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Production and energy efficiency as influenced by different fodder based cropping system

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Abstract
The present study, entitled "Production Potential and Economic Viability of Food– Forage-Based Cropping Sequences under Irrigated Conditions of Jabalpur, Madhya Pradesh," was carried out under the All India Coordinated Research Project on Forage Crops at Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh. The experiment consisted of 10 food–forage-based cropping sequences arranged in a randomized block design with three replications. The cropping sequence maize (green cob) + ricebean–berseem–maize (fodder) + ricebean recorded the highest nitrogen uptake of 642.1 q/ha. The maximum energy productivity of 4.61 kg/MJ was obtained from maize (baby corn) + ricebean–berseem–maize (baby corn) + ricebean. However, this sequence recorded the lowest specific energy requirement of 21.65 MJ/kg. It was followed by maize (baby corn) + ricebean–berseem–maize (fodder) + ricebean, which achieved an energy productivity of 4.24 kg/MJ. In contrast, the rice– berseem–moong sequence recorded the lowest energy productivity of 2.78 kg/MJ but showed the highest specific energy requirement of 35.72 MJ/kg. The highest total energy input requirement, amounting to 64.15×10 ³ MJ/ha, was observed in the maize (green cob) + ricebean–oat–maize (green cob) + ricebean and maize (green cob) + ricebean–oat–maize (fodder) + ricebean cropping sequences. The minimum energy input of 36.50×10 ³ MJ/ha was recorded in the perennial grass-based sequence. The highest energy output of 652.12×10 ³ MJ/ha was obtained from maize (green cob) + ricebean–berseem–maize (fodder) + ricebean, followed by maize (green cob) + ricebean– maize (green cob) + ricebean, which produced 622.39×10 ³ MJ/ha. The hybrid Napier grass sequence recorded the lowest energy output and energy balance, at 341. . 41×10 ³ MJ/ha and 304.90×10 ³ MJ/ha, respectively. The highest energy balance of 588.33×10 ³ MJ/ha was recorded in maize (green cob) + ricebean–berseem–maize (fodder) + ricebean.

Keywords: Food–forage cropping system, production efficiency, energy efficiency, maize–ricebean, berseem, hybrid Napier

Introduction
The inclusion of suitable food and forage crops or varieties in existing rice-based cropping systems can promote crop intensification under irrigated production conditions. Fodder crops are estimated to provide essential feed ingredients at a cost that is approximately 5–
14 times lower than that of other feed sources. Forage-based cropping systems can be equally or even more profitable than the dominant cropping systems practised in a particular region.

Forage crops also offer considerable potential for contingency planning because they can be cultivated as short-duration catch crops, intercrops, or alley crops under different resource-use situations. Their inclusion can support farmers' livelihoods by improving livestock productivity. Considering the current growth in the demand for livestock products, agricultural strategies should promote forage-based cropping systems or the incorporation of forage crops as sole crops, mixed crops, or intercrops within existing cropping systems. Such approaches may help reduce the gap between fodder demand and supply while remaining compatible with the agro-economic and environmental conditions of the region (Agrawal *et al.*, 2008; Shrivastava *et al.*, 2014) [1, 2].

Food–forage-based production systems are particularly beneficial for small and marginal farmers, as they enable a portion of agricultural land to be allocated specifically to forage production within grain-based crop rotations. Forage crops should therefore be integrated into existing food-based cropping systems through intensification in space, such as intercropping, in time, such as sequential cropping, or through a combination of both approaches. Such diversification and intensification can fulfil household requirements, improve farm income and profitability, and contribute to the maintenance and improvement of soil health.

Methodology

The field experiment was conducted during 2010–2011 and 2011–2012 at the Adhartal Research Farm of Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh. The investigation was undertaken under the All India Coordinated Research Project on Forage Crops. The experiment was initiated during the kharif season of 2010–2011 and continued for two consecutive years at the same location without altering the treatments or experimental layout. An already-established hybrid Napier crop was used under treatment T_1

The soil of the experimental field was sandy clay loam in texture and slightly alkaline in reaction, with a pH of 7.60. It contained a low level of organic carbon, at 0.6%, and had a normal electrical conductivity of 0.49 dS/m. The soil was low in available nitrogen at 235.8 kg/ha and medium in available phosphorus and potassium at 16.2 and 395.5 kg/ha, respectively.

The experiment comprised 10 cropping-sequence treatments evaluated in a randomized block design with three replications:

- T_1 : Hybrid Napier + ricebean–hybrid Napier + berseem–hybrid Napier + ricebean; an established Napier crop was used.
- T_2 : Maize (baby corn) + ricebean–berseem–maize (baby corn) + ricebean.
- T_3 : Maize (baby corn) + ricebean–oat–maize (baby corn) + ricebean.
- T_4 : Maize (baby corn) + ricebean–berseem–maize (fodder) + ricebean.
- T_5 : Maize (baby corn) + ricebean–oat–maize (fodder) + ricebean.
- T_6 : Maize (green cob) + ricebean–berseem–maize (green cob) + ricebean.
- T_7 : Maize (green cob) + ricebean–oat–maize (green cob) + ricebean.
- T_8 : Maize (green cob) + ricebean–berseem–maize (fodder) + ricebean.
- T_9 : Maize (green cob) + ricebean–oat–maize (fodder) + ricebean.
- T_{10} : Rice–berseem–moong.

The crop varieties used in the experiment included JM-216 for baby corn, Priya Sweet Corn for green-cob maize, African Tall for fodder maize, JRBJ-05-2 for ricebean, NB-1 for hybrid Napier, JB-1 for berseem, and JO-1 for oat.

Results

Production Efficiency

Production efficiency represents the productivity of a particular cropping sequence per unit area per day. Data related to the production efficiency of the different cropping sequences are presented in Table 1. The duration of a crop is influenced by its phenological characteristics and varietal traits. In addition to the genetic potential of a crop or variety, local agro-climatic conditions and crop-management practices have a substantial influence on crop growth, development, and yield.

The hybrid Napier-based sequence recorded the lowest production efficiency of 4.22 q/ha/day because of its longer duration and lower maize green-fodder-equivalent yield. The rice–berseem–moong sequence ranked second lowest, with a production efficiency of 5.54 q/ha/day, because of its longer duration and comparatively lower maize green-fodderequivalent yield. Similar observations have been reported by Verma *et al.* (2016b) [3], Verma *et al.* (2024) [4], Yadav *et al.* (2023) [5], and Yadav *et al.* (2024) [6].

The sequence involving baby corn intercropped with ricebean during the kharif and summer seasons and berseem during the rabi season recorded the highest production efficiency of 11.35 q/ha/day among all the evaluated sequences. It was followed by maize (baby corn) + ricebean–oat–maize (baby corn) + ricebean, which recorded a production efficiency of 10.95 q/ha/day. The higher production efficiency of these sequences may be attributed to their shorter duration and higher maize green-fodder-equivalent yield.

In comparison, cropping sequences involving maize grown for green cobs during the kharif and summer seasons required more time for cob development. Consequently, these sequences had a longer total duration than the corresponding baby-corn-based sequences. These findings are consistent with those reported by Nirala *et al.* (2022) [7], Tomar *et al.* (2023b) [8], and Tiwari *et al.* (2011) [9].

Table 1: Production efficiency (q/ha/day) and land use efficiency as influenced by different food-forage based cropping sequences

Treatment		Duration of crop sequence		Production efficiency (q/ha/day)			Land use efficiency (%)		
		2010-11	2011-12	2010-11	2011-12	Mean	2010-11	2011-12	Mean
T_1 -	Hybrid Napier + rice-bean - hybrid Napier + berseem - hybrid Napier + rice-bean	324	325	4.227	4.224	4.225	88.767	89.014	88.890
T_2 -	Maize (BC) + rice-bean - berseem - maize (BC) + rice-bean	246	243	11.255	11.441	11.348	67.397	66.575	66.986
T_3 -	Maize (BC) + rice-bean - oat - maize (BC) - rice-bean	212	211	10.891	11.011	10.951	58.082	57.808	57.945
T_4 -	Maize (BC) + rice-bean - berseem - maize (F) + rice-bean	275	272	9.869	10.000	9.934	75.068	74.520	74.794
T_5 -	Maize (BC) + rice-bean - oat - maize (F) + rice-bean	240	240	9.298	9.408	9.353	65.753	65.753	65.753
T_6 -	Maize (GC) + rice-bean - berseem - maize (GC) + rice-bean	295	295	8.954	9.020	8.987	80.821	80.821	80.821
T_7 -	Maize (GC) + rice-bean - oat - maize (GC) + rice-bean	261	263	8.378	8.388	8.383	71.506	72.054	71.780
T_8 -	Maize (GC) + rice-bean - berseem - maize (F) + rice-bean	295	293	9.135	9.237	9.186	80.821	80.273	80.547
T_9 -	Maize (GC) + rice-bean - oat - maize (F) - rice-bean	261	261	8.455	8.569	8.512	71.506	71.506	71.506
T_{10} -	Rice - berseem - moong	321	321	5.521	5.572	5.546	87.945	87.945	87.945
SEm±				0.07	0.19	0.10	-	-	-
CD at 5%				0.22	0.57	0.31	-	-	-

Table 2: Energy input, output and balance (10^{3}MJ / ha) as influenced by different food-forage based cropping sequences

Treatments	Energy input (103MJ/ha)	Energy output (103MJ/ha)			Energy balance (103MJ/ha)		
		2010-11	2011-12	Mean	2010-11	2011-12	Mean
T_1 - Hybrid Napier + rice-bean - hybrid Napier + berseem - hybrid Napier + rice-bean	36.50	339.41	343.42	341.41	302.91	306.92	304.91
T_2 - Maize (BC) + rice-bean - berseem - maize (BC) + rice-bean	61.50	489.90	492.60	491.25	428.40	431.10	429.75
T_3 - Maize (BC) + rice-bean - oat - maize (BC) - rice-bean	61.91	414.82	420.11	417.47	352.91	358.20	355.55
T_4 - Maize (BC) + rice-bean - berseem - maize (F) + rice-bean	62.99	551.65	557.43	554.54	488.9	494.77	491.88
T_5 - Maize (BC) + rice-bean - oat - maize (F) + rice-bean	63.01	478.14	489.41	483.77	415.13	426.40	420.76
T_6 - Maize (GC) + rice-bean - berseem - maize (GC) + rice-bean	63.85	619.36	625.42	622.39	555.51	561.57	558.54
T_7 - Maize (GC) + rice-bean - oat - maize (GC) + rice-bean	64.14	544.43	553.44	548.93	480.29	489.30	484.79
T_8 - Maize (GC) + rice-bean - berseem - maize (F) + rice-bean	63.79	647.66	656.58	652.12	583.87	592.79	588.33
T_9 - Maize (GC) + rice-bean - oat - maize (F) - rice-bean	64.14	568.84	574.46	571.65	504.70	510.32	507.51
T_{10} - Rice - berseem - moong	63.60	438.57	446.44	442.50	374.97	382.84	378.90
SEm±	-	1.58	1.43	1.26	1.71	2.11	1.39
CD at 5%	-	4.68	4.26	3.74	5.08	6.26	4.13

Land use efficiency

The year-round forage production system comprising Napier–bajra hybrid (perennial) + ricebean–berseem–ricebean recorded the highest land use efficiency of 88.9%, followed by the rice–berseem–moong sequence, which achieved 87.9%. The hybrid Napier crop remained in the field throughout the year, with ricebean grown as an intercrop during the kharif and summer seasons and berseem during the rabi season. Similar findings regarding land-use efficiency were reported by Kumar and Faruqui (2009) and Singh *et al.* (2002)[10]

The maize (baby corn) + ricebean–oat–maize (baby corn) + ricebean sequence recorded the lowest land-use efficiency of 57.9%, mainly because of its shorter crop duration. Baby corn occupied the field for a comparatively short period during both the kharif and summer seasons, while oat also required less time to reach harvest than berseem. These factors may have contributed to the lower land-use efficiency of this system.

The remaining cropping sequences recorded land-use efficiency values ranging from 66.9% to 80.8%, depending on the duration for which each sequence occupied the field during the year. Comparable results were reported by Singh *et al.* (2013a) [11], Singh *et al.* (2013b) [12], Nirala *et al.* (2022) [7], Tomar *et al.* (2023b) [8], and Tiwari *et al.* (2011) [9].

Energy Input

The highest total energy input requirement of 64.1 × 10[13] MJ/ha was recorded in the maize (green cob) + ricebean–oat–maize (green cob) + ricebean and maize (green cob) + ricebean–oat–maize (fodder) + ricebean cropping sequences. These systems also recorded the highest energy consumption through fertilizer application.

The hybrid Napier grass-based system required the lowest total energy input, amounting to 36.5 × 10[13] MJ/ha. However, this sequence consumed the greatest amount of energy through human labour because of its longer duration compared with the other cropping sequences

The maize (baby corn) + ricebean–berseem–maize (baby corn) + ricebean sequence required an energy input of 61.5 × 10[13] MJ/ha, while maize (baby corn) + ricebean–oat–maize (baby corn) + ricebean recorded an input of 61.9×10^{3} MJ/ha. The slight difference between these sequences was primarily associated with variation in fertilizer-related energy consumption. Similar observations were reported by Patel *et al.* (2023) [14], Sahu *et al.* (2023) [15], Raghuwanshi *et al.* (2023) [16, 17], Shri *et al.* (2015) [18], Shrivastava *et al.* (2014) [2], and Verma *et al.* (2016a) [19]. The remaining cropping sequences showed energy-input requirements according to their respective input-use patterns.

Energy Output

The maize (green cob) + ricebean–berseem–maize (fodder) + ricebean cropping sequence recorded the highest energy output of 652.1×10^{3} MJ/ha. It was followed by maize (green cob) + ricebean–berseem–maize (green cob) + ricebean, which produced 622.3 × 10[13] MJ/ha. The greater energy output of these sequences was attributed to their higher yield in terms of green cobs and green fodder.

The lowest energy output of 341.4 × 10[13] MJ/ha was recorded in the hybrid Napier + ricebean–hybrid Napier + berseem–hybrid Napier + ricebean sequence. This may be because the system produced only green fodder without any grain or cob yield.

The rice–berseem–moong sequence recorded an energy output of 442.5 × 10[13] MJ/ha, which was comparatively higher than the 417.4×10^{3} MJ/ha obtained from maize (baby corn) + ricebean–oat–maize (baby corn) + ricebean.

Energy Balance

The hybrid Napier + ricebean–hybrid Napier + berseem–hybrid Napier + ricebean cropping sequence recorded the lowest energy balance of 304.9 × 10[13] MJ/ha. In contrast, the highest energy balance of 588.3 × 10[13] MJ/ha was obtained from maize (green cob) + ricebean–berseem– maize (fodder) + ricebean. The lower and higher energy balances of these respective sequences were directly associated with their corresponding energy-output levels.

The rice–berseem–moong cropping sequence recorded an energy balance of 378.9 × 10[13] MJ/ha, which was higher than the 355.5×10^{3} MJ/ha obtained from maize (baby corn) + ricebean–oat–maize (baby corn) + ricebean.

All other cropping sequences recorded energy balances above 400 × 10[13] MJ/ha, ranging from 420.7 to 507.5 × 10[13] MJ/ha. Similar findings were reported by Tiwari *et al.* (2013) [20], Singh *et al.* (2013) [11, 12], Bhalse *et al.* (2023) [13], Bhayal *et al.* (2022) [21], Jha *et al.* (2022) [22], Jha *et al.* (2020) [23], and Tiwari *et al.* (2011b)[9, 24].

Table 3: Energy use efficiency and energy output efficiency as influenced by different food-forage based cropping sequences

Treatment	EUE (MJ/ha)			Energy output efficiency (10^3 MJ/day)		
	2010-11	2011-12	Mean	2010-11	2011-12	Mean
T_1 - Hybrid Napier + rice-bean - hybrid Napier + berseem - hybrid Napier + rice-bean	31.182	31.479	31.330	1.047	1.056	1.052
T_2 - Maize (BC) + rice-bean - berseem - maize (BC) + rice-bean	24.025	24.337	24.181	1.991	2.027	2.009
T_3 - Maize (BC) + rice-bean - oat - maize (BC) - rice-bean	20.186	20.440	20.313	1.956	1.991	1.973
T_4 - Maize (BC) + rice-bean - berseem - maize (F) + rice-bean	26.505	26.766	26.635	2.013	2.049	2.031
T_5 - Maize (BC) + rice-bean - oat - maize (F) + rice-bean	22.745	23.272	23.008	1.992	2.039	2.015
T_6 - Maize (GC) + rice-bean - berseem - maize (GC) + rice-bean	29.495	29.765	29.630	2.099	2.120	2.109
T_7 - Maize (GC) + rice-bean - oat - maize (GC) + rice-bean	25.666	26.078	25.872	2.085	2.104	2.095
T_8 - Maize (GC) + rice-bean - berseem - maize (F) + rice-bean	30.767	31.191	30.979	2.195	2.240	2.218
T_9 - Maize (GC) + rice-bean - oat - maize (F) - rice-bean	26.762	27.019	26.890	2.179	2.201	2.190
T_{10} - Rice - berseem - moong	21.301	21.723	21.512	1.366	1.390	1.378
SEm±	0.36	0.40	0.32	0.0027	0.0035	0.0024
CD at 5%	1.07	1.20	0.95	0.008	0.0103	0.072

Energy use efficiency

The hybrid Napier + ricebean–hybrid Napier + berseem–hybrid Napier + ricebean cropping sequence recorded the highest energy-use efficiency of 31.33 MJ/ha. This higher efficiency was primarily attributed to the lowest energy-input requirement of the system. It was followed by maize (green cob) + ricebean–berseem–maize (fodder) + ricebean, which recorded an energy-use efficiency of 30.97 MJ/ha because of its maximum energy output.

The lowest energy-use efficiency of 20.31 MJ/ha was observed in maize (baby corn) + ricebean–oat–maize (baby corn) + ricebean. This may be attributed to its comparatively lower energy output than the other cropping sequences. The rice–berseem–moong sequence recorded an energy-use efficiency of 21.51 MJ/ha and ranked second lowest because of its higher energy-input requirement and relatively lower energy output (Jha *et al.*, 2007; Jha *et al.*, 2016; Malviya *et al.*, 2012; Kumhar *et al.*, 2022; Tiwari *et al.*, 2011b; Tomar *et al.*, 2023b) [25, 26, 27, 28, 9, 8].

Energy-Output Efficiency

The highest energy-output efficiency of 2.21 × 10[13] MJ/ha/day was recorded in the maize (green cob) + ricebean–berseem–maize (fodder) + ricebean sequence because of its high energy output. In contrast, the hybrid Napier + ricebean–hybrid Napier + berseem– hybrid Napier + ricebean sequence recorded the lowest energy-output efficiency of 1.05 × 10[13] MJ/ha/day. This was mainly due to its lowest energy output and the longest duration among all the cropping sequences evaluated in the experiment (Jha *et al.*, 2011; Jha *et al.*, 2023; Kumar *et al.*, 2023; Kumbhare *et al.*, 2023a) [30, 31, 32, 33, 34].

The rice–berseem–moong sequence recorded the second-lowest energy-output efficiency of 1.37 × 10[13] MJ/ha/day. The lower efficiency of this sequence may be attributed to the longer time required by the crops to complete their growth cycles and their comparatively lower energy output. Similar findings for rice-based cropping sequences were reported by Kachroo *et al.* (2012).

The energy-output efficiency of the remaining cropping sequences ranged from 1.97 to 2.19 × 10[13] MJ/ha/day, depending on their respective energy outputs and total crop durations (Chand *et al.*, 2025; Bhalse *et al.*, 2024; Gajbhiye *et al.*, 2024; Dwivedi *et al.*, 2012; Gangwar *et al.*, 2011; Jha *et al.*, 2014; Jha *et al.*, 2016) [35, 36, 37, 38, 39, 40, 19].

Energy Productivity

Among the different cropping sequences, maize (baby corn) + ricebean–berseem–maize (baby corn) + ricebean recorded the highest energy productivity of 4.61 kg/MJ. It was followed by maize (baby corn) + ricebean–berseem–maize (fodder) + ricebean, which achieved an energy productivity of 4.24 kg/MJ. The higher energy productivity of these systems was mainly associated with their greater maize green-fodder-equivalent yield. The rice–berseem–moong sequence recorded a comparatively low energy productivity of 2.78 kg/MJ because of its lower maize green-fodder-equivalent yield and higher energy-input requirement. However, the hybrid Napier + ricebean–hybrid Napier + berseem– hybrid Napier + ricebean sequence recorded an energy productivity of 3.75 kg/MJ because of its relatively low energy-input requirement (Raghuwanshi *et al.*, 2023b; Dubey *et al.*, 2022b) [16, 41].

The remaining cropping sequences recorded energy-productivity values ranging from 3.33 to 4.15 kg/MJ, depending on their maize green-fodder-equivalent yields and total energy-input requirements.

Specific Energy

Specific energy was calculated by dividing the total energy input of a cropping sequence, expressed in MJ/ha, by the maize greenfodder-equivalent yield of the corresponding sequence. The rice–berseem–moong cropping sequence recorded the highest specific energy of 0.357 MJ/kg because of its lower maize green-fodder-equivalent yield and greater total energy-input requirement.

In contrast, maize (baby corn) + ricebean–berseem–maize (baby corn) + ricebean recorded the lowest specific energy of 0.216 MJ/kg. This lower value resulted from the combined effect of its highest maize green-fodder-equivalent yield and comparatively lower total energy-input requirement.

Overall, cropping sequences with higher maize green-fodder-equivalent yields recorded lower specific-energy values than those producing lower equivalent yields. Similar results were reported by Jha *et al.* (2024) [42] in different rice-based cropping sequences. In the perennial hybrid Napier-based sequence, both the energy input and maize green-fodder-equivalent yield were lower than those of the other cropping sequences, at 36.5 × 10[13] MJ/ha and 1371.37 q/ha, respectively. This system recorded a specific energy of 0.266 MJ/kg because of its comparatively low maize green-fodder-equivalent yield (Tiwari *et al.*, 2013; Tomar *et al.*, 2023a; Bhalse *et al.*, 2024; Chauhan *et al.*, 2017; Dubey *et al.*, 2022a; Kumhar *et al.*, 2025) [20, 29, 8, 36, 43, 41, 44].

Table 4: Specific energy and energy productivity as influenced by different food-forage based cropping sequences

Treatment	Specific energy (MJ/kg)			Energy productivity (kg/MJ)		
	2010-11	2011-12	Mean	2010-11	2011-12	Mean
T_1 -Hybrid Napier + rice-bean - hybrid Napier + berseem - hybrid Napier + rice-bean	0.266	0.265	0.265	3.751	3.761	3.756
T_2 -Maize (BC) + rice-bean - berseem - maize (BC) + rice-bean	0.216	0.216	0.216	4.612	4.620	4.616
T_3 -Maize (BC) + rice-bean - oat - maize (BC) - rice-bean	0.259	0.258	0.259	3.845	3.861	3.853
T_4 -Maize (BC) + rice-bean - berseem - maize (F) + rice-bean	0.236	0.235	0.236	4.249	4.269	4.259
T_5 -Maize (BC) + rice-bean - oat - maize (F) + rice-bean	0.287	0.284	0.286	3.473	3.511	3.492
T_6 -Maize (GC) + rice-bean - berseem - maize (GC) + rice-bean	0.241	0.239	0.240	4.136	4.167	4.151
T_7 -Maize (GC) + rice-bean - oat - maize (GC) + rice-bean	0.293	0.290	0.292	3.408	3.439	3.423
T_8 -Maize (GC) + rice-bean - berseem - maize (F) + rice-bean	0.244	0.243	0.243	4.085	4.112	4.098
T_9 -Maize (GC) + rice-bean - oat - maize (F) - rice-bean	0.246	0.244	0.245	3.310	3.356	3.333
T_{10} - Rice - berseem - moong	0.358	0.355	0.357	2.786	2.812	2.799
SEm±	0.06	0.07	0.06	0.014	0.003	0.006
CD at 5%	0.18	0.21	0.18	0.041	0.010	0.019

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