have no significant difference (P >0.05); comparison is among means in a row

for different locations, production time and farming practices, and it is specific for each agricultural product, location and time as described by Ortiz-Cañavate and Hernanz (1999).

According to Devi et al. (2018), variation of the planting techniques in wheat production resulted in different net energy, specific energy, energy productivity, energy intensiveness and energy profitability. Energy efficiency of 6.2 to 8.4 reported by Abdalla and. Mohamed (2013), was higher than the energy ratio recorded in this study. Lower mean values of 1.92 energy ratio, 0.096 kg·MJ^{-1} and 10.43MJ·kg^{-1} were reported by Jafari et al. (2008) for wheat production. Though the energy ratio obtained seems closer to the values reported by different authors like Jankowski et al. (2020) and Shafique et al. (2015), the magnitudes of energy input and output recorded in this indicated lower values. The total energy input and output per unit area obtained for early maturing sorghum varieties in this study were lower than most of energy input and output reported by different authors. The differences of this study result from the already published studies might be due to the use of the early maturing varieties, those are specifically developed for moisture-stressed low land areas.

The significance of this study is that it dealt with sorghum varieties of short maturing period production energy analysis under extreme lowland conditions. The result obtained could serve professionals in agriculture and researchers concerned with such early maturing sorghum varieties and farming system in dry land areas.

CONCLUSION

Sorghum production energy input-output balance under the traditional farmers' practices was studied for *Makko, Qaqqaba,* and *Malkam* sorghum varieties. The study also indicates that different energy output was obtained from the varieties for similar energy input.

The most considerable production energy consumed was biochemical energy which contributed 50.73% of the 12 188.07 MJ·ha^{-1} mean total energy input, followed by 43.60% contribution of mechanical energy under the investigated production method. The urea top-dressing stage was the most energy intensive practice, followed by the tillage stage under the studied traditional method consuming 33.70 and 25.17% of the total input, respectively.

Makko variety yielded the highest total output of 77 284.59 MJ·ha^{-1} and a net energy gain of 65 039.13 MJ·ha^{-1} exceeding *Malkam,* the least yielder by 19.23% net energy gain.

The total sorghum production energy input and output obtained was low and labour intensive compared to the values reported from different countries. Thus, this information can be referred and used towards improvement of the energy inputs for better productivity and sustainability of sorghum production particularly for the varieties studied.

Acknowledgement. We thank to Oromia Agricultural Research Institute (IQQO) and the Fadis Agricultural Research Center (FARC) for providing the budget and logistics required to conduct this study.

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Received: January 24, 2023
Accepted: April 20, 2023
Published online: November 21, 2023