Original Research Article

Enhancing Sustainability, Profitability, and Energy Efficiency through Input Interventions in Existing Farming System in Southern Plain Zone of Rajasthan, India

Abstract

India is one of the major players in the agriculture sector worldwide and it is the primary source of livelihood for around 55% of India's population. According to second advance estimates, agriculture & allied sector share 17.60 % in total GVA at current prices in year 2023-24 and the share of industry and service is 27.60 % and 54.90 % respectively. For strengthening the agriculture and enhancing the contribution of agriculture in total GVA, we need to some interventions in for achieve the stated objectives. This study examines input interventions to enhance the sustainability, profitability, and energy efficiency of small and marginal farmers in the Southern Plain Zone of Rajasthan, India.

Methodology: -

A. **Analytical tools: -** Tabular analysis and energy efficiency tools were used for the reached to findings of the study.
B. **Data Collection: -** The primary data collection were conducted from two study period, *i.e* Period-I (2012-13 to 2015-16), Period-II (2016-17 to 2021-22). In period-I, 60 farmers were selected from Udaipur district and in period-II, 60 farmers were selected from Dungarpur district. A multistage sampling technique was used for the sampling. The District were selected on the basis of higher and lower productivity of maize and wheat crop in tribal area, respectively, and the village were selected by random sampling.

Findings: - Introduction of improved maize and wheat cultivars resulted in yield increases of 25%-43% in Udaipur and 47%-61% in Dungarpur compared to conventional varieties. Successful vegetable cultivation led to average net returns of 145.9% (₹127989) in Udaipur and 153.17% (₹121039) in Dungarpur, increasing employment opportunities. Livestock management interventions improved milk yield by 650-850 liters per lactation, and Goatery and poultry farming revenue increased by 16.07% and 14.20%-15.70%, respectively.

Energy efficiency ratios varied across farming systems, with Crop alone exhibiting the highest ratio (3.25) in Udaipur and Crop + Dairy + Horticulture showing notable efficiency (1.56) in Dungarpur. Integration of goat rearing decreased energy use efficiency by up to 10.88%, while vegetable cultivation and poultry rearing increased efficiency by up to 7.58% and 2.75%, respectively.

Conclusion: - Intervention of high yielding varieties enhance the farm income of sample farmers in study area but livestock systems were least efficient due to high feed requirements. Dungarpur showed higher energy efficiency in crop and vegetable production but lower efficiency in Goatery compared to Udaipur. These findings highlight the significance of technological interventions for improving farming sustainability, profitability, and energy efficiency.

Key Word: Farming systems, Interventions, Profitability, Energy use efficiency, and Sustainability

Introduction

India is one of the major players in the agriculture sector worldwide and it is the primary source of livelihood for around 55% of India's population. According to second advance estimates, agriculture & allied sector share 17.60 % in total GVA at current prices in year 2023-24 and the share of industry and service is 27.60 % and 54.90 % respectively (Agricultural Statistics at a Glance 2023). Agriculture in India is dominated by smallholders, with 86% having scattered fragmented holdings on marginal land. The primary restriction has been a lack of enough investment capital, resulting in a decrease in agricultural production. As a result, agricultural production must be diversified and integrated with the production of high-value commodities such as milk, meat, fish, fruits, and vegetables.

A Farming System is an approach that involves allocating a farm's available resources to its production enterprises, or different areas of production, such as crops or livestock rearing, in order to achieve the goals of farm income maximization, food security, and employment. Food security in a humanitarian setting entails guaranteeing an adequate supply of food while also meeting nutritional demands and cultural expectations, both before and after a catastrophe. The environment, food security, and livelihoods are interdependent. If the land is deteriorated or vulnerable to natural disasters, less food is produced, resulting in serious food shortages. Food-secure societies, particularly those dependent on the environment for a living, require healthy and productive ecosystems.

The Sphere Standards (2018) make the link between environment and food security, livelihoods and nutrition. They state that food assistance should be delivered in a way that protects, preserves and restores the natural environment from further degradation, and highlights the impacts of cooking fuel on the environment and the importance of livelihoods strategies that do not contribute to deforestation or soil erosion (Sphere Standards: Food security standard 5.1, Key Action 4). The Sphere Standards also state that environmentally sensitive options for income generation should be chosen for livelihoods interventions whenever possible (Livelihoods standard 7.2: Income and employment, Key Action 6).

Mixed farming is a feature of Indian agriculture, which combines crop production with one or more animal industries such as cattle, sheep, goats, and poultry. A farmer typically builds his farming system not just with the goal of maximising net profits, but also with family welfare in mind, such as family nourishment, risk aversion, and certainty of returns from particular operations. A farming system that includes a variety of industries such as crops, dairy, poultry, and horticulture can assist a farmer obtain consistent and safe work opportunities throughout the year, as well as higher farm income.

The average maximum temperature in the research region is 43.8°C, with an average minimum temperature of 11°C. The average annual rainfall ranges between 550 and 1052 mm, with around 85% received through the south-west monsoon from June to September and the remainder received during the winter months. The main cropping systems are maize-wheat systems. Crop-livestock interaction is a distinctive aspect of the region. Approximately 90% of farmer households are small and marginal farmers.

The energy efficiency of agricultural production systems has been used as a measure of crop performance. As a result, evaluating agricultural productivity based on the energy input-output connection is critical for making optimum use of available natural resources and ensuring the economic and environmental sustainability of farming methods.

Agricultural productivity assessment using energy budgeting is essential to make efficient use of the available natural resources (Singh and Mittal 1992, Moraditochaee 2012, Soni *et al.* 2013). The energy consumption in agriculture has increased consistently in form of various inputs such as fossil fuel, fertilizers, pesticides, herbicides, electricity, machineries etc. causing environmental and human health problems (Chaudhary *et al.* 2009, Fadvi *et al.* 2011, Rahman and Barmon 2012). It has been realized that amount of energy used in agricultural production, processing and distribution should be significantly high in order to feed the expanding population and to meet other social and economic goals and therefore, sufficient availability of the green energy and its effective and efficient use are prerequisites for improved agricultural production (Stout 1990). Hence, to maximize the efficiency of modern agricultural technology to farms in a specific region, the farming system should be first characterized to capture the diversity of farming systems (Fadvi *et al.* 2011). It has been concluded in many studies that the yield and economical parameters increased linearly as level of fertility increased, while reverse trend was observed with energy use efficiency and energy productivity (Erdal *et al.* 2007, Tuti *et al.* 2012, Shahamat *et al.* 2013). An input-output energy analysis provides farm planners and policy makers an opportunity to evaluate economic intersection of energy use (Ozkan *et al.* 2004). Nowadays, increasing demand for food resulted in intensive use of energy inputs in modern agricultural production systems than earlier (Shahamat *et al.* 2010).

Crops, livestock, goats, and poultry were the most prevalent farming enterprises for the integrated farming system in Rajasthan's southern region, and the majority of farmers in this region are marginal. As a result, the current study was conducted to determine the most income-generating and profitable farming system, as well as to estimate the energy input and output of crops (cereals, fodder, and vegetables)-livestock (cattle, goat)-poultry in a 0.5 ha integrated farming system model, and to assess its energy use efficiency.

Objectives of the study:-

I. To find out the effect of the input interventions in existing farming system in Udaipur and Dungarpur district of Rajasthan.

II. To estimate the energy efficiency of input and output in farming system in Udaipur and Dungarpur district of Rajasthan.

Methods of Data Collection:

Study was under taken in Udaipur and Dungarpur district of Southern region of Rajasthan between 2012 and 2016 and further research between 2016 and 2022. The purposed study was based on primary data that were collected by using personal interview schedule. A cluster of 6 villages in Salumber, Sarada block (Udaipur) and a cluster of 6 villages in Aspur and Sabla block (Dungarpur) were selected on the basis of higher and lower productivity in tribal area, respectively, and the village were selected by random sampling. Climate of the region is mild hot in summers and serve cold winter. A structured interview schedule was prepared for the purposed study of selected farmers in benchmark and after interventions. Component-wise detailed interventions are listed in Table 1.

Table 1: Module-wise technological interventions.

Modules of IFS	Technological Interventions
Crop and cropping system	• Intensification and diversity of cropping. • HYV, intercropping, INM, IPM, and IWM are all examples of enhanced production technology.
Livestock	• Management of fertility and nutrition in dairy animals. • Vaccination, deworming, and mineral supplements for livestock. • Introduction of improved poultry (Pratapdhan) and goat (Sirohi) breeds. • Diversification of agricultural system for feed and fodder management.
Horticulture	• Demonstration of the enhanced vegetable crop production package of practices. • Growing vegetables for a bigger profit. • Promotion of a nutritional kitchen garden.
Capacity building	• Value addition of farm products. • Composting and vermicomposting. • Skill development (composting/vermicomposting, nursery raising, on-farm processing, appropriate agricultural practices. • Visit to agri-fairs, awareness program, and Kisan gosti. • Literature dissemination in local languages.

Based on the constraint identified, critical input interventions were made to uplift the existing farming situation at 10 households in each village (A total of 60 households in each block) during 2012-13 to 2015-16 (Udaipur) and 2016-17 to 2021-22 (Dungarpur). To assess the impact of critical input intervention under different enterprises at the household level and other related farming aspects, benchmark households were revisited regularly and information was recorded.

Energy Efficiency

The IFS model includes various agricultural production sub-systems such as field crops (wheat-maize), vegetables (okra-tomato-cauliflower), green fodder crops (sorghum-oat), and goats (four Sirohi goats). The IFS model was developed only after characterizing the principal agricultural production systems in the state's southern regions, which are primarily practiced by small and marginal farmers in rainfed ecosystems. Three farming seasons were seen in this region: kharif (June-October), rabi (November-February), and summer (March-May). The field experiment was designed to determine the energy input-output ratio, energy use efficiency, net energy gain, and other energy indices for various agricultural components. These energy indices are: (Soni *et al.* 2018, Kosemani and Bamgboye 2020).

$$Energy\ use\ efficiency\ ratio(EUE) = \frac{Total\ Energy\ Output\ (TEout}{Total\ energy\ Input\ (TEin)}$$

$$Net\ Energy\ Gain\ (NEG) = [Total\ Energy\ Output - Total\ Energy\ Input\ ]$$

$$Energy\ Profatibility\ (EP) = \frac{Net\ Energy\ Gain\ (NEG)}{Total\ Energy\ Input\ (TEI)}$$

$$Human\ Energy\ Profatibility\ (HEP) = \frac{Total\ Output\ Energy}{Labour\ \ Input\ Energy}$$

Table-2: Location Details

Village Name	No. of House Holds	Block	District	Geographical Location	AMSL
Tulsio ka Namla	10	Salumber	Udaipur	24.22^0 N, 73.99^0 E	268 m
Roba	10			24.21^0 N, 73.99^0 E	249 m
Bhujhfala	10			24.21^0 N, 73.97^0 E	232 m
Bovas	10	Sarada		24.27^0 N, 73.85^0 E	264 m
Chanda ji ka Guda	10			24.26^0 N, 73.87^0 E	255 m
Padarda	10			24.24^0 N, 73.92^0 E	237 m
Dhani Katara	10	Sabala	Dungarpur	23.85^0 N, 74.18^0 E	108 m
Dhani Vaglai	10			23.85^0 N, 74.19^0 E	141 m
Dholi Red	10			23.86^0 N, 74.18^0 E	152 m
Chilora Fala	10	Aspur		23.97^0 N, 74.09^0 E	146 m
Lalpura	10			23.96^0 N, 74.06^0 E	119 m
Karkoli Fala	10			23.96^0 N, 74.05^0 E	168 m

Various inputs such as labour, fossil fuel, electricity, feed, seed, organic manures and inorganic fertilizers, chemicals, machineries, water etc. and yield as grains, vegetables, fodder, meat, manure and other products and by-products were taken into consideration to calculate total energy input and output. The energy output for the green fodder crops was estimated based on the dried mass. The average input and output data of all the modules for the duration of 4 years with similar components were considered for the energy analysis. Various farm machineries used for different purposes therefore, their energy was estimated based on distributed weight utilized. Distributed weight was derived as [machinery unit weight/ (economic life*365 (366 for leap year)*8))] (Soni *et al.* 2013). The resource inputs and outputs converted from physical to energy unit (MJ) through various published conversion coefficients (Table 3, 4). The recommended dose of fertilizers and chemicals were applied as per the need of different crops. All crops were prepared using a tractor-drawn disc harrow, cultivator, rotavator, and by hand. All data for each input in various agricultural components was kept, and once the crop was produced, the harvested yields of each component's main and by-products were measured and documented.

Table 3 Resource input and their energy equivalent in MJ/unit

Resource Input	Unit	Equivalent (MJ/unit)	Reference
Labour	hr	1.96	Singh & Mittal (1992)
Diesel fuel	l	47.87	Singh & Mittal (1992)
Electricity	kWh	3.60	Ozkan *et al*. (2004)
Nitrogen (N)	kg	60.60	Singh & Mittal (1992)
Phosphorous (P2O5)	kg	11.10	Singh & Mittal (1992)
Potassium (K2O)	kg	6.70	Singh & Mittal (1992)
Zinc sulphate (ZnSO4)	kg	20.90	Singh & Mittal (1992)
Manure/FYM	kg	0.30	Taki *et al*. (2012)
Vermi-compost	kg	0.50	Ram & Verma (2015)
Farm machinery	kg	62.70	Tuti *et al*. (2012)
Herbicides	kg	254.45	Pimentel (1980)
Insecticides	kg	184.63	Pimentel (1980)
Water	m3	1.02	Tuti et al. (2012)
Minerals	kg	2.00	Wells C (2001)
Seed			
Wheat, maize, sorghum, oat	kg	14.70	Singh & Mittal (1992)
Okra, tomato, cauliflower, cabbage	kg	0.80	Tuti *et al*. (2012)
Chick (poultry)	kg	4.56	Gopalan *et al*.(1971)
Goat	kg	8.12	Gopalan *et al*. (1971)
Cow	kg	9.22	

Table 4 Resource output and their energy equivalent

Output	Unit	Equivalent (MJ/unit)	Reference
Wheat, maize, tomato, cabbage, cauliflower, chicken and goat meat	kg		Same as input
Okra	kg	1.9	Tuti *et al*.(2012)
Sorghum, oat and maize (dry mass)	kg	18.0	Singh & Mittal (1992)
Manure	kg	0.30	Taki *et al*. (2012)
By-product (dry mass)			
Straw (Rice and Wheat)	kg	12.5	Singh & Mittal (1992)
Okra, tomato, cabbage, cauliflower, onion, banana (leaves and stem)	kg	10.0	Singh & Mittal (1992) Soni *et al.* (2013)
Cow Milk	kg	7.14	Coley DA *et al.* (1998)

Result and Discussion:

To improve livelihoods in Rajasthan's southern region, major restrictions in various farm enterprises were identified, and prospects for further improvement were explored. The key restrictions noted in the area were water shortages, the use of conventional crop, fruit, and vegetable cultivars, imbalanced/inadequate nutrition, insect-pest and disease infestation, limited market accessibility, and a lack of technical understanding on improved package of techniques.

Farmers holding size

Characterization of farm holding revealed that on an average, 86.1% farmers were under marginal and 13.9% farmers were under small farmer category. None of the farmers was belonging to medium and large farmers categorize in both the studied area.

Socio-personal characteristics

In terms of age, education, occupation, home size, family type, monthly income, and involvement in social activities, the socio-personal characteristics of the farmers who were questioned were examined. The results showed that the majority of farmers in the cluster under study were between the ages of 40 and 55, followed by older farmers (>55) and younger farmers (35). A very small portion of the young farmer population moved to urban areas in search of employment. Farming was the primary occupation of the majority of farmers, who were either illiterate or only had a rudimentary education. More than five people lived in the typical household, which earned less than ₹5000 per month.

Pre-Dominant Cropping/Farming System

In every village under study, crop + dairy farming was the predominant farming practice. The most often grown crops were wheat, mustard, maize, and soybeans, however vegetables and fodder were grown in remote areas with access to irrigation water (Bhagat *et al*. 2024). Dairy farming is dominated by cows and buffalo, while goats and fowl are raised mostly for their flesh and eggs (Bhati *et al.* 2024).

Table 5: Pre-Dominant Cropping system for Wheat and Maize

District	Block	Wheat (kg ha^{-1})			Maize (kg ha^{-1})		
		Benchmark	After intervention	Percentage Increase	Benchmark	After intervention	Percentage Increase
Udaipur	Salumber	3020	3780	25.17	1815	2925	37.95
	Sarada	2935	3760	28.11	1710	2550	32.94
Dungarpur	Sabala	2800	3730	33.21	1785	2625	32.00
	Aspur	2535	3625	43.00	1645	2535	35.11

The study found that crop + dairy farming is the most common farming system among households in the study area. It was also observed that the adoption of improved cultivars in maize and wheat crops was very low and farmers mostly relying on the traditional cultivars. Farmers used to depend on local varieties because of ease of reusing the same varieties for raising next crop due to non-availability of quality seeds in time in the region and lower affordability to purchase seeds of high yielding varieties (Bhagat *et al*. 2024). Mutual exchange of seeds and planting material is a common practice among villagers. The lower yield of traditional cultivars results in lower crop productivity in the region. Composting of cow dung was also not in practice. Farmer use un-decomposed FYM which become harbor for insect and pest and ultimately lower yield. Very few (<20 %) farmers were using inorganic fertilizer like urea as revealed from survey. Due to irregular availability of fodder for dairy, enterprise was also a neglected component of existing farming system as most families were in the process of downsizing the number of cattle. They are now keeping cows enough only for milk and ploughing the field. The significant decline of cattle adversely impacts soil revitalization coming from manure.

Critical input intervention under different farm enterprise

Promotion of improved cultivars of wheat and maize for higher productivity and profitability:

Technical interventions such as introducing of improved cultivars of wheat (Raj 4079) and maize (PHEM-2) gave additional yield of 25 to 43% in wheat and 47 to 61% in maize (fig-1) over traditional cultivars in both the cluster (Udaipur and Dungarpur), resulting in net gain in income and forms a more practical consideration.

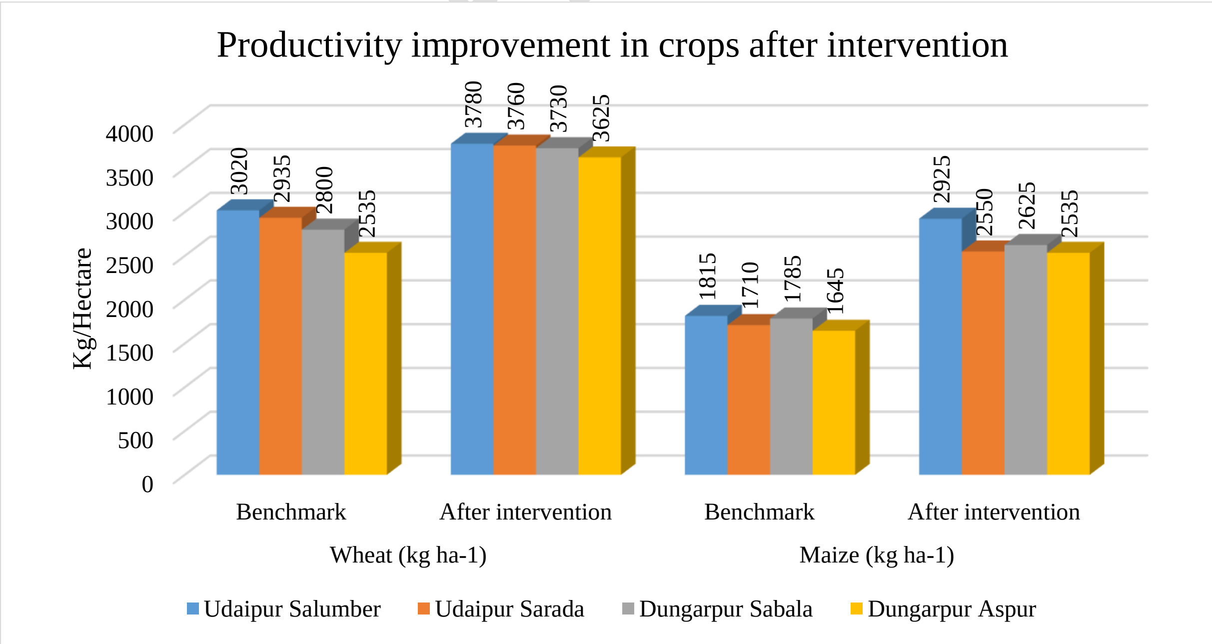

Fig 1: Productivity improvement in crops after intervention

Balance fertilization:

A total of 24 trials were conducted in both the cluster to improve crop yield and quality by managing nutrients with seven treatment. Application of 90 kg N, 35 kg P2O5 and 30 kg K2O/ha along with 25 kg ZnSO4 to maize and 120 kg N, 40 kg P2O5 and 30 kg K2O/ha to wheat significantly improved grain yields of maize and wheat over all the other treatments. Compared to farmers' practice, maize output increased to 88.8, and 72.4% and wheat yield increase to 47.6 and 51.8 % in Udaipur and Dungarpur, respectively (Table 6).

Table 6: On-Farm crop response to plant nutrients in predominant cropping systems

Nutrient level (kg/ha)		**Udaipur** Grain yield (kg/ha)		**Dungarpur** Grain yield (kg/ha)	
Maize	Wheat	Maize	Wheat	Maize	Wheat
Control	Control	763	1223	785	1281
N_{90}	N_{120}	1617	2388	1490	2513
N_{90} P_{35}	N_{120} P_{40}	2883	2988	2508	3104
N_{90} K_{30}	N_{120} K_{30}	2363	2756	2350	2873
N_{90} P_{35} K_{30}	N_{120} P_{40} K_{30}	3181	3240	2808	3515
$N_{90}P_{35}$ K_{30} Zn_{25}	**N_{120} P_{40} K_{30}**	**3458**	**3475**	**3069**	**3783**
Farmer's practice	Farmer's practice	1831	2354	1779	2492

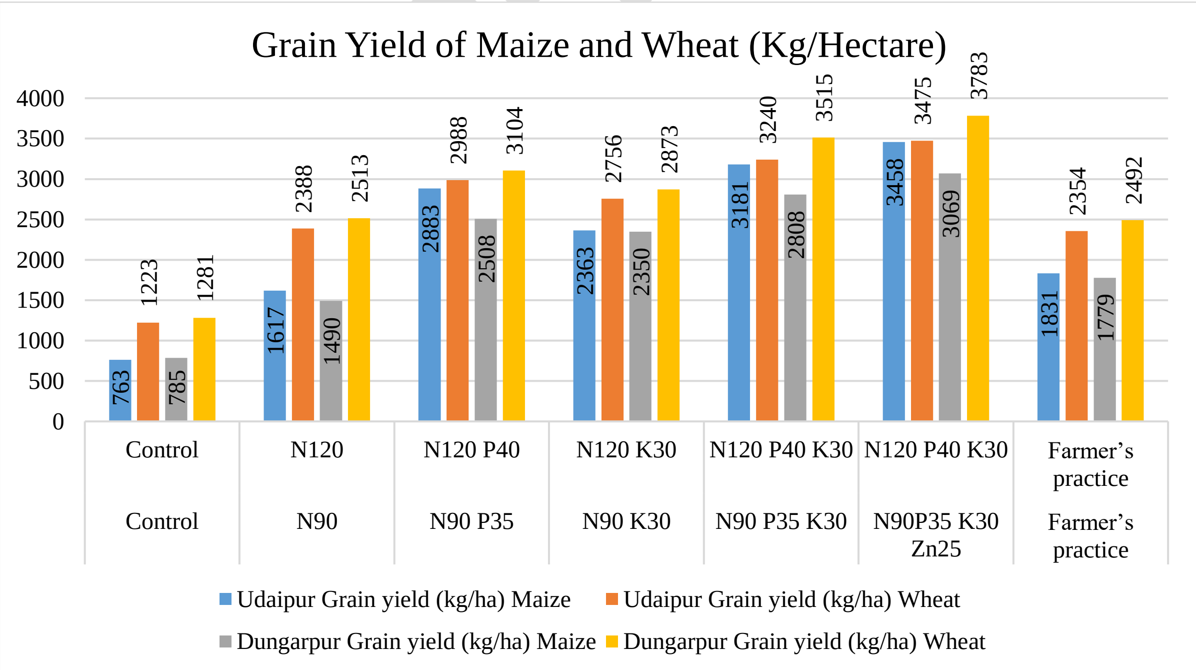

Fig 2: Grain yield of maize and wheat under different nutrient levels

Nutritional Kitchen Gardening/Vegetable cultivation

In both the clusters, farmers use to purchase vegetables from market for their own consumption and spend a sizeable income on it. To make them self-reliance, 48 Farmers were given a better package of practice in the vegetable module for the successful cultivation of vegetables such as tomato, chili, cabbage, cauliflower, brinjil and melon crops for increased profitability and reduce the risk of heavy reliance on a single crop while also generating year-round income and 12 farmers were selected for promotion of kitchen gardening on bare land nearby house/water sources etc. was done by providing mini kit of seasonal vegetables in both cluster.

Cost of these mini kits were ₹ 1200 each. With such intervention, monthly vegetable availability increased from 75 to 110 kg household in both the cluster. Initial bench mark survey made in the study revealed that farmers usually spend about 450 to 650 per month on vegetables, which could be easily saved with kitchen gardening of nutritious vegetables. Among the different season, maximum net saving through kitchen gardening was accrued during Rabi (winter) Kharif season. Over all annual net savings due to kitchen gardening per household was ₹15000 at Udaipur and 12000 at Dungarpur district.

Since adopting a diverse vegetable-based cropping scheme, average net returns of household improved to 145.9 % (₹ 1, 27,989) in Udaipur and 153.17% (₹1, 21,039) in Dungarpur. With only a ₹2000 to 5963 rise in cultivation costs.

Dairy enterprise:

The issue of infertility was resolved by artificial insemination using premium sperm. To boost milk production, dairy cows were fed a balanced diet and a mineral cocktail. Infertility and nutrition management in dairy animals, mineral combinations, calcium and vitamin supplements, promoting and improving native cow breeds (Karthik *et al.* 2024), deworming, and disease control were among the technological interventions conducted under the livestock module.

Data collected from various villages shows that better dairy management techniques have a significant impact on milk yield. Compared to current dairy management techniques, enhanced management techniques resulted in an additional milk yield of 650 to 850 liters per lactation. Economic calculations for various enhanced dairy management techniques showed that, in comparison to current management techniques, improved dairy management techniques increased average income by ₹24285 in Udaipur and ₹16447/lactation/household in Dungarpur. More farmyard manure output, shorter dry periods, longer lactation periods, and higher milk yields were the primary causes of the increased revenue

Effect on Goatery enterprises:

Goat rearing on natural pasture was the most prevalent business in Southern Rajasthan, with marginal households (less than 1 hectare). Goat development and survival rates were extremely low as a result of indigenous breed rearing, unbalanced diet, and inadequate management techniques. Farmers in the Udaipur cluster were given Sirohi breed and mineral mixture as a food supplement and medicines, specifically anti-mastitis, anti-parasites (Bhati *et al.* 2024), and reproductive control, in order to promote health and increase income through Goatery activity. In addition to improving the health of these goats, this intervention greatly increased the number of goats per household, which in turn greatly raised the yearly income from these businesses. An estimated gain of ₹25800/household/year above the benchmark income (₹8000/household/year) from Goatery enterprise was observed when evaluating the change in income through Goatery enterprise at the household level.

Promotion of Backyard Poultry:

Backyard poultry were given to marginal farmers in order to improve their standard of living. There were twenty Pratap Dhan birds for every farmer. The findings show that their revenue from raising chickens increased by an average of ₹17000 and 18250/-in both clusters.

Effect on overall household income, employment, and nutritional security:

Household income from various businesses was compared to the original benchmark year (2011) at the conclusion of the study. The findings show that the combination of crops and other component businesses (dairy, horticulture, Goatery, and poultry) increases household income overall. Crops generated the highest net economic gain among the various components, followed by horticulture, dairy, and goat husbandry. Aside from providing high-quality veggies and nutritional security, using bare land close to the hand pump and water sources for kitchen gardening also increased net savings by ₹12000 to ₹15000 per household annually. In comparison to Dungarpur, Udaipur had a greater total family income.

Product diversification of FYM to vermicomposting reduces fertilizer cost of crops and vegetables and also adds extra average net amount of ₹1188 to ₹5131per household in Udaipur (Table 7) and ₹ 827 to ₹916per household in Dungarpur (Table 8) compared with benchmark year. The net annual income improvement through different component enterprises of integrated farming system approaches was to the tune of 128.94% to 167.54 % at the Udaipur cluster (Table 7) and 115.18% to 153.17% in the Dungarpur cluster (Table 8).

Farming system enterprise diversification:

At the onset of the study, crop component enterprises of the farming system were the most prevalent and occupied about 70-80% of the total household income followed by dairy (20-30%) and Goatery or poultry enterprise (5-10%). With different critical input interventions and improved farming awareness programs household enterprise diversification also took place. After 04 years of study, the contribution of dairy, horticulture Goatery, and poultry enterprises to total household income was not only improved, but the other ancillary/complimentary enterprises like kitchen gardens and product diversification were also having a sizable contributions to household income (Singh, Hari *et.al* 2017). Such diversification not only led to total higher house hold income but also reduced the dependency on single enterprises of crops.

Similar performances of integrated farming systems (IFS) have been reported by Frei and Becker (2005) and Poonam Kashyap *et al*. (2017) where synergism between farm enterprises increased productivity most studies have focused on the sustainability of IFS in terms of productivity and economic viability.

Employment generation through an integrated farming system approach:

The table number 9 compares the employment performance of various farming enterprises in the Udaipur and Dungarpur clusters, both before and after certain interventions. The data reveals notable improvements in man days across both clusters following the interventions, as indicated by the percentage increases. For Crop the Udaipur cluster saw an increase in man days from 150 to 192, representing a 28 percent rise, while the Dungarpur cluster experienced a higher increase by 37.68 percent. When combining Crop and Dairy, Udaipur's man days jumped by 75.24 percent and Dungarpur by 75 percent increase.

The addition of Horticulture to Crop and Dairy resulted in one of the most substantial man days increases. Udaipur's employment surged from 280 to 538, a 92.14 percent rise, while Dungarpur's man days grew from 230 to 450, marking a 95.65 percent improvement. Similarly, combining "Goat farming" with "Crop and Dairy" led to the largest employment boosts: Udaipur's man days nearly doubled from 260 to 516, a 98.46 percent increase, while Dungarpur saw a significant 108.57 percent rise. Finally, for "Crop, Dairy, and Poultry," Udaipur's employment increased from 230 to 393, a 70.87 percent rise, and Dungarpur's employment went from 225 to 375, reflecting a 66.67 percent increase. Resulting, the interventions led to substantial gains across all farming enterprise combinations, with the addition of more components (such as dairy, horticulture, and livestock) resulting in higher employment increases. The Dungarpur cluster generally exhibited slightly higher percentage improvements than the Udaipur cluster, particularly when goat farming was included.

Nutrition security under the farming system approach:

Our result demonstrated that the integration of Crop + Dairy + Horticulture + Goatery + Poultry had substantial improvement on total protein and carbohydrate production at the household level. As per the Indian Council of Medical Research recommendation annual requirement of protein and carbohydrate for a > 5-member family ranges between 110-125 kg protein and 550- 575 kg carbohydrate which can be easily be met out through an integrated farming system approach.

Table 7 Changes in overall household income (all values in ₹/ha) under different farming systems scenarios in the Udaipur cluster (2012-13 to 2015-16)

Farming system	Crop		Vegetable		Dairy		Goatery		Poultry		Kitchen gardening		Product diversification		Total Household Income		% Increase
	Benchmark	Af. Inv.	Benchmark	Af. Inv.	Bench mark	Af. Inv.	Bench mark	Af. Inv.	Bench mark	Af. Inv.	Bench mark	Af. Inv.	Bench mark	Af. Inv.	Bench mark	Af. Inv.	
Crop alone	50000	62120	-	51161	-	-	-	-	-	-	-	-	-	1188	50000	114469	128.9
Crop+ Dairy	50400	64145	18800	36923	-14200	23655	-	-	-	-	-	-	-	3539	55000	128262	133.2
Crop+ Dairy + Goat	51000	64908	24000	41749	-23000	24250	8000	25800	-	-	-	-	-	3816	60000	**160523**	**167.5**
Crop+ Dairy + Poultry	43100	57625	-	-	-1700	24949	-	-	5800	17000	-	15000	-	5131	47200	119705	153.6
Average	**48625**	**62200**	**10700**	**32458**	**-12967**	**24285**	**8000**	**25800**	**5800**	**17000**	-	**3750**	-	**3418**	**53050**	**130739**	**146.4**

Table 8 Changes in overall household income (all values in ₹/ha) under different farming systems scenarios in Dungarpur cluster (2016-17 to 2021-22)

Farming system	Crop		Horticulture		Dairy		Poultry		Kitchen garding		Product diversification		Total Household Income		% Increase
	Bench mark	Af. Inv.	Bench mark	Af. Inv.	Benchmark	Af. Inv.	Bench mark	Af. Inv.	Benchmark	Af. Inv.	Bench mark	Af. Inv.	Benchmark	Af. Inv.	
Crop+ Dairy	46485	70490	0	0	1000	18558	0	0	0	12216	0	916	47485	102181	115.18
Crop+ Dairy +Horti	45545	75400	0	27314	2265	17427	0	0	0	0	0	898	47810	**121039**	**153.17**
Crop+ Dairy + Poultry	43113	70835	0	0	4040	13356	0	18230	0	12216	0	827	47153	115465	144.87
Average	**45048**	**72242**	**0**	**27314**	**2435**	**16447**	**0**	**18230**	**0**	**8144**	**0**	**881**	**47483**	**112895**	**137.76**

Note: - Af. Indicates **After** and Inv. Indicates **Intervention**

Table 9 Employment (man-days/ha) generation through different farming systems approaches

Farming enterprise	Udaipur Cluster			Dungarpur Cluster		
	Benchmark	After Intervention	Percentage Increase	Benchmark	After Intervention	Percentage Increase
Crop alone	150	192	28	138	190	37.68
Crop+ Dairy	210	368	75.24	200	350	75.00
Crop+ Dairy+ Horticulture	280	538	92.14	230	450	95.65
Crop+ Dairy + Goat	260	**516**	98.46	210	**438**	108.57
Crop+ Dairy + Poultry	230	393	70.87	225	375	66.67

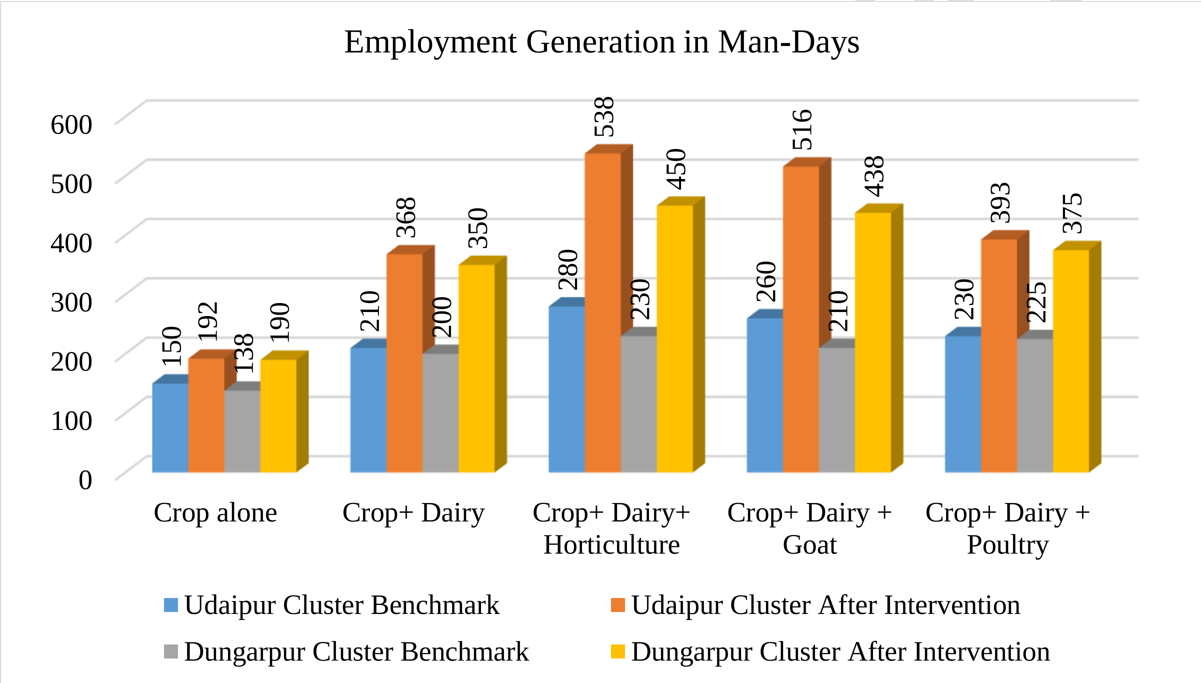

Fig 3 : Employment Generation: Benchmark vs After intervention in Udaipur and Dungarpur.

Energy Efficiency

The energy flow in system studied by evaluating the energetics for each component of IFS models in both the district (Table-10 & 11). The fodder showed the highest energy use efficiency ratio (7.29 & 7.37) due to higher energy output (25.92 GJ) as against the energy input of 3.55 & 3.52 GJ in both the district respectively. This was followed by cropping system (2.88 & 4.56) and vegetable (1.88 & 2.95) respectively in both district.

The reduced energy ratio in IFS was attributed to low energy output against energy input in animal component due to this the dairy, goatry and poultry was recorded the least energy use efficiency ratio in both districts.

The maximum net energy gain was recorded in wheat-maize (26.97 & 47.01 GJ) cropping system followed by fodder (22.37 & 22.40 GJ). Whereas, dairy and Goatery in both district and poultry component in Dungarpur district calculated to be negative energy gain ratio due to low energy output against high energy input.

The energy profitability of different agricultural component was analysed and it was found that green fodder cultivation was most profitable in terms of energy and produced Ep ratio as 6.29 in Udaipur and 6.37 in Dungarpur followed by field crops and vegetables in both study area.

Similarly human energy profitability was also found higher in fodder (78.71 & 88.16) followed by crops (32.03 & 44.78) in both districts. Whereas in livestock component poultry show high HEP ratio (32.75) in Dungarpur followed by Dairy in both districts. Goat rearing found least human energy profitable in both study area.

Table-10: Energy indices of different components of farming system at Udaipur

Components	Area/ Nos	En-Input (in GJ)	En-Output (in GJ)	NEG (in GJ)	EUE	EP	HEP
Crop	0.3 ha	14.35	41.31	26.97	2.88	1.88	32.033
Vegetable	0.1 ha	6.61	12.45	5.84	1.88	0.88	11.029
Fodder	0.1 ha	3.55	25.92	22.37	7.29	6.29	78.717
Dairy	02 nos	46.73	24.73	-22.00	0.53	-0.47	23.02
Goat	04 nos	20.15	15.25	-4.90	0.76	-0.24	5.38

Table-11: Energy indices of different components of farming system at Dungarpur

Components	Area/ Nos	En-Input (in GJ)	En-Output (in GJ)	NEG (in GJ)	EUE	EP	HEP
Crop	0.3 ha	13.20	60.21	47.01	4.56	3.56	44.780
Vegetable	0.1 ha	6.86	20.28	13.42	2.95	1.95	14.700
Fodder	0.1 ha	3.52	25.92	22.40	7.37	6.37	88.163
Dairy	02 nos	46.73	24.73	-22.00	0.53	-0.47	23.02
Goat	04 nos	23.25	14.84	-8.42	0.64	-0.36	3.13

Poultry	20 nos	3.12	8.34	-8.42	0.64	1.67	32.750

Among the different IFS models it was found that the total energy input was required utmost for Crop + Dairy + Goat (91.40 GJ) system in Udaipur and Crop + Dairy + Horticulture (93.57 GJ) in Dungarpur district. Whereas Crop + Dairy system required more energy input in Dungarpur (86.71 GJ) as compare to Udaipur (71.25 GJ), Crop + Dairy + Poultry system was recorded 89.83 GJ energy input in Dungarpur. Least energy input required by Crop alone i.e. 24.51 GJ in Udaipur. Similar trend was found in energy output in which Crop + Dairy + Goat in Udaipur (119.66 GJ/year and Crop + Dairy + Poultry system (134.04 GJ/year) in Dungarpur produced more energy than other models (Table-12 &13).

Moreover, the energy use efficiency ratio was estimated and found to be highest in crop alone (3.25) in Udaipur (Table-12) followed by Crop + Dairy + Horticulture system (1.56) in Dungarpur (Table-13). It is important to mention that livestock were least energy efficient agricultural production system which have produced negative energy mileage (Table-10 & 11). The livestock system required utmost energy input in the form of feed and the energy analysis indicated that their feeds energy efficiency was lesser and required improvement in the feed nutrition (Safeedpari, 2012 & Sanjeev kumar et.al, 2019). In this study it was also found that the goat rearing with dairy animal, decreased the energy use efficiency up to 10.88% whereas, growing vegetables and rearing poultry with C+D increased the energy use efficiency up to 7.58% and 2.75% respectively in farming system module.

Table-12: Energy input-output and energy efficiency of IFS modules at Udaipur

IFS Modules	Area (ha)	En-Input (in GJ)	En-Output (in GJ)	NEG (in GJ)	EUE	EP	HEP
Crop Alone	0.5	24.51	79.68	55.17	3.25	2.251	29.00
C+D	0.5	71.25	104.41	33.17	1.47	0.466	27.32
C+D+G	0.5	91.40	119.66	28.27	1.31	0.309	17.79

Table-13: Energy input-output and energy efficiency of IFS modules at Dungarpur

IFS Modules	Area (ha)	En-Input (in GJ)	En-Output (in GJ)	NEG (in GJ)	EUE	EP	HEP
C+D	0.5	86.71	125.69	38.99	1.45	0.450	43.80
C+D+H	0.5	93.57	145.98	52.41	1.56	0.560	34.35
C+D+P	0.5	89.83	134.04	44.21	1.49	0.492	42.90

During the study it was observed that energy use efficiency of crop &vegetable in Dungarpur is 58.35% & 56.95% higher as compare to Udaipur respectively. Whereas, in Goatery energy use efficiency is 15.7% less in Dungarpur as compare to Udaipur.

The increasing demand for food to meet food, nutritional and health security has resulted in intensive use of energy inputs in agricultural production which is threatening public health as well as environment, therefore energy budgeting in agricultural production systems is very essential to get sustainability, profitability in the farming practices and to identify the best performing agricultural practice that can be adopted in the specific agricultural regions (Erdal *et al.* 2007, Taki *et al.* 2012, Soni *et al.* 2013).

The present study revealed that crops (cereals, fodder and vegetables)- livestock (cow)-Goat in an 0.5 ha land based IFS model is more profitable, income generating and an energy efficient module and can be promoted and adopted in the humid and sub humid southern plain zone of Rajasthan. Moreover, the education, awareness and training about the energy use efficiency of farming systems and its importance in agriculture should be provided to the farmers to bring the sustainability in the agriculture sector in India.

The study highlighted the effectiveness of integrated farming systems in enhancing agricultural productivity, household income, and livelihoods in Southern Rajasthan. By addressing constraints and promoting sustainable farming practices, the interventions contributed to improved food security, income stability, and rural development in the region.

Overall, the study underscores the importance of holistic and integrated approaches to agriculture for promoting sustainable livelihoods and rural development in resource-constrained regions like Southern Rajasthan.

Conclusion: - The study in selected district was performed with specified objectives to see the effect of the input interventions and energy efficiency of the input and output of different farming systems. The findings of the objectives conclude that productivity of wheat and maize was increase more than 26 percent in selected district due to intervention of high yielding cultivars of wheat (Raj 4079) and maize (PHEM-2).The improved cultivars were tested on different nutrient level and the productivity was highest on N_{120} P_{40} K_{30} and $N_{90}P_{35}$ K_{30} Zn_{25} nutrient level for wheat and maize respectively. Introduction of vegetable cultivation through kitchen gardening, dairy animal and their feed, introduction of Sirohi breed and mineral mixture as food supplement and medicine and Pratap Dhan breed of poultry in backyard etc. significantly increase the income of selected farmers and also ensure the household income, employment and nutritional security. In Udaipur district, highest household income was increase by 167.50 percent by using Farming system of Crop + Dairy +Goat. While in Dungarpur district have 153.17 percent increments in household income by using Crop + Dairy + Horticulture farming system.

The findings of the energy efficiency conclude that human energy profitability was highest for the fodder due to more output at lower management cost by labour and net energy gain was highest for the crop. In reference to dairy animal and goat, net energy gain was negative because lower milk productivity of dairy animal and goat, that produce lower energy output as compare to energy input consume. In further, the findings of the energy efficiency in integrated farming system conclude that crop + dairy + horticulture system is highest in bet energy gain, energy use efficiency and energy profitability but lower in human energy profitability, so this farming system indicates more labour intensive module.

Recommendations: - The findings of the study revealed a significant positive effect of input intervention in sample tribal districts. There is need of technological interventions in tribal districts and also need of input interventions in other tribal district for betterment of tribal farmers and livelihood security.

Point Summery or Highlights

1. This study examines technological interventions to enhance the sustainability, profitability, and energy efficiency of small and marginal farmers in the Southern Plain Zone of Rajasthan.
2. Study was under taken in Udaipur and Dungarpur district of Southern region of Rajasthan during 2012-13 to 2015-16 and 2016-17 to 2021-22. A cluster of 6 villages in Salumber, Sarada block (Udaipur) and a cluster of 6 villages in Aspur and Sabla block (Dungarpur) were selected on the basis of higher and lower productivity, using stratified random sampling.
3. Module-wise (Farming System) technological interventions were classified.
4. Resource input, output and their energy equivalent were calculated.
5. Critical input intervention under different farm enterprise and productivity improvement in crops after intervention were observed.
6. Crop response to plant nutrients in predominant cropping systems was calculated
7. Effect on overall household income, employment, and nutritional security were examined.
8. Employment generation through an integrated farming system approach and Nutrition security under the farming system approach were calculated
9. Energy input-output and energy efficiency of IFS modules at Udaipur and Dungarpur were calculated.

Disclaimer (Artificial intelligence)

I Narendra Yadav as corresponding author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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