



Investment on Farm Mechanization Intensifies Cropping and Enhance Farmer's Income: A Meso Analysis from Semi-arid Tropics of India

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Abstract: Despite the gloomy prospects for farm tractor use in the irrigated region of India depicted in studies from the 1970s and 1980s, over time the region's farmers have adapted tractor technology innovatively and used it for many purposes. Over one third of India's geographical area i.e. 116.4 m ha is in the semi-arid tropics in India which support about 265 m people in the rural areas. Low and unpredictable rainfall, combined with extreme temperatures and intense solar radiation, render these regions among the most vulnerable in India. In Semi-Arid Tropic India, tractors are widely used for farming operation, rural transportation and for various non-farm activities in urban areas, as well. This study analyzes the determinants of the tractor use as well as consequence of tractors on crop productivity, and the intensification of agriculture in SAT India. Panel regression model used to study the impact and determinants of tractor use in SAT India. Data was collected from Village Dynamics of South Asia (VDSA) published by ICRISAT. Tractor use across the semi-arid region of India was positively affected by the amount of institutional credit, higher cropping intensity, and higher literacy of HH head. It was concluded that tractor use has positively impacted both the intensification of agriculture and farm productivity. Further, it is revealed that, uses of the tractor in SAT India is helping in increasing farm productivity and cropping intensity. Tractor intensity grew at a fast pace even in low-wage regions of India, indicating that relatively lower labor wages might not have been a binding factor for diffusion of farm machinery and tractors among smallholding farmers in India.

Key words: Farm mechanization, semi-arid tropics, panel regression modeling, tobit model.

Farm mechanization in India, particularly the adoption of tractors has advanced substantially, and its critical contribution to agricultural growth is well established (Binswanger, 1986; Pingali, 2007; Bhattarai *et al.*, 2017). Over the decades, the country has experienced a decisive transition from human and draught-animal power to mechanical and motorized sources. Available estimates indicate that animate power contributed about 91.20% of total farm power availability in 1961-62, but its share had fallen to 4.45% by 2024-25, (Singh *et al.*, 2025). A similar trend is evident in earlier assessments, where animate power constituted 69% of total farm power in 1971-72. By 2021-22, mechanical and electrical power had come to dominate, accounting for approximately 95% of the total farm power availability of 3.04 kW ha⁻¹ (Mehta *et al.*, 2023). Among mechanical sources, tractors play the most prominent role, contributing approximately 48% of total farm power (Gulati and Juneja, 2020) which further increased to 51.84% of farm power availability in India (Singh *et al.*, 2025). Overall, the share of mechanical sources including tractors, power tillers, combine harvesters, and diesel engines have continued to rise, increasing from 6.39% in 1961-62 to about 75.57% in 2024-25 (Singh *et al.*, 2025).

The number of tractors in India has expanded rapidly, growing at an average rate of more than 8% yr⁻¹ over the past three decades (Bhattarai *et al.*, 2017). In recent years, India has consolidated its position as the world's largest tractor producing nation, manufacturing close to one million units annually in 2021, 2022, and 2023, and exporting approximately 100,000 tractors yr⁻¹ during the same period. Nonetheless, above 9.17 m tractors are currently available for farm operations in India, but their density is highly skewed across the states (Mehta *et al.*, 2023). The states of Indo-Gangetic regions like Punjab, Haryana, and Uttar Pradesh have higher density of tractors compared to the national average of around 50 tractors per thousand hectares, but for the states falling under Semi-Arid Tropics (SAT), the density is below the national average (Tractor and Mechanization Association, 2019).

The Indian SAT is one of the most significant agro-ecological zones in the country's agricultural economy. It accounts over 1/3rd of India's geographical area (116.4 m ha) and

contributes nearly half of the nation's food grain output and 2/3rd of its oilseed production (Katyal *et al.*, 1997). Enhancing agricultural productivity in rainfed areas particularly in the SAT regions is crucial for ensuring national as well as global food security in the 21st century (Joshi *et al.*, 2001; Wani *et al.*, 2011). A survey of the literature highlights the crucial role of investment in farm mechanization in boosting crop yields across the Gangetic plains of India (Randhawa, 1977; Sindhu and Grewal, 1991; Singh, 2001; Gulati *et al.*, 2021), however evidence of farm-level impacts from Indian SAT is currently limited. Additionally, factors influencing investment in farm mechanization by the farmers in these ecologically fragile regions are poorly explored. The present study, therefore, focusing on tractor use as a case, aims to address this literature gap by exploring two important research questions: (i) what are the key determinants influencing farmers' decisions to invest in farm tractors in SAT, and (ii) does investing in tractor use prove to be profitable in terms of farm income

Materials and Methods

The study uses 6 years (2009-2014) household level panel data from five states namely Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh and Maharashtra. The secondary data was sourced from Village Dynamics of South Asia (VDSA) published by ICRISAT, Hyderabad. The study area is true representative of semi-arid region India. Although the dataset is dated, it remains valuable from a methodological perspective, particularly because large, household level datasets covering the entire SAT (Semi-Arid Tropics) region of India are not readily available. Drawing from the extensive literature on farm mechanization (Pingali, 2007; Singh *et al.*, 2014; Bhattarai *et al.*, 2017), a total of 12 variables were hypothesized to influence farmers' decisions to use tractors in the study region. Since, household is the ultimate clientele of farm technology; hence household characteristics like age of the family head, household size and education status are important parameters to be considered in adoption process (Nkegbe and Shankar, 2014). Further, farm characteristics and institutional factors have also been reported as key influential factors in technology use process (Sharma *et al.*, 2021). Further considering access to credit

services is important as they influence farmer’s decision through transaction costs.

Analytical framework

Determinants of tractor use: Tobit regression model (Tobin, 1958 and Wooldridge, 2002) was used to know the factors influencing tractor uses in the selected Indian states

$$Y_{it}^* = \beta_i X_{it} + u_{it} \quad \dots 1$$

where Y_{it}^* = Unobserved latent variable, β_i is regression parameter vector, X_{it} are explanatory variables and u_{it} is random error with $N(0, \sigma^2)$

$$Y_{it} = Y_{it}^* \text{ if } Y_{it}^* > 0$$

$$Y_{it} = 0 \text{ if } Y_{it}^* \leq 0$$

Y_{it} = Observed dependent variable

$$D_i = 1 \text{ if } Y_{it} > 0$$

$$D_i = 0 \text{ if } Y_{it} \leq 0$$

The probability of an observation representing a household that does not use tractor:

$$P_i \left\{ Y_{it} = \frac{0}{Y_{it}^*} \right\} = P_i \{ D_i = 1 \} = P_i \{ X_{it} \beta_i + e_i \leq 0 \} \\ = \left[1 - F \left(\frac{X_{it} \beta_i}{\sigma} \right) \right]$$

Disturbance term follow the normal distribution with σ , therefore, maximum likelihood function can be employed to get the estimation of slope coefficients

$$L = \prod [1 - F(X_{it} \beta_i / \sigma)]^{(1-D_i)} \{ 1/\sigma f[Y_i - (X_{it} \beta_i / \sigma)]^{D_i} \} \\ \ln L = \sum (1 - D_i) \ln [1 - F(X_{it} \beta_i / \sigma)] + D_i \ln \{ 1/\sigma f[Y_i - (X_{it} \beta_i / \sigma)] \}$$

where, $F((X_{it} \beta_i) / \sigma)$ = standard normal cumulative distribution

Slope coefficient in the tobit model is not a marginal effect of explanatory variables, this is the total effect of two components i.e.;

1. Change in the probability that the HH will use tractor
2. Change in the value of dependent variable if it is already used.

Similarly, elasticities can be calculated separately for both i.e. the elasticity of probability that HH will use tractor and the income elasticity of HH who already used tractor.

The expected value in the tobit model calculated as:

$$E(y) = X_{it} \beta_i F(X_{it} \beta_i / \sigma) + \sigma f(X_{it} \beta_i / \sigma)$$

The marginal effect of expected value $E(y)$ with respect to explanatory variables will be calculated as:

$$dE(y)/dX_{it} = X_{it} \beta_i F(X_{it} \beta_i / \sigma)$$

The elasticity of expected value $E(y)$ with respect to explanatory variables

$$\eta_{yx} = (dE(y)/dX_{it})(X_{it}/E(y))$$

$$\eta_{yx} = \beta_i F(X_{it} \beta_i / \sigma)(X_{it}/E(y))$$

The elasticity represents the total effect of the probability that HH use tractor and income elasticity represents that of HH who already used tractor.

The elasticity of the probability that HH will use tractor is defined as:

$$\eta_{pr,x} = (\beta_i / \sigma) f(X_{it} \beta_i / \sigma) [X_{it} / F(X_{it} \beta_i / \sigma)]$$

The income elasticity is calculated by subtracting the elasticity of the probability from the total elasticity:

$$\eta_{p^*x} = \eta_{yx} - \eta_{pr,x}$$

Impact of tractorization: To assess the impact of tractor use on crop intensification and farmer’s income from crops, two panel models was constructed. Panel modeling allows us to control the household heterogeneity and separate out impact of tractorization from other associated factors like irrigation and input use.

Model I was defined as

$$Y_{it} = \beta_0 + \beta_1 X_{1it} + \beta_2 X_{2it} + \dots + \beta_n X_{nit} + u_{it} \quad \dots (2)$$

where, Y_{it} represents cropping intensity of i^{th} household ($i = 1, 2, \dots, 850$) in the t^{th} year value ($t = 2009, 2010, \dots, 2014$), X 's are the explanatory variables (tractor use, lagged irrigation intensity, lagged credit, etc.) and u_{it} are disturbance term.

The other model was the same as Model 1, but farmers’ income (Rs. per acre) replaced the cropping intensity in the Model 2.

The panel data estimation technique involves fixed and random effect model; however, choice of the model is guided by the Hausman test (Hausman, 1978). The fixed effects assume that the individual specific effect is correlated to the regressors, while random effects assume that individual specific effects are uncorrelated with the regressors (Choudhary and Sirohi, 2020; Singh *et al.*, 2021). Both fixed and random effects model were attempted and based on

Table 1. Definitions and summary statistics of selected variables

Variables	Description	Mean	SD
Income	Farmer's average income from crops cultivation (rupees per acre)	19537.92	27582.83
CI	Cropping intensity (%)	132.34	35.86
TRACTOR	Investment in tractor use (rupees per acre)	1411.45	779.99
Gender_HH_Decision	Gender of Household who take decision (female = 1, 0 otherwise)	0.093	0.29
AGE_HH	Age of household head (in years)	50.78	12.41
EDU_HH	Number of year studied (in years)	4.98	4.78
HH_SIZE	Family size (Number)	2.86	1.86
LAND	Operational land holding (acre)	7.82	7.19
IRRI	Irrigated area to gross cropped area (%)	47.78	43.09
Area foodgrains	Area under food grain to gross cropped area (%)	98.94	7.49
Credit_NI	Non-institutional credit (rupees per acre)	4026.41	14493.00
Credit_I	Institutional credit (rupees per acre)	3178.98	17739.84
HL	Hired labor (rupees per acre)	2710.64	5243.61
FL	Family labor (rupees per acre)	3458.42	3485.41

the Hausman test, and fixed effect model was selected.

Results and Discussion

Choice of variables and its descriptive statistics

Table 1 depicts the definitions and summary statistics of the selected variables used in the present study.

Determinants of tractor use

The estimates of panel tobit model are presented in Table 2. Concerning the household characteristics, we found that if female is taking the decision of farming operation, then investment in tractor use is more. This is probably because women are sensitive to farm drudgery and hence opt for mechanization. Households with more family members are less likely to invest in tractors. This could be attributed to the fact that more family labor is usually available for farm work in large sized households.

Unsurprisingly, cropping intensity which connotes farm intensification positively influences investment on tractor use. These findings are in congruence with the study of Singh (2015) and Bhattarai *et al.* (2017) on tractor density across the major state of India.

The results further indicates that if household use more hired labor on farm than probability of their investment on tractor is more. The logical reasoning is that investing in farm

mechanization is better option than investing in hiring labor for timeliness and efficiency of farm work. It was found that the ratio of acreage under food grains to the gross cropped area is negatively associated, exhibiting a high elasticity value. This result contrast with prior information from earlier studies conducted in irrigated regions (Agarwal, 1981). Further, the positive and significant relationship between access to institutional credit and investment decision regarding tractor use. Credit relaxes liquidity constraints and increases household's risk bearing ability and thus and stimulates farm investment and technology adoption decisions (Ghimire *et al.*, 2015).

The coefficient of variable "time trend" is very high and positive (177.87) and with an elasticity value (0.64) indicates steep growth trend of tractor use in SAT India. These may be improvements in general technologies for tractors or implements or production technologies that universally tractors use in SAT India.

Impact of Tractor Use

The estimated results of the Fixed effect models are presented in Table 3. The estimated results of the random effects model and the Hausman test are presented in Table 4 and 5 respectively. The Hausman test indicates that the fixed effects model provides a better fit for this dataset. The Model 1, one-year lag value of the irrigated acreage and credit (both institutional and non-institutional credit) was used (Table 3) as cropping acreage is decided on the basis

Table 2. Factors affecting investment in the tractor use

Determinants	Coefficients (β)	Elasticity (e_y/e_x)	p values
Gender of household	135.96*	0.006	0.08
Age of household head (in years)	0.57	0.03	0.69
Number of year studied (in years)	2.93	0.02	0.41
Family size (Number)	-32.05***	-0.15	<0.001
Cropping intensity (%)	1.08***	0.15	<0.001
Operational land holding (acre)	1.19	0.008	0.60
Irrigated area to gross cropped area (%)	0.25	0.01	0.46
Area under food grain to gross cropped area (%)	-4.33***	-0.44	<0.001
Non-institutional credit (rupees per acre)	-0.00004	-0.0003	0.921
Institutional credit (rupees per acre)	0.001***	0.006	0.004
Hired labor (rupees per acre)	0.03***	0.06	<0.001
Family labor (rupees per acre)	0.005	0.01	0.36
Time trend (1 to 6)	177.87	0.64	<0.001
sigma_u	453.17		<0.001
Sigma_e	538.16		<0.001
Rho	0.41		

Likelihood-ratio test of sigma_u=0: chibar2(01) = 788.20, prob<0.001

Source: Author's estimation

The average elasticity value is estimated after running the model. The elasticity value reported is the average of a series of elasticity values generated at the sample mean of the dependent variable and each point of the independent variables by Stata/MP 15.1 software. The sign ***, ** and * indicate significance at the 1%, 5% and 10% level of significance, respectively.

of previous year expectation instead of current event (Nerlove and Bachman, 1960; Narayana and Parikh, 1981; Mythili, 2008). Our estimates suggest a positive and statistically significant relationship between investment in tractor use and crop intensification. A unit percentage increase in investments on farm tractor in SAT significantly increases cropping intensity by 0.03% points. The plausible explanation is that use of tractor in ensures timeliness of various farm operations such as such as land levelling, sowing and planting, harvesting and threshing and increases input use efficiency at farm. This helps in increasing area under cultivation and increase in cropping intensity.

Our finding is in congruence with the results reported from by Agarwal (1984) from Indian state of Punjab. The study of Sarkar *et al.* (2013) and Barman *et al.* (2019) from the eastern Indian states also confirms the positive relation between farm mechanization and cropping intensity. The significant and positive association of previous year irrigated area with cropping intensity is as per our hypothesis and in agreement of the previous studies (Binswanger, 1978; 1986; Sarkar, 2013).

However, food grains acreage found to deter the crop intensification in the semi-arid tropics.

Our Model 2 establishes that a 1% increase in investment in tractor use increases the monetary gains from an acre of crops by 0.05% and the estimated impact is statistically significant. The crucial role of farm mechanization in accentuating land productivity is widely established (Verma, 2006; Barman *et al.*, 2019). Moreover, mechanization provides good scope for commercialization of agriculture. Nonetheless, farm machinery substitutes human labor inelastically (Srivastava *et al.*, 2017), its role in saving the labor cost, both human and bullock, and hence reducing the cost of production cannot be denied in Indian agriculture (Sarkar *et al.*, 2013).

The others variables which positively influences crop income in SAT includes acreage under foodgrains and size of household. One per cent increase in acreage under food grain is associated with 1.59% higher income from crop farming. Nonetheless, contrasting effect of household size on farm income has been reported in economic literature (Carter, 1984; Ali and Deininger, 2015; Emran *et al.*, 2021),

Table 3. The regression estimates of fixed effect models

Parameters	Crop intensification model		Income model	
	Coefficients (SE)	Elasticity (e_y/e_x)	Coefficients (SE)	Elasticity (e_y/e_x)
Tractor use (Rs. per acre)	0.004***	0.03	1.05**	0.05
One year lagged irrigated area to gross cropped area (%)	0.05**	0.01	8.85	0.02
Area under food grain to gross cropped area (%)	-0.21***	-0.16	339.49***	1.59
Cropping Intensity (%)	-	-	-4.22	-0.03
Institutional credit (rupees per acre)	-7.9e-07	-0.00007	-0.01	-0.003
Non-institutional credit (rupees per acre)	0.00003	0.001	0.02	0.005
Family size (Number)	0.51	0.02	375.67**	0.08
Number of year studied (in years)	0.10	0.004	-41.20	-0.01
Age of household head (in years)	0.03	0.01	-186.37**	-0.44
Gender of Household head who take decision	-11.43	-0.004	-532.79	-0.001
Time trend (1-6)	0.68	0.02	2764.89***	267.47
Sigma_u	24.09		17901.96	
Sigma_e	30.70		14268.41	
Rho	0.38		0.61	
F statistics	2.51, prob> F <0.0001		2.45, prob> F <0.0001	

Source: Author's estimation

The sign ***, ** and * indicate significance at the 1%, 5% and 10% level of significance, respectively.

but in semi-arid regions, household with large number of economically active members saves the hired labor cost in farm operations (Noack and Larsen, 2019). The negative and significant coefficient of age of household in Income model suggests that younger farmers are more productive in the farming operations

in the Indian SAT regions. Therefore, policy for incentivizing youths in agriculture would be more imperative in accentuating crop productivity and farmer's income in long run.

Time trend has very high elasticity value (267.47%), which indicates a very steep growth

Table 4. The regression estimates of random effect models

Parameters	Crop intensification model		Income model	
	Coefficients (SE)	Elasticity (e_y/e_x)	Coefficients (SE)	Elasticity (e_y/e_x)
Tractor use (Rs. per acre)	0.003***	0.02	1.24***	0.06
One year lagged irrigated area to gross cropped area (%)	0.11**	0.03	71.18***	0.15
Area under food grain to gross cropped area (%)	-0.09**	-0.07	232.68***	1.11
Cropping Intensity (%)	-0.00002	-0.0007	-14.78*	-0.10
Institutional credit (rupees per acre)	-0.00004	-0.002	0.02	0.004
Non-institutional credit (rupees per acre)	1.14***	0.04	0.05***	0.01
Family size (Number)	0.33**	0.01	224.12	0.05
Number of year studied (in years)	0.03	0.01	-12.82	-0.003
Age of household head (in years)	-8.70	-0.003	-132.01***	-0.32
Gender of household head who take decision	1.22***	0.03	-841.18	-0.001
Time trend (1-6)	0.003***	0.02	2663.81***	261.88
Sigma_u	15.23		12336.66	
Sigma_e	30.70		14268.41	
Rho	0.20		0.43	
F statistics	2.42, prob> F <0.0001		2.54, prob> F <0.0001	

Source: Author's estimation

The sign ***, ** and * indicate significance at the 1%, 5% and 10% level of significance, respectively.

Table 5. Hausman test

Particulars	Cropping intensity			Farm productivity		
	fe (b)	re (B)	Std. Error	fe (b)	re (B)	Std. Error
Tractor use (Rs per acre)	0.004	0.003	0.0006	1.05	1.24	0.19
Lagged irrigated area to GCA	0.05	0.11	0.01	8.85	71.18	4.37
Area under food grains to GCA	-0.21	-0.09	0.03	339.49	232.68	8.09
Cropping intensity (%)	-	-	-	-4.22	-14.78	1.84
Lagged institutional credit (Rs per acre)	-7.95e-07	-0.00002	0.00001	-0.01	0.02	0.001
Lagged non-institutional credit (Rs per acre)	<0.001	-0.00004	0.00001	0.02	0.05	0.0007
Total family size	0.51	1.14	0.34	375.67	224.12	118.48
Number of year studied	0.10	0.33	0.32	-41.20	-12.82	130.96
HH head age	0.03	0.03	0.16	-186.37	-132.01	67.65
HH decision	-11.43	-8.70	7.44	-532.79	-841.18	3093.11
Time trend (1-6)	0.68	1.22	0.23	2764.89	2663.81	72.92

$$\chi^2 = (b-B)'[(V_b - V_B)^{-1}](b-B)$$

$$\text{Prob} > \chi^2 = <0.001$$

trend of farm productivity across the SAT India. In the panel regression model estimated, the time trend variable (1=2009 to 6=2014) controls for other SAT India factors that linearly affects farm productivity levels over time. Those may include improvements in general technologies at the international or India level including improved cultivation or agronomic practices, inclusion of high yielding varieties that universally raise production efficiency.

Conclusion

After the assessment of determinants affecting tractor use in SAT India, it is concluded that the level of tractor uses in SAT India is determined by availability of high amount of institutional credit, higher cropping intensity, and higher literacy of HH head. Despite the relatively low rural wage economy, the use of tractor in SAT India is increasing. It is reported that area under food grain crop is not a binding factor for tractor use in SAT India. This could be due to uses of tractors in other crops than food grain crops which are mostly found in irrigated area. The results imply that education and wage rate (for hired labor) are factors which promote the tractor uses. Although a formal analysis is precluded due to the changes in costs between tractor use and animal traction use rather than changes in labor wages and institutional innovations in hiring service.

Based on research findings it was concluded that tractor use has positive and significant impact on both cropping intensity and farm productivity (rupees per acre). Hence, research

findings revealed that, higher uses of tractor in SAT India are helping in increasing farm productivity and cropping intensity. This study concludes that factors affecting cropping intensity and farm productivity are differing to each other but tractor uses in term of rupee per acre is a common factor which influences both cropping pattern and farm productivity by same pattern.

Declaration of conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Declaration about use of data: The dataset used in the manuscript is derived from ICRISAT VDSA. The dataset is freely available in the public domain and accessible for research purpose only.

Contribution of Authors

Ravindra Singh Shekhawat: designed the study, conceptualization, investigation and writing.

V.S. Rathore: Preparation of original draft and review.

Dinesh Kumar: Investigation and editing

K.N. Singh: Supervision and conceptualization

Achal Lama: Formal Analysis and drafting of the manuscript.

Bishal Gurung: Methodology and formal analysis

Bishwa Bhaskar Choudhary: Review and editing

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