



Original Research Paper

THE IMPACT OF FARM POWER AVAILABILITY AND ENERGY-USE DYNAMICS ON RICE PRODUCTIVITY: AN ANALYSIS ACROSS AGRO-CLIMATIC ZONES OF ASSAM

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ABSTRACT

This paper highlights the structure of impact of availability of farm power and its energy dynamics on the productivity of rice production in three distinct agro-climatic regions of Assam such as Sivasagar, Nagaon, and Barpeta. Based on primary survey data collected from 360 agricultural households, the analysis estimates the inventory of mechanized machines, Effective Field Capacity (EFC), Man-Machine Ratio (MMR), energy intensity in terms of megajoules per bigha (MJ/bigha), and the total Man-Machine Productivity. The results of the research show significant differences within the state that are caused by cropping intensity and machinery adoption. The largest value of Man-Machine Productivity was found in Barpeta (8.87), whereas it is slightly lower in Nagaon (6.89) and Sivasagar (5.29). The energy intensity in Barpeta (683.55 MJ/bigha) and Nagaon (663.72 MJ/bigha) is the highest one because of intensive use of groundwater irrigation and multi-seasonal agriculture. Even though mechanical power such as power tillers, tractors, and diesel/electric pump sets have substituted traditional draught animal power for seedbed preparation and water management, post-tillage activities (transplanting, weeding, and harvesting) are carried out manually in all three agro-climatic zones. Such structure of the farming process leads to a severe labour constraint and high labour hours (73,112 hours in Nagaon and 54,704 hours in Barpeta), thereby reducing potential productivity benefits. Mechanization leads to increased cropping intensity (152-162%) and improved productivity, rising from 2271 kg/ha in 2018-2019 to 2652 kg/ha in 2022-2023, with Nagaon and Barpeta achieving 3250 kg/ha and 4157 kg/ha respectively.

Keywords: *Agricultural Mechanization, Effective Field Capacity (EFC), Man-Machine Ratio (MMR), Man-Machine Productivity.*

INTRODUCTION

Agriculture continues to be the backbone of Assam's agrarian economy, supporting about 70 percent of its Labour force and offering basic security of livelihood to the rural population [1]. In this agrarian context, rice (*Oryza sativa*) is not only an important cereal crop but the chief criterion for determining the agrarian economy, rural employment, and food security. Though possessing agro-ecological strengths such as heavy rainfall, rich alluvial soil, and riverine systems that flow throughout the year, rice production in Assam has always been lower than the national average [2]. A crucial bottleneck that limits the growth of output is the inadequacy and uneven distribution of farm power. Agricultural mechanization acts as a critical driving force for contemporary agricultural development through timely seedbed preparation, transplantation, inter-culture operations and post-harvest loss minimization [3]. The total FPA in Assam is far less than the national level benchmark of 2.5 kW/ha being in the range of 1.0 to 1.2 kW/ha with the predominance of traditional draft animal power and

animate human power in the energy structure [4, 5]. Such inadequacy of mechanical and electrical power limits the cropping intensity and creates Labour bottlenecks during peak agricultural periods. It also hampers the adoption of HYV. Hence, studying the structural relationship between the farm power structure and cereal productivity has become a vital issue in the regional development economics of northeast India [6, 1]

The development of mechanical traction potential apart from being the essence of the transformation process in modern agricultural practices has a profound connection with the energy inputs which include not only direct but also indirect ones. Direct energy is used for the actual operation in the field and includes human Labour, draught animals, fossil fuels and grid electricity, whereas the indirect ones include chemical fertilizers, plant protection agro-chemicals and certified seeds which decide the biological yield potential [7, 8, 2]. The input energy use in the case of intensive rice farming has shown an increase at a very fast pace, but the marginal

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productivity and efficiency of energy use becomes less and less as the input is not accompanied by the mechanical power and irrigation control measures [9]. In east India, the combination of the inputs results in poor energy ratio and high costs without proportional yield increases [10]. In Assam, the situation regarding the energy ratio is worsened with the changing energy composition: although there has been an increase in the fuel use in the case of small power tillers and shallow tube wells, there has not been any electrical energy use because of fragmented rural power supply network.

Agriculture in Assam is characterized by marked heterogeneity in the geo-physical and agro-climatic environment, which constrains the application of technology uniformly throughout the state. Assam falls into six distinct Agro-Climatic Zones namely: Upper Brahmaputra Valley, Central Brahmaputra Valley, Lower Brahmaputra Valley, North Bank Plain, Hills Zone and Barak Valley. Different zones have unique soil types, micro-climate, hydro-geological risks and history of capital accumulation [11]. In the first place, while the Lower Brahmaputra Valley and North Bank Plains are prone to annual flooding during the Sali (winter rice) period and, thus, make farm equipment susceptible to damages and low utility, the boro (summer rice) lands of the Central and Lower Valleys depend on diesel irrigation pumps extensively [12]. Furthermore, extreme land fragmentation, large proportion of marginal and small holdings, along with insecure tenures significantly constrain the adoption of farm equipment. This variation of power regimes for farms and creates productivity disparities within the state which cannot be captured through state-level analysis.

In spite of the abundant literature on mechanization of agriculture in India at national level, studies using empirical methods that have focused on the relationship between the availability of farm power on one hand and the usage of energy in different agro-climatic zones and its effect on crop productivity on the other hand are very few [13]. Past literature in this regard has been limited mostly to the use of descriptive statistics and cross-sectional equations without considering heterogeneity in zones, input elasticities and endogenous input adoption [14].

METHODOLOGY AND STUDY AREA

This study involved a multistage stratified random sampling process in which a primary survey was undertaken among 360 farm households equally allocated across three agro-ecological zones of Assam (120 households each). The data analysis phase entailed quantifying and itemizing the total number of agricultural mechanized tools including owned and custom hiring tractors, power tillers, diesel and electric pump sets, reapers and threshers. Further, the computation of the mechanization index (MI) was done by measuring the proportion of mechanical power (kW) over the total animate and mechanical power use. Thereafter, the

calculation of man-machine ratio (MMR) was done to ascertain the extent of factor substitution and Labour displacement in operation of farms. The computation of mechanical energy use intensity involved quantifying machine energy use in megajoules per bigha (MJ/bigha) based on standard values for conversion of energy of thermal and electrical forms per production operation.

The area is distinguished by humid subtropical type of climate, abundant rainfall of more than 2,200 mm annually, and fertile soil, both alluvial and red, with a moderate level of acidity. The agriculture industry is the leading one here, involving the monoculture of Sali (winter) rice, as well as the growing of tea. Although the prevailing form of agriculture here is still peasant, the introduction of traditional tractorization and power tillers in seedbed preparation has become possible [1, 5, 15].

Nagaon is one of Assam's key agricultural centers that operates in a transitional agroecology with lower rainfall (1,200–1,800 mm) compared to other zones. Here there are fertile alluvial soils along the Brahmaputra and Kolong river basins with intensive multi-cropping. Nagaon is known for high cropping intensity, growing of Sali, Ahu, and Boro (summer) rice, which is irrigated and grown in the winter months, as well as jute and vegetables.

Barpeta is flood-prone and low-lying alluvial plain that is heavily influenced by the Brahmaputra, Manas, and Beki rivers. Abundant annual rainfall and seasonal flooding determine the cropping cycle, which leads to risks in Sali season while creating favorable conditions for growing intensive Boro rice and commercial vegetables.

RESULTS AND DISCUSSION

Application of energy in agriculture is a determinant of crop productivity potential, timely operations, and total factor productivity through the biological and physical transformation processes [16, 25]. Energy in agricultural systems is utilized in two interrelated forms, namely direct energy (human labour, draft, fossil fuel, and electricity) and indirect energy (embedded in synthetic chemical fertilizers, plant protection chemicals, machinery manufacturing, and hybrid seeds) [17]. Switching to energy from animate sources to mechanical and electrical energy uses leads to an increased number of crops due to precise tillage, proper seed planting, effective weed removal between plants, and proper delivery of irrigation water. Evaluations using the Cobb-Douglas production function have shown positive output elasticities regarding direct energy use and chemicals used in agriculture [18]. This shows that there is an optimal energy deepening that maximizes yield per unit area of land. Energy from machines solves Labour constraints for transplanting and harvest periods, leading to minimized losses [2]

Energy utilization, however, adheres to neoclassical principles of decreasing marginal returns. Excessive utilization of indirect, non-renewable energy resources,

particularly synthetic nitrogen, in intensive cereal monoculture often leads to decreasing marginal physical productivity and low energy use efficiency (EUE) in the absence of precision delivery. The maximization of

energy return does not only hinge on the growth in energy utilization, but also on its optimal allocation of direct mechanical energy and indirect energy sources [10].

Table 1: Total agricultural mechanized assets hold by the surveyed households in the Sivasagar, Nagaon, and Barpeta District of Assam.

Sl. No.	Equipment/Tools/Machines	Districts		
		Sivasagar	Nagaon	Barpeta
1	Tractor	5	9	14
2	Powertiler	11	14	16
3	Daught Animal	8	13	7
4	Total Pumpsets	13	15	22

Source: Primary Survey

The table 1 shows agricultural capital among the three surveyed districts point to an evident gradient of mechanization, characterized by rising density of asset endowments from Upper to Lower Assam districts. The district showing highest levels of investment in mechanized equipment is Barpeta with 59 pieces of assets, while the lowest is Sivasagar (37). Power tiller (41 pieces) is more in number than four-wheel tractor (28 pieces), indicating preference of farmers for light-weight

machinery which can be conveniently used for tilling on fragmented plots of lands and puddling of wet land. Irrigation capital dominates the capital structure with 50 pieces of pump sets, mostly in Barpeta (22) and Nagaon (15). High dependency on irrigation capital in these two districts is due to intensive Boro (summer) rice cultivation using groundwater. However, in Sivasagar district low level of irrigation capital is associated with rainfed Sali crops.

Table 2: Total mechanized equipment employed in paddy fields by the surveyed households in the Sivasagar, Nagaon, and Barpeta District of Assam.

Districts	Equipment	Equipment Used in Hours		
		S1	S2	S3
Sivasagar	Tractor	0	4.4	704
	Power tiller	0	16	2560
	Pumpset	0	15	533.34
	Draught Animal	0	30	172.5
Nagaon	Tractor	0	756.8	789.8
	Power tiller	0	2752	2872
	Pumpset	0	7347.84	646.2
	Draught Animal	0	120	195.8
Barpeta	Tractor	33	881.1	821.7
	Power tiller	52.8	1409.76	1314.72
	Pumpset	87	6194.7	517.92
	Draught Animal	97.5	157.5	165

Source: Primary Survey

Table 2 illustrates the working hours of different kinds of machine power and animate power on three types of farms (S1, S2, and S3) of Sivasagar, Nagaon, and Barpeta districts. As per the table, there exist significant variations between the utilization of farm machines and equipment on different spatial scale and farm size. In Sivasagar and Nagaon districts, the utilization of farm machinery and equipment is non-existent on S1 type farm while in Barpeta district the active use of all power sources is reported with the use of draught animals being the highest (97.5 hours) and pump set (87 hours). Sivasagar district utilizes the largest amount of machinery on S3 type of farm, consisting of power tiller (2,560 hours) and tractor (704 hours). On the other hand,

in Nagaon and Barpeta district, there exists extensive use of pump set in S2 farm (7,347.84 hours and 6,194.7 hours, respectively) depicting intense irrigation need from the underground water source.

There is an immense increase in the number of hours devoted to mechanical power which greatly enhances the Effective Field Capacity (EFC). This is made possible through replacing draught animals that work slowly and laboriously with tractors and power tillers, through doing so, farmers gain increased widths of working range, higher speeds of the ground operation, and decreased times of making field turns. The highly increased mechanical working hours will result in decreasing the

time taken to conduct important operations like puddling, soil preparation, and irrigation per unit area (per bigha/hectare). Thus, mechanical working hours being

high will lead to optimizing efficiency of field machines, ensuring timely agronomic operations, and increasing the total amount of area a farmer can handle.

$$\text{Effective Field Capacity (EFC)} = \frac{\text{Actual area covered (hectares or Bigha)}}{\text{Actual time taken (hours)}} [19, 20]$$

Table 3: Calculated values of Effective Field Capacity (EFC) in Sivasagar, Nagaon, and Barpeta Districts of Assam.

Districts	Equipment	Effective Field Capacity (EFC)
Sivasagar	Tractor	0.909
	Power tiller	0.25
	Pumpset	1.174
	Draught Animal	0.135
Nagaon	Tractor	0.909
	Power tiller	0.25
	Pumpset	0.175
	Draught Animal	0.135
Barpeta	Tractor	0.606
	Power tiller	0.378
	Pumpset	0.154
	Draught Animal	0.135

Source: Primary Survey

The Effective Field Capacity (EFC) ratios calculated in Table 3 reveal clear differences in terms of technology and operation amongst power sources in Sivasagar, Nagaon and Barpeta. Tractors exhibit the highest levels of operational efficiency, having an EFC of 0.909 in Sivasagar and Nagaon and 0.606 in Barpeta. Power tillers follow close behind, having a range of 0.25 – 0.378. On the other hand, draft animals exhibit the lowest level of capacity at 0.135 in all the three districts, while pump sets exhibit levels of capacity from 1.174 in Sivasagar to 0.175 in Nagaon and 0.154 in Barpeta.

The EFC differences directly have a structural impact on the Man-Machine Ratio (MMR). MMR refers to the ratio of total man hours to total machine hours. Implements with a higher EFC take less hours than those with low EFC to perform essential land preparation and operations in terms of area. This is because implements that exhibit low EFC use animate form of energy. The use of implements that have a high EFC makes it possible to reduce total man hours while increasing mechanical hours. This results in factor substitution and thus reduces the MMR [2].

$$\text{Man – Machine Ratio} = \frac{\text{Total human labour used in hours}}{\text{Total machine power used in hours}}$$

Table 4: Human labour (in hours) and machine operation (in hours) in paddy cultivation in Sivasagar, Nagaon, and Barpeta District of Assam.

Operation	Sivasagar		Nagaon		Barpeta	
	Human Labour	Machine Hours	Human Labour	Machine Hours	Human Labour	Machine Hours
Land Preparation	9660	4035.24	25308	15480.44	18936	11732.7
Transplantation	10304		22496		16832	
Weeding	1288		2812		2104	
Harvesting	10304		22496		16832	
Total	31556	4035.24	73112	15480.44	54704	11732.7

Source: Primary Survey

Table 4 provides an extensive analysis of human labour and machine time utilization throughout the major stages of agriculture including land preparation, transplantation, weeding, and harvesting in the three districts of Sivasagar, Nagaon, and Barpeta. The first point to be noted is that the use of machinery is limited to the land preparation phase alone, wherein the machine time is 4,035.24 hours in Sivasagar, 15,480.44 hours in Nagaon,

and 11,732.7 hours in Barpeta. On the other hand, transplantation, weeding, and harvesting phases continue to remain completely manual in all the three districts. Thus, in terms of total labour utilized, human labour hours overwhelmingly exceed machine hours in all the three districts, wherein Nagaon has the maximum number of human labour hours of 73,112 (15,480.44 machine hours), Barpeta has 54,704 human labour hours

(11,732.7 machine hours), and Sivasagar has 31,556 human Labour hours (4,035.24 machine hours).

As only the modern machinery is used for land preparation, the denominator of productivity is highly inflated due to large person-hour labour input involved in transplanting, weeding, and harvesting manually [21]. The use of mechanized equipment for land preparation not only results in better quality of seedbed but also

increases efficiency of land preparation but because of non-mechanization of other activities, there is a serious congestion in terms of labour input, resulting in reduced productivity gains. In case of districts like Nagaon and Barpeta, wherein the higher person-hour of machine input used for land preparation reflects higher total production level, Man-Machine Productivity is significantly hampered by the amount of person-hour labour input needed to mature the crop.

$$\text{Man - Machine Productivity} = \frac{\text{Total Agricultural Output}}{\text{Total Human Labour+Machine Input}} [22]$$

Table 5: Calculated results of Man-machine Productivity in Sivasagar, Nagaon, and Barpeta District of Assam.

Districts	Paddy Cultivating Seasons			Total Human Labour (in hours)	Machine Inputs (in hours)	Man-machine Productivity
	S1	S2	S3			
Sivasagar	0	1233.43	187380.76	31556	4035.24	5.29
Nagaon	0	396838.4	214106.63	73112	15480.44	6.89
Barpeta	10253.78	369857.05	208945.99	54704	11732.7	8.87

Source: Primary Survey

Table 5 represents the empirical estimate of Man-Machine Productivity of Sivasagar, Nagaon, and Barpeta districts based on the seasonal output of paddy vis-à-vis the total amount of labour and machines used. There exist significant spatial and structural differences in the productivity index, where Barpeta shows the highest score of 8.87, followed by Nagaon at 6.89, while Sivasagar registers the lowest one of 5.29.

The high level of productivity of Barpeta district is determined by the diversified production structure within all three seasons (10,253.78 units in S1, 369,857.05 in S2, and 208,945.99 in S3), which provides a considerable level of total output in respect of a low input base (the total amount of human labour 54,704 hours and machine

hours 11,732.7). On the other hand, Nagaon produces the highest level of output in S2 and S3 seasons (over 610,945 units), however, its intensive human labour (73,112 hours) and machines (15,480.44 hours) usage increase the denominator and provide for the middle-level of productivity. Finally, the lowest productivity score of Sivasagar (5.29) is associated with the heavy reliance on the single season production (S3 producing 187,380.76 units with almost no S2 and S1 outputs), providing a low level of total output in spite of a low absolute level of labour hours (31,556 hours human and 4,035.24 machines). Thus, the analysis shows that the diversified cropping season and optimal machine application provide a higher productivity.

Table 6: Energy used in paddy cultivation in the Sivasagar, Nagaon, Barpeta District of Assam (in Megajoule).

Districts	Tractor	Power tiller	Human Labour	Draught Animal	Pumpset	Total	Average MJ per Bigha
Sivasagar	44416.68	111283.2	61534.2	350.325	30877.0254	248461.4	385.8097
Nagaon	96971.82	242956.8	142568.4	546.334	450144.3924	933187.7	663.7182
Barpeta	108834.7	119978.496	106672.8	726.6	382886.6022	719099.2	683.5543

Source: Primary Survey

The operational energy use patterns in Megajoules for paddy farming in Sivasagar, Nagaon, and Barpeta districts have been demonstrated in Table 6. The highest overall energy use is recorded in Nagaon district at 933,187.7 MJ, followed by Barpeta district at 719,099.2 MJ and Sivasagar district at 248,461.4 MJ. In terms of energy intensity on a per unit area basis, however, Barpeta district comes first at 683.55 MJ/bigha, followed closely by Nagaon district at 663 MJ/bigha.

The results show that with an increase in mechanization, cropping intensity goes up to 152-162%, while productivity improves and labour involvement reduces

[24]. The average productivity of rice in Assam during the year 2018-2019 was 2271 kg/ha [25], which increased to 2652 kg/ha during 2022-2023. Rice productivity in two out of three districts analyzed for this study, namely Nagaon and Barpeta, reached 3250 kg/ha and 41 57 kg/ha, respectively.

In the case of the regression analysis model in Sivasagar, the value of the ANOVA coefficient beta score is 0.001, thus justifying its validity and applicability. In the case of the constant quantity of mechanical energy, the constant yield is 2086.97 kg/ha. On using additional 1 MJ of mechanical energy, there is an increase of 0.032 kg/ha in

the productivity of rice. This is a yield of 39.424 kg/ha on the use of the maximum possible amount of mechanical energy per hour, which results in 5.277 kg/bigha of rice.

The ANOVA coefficient in Nagaon district is 0.000, meaning there is a significant level of importance here. It also shows how the rise in productivity of rice occurs, with a value of 0.07 kg/ha per each increment of 1 MJ of mechanical energy per hectare. The base value of rice productivity remains 2705.711 kg/ha with constant consumption of mechanical energy. With the maximum consumption of mechanical energy, it produces 86.27 kg/ha of rice per hour, or 11.55 kg/bigha.

Using the base level of rice production, kg/ha, the ANOVA coefficient for the Barpeta region is 0.002, thus validating the significance level of the model. As per the model, the capacity of producing 119.557 kg/ha in the maximum utilization of mechanical energy inputs is 16.005 kg/bigha in an hour and increases by 0.097 kg/ha for each 1 MJ of mechanical energy used.

The districts of Sivasagar, Nagaon, and Barpeta have a positive relationship between mechanical energy employed in cultivating rice and its productivity; yet the level of the correlation differs in relation to the amount of energy spent. In the process of cultivating rice, all three districts employ different technologies in differing levels. For the same level of mechanical energy in 1 MJ, the productivity of rice differs in 0.032, 0.07, and 0.098 kg/ha depending on the level of mechanical skills in the three districts respectively. For the same input of mechanical energy, Barpeta District is more probable to produce productively compared to Nagaon District.

CONCLUSION

Empirically speaking, the need for modernization of farm power regimes is a key to revolutionizing rice productivity in the agro-climatic regions of Assam. The structural shift from animate to motorized power has led to increased field capacity and multi-seasonal cultivation practices in the Central and Lower Brahmaputra Valley areas. The current state of mechanization displays considerable operational imbalance: while costly equipment is limited to initial land preparation stages only, the tasks of transplanting and harvesting are still performed manually. Consequently, high amounts of labour absorption, constraining the man-machine productivity potential and creating wage/labour shortages during peak seasons, occur. Moreover, severe land fragmentation, scarcity of resources of the marginal smallholders and agro-ecological problems still prevent equal access to mechanical means of production. To ensure a sustainable increase in productivity levels, policy efforts have to go beyond mere tractorization. Relevant steps should be taken to improve decentralized hiring systems, develop micro-machinery suitable for fragmented parcels, provide for electricity-powered irrigation in order to cut down operational costs of fuel

and introduce mechanized transplanters and combine harvesters.

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