Indian Journal of Agricultural Economics 80: 4 (2025):1418-1434
DOI:10.63040/25827510.2025.04.012

RESEARCH NOTE

Surface Seeding Technology for Bridging the Paddy-Wheat Gap: Assessment of Economic Viability and Environmental Sustainability

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ABSTRACT

Paddy residue management and high soil moisture content are the two major issues faced by farmers of lowland area of Indo-Gangetic Plains, obstructing the seamless paddy-wheat transition. Surface seeding technology is a resource-conserving technology that can overcome both constraints, increase productivity, and reduce resource depletion altogether. In economic terms, SST in comparison to conventional tillage was profitable due to reduced cost of cultivation and increased returns. SST has the potential to optimize resource utilization as the resources are underutilized. Environmentally, the technology can earn carbon credits by reducing carbon emissions. Additionally, SST contributed in mitigating the overexploitation of groundwater by enhancing water productivity, reflecting higher output production per unit of water. Mass adoption of SST can transform wheat cultivation in lowland areas in a sustainable and economically viable way. .

Keywords: Surface seeding technology, wheat, resource conservation technology, carbon emission, Uttar Pradesh

JEL codes: C83, Q01, Q16, Q56

I

INTRODUCTION

India's transformation from a deficit to a surplus nation was majorly attributed to advanced technologies such as tillage, substantially increasing rice and wheat production (Hazell, 2009). Although conventional tillage contributed in maintaining food security, it came at the significant cost of loss of soil fertility (Ladha et al., 2009), carbon loss (Ahmad et al., 2024), high energy consumption, water scarcity (Chaki et al., 2021), low economic productivity, residue retention and rising environmental degradation (Bhatt et al., 2016). Across the globe, tillage has been ranked the third largest consumer of fossil fuel and a significant contributor to greenhouse gas emissions (Saber et al., 2020; Ahmad et al., 2024). Over exploitation of natural resources over decades had resulted in stagnated productivity of rice-wheat cropping system (Bhatt et al., 2021; Dhanda et al., 2022). The rice-wheat cropping system is the backbone of the Indo-Gangetic region and critically contributes to food security and employment generation (Kumar et al., 2019; Nawaz et al., 2019). Promoting a sustainable agricultural production, shift from conventional tillage to conservation agriculture is the need of the hour.

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1.1 Challenges in Paddy to Wheat Transition

In India, the transition from paddy (Kharif) to wheat (rabi) in traditionally rice-wheat growing dominant regions of Indo-Gangetic Plains is faced with several problems of agronomic, environmental and socio-economic nature. The two significant issues that majorly concern the transition every year are:

1.1.1 Paddy Residue Management

Paddy stubble burning is one of the prime contributors to air pollution in the month of October-November in north India. The occurrence of stubble burning is high in north India because farmers only get 15-20 days gap between paddy harvesting and wheat sowing for in-situ management of paddy stubbles (Reddy and Chhabra, 2022). Any delay in the process would restrict the tillage and sowing operations of the successive wheat crop (Dhanda et al., 2022) and adversely affect the quality and quantity of the crop yield (Kedia et al., 2020). Across the globe, burning rice and wheat stubble produces 13.79 million tons of CO2 equivalent. In the Indian scenario, of the total crop residue (620 MT), nearly 92 MT is burned in the fields directly, of which 62 percent is rice and wheat residue (Singh et al., 2020). The economic cost of air pollution caused by intense crop residue burning (CRB) is estimated to be around $30 billion annually (Air Pollution from stubble burning, 2019). On average, burning 1 ton of paddy stubbles leads to the loss of soil's macronutrients in bulk (Kumar et al., 2019) and also radiates heat, which is responsible for killing the fungus and bacteria present in the soil resulting in soil degradation (Arora, 2022). Rice residue management is complex due to its limited use in animal husbandry (Arora and Sehgal, 1999; Dhanda et al., 2022) and nitrogen immobilization by incorporating fresh paddy stubbles in soil (Singh and Sidhu, 2014).

1.1.2 High Soil Moisture Content

Rice, a water-intensive crop grown in flooded fields, leaves behind standing water; this condition worsens in lowland areas of Indo-Gangetic plains due to poor natural drainage as most parts of the lower IGP comprise heavy soils like clay soil. Waterlog fields make unfavourable conditions for conventional tillage and also delay the process of seedbed preparation, resulting in late sowing and impacting the quality and quantity of the produce. This forces small-scale farmers with limited resources to leave their lands fallow, thus increasing their economic vulnerability and food insecurity (Mahto et al., 2006). High soil moisture levels in heavy soils or fine-textured soils make the soil sticky, leading to clod formation and making it more difficult to plough.

1.1.3 Surface Seeding Technology

Surface seeding technology is a resource conservation technology beneficial in regions with fine textured and poor drainage soils where land preparation is difficult due to clod formation (Mahto et al., 2006). Under this technology, farmers broadcast the wheat seeds directly onto the wet soil surface before or after the standing paddy is harvested without any prior tillage operation (Hobbs and Gupta, 2004; Dey et al., 2022). SST provides a sustainable solution to two bottlenecks: stubble burning and high soil moisture content at the time of paddy harvesting. In addition to this, SST has several other advantages; some of them are- enhances productivity and profitability, reduces irrigation water requirement, is suitable for any size of the field, advances wheat sowing, reduces the cost of cultivation, reduces carbon footprint, enhances soil organic content etc. (Erenstein et al. 2007; Singh et al. 2022).

1.2 Research Gap

Western Uttar Pradesh is agriculturally more developed than Eastern Uttar Pradesh, with better infrastructure, advanced mechanization and larger landholding size (Nawaz et al., 2019; Bhatt et al., 2021). Agronomically, western U.P. has fertile soil with better natural drainage. The rice-wheat cropping system in the region is mainly mechanized, input-intensive and farmers do conjunctive use of water for irrigation. In contrast, the eastern U.P. region faces problems such as moderate to low soil fertility with poor drainage, leading to waterlogging and salinity conditions (Gupta and Seth, 2007). The farmers due to socio-economic constraints have low input use. Therefore, surface seeding technology is a boon in regions with poor soil conditions and smaller fragmented landholdings. Despite its remarkable benefits, technology has failed to grab the attention of both farmers and researchers. Moreover, very little research has been conducted on studying the effects of SST, and not much information is available about the economic aspect of the technology. Thus, the study is focused on unleashing the economic and environmental potential of surface seeding technology in Eastern Uttar Pradesh, which showcases SST as the future of sustainable wheat cultivation by subduing the issue of stubble burning.

II

METHODOLOGY

The current study was designed as a collective case study to analyze the extent of SST's economic and environmental benefit (i.e., the case of both SST adopters and conventional adopters/SST non-adopters). These comparisons face severe methodological limitations (Nemes, 2009), and the process gets complicated, where record keeping is poor and high variations are found in quantitative data (Keita et al., 2010).

2.1 Primary Data

A preliminary survey was conducted to identify the districts with the maximum adoption of SST in Eastern Uttar Pradesh. During the survey, a list of districts where SST was adopted and continued was prepared. Based on this, Chandauli and Mirzapur districts were purposively selected due to the higher prevalence of the technology in both districts. One adopter block and one non-adopter block under each district were selected. The snowball sampling method was used to identify the adopters and non-adopters. A total of 160 adopters and 160 non-adopters, respectively, were selected randomly. Non-adopters were selected considering their proximity to the adopter block to ensure similar agro-climatic conditions for wheat cultivation. Therefore, data was collected from a total of 320 respondents.

2.2 Analytical Tools

2.2.1 Costs and returns

Quantitative analysis is mainly comprised of calculating the cost of cultivation and various income measures based on cost concepts given by the Commission for Agricultural Costs and Prices (CACP) (Rao, 2001). The profitability of adopting SST was compared by calculating the net rupee per investment for adopters and non-adopters

The different costs incurred by both adopters and non-adopters is given below:

Cost A1: Wages of human labour + Charges of implements and machinery + Costs incurred on seed + Cost incurred on fertilizers + Cost incurred on plant protection chemicals + Irrigation charges + Interest on working capital + Land revenue + Miscellaneous expenses

Cost A2: Cost A1 + Rent paid for leased in land

Cost B1: Cost A2 + Interest on owned fixed capital assets excluding land

Cost B2: Cost B1 + Rental value of owned land

Cost C1: Cost B1 + Imputed value of family labour

Cost C2: Cost B2 + Imputed value of family labour

Cost C3: Cost C2 + 10 % of cost C2 (managerial cost)

Income measures: These are derived as difference between returns and costs. The different income measures are given below:

Gross farm income = average yield per ha (kg) × average price per kg (₹)

Net income = Gross income – Cost C_2

Net return per rupee of investment = $\frac{\text{Net Return (₹)}}{\text{Total Cost (₹)}}$

The economic benefits received by SST adopters were also calculated by finding the difference of different costs incurred by adopters and non-adopters.

2.2 Allocative Efficiency

To estimate the allocative efficiency, Cobb-Douglas production function was exercised to analyse the effect of resource variables such as seed, fertilizers, human and machine labour, plant protection chemicals and manures on the wheat production under SST adopter and non-adopter farms.

In mathematical form the production function can be presented as:

$$Y = a\, X_1^{b_1} X_2^{b_2} X_3^{b_3} X_4^{b_4} X_5^{b_5} X_6^{b_6} \quad \ldots\ldots\ldots\ldots (1)$$

Where

Y is the Income from yield (₹) per hectare and Xi s are the various inputs used (in ₹) per hectare. The explanatory variables considered for the study were:

X_1 =Expenditure on seed (₹)
X_2 =Expenditure on fertilizers (₹)
X_3 = Expenditure on human labour (₹)
X_4= Expenditure on plant protection chemicals (₹)
X_5= Expenditure on manures (₹)
X_6 = Expenditure on machine labour (₹)
a = constant
b_i = elasticities of resources/inputs (X_i's)
e_μ = error term

The log form of the production functions in equation (1):

$$\ln y = \ln a + b_1 \ln X_1 + b_2 \ln X_2 + b_3 \ln X_3 + b_4 \ln X_4 + b_5 \ln X_5 + b_6 \ln X_6 + U$$

for functional analysis the above equation was converted into value terms, which was then represented in the following form:

ln (Income) = ln a + b_1 ln (Seed) + b_2 ln (Fertilizer) + b_3 ln (Human Labour) + b_4 ln (Plant Protection Chemicals) + b_5 ln (Manure) + b_6 ln (Machine Labour) + U

The coefficients β_i (i=1,2,3,4) are the elasticities of the respective resource variables relating to the income earned from wheat production by both SST adopters and non-adopters, with the assumption that $\beta i > 0$.

The resource use efficiency of wheat was studied as expressed below:

$$r = MVP/MFC$$

Where,

r is the allocative efficiency ratio
MVP is the marginal value product of the respective input; MVPi $= b_i \frac{\bar{y}}{\bar{x}}$
[$\bar{y}$ = Geometric mean of output; $\bar{x}$ = Geometric mean of i^{th} input]

MFC is the marginal factor cost or price per unit of input and assumed as ₹1 for all the inputs

Decision rule:

If r = 1, then the level of resource use is at optimum suggesting efficient resource utilisation.

If r <1, then the resource is over-utilised implying decrease in quantity is expected to maximise profits till *r* becomes equal to 1.

If r > 1, the resource is under-utilised, indicating an increase in inputs will increase the profit to the level when r falls to 1.

2.3 Environmental Benefits

2.3.1 Reduction in Carbon Emission

The environmental benefit of adopting SST was measured in terms of reduction in carbon emissions and improvement in carbon/organic content through crop residue management. To calculate the carbon emission the following methodology was undertaken:

1 litre diesel = 2.6 kg of CO_2 (Jat et al, 2006)

1 kg CO_2 = 0.27 kg of carbon (Paustian et al, 2006)

Many countries and the international organizations have realised the need to put a price tag on carbon emissions. The International Monetary Fund had suggested a price tag of $50 per ton. An effort was made to convert the reduction in carbon dioxide by adoption of SST into monetary terms to analyse how much cost farmers save and also how much the nation can benefit if different percentage of cropped area under wheat adopts the SST.

2.3.2 Water Productivity

Reduction in irrigation water has environmental benefits (Singh et al, 2016). Though the major source of irrigation in the study area was canal irrigation, it was assumed that farmers would use equal quantity of irrigation water from canal as they had used from groundwater source.

For quantification of water used for irrigation in wheat production following methodology was used (Singh, 2004).

$$\theta\ (m^3/ha) = I_n \times H_{pi} \times P_d$$

Where,

$\theta (m^3/ha)$ = Total irrigation water used for wheat production

In = No. of irrigation given to wheat crop during crop period

Hp_i = Hours required to provide one irrigation

P_d = Pump discharge rate

$$P_d\ (m^3/hrs) = \frac{HP \times 75 \times Pe}{1000 \times DW}$$

Where,

P_d = Pump discharge rate

HP = pump capacity

P_e = Pump efficiency

DW = Depth of water level + Head of delivery pipe (m)

Agronomic/Physical water productivity (kg/m3) for wheat was assessed using the crop yield data and the estimated volume of water applied to wheat crop for irrigation purpose. It was estimated through following equation:

$$PWP\ (kg/m^3) = \frac{Q\ (kg/ha)}{\theta\ (m^3/ha)}$$

Where,

WP = Physical water productivity

Q = Wheat yield (kg/ha)

θ = Total irrigation water used during entire crop period (m^3/ha)

Net Economic Water Productivity for wheat was estimated using the data on crop yield, farm harvest price and total input costs. It was estimated through the following equation:

$$WP\ (Rs/m^3) = \frac{NI\ (Rs)}{\theta(m^3)}$$

Where,

θ = Total irrigation water used during entire crop period

WP = Water productivity

NI = Net Income (₹)

III

RESULTS AND DISCUSSION

3.1 Costs and Returns

Wheat cultivation using surface seeding technology emerged to be an economically viable option. A detailed study regarding the economics of the cost of wheat cultivation under SST is done below; in order to compare its effectiveness, the cost of cultivation of wheat under conventional tillage was also calculated. Table 1 depicts the different costs involved in the cultivation of wheat. It is observed from the table that per hectare, the total cost of cultivation of wheat for SST was ₹ 36737, whereas it was ₹ 39735 for non-adopters. The variable cost or Cost A1 was ₹ 22987 for SST adopters which was comparatively lower than that incurred by non-adopters which was ₹ 25306. All the respondents owned their lands and there was no case of land lease-in in the study area the rent paid in for leased-in land was zero because of which Cost A1 and Cost A2 were equal.

TABLE 1. COST OF CULTIVATION INCURRED BY SST ADOPTERS AND NON-ADOPTERS (RS/HA)

Costs	Surface Seeding Technology	Conventional tillage
Wages of hired human labour	3866	4371
Land preparation cost	0	1973
Cost incurred on manures	0	129
Cost incurred on fertilizers	5245	5170
Cost incurred on seeds	6675	5211
Cost incurred on plant protection chemicals	1025	0
Irrigation charges	150	150
Land revenue	88	88
Depreciation on farm machinery, equipment, farm building etc.	230	230
Interest on working capital (@3%)	692	737
Harvesting and threshing	5016	7247
Cost A_1	22987	25306
Cost A_2	22987	25306
Interest on owned fixed capital assets excluding land (@10%)	640	640
Cost B_1	23627	25946
Rental value of owned land	9000	9000
Cost B_2	32627	34946
Imputed value of family labour	770	1177
Cost C_1	24397	27123
Cost C_2	33397	36123
10% managerial cost	3340	3612
Cost C_3	36737	39735

One of the agronomic benefits of adopting SST was that it involved zero land preparation as the wheat seeds were directly broadcasted in standing paddy crops without any prior application of manure, thus costing zero money for land preparation or manure application. Interestingly, it was observed that the seed rate was higher under SST because of the broadcasting method used, whereas in conventional tillage, farmers did line sowing, which reduced the seed rate as well as seed cost. Contrary to SST, conventional farmers paid negligible cost for plant protection chemicals because there was low or insignificant incidence of pests and weeds, which may be attributed to the outcome of rigorous tillage operations leading to the proper mixing of soil debris as well as pathogens from previous crop exposing the pests to sun. As the irrigation charges were waived by the Uttar Pradesh government, a standard irrigation charge of ₹ 150 was paid by both adopters as well as non-adopters.

TABLE 2. RETURNS FROM WHEAT CULTIVATION BY SST ADOPTERS AND NON-ADOPTERS

Returns	Surface Seeding Technology	Conventional tillage
Quantity of Main product (Qt./ha)	30.15	25.8
Quantity of By-product (Qt./ha)	20.18	17.3
Revenue from Main product (₹/ha) (@₹ 1975/Qt.)	59556	50969
Revenue from By-products (₹/ha)	6858	5362
Gross income (₹/ha)	66414	56331
Net income (₹/ha)	29677	16596
Net return per rupee of investment	0.81	0.42

The income received by wheat cultivators was the combined revenue earned from the sale of wheat grain and straw. The estimated per ha returns under both SST and conventional tillage is represented in table 2. Early or timely sowing of wheat under SST leads to higher yields than traditional tillage; the primary reason behind it was the elimination of the land preparation process, giving the crop more time to mature, thus resulting in better grain quality and quantity. The net income received by SST adopters was ₹ 13081 per ha more than non-adopters. The net return per rupee of investment was nearly double under SST as compared to conventional tillage, attributed to lower cost of cultivation and higher net income (Singh et al, 2022).

3.2 Economic Benefits

The above section observed that SST was an economically beneficial technology for wheat cultivation in the Indo-Gangetic plains. An element-wise detailed economic analysis of the benefits is represented in Table 3. The total economic benefit achieved by SST adopters was ₹16004 per ha. The major benefit experienced by the SST adopters was due to higher yields (₹10083 per ha). SST also helps farmers to reduce cost of cultivation by reducing the fuel cost, which was nearly Rs 3240 per ha. Skipping the step of land preparation also adds to the economic benefits. Though the SST adopters had to pay more amount for variable resources such as seed, fertilizer, and plant protection chemicals, the overall economic benefits surpass this over payment.

TABLE 3. ECONOMIC BENEFITS DUE TO ADOPTION OF SST

Economic Benefits	Amount (Rs/ha)
Due to reduction in cost of human labour	912
Due to reduction in land preparation cost	1973
Due to reduction in cost of manures	129
Due to reduction in cost of seed	-75
Due to reduction in cost of fertilizer	-1464
Due to reduction in cost of plant protection chemicals	-1025
Due to reduction in cost of harvesting & threshing	2231
Due to yield benefits (both main & by-product)	10083
Due to diesel saving (@ ₹ 90/Lt)	3240
Total benefits (₹/ha)	16004

3.2.1 Allocative efficiency

Cobb Douglas production function was applied to analyze the allocative efficiency of resources under SST and conventional tillage. To estimate the resource use efficiency, regression analysis was done, taking gross income as the dependent variable while expenditure on different variable resources such as seed, fertilizer, plant protection chemicals, manure and machine labour as independent variables. Table 4 depicts the regression estimates under SST and conventional system. The high R2 value under both methods indicates the fitted function was a good fit; it was 0.89 under SST and 0.97 under conventional tillage. The R^2 values signify that under SST 89 percent and under conventional tillage 97 percent variation in the gross income was due to the independent variables under study. The summation of coefficients ($\sum bi$) value indicates increasing returns to scale under both methods of wheat cultivation.

Under SST, the regression coefficients of expenditure on seed, expenditure on fertilizer, and expenditure on human labour were significant at a 5 percent level probability level, whereas expenditure on plant protection chemicals was significant at a 1 per cent probability level. The value of regression coefficients of seed (0.281), fertilizer (0.256), plant protection chemicals (0.898) and human labour (0.034) was worked out; the values signify a unit change in these inputs/independent variables lead to a change in the dependent variable (gross income) by the coefficient value. The positive values imply that the adoption of SST has a positive impact on gross income. For conventional tillage, the regression coefficient of variables such as expenditure on fertilizer, expenditure on human labour and expenditure on machine labour were significant at 1 percent probability level. The regression coefficient of seed (0.041), fertilizer (0.504), human labour (0.285), manure (0.204) and machine labour (0.552) were worked out. Positive values of all coefficients state that an increase in these inputs would increase the gross income.

TABLE 4. REGRESSION COEFFICIENTS UNDER SST AND CONVENTIONAL TILLAGE

Variables	Surface Seeding Technology			Conventional tillage		
	Coefficients	SE	t value	Coefficients	SE	t value
Expenditure on seed	0.281*	0.127	2.20	0.041	0.044	0.92
Expenditure on fertilizer	0.256*	0.112	2.28	0.504**	0.098	5.12
Expenditure on plant protection chemicals	0.898**	0.190	4.72	-	-	-
Expenditure on human labour	0.034*	0.016	2.12	0.285**	0.095	2.98
Expenditure on manure	-	-	-	0.204*	0.087	2.35
Expenditure on machine labour	-	-	-	0.552**	0.155	3.55
Returns to scale	1.47			1.59		
R^2	0.89			0.97		

Significant at 5 percent* * Significant at 1 percent*

The allocative efficiency of wheat under SST and conventional tillage is represented in Table 4. The value of 'r' was computed for each resource under both the wheat cultivation methods. The marginal factor cost (MFC) was taken to be Re. 1 as already stated in the methodology. The resources whose 'r' value was greater than unity under SST were seed (2.49), fertilizer (3.01) and plant protection chemicals (53.83), whereas under conventional tillage, it was for fertilizer (5.33), human labour (4.36), manure (6.97) and machine labour (14.91). Value of 'r' > 1 signifies under-utilization of the resources, and an increase in the inputs would lead to an increase in the output. The resources with r value more than 1 fall in region I of the production curve, indicating the possibility of earning higher profits by increasing the inputs to the level where the value of 'r' falls to unity. In case of SST, the value of 'r' lies between 0 to 1 for the human labour (0.68) resource and for conventional it was for seed (0.46) indicating optimum use of the resources as they lie in zone II of production curve.

3.3 Environmental benefits

3.3.1 Reduction in Carbon Emission

The agricultural sector has been a significant contributor to rising carbon dioxide levels, emitting 2647 metric tons of CO2 in 2019 (Yadav, 2024). The reduction in carbon emission under SST in comparison to conventional tillage is represented in Table 5. The diesel consumption was nil under SST due to the elimination of diesel-fuelled machinery during land preparation, and seeds were directly broadcasted in the standing kharif crop. Thus, zero diesel consumption led to zero carbon emission, which, when compared to conventional, resulted in a reduction in carbon emission by an amount of 25.27 kg/ha. As we know, the sowing season of wheat coincides with high pollution level months, especially in Delhi and nearby regions, reduction in carbon emission can protect the environment by reducing air pollution (Table 6). Moreover, SST not only aids farmers in cultivating wheat in a sustainable manner but also reduces fuel costs, which benefits them economically. This clearly projects surface seeding technology as an eco-friendly replacement to conventional tillage.

TABLE 5. ALLOCATIVE EFFICIENCY IN WHEAT CULTIVATION UNDER SST AND CONVENTIONAL TILLAGE

Variables	Surface Seeding Technology			Conventional tillage		
	Production Elasticities	MVP	MVP/ MFC (r)	Production Elasticities	MVP	MVP/ MFC (r)
Seed	0.281*	2.49	2.49	0.041	0.46	0.46
Fertilizer	0.256*	3.01	3.01	0.504**	5.33	5.33
Plant Protection Chemicals	0.898**	53.83	53.83	-	-	
Human Labour	0.034*	0.68	0.68	0.285**	4.36	4.36
Manure	-			0.204*	6.97	6.97
Machine Labour	-			0.552**	14.91	14.91
Total Allocative Efficiency			60.01			32.03

TABLE 6. ENVIRONMENTAL BENEFITS OF SST IN COMPARISON TO CONVENTIONAL TILLAGE

Particulars	SST	Conventional tillage
Diesel consumption (Lt/Ha)	0	36
CO_2 emission (Kg/Ha)	0	93.6
Carbon emission (Kg/ Ha)	0	25.272
Reduction in carbon emission (Kg/Ha)	25.272	

3.3.2 Scenario Analysis

As we know use of conventional tillage in rice-wheat cropping system is one of the prime contributors to carbon dioxide emission in India. A scenario analysis was conducted to compute the carbon credits generated from reduction in carbon dioxide emission if the whole area under wheat cultivation is brought under surface seeding technology. This was done to get an economic view of environmental benefits that can be experienced by Indian farmers on mass adoption of surface seeding technology. The analysis was done for Eastern Uttar Pradesh, Uttar Pradesh and India respectively. The per ton price of carbon as proposed by International Monetary Fund in the International Carbon Price Floor (ICPF) agreement $50 for middle-income countries (Chateau et al, 2022) such as India. It is evident from the table if all the wheat farmers adopt SST then as nation we can earn carbon credits worth 13.03 billion rupees. India being second largest wheat producer with nearly 31.8 million ha land under wheat cultivation can reduce carbon emission tremendously by just switching from conventional tillage to conservation agriculture options. In India, Uttar Pradesh is the leading state in wheat cultivation, thus have the potential to play crucial role in wheat economy by earning carbon credit of 3.9 billion rupees by reducing the carbon dioxide emission. Mass adoption of resource conserving technologies such as SST are not only environmentally beneficial but also have potential to help farmers earn the extra penny.

TABLE 7. COMPUTATION OF CARBON CREDITS EARNED BY SST ADOPTERS

Particular	Area under wheat cultivation (ha)	Carbon dioxide emission (tonnes)		Carbon price per tonne	Carbon credit (in rupees)
		SST	Conventional		
Eastern Uttar Pradesh	5,240,000*	0	490464	\$50 or ₹4369	2,142,837,216
Uttar Pradesh	9,590,000#	0	897624		3,921,719,256
India	31,868,260#	0	2982869		13,032,154,661

#*PIB report; March, 2023* **Source- Singh et al., 2020*

3.3.3 Physical and Economic Water Productivity

With mounting pressure on groundwater resources, reduction in irrigation water use plays a vital role in protecting water quality and sustainability. Though the source of irrigation in the study area for a large proportion of farmers was canal irrigation, there were some farmers who relied on tube wells for irrigation. The water productivity of SST, both physical and economic, under tubewell irrigation was analyzed and is represented in Table 8. On adoption of SST, farmers could save 810 m3 of water per ha. Physical water productivity depicts how more output can be produced per unit of water; this helps to manage our groundwater levels. The incremental physical water productivity was 0.7 kg/m3 on the adoption of SST for wheat cultivation. In monetary terms, the net economic water productivity was ₹ 7.87 per cubic metre of irrigation water. Higher productivity leads to lower cost of cultivation accompanied by higher returns and reduces exploitation of groundwater resources.

TABLE 8. PHYSICAL AND ECONOMIC WATER PRODUCTIVITY UNDER SST

Particulars	SST	Conventional
Irrigation water use (m^3/ha)	1782	2592
Reduction in irrigation water use (m^3/ha)	810	
Physical water productivity (kg/m^3)	1.7	1
Incremental physical water productivity (kg/m^3)	0.7	
Net economic water productivity (₹/m^3)	14.5	6.63
Incremental net economic water productivity (₹/m^3)	7.87	

IV

SUMMARY AND CONCLUSION

During the green revolution, widespread adoption of conventional tillage practices played a pivotal role in ensuring and enhancing the country's food security. However, this agricultural intensification has left an enormous environmental footprint. The rice-wheat cropping system in the Indo-Gangetic Plains has been a central source of ending food scarcity in India, which is currently facing the problem of declining productivity and resource depletion, notably necessitating a shift towards more sustainable farming practices. Surface seeding technology is a resource conservation technology that addresses two major issues involved in the seamless paddy-to-wheat transition- paddy residue management and high soil moisture content. SST has significant economic and environmental advantages over conventional tillage. Economically, it benefitted the adopters by reducing the cost of cultivation and enhancing returns. Higher resource use efficiency value indicates the potential to optimize resource utilization, thereby enabling farmers to enhance output by proportionally increasing input application. Environmentally, the elimination of tillage operations during land preparation led to a reduction in carbon emissions. Scenario analysis depicted that mass adoption of SST by all wheat growers across the country could yield carbon credits worth ₹13 billion alongside conserving the natural resource base. Additionally, the technology contributed in mitigating the overexploitation of groundwater by enhancing water productivity, reflecting higher output produced per unit of water.

To promote mass adoption of SST among wheat farmers government can adopt following policy implications:

- Provide financial incentives to farmers for the initial 2-3 years of adoption of SST.
- To build farmer’s confidence, frontline demonstrations and field visits can be given by government extension agencies. Paired plot comparisons would boost their confidence.

- In lowland areas with heavy soils with poor drainage, government can mandate adoption of surface seeding technology with provision of full support from government agencies.
- On development of carbon markets, sale of carbon credits can be done and the revenue earned can further be used to provide greater subsidy to small and marginal farmers
- Awareness campaigns can be run through mass media such as radio talks, mobile alerts, documentaries on success stories etc. to inform farmers about benefits of the technology.
- Thus, SST promises to transform wheat cultivation in lowland areas in a sustainable and economically viable way.

Received May 2025 *Revision accepted July 2025.*

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