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Analysis of energy consumption in the maize fodder production system within the chosen Himalayan Tarai region

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Abstract
Maize (*Zea mays* L.) holds significant importance as a green fodder crop in India, playing a crucial role in animal husbandry. Conducting an energy audit for various resources in agricultural production is vital for resource management. This study aimed to determine the contribution of diverse energy sources during the zaid season maize production at the Instructional Dairy Farm (IDF) Nagla Pantnagar, Uttarakhand, India. Human energy, machinery, diesel fuel, energy use efficiency, net energy, and energy productivity were assessed. The total input and output energy for maize fodder cultivation were 11466.57 MJha^{-1} and 753989.22 MJha^{-1}, respectively. Energy use efficiency was 65.75 percent, net energy stood at 742522.65 MJha^{-1}, and energy productivity was 3.65 kg MJ^{-1}. Fertilizer energy consumption was 4389 MJ ha^{-1}, comprising 3878.4 MJha^{-1} nitrogen and 510.6 MJha^{-1} phosphorus. Diesel fuel and human energy consumption were observed at 1903.16 MJ ha^{-1} and 747.5 MJ ha^{-1}, respectively. Seed bed preparation energy consumption and green fodder crop harvesting consumption were determined as 2011.46 MJha^{-1} and 691.39 MJ ha^{-1}, respectively.

Keywords: Fodder from maize, net energy, efficiency in energy use, and productivity of energy

Introduction

The global population surge has compelled humanity to prioritize food grain production to meet escalating demands. Despite reaching a record high of 1.06 billion tonnes in the 2021-22 output of food grains, there is a looming concern that agricultural efforts may become less responsive, hindering the ability to address the challenges of an increasing demand for food. India, holding only 2 percent of the world's geographical area, accommodates approximately 15 percent of the world's livestock population. Green fodder plays a vital role in animal husbandry [5], particularly in sustaining the growth of the dairy sector. The economic viability of milk production is intricately linked to the quality of nutritious fodder provided to milch animals. Opting for green fodder over concentrates significantly reduces the cost of milk production, impacting animal husbandry practices. With India hosting 15 percent of the world's cattle population and limited arable land due to the increasing human population, most arable land is utilized for food and cash crops. This scenario poses a challenge in securing good quality arable land for fodder production until milk production becomes financially rewarding for farmers compared to other crops [11].

In rural areas of India, there is a lack of fodder production practices, and animals primarily rely on naturally grown grasses and shrubs, which are deficient in protein and available energy. This dependence on seasonal variations results in fluctuations in fodder supply, affecting milk production throughout the year. The study aims to investigate energy input and output per unit area, energy output-input ratio, crop yield, specific energy, energy productivity, and net energy for fodder crop production [7, 1, 5]. Additionally, a cost and economic analysis will be conducted for crop production in the study area, the Centre IDF Nagla Pantnagar, Uttarakhand, considering different levels of technology and machinery ownership status. The increasing number of livestock and evolving animal husbandry practices necessitate a corresponding increase in fodder to meet the needs of livestock. However, the current availability of fodder in the country falls well below its demand. Given the large number of resource-poor households relying on open grazing for their livestock, revitalizing degraded common fodder and pasture resources and enhancing their productivity are imperative. Various studies have explored the demand and supply of green and dry fodder resources [5]. In this context, the Planning Commission's Working Group on Animal Husbandry and Dairying has estimated the demand and supply of fodder resources in India, as presented in Table 1. Fodder production and utilization are influenced by cropping patterns, climate, livestock type, and socio-economic conditions. The deficit in fodder, dry crop residues, and feed must be addressed by increasing productivity, utilizing untapped feed resources, expanding land area, or resorting to imports, as discussed in Table 2. The situation is exacerbated by the growing numbers of livestock, especially genetically improved ones, while available forage is lacking in quality and deficient in energy, protein, and minerals [5].

Table 1: Illustrates the demand and supply of fodder in India (measured in million tonnes) across various years, along with the anticipated projections for both demand and supply

Year	Demand		Supply		Deficit		Deficit as %	
	Green	Dry	Green	Dry	Green	Dry	Green	Dry
1995	947	526	379.3	421	568	105	59.95	19.95
2000	988	549	384.5	428	604	121	61.10	21.93
2005	1025	569	389.9	443	635	126	61.96	22.08
2010	1061	589	395.2	451	666	138	62.76	23.46
2015	1097	609	400.6	466	696	143	63.50	23.56
2020	1134	630	405.9	473	728	157	64.21	24.81
2025*	1170	650	411.3	488	759	162	64.87	24.92

* Figures are projections.
Source: Based on Xth Five-Year Plan Document, Government of India.

Table 2: Requirement, availability, and deficit of Crude Protein (CP) and Total Digestible Nutrients (TDN) in India (in million tonnes) over the years and projected figures

Year	Requirement		Availability		Deficit (percent)	
	CP	TDN	CP	TDN	CP	TDN
2000	44.49	321.29	30.81	242.42	30.75	24.55
2005	46.12	333.11	32.62	253.63	29.27	23.86
2010	47.76	344.93	34.18	262.02	28.44	24.04
2015	49.39	356.73	35.98	273.24	27.15	23.41
2020	51.04	368.61	37.50	281.23	26.52	23.70
2025*	52.68	380.49	39.31	292.45	25.38	23.14

* Figures are projections.
Source: Based on Xth Five-Year Plan Document, Government of India.

Materials and Methods

The objective of this study was to evaluate the performance of an organized dairy production system. The Livestock Research Centre at Govind Ballabh Pant University of Agriculture and Technology, located in Pantnagar district, Udham Singh Nagar, Uttarakhand, India, managed the organized dairy selected for this study. To assess the performance, data regarding energy auditing in the fodder production system was gathered, specifically focusing on the economical production of maize fodder. The study outlines and methodology were detailed for the maize fodder crop under the zaid season of 2022. Data collection involved recording various operational energy inputs and outputs in the production system. Information on input sources for cultivating one hectare of maize fodder crop was collected. To estimate the approximate energy input from each source, the number of units of energy sources used was multiplied by their respective energy equivalents, as indicated in Table 1. Different input energy resources were categorized into direct and indirect, as well as renewable and non-renewable forms. Direct energy sources included diesel and human energy, while chemical fertilizer, seeds, and farm machinery (tractor, disc harrow, and roller) were considered indirect energy sources. Diesel fuel, farm machinery, and chemical fertilizers were classified as non-renewable energy sources. The energy requirements for each operation were computed based on the different sources used in that particular operation. For instance, seed bed preparation involved plowing the land with a tractor-drawn disc harrow to create favorable seedbed conditions [14, 1]. Manure was transported to the field by tractor and manually spread over the field. The sowing operation utilized a disc harrow with patella. Inorganic fertilizer (UAN) was manually applied twice during the crop's sowing and development stages. Maize fodder crop harvesting was done manually, and the harvested fodder was transported to a suitable location for tractor handling. To evaluate various energy measures, parameters such as human energy, machinery, diesel, total input energy, energy productivity, and fodder were calculated using the equations provided in the references [1, 6, 11, 12].

Human Energy = No. of labour x Energy Equivalent (MJ/man-hr) x Time (hr)

Machinery energy = wt. (kg) ×Energy Equivalent (MJ/kg-yr) ×time (hr) ÷ life (Yrs) ×annual use (hr)

Diesel = Fuel consumption (lit/hr) ×Energy Equivalent (MJ)

Net energy = Energy output (MJ ha^{-1}) – energy input (MJ ha^{-1}),

Energy Use efficiency= Energy output (MJ ha^{-1}) /energy input (MJ ha^{-1}),

Energy Productivity = fodder yield (kg ha^{-1}) / Total input energy (MJ ha^{-1})

Results and Discussion

The illustration in Figure 1 presents the average energy expenditure per operation by the Instructional Dairy Farm (IDF) in Nagla Pantnagar, Uttarakhand, for maize production in the selected Himalayan Tarai Region. The key energy-consuming operations identified for maize production were seedbed preparation (2011.46 MJ ha^{-1}), sowing operation energy (1471.22 MJ ha^{-1}), irrigation energy (2901.04 MJ ha^{-1}), chemical energy (4391.45 MJ ha^{-1}), and harvesting energy (691.4 MJ ha^{-1}). The seedbed preparation accounted for 18 percent of the total operation-wise energy expenditure, followed by sowing operation energy at 13 percent, irrigation energy at 25 percent, chemical energy at 38 percent, and harvesting energy at 6 percent of the total operational energy, respectively. Similar findings were observed in a related study. Different forms of energy used in maize production are depicted in Figure 2. In terms of diesel fuel consumption, the direct energy utilized for maize crop production was 31.78 lha^{-1}, with human energy contributing 12 man-h ha^{-1} for men and 24 man-h ha^{-1} for women. The IDF Nagla Pantnagar applied chemical fertilizer based on the nutritional demand of the field. The energy contribution from chemical fertilizer was the highest (56 percent) compared to other inputs, such as seedbed preparation (25 percent) and seeds (19 percent), in the case of indirect energy. This was primarily due to the nitrogen content, accounting for approximately 64 kg ha^{-1}, followed by phosphorus at 46 kg ha^{-1}. The majority of non-renewable energy was fulfilled by chemical fertilizer (56 percent) and diesel fuel (72 percent), followed by seedbed preparation at 25 percent. The results align with previous research, indicating that the energy requirement was 3.65 $kgMJ^{-1}$, net energy stood at 742522.65 $MJha^{-1}$, and energy use efficiency was 65.75 percent. The total input energy and output energy for green fodder were 11466.56 MJ ha^{-1} and 753989.22 $MJha^{-1}$, respectively.

Table 3: Energy Equivalents for both Direct and Indirect Sources

Power source	Energy equivalent, MJ
Human	
Man (man-hour)	1.96 one adult women = 0.8 adult man
Women (Women-hour)	1.56
Children (Children-hour)	0.98 One child = 0.6 adult man
Animal (pair-hour)	10.10
Diesel (litre)	56.31
Electricity (kWh)	16.93
Seed (kg)	14.7
Fodder crop (kg) Oats, maize bajra, sorghum, barseen	18
Fertilizer	
Nitrogen (kg)	60.6
Phosphorus (kg)	11.1
Potash (kg)	6.7
Electric motors (kg)	64.80
Prime mover (kg)	68.40
Farm machinery (kg)	62.10

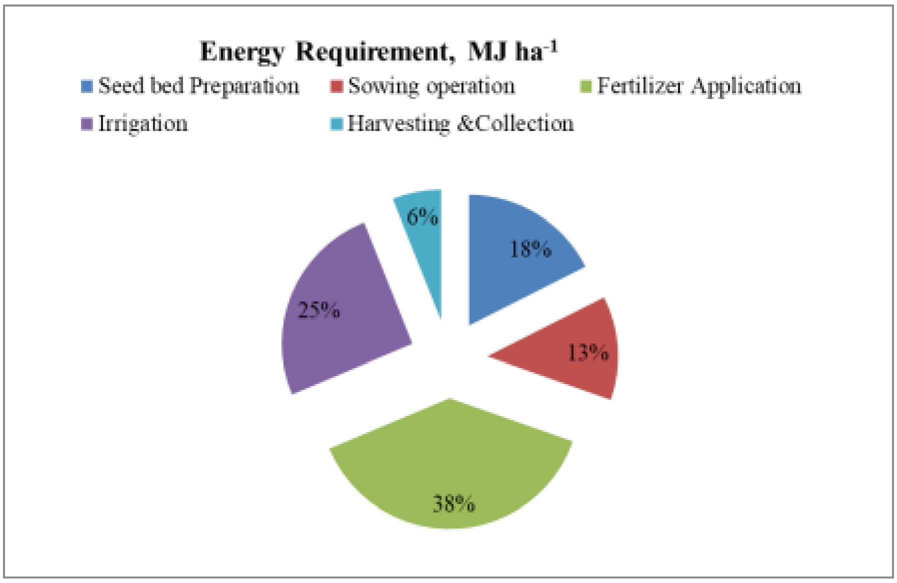

Fig 1: Energy Equivalents for Various Sources in maize fodder crop production

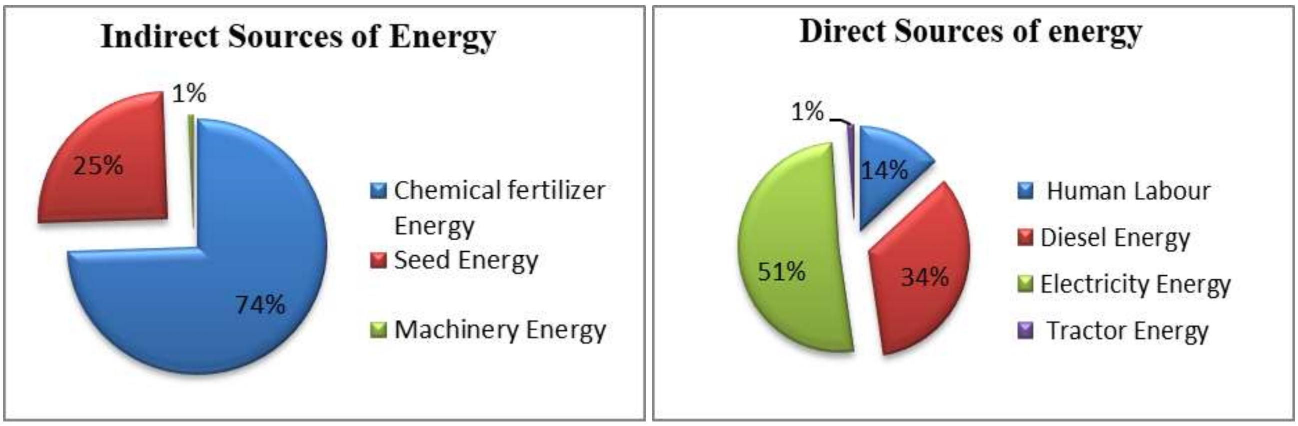

Fig 2: Different Energy Sources in maize fodder crop production

Conclusion

The overall energy expenditure per hectare for maize fodder system production in the Himalayan Tarai Region amounts to approximately 11466.57 MJ ha^{-1}. The direct and indirect energy contributions were 2650.65 MJ ha^{-1} and 7870.46 MJ ha-1, respectively. The primary energy-consuming operation was chemical fertilizer, followed by irrigation, seed bed preparation, energy use efficiency, net energy, and harvesting. Fertilizer application was conducted through the manual broadcasting method without considering the nutritional demand of the field, indicating the need for proper management to provide nutrients on a necessity basis. In this context, the use of a disc harrow could help save fuel energy. The by-products generated were not effectively utilized for commercial purposes. Among all operations, sowing, irrigation, and harvesting were the most labor-intensive. Women's labor accounted for 66.66 percent of the total working hours in maize production, with male labor contributing the remaining 33.33 percent.

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