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Economic and Environmental Efficacy of Sustainable and Conventional Systems in Paddy-Wheat Cropping System: Insights from Farmer FIRST Project in Punjab

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Abstract: Under Farmer FIRST Project, sustainable technologies including the adoption of short-duration varieties (SDV) of paddy and in-situ residue management techniques like happy seeder were introduced in adopted villages of Punjab. A total of 1500 Frontline Demonstrations conducted across the adopted villages. Sustainable practices consistently resulted in lower costs of cultivation compared to conventional methods ranging from Rs. 3241 to Rs. 6425 per ha resulted in comparable net returns. Furthermore, these practices reduced water usage by 4,190 thousand litres per hectare and mitigated significant amount of atmospheric pollution. The findings of the study revealed the potential of sustainable agricultural practices to enhance both economic profitability and environmental sustainability in paddy-wheat system in Punjab.

Keywords: In-situ management, Short duration varieties, Residue burning

The policy design revolving around food security of the country in the 1960s encouraged a “green revolution” through subsidized input use and high procurement prices. Punjab became the food basket of the country with an increasing area under paddy and wheat by such subsidization. The modern agricultural practices of high yield varieties (HYV) technology in Punjab also simultaneously ushered in the shift from canal irrigation to tube well irrigation as it was a more reliable and flexible source of irrigation (Kaul and Sekhon 1991). Apart from deteriorating soil and water quality, major concern came up for the farming community of Punjab and Haryana is utilization of huge rice residue due to unavailability of economically viable options. Paddy is cultivated on 43.8 Mha in India, producing 118.43 Mt grain and an estimated 165.8 Mt straw (Kaur et al 2022). Every Megagram (Mg) of rice grain harvested produces around 1.4 Mg straw (Satpathy and Pradhan 2020). Due to various socio-economical, institutional, technological and commercial glitches farmers are compelled to burn the residue which leads to onset of an array of problems for the ecosystem. In the year 2023, 36663 farm fire events were recorded in the *kharif* season (PRSC 2023). Similarly, water table of the state is declining day by day. The total annual groundwater recharge of Punjab has been assessed at 18.84 bcm, while annual groundwater extraction stands at 27.8 bcm, resulting in a stage of groundwater extraction of 163.76%. Out of the 150 assessed blocks and 3 urban areas included in the study, 114 blocks and all 3 urban areas (76.47%) have been categorized as 'over-exploited'. Additionally, 3 blocks (1.96%) have been classified as 'critical', and 13 blocks (8.5%) as 'semi-critical' (GOP 2023).

Thus, both the technological shift and the policy directions led to a wide development of natural resources viz soil, water and air necessitated the need of introduction of sustainable systems of paddy-wheat cultivation (Chauhan et al 2012, Bhatt et al 2016). Researcher and policy makers are consistently putting efforts in this direction, resulting in the introduction of technologies which could contribute to the cultivation of these crops in sustainable way. One of the technologies are introduction of short duration varieties of paddy. As long duration varieties of paddy such as Pusa 44 consumes huge amount of water, nutrients and human resources, alternatively short duration varieties of paddy such as PR 121, PR 126 can be grown with less resources (Singh et al 2022a). Similarly, techniques were developed by the researchers to curb paddy residue burning, involving in-situ management of paddy residue through various technologies such as happy seeder, super seeder, smart seeder with the help of these technologies, wheat can be sown in the standing stubbles (Singh et al 2022b).

Thus, blend of short duration varieties of paddy and in-situ management of paddy stubble is a sustainable way to grow paddy and wheat. Further to transfer various sustainable technologies to farmers fields' and popularize among them, Farmer FIRST Programme (FFP) was started by ICAR, and under this programme two villages in Sangrur District of Punjab were adopted by the PAU, Ludhiana in the year 2016-17. To convince the farmers through the grass root level methodology, Frontline Demonstrations (FLDs) short duration varieties of paddy and in-situ management of paddy

stubble were conducted in the adopted villages. So, this study was conducted to evaluate the performance of sustainable (SDV+ in-situ management) and conventional approach (LDV + normal sowing of wheat) to generate the research feedback and for policy interventions.

MATERIAL AND METHODS

Farmer FIRST Programme was implemented in Punjab in 2016-17 and two villages from district Sangrur were selected under this programme. To sensitize the farmers regarding water saving and popularization of recommended short duration varieties, 300 Front Line Demonstrations (FLDs) having an area of 0.4 ha for each demonstration of PAU recommended short duration varieties (PR 121 & PR 126) were conducted on farmers' fields in each year from 2017-18 to 2022-23 thus totaling 1500 FLDs in last five years (Table 1). Similarly, demonstrations of in-situ management of paddy residue through Happy Seeder/Super Seeder/Smart Seeder were conducted in the years from 2017-18 to 2022-23.

RESULTS AND DISCUSSION

The yield of SDV paddy remained relatively stable across the years, ranging from 76.38 q/ha in 2022-23 to a peak of 80.65 q/ha in 2017-18 (Table 1). In contrast, LDV paddy generally produced higher yields, particularly in the 2017-18 and 2020-21 seasons with yields of 82.28 q/ha and 82.35 q/ha, respectively. However, decline in LDV yield was observed in 2022-23, dropping to 68.90 q/ha, which is significantly lower compared to the SDV yield of the same year.For wheat, the yields under the in-situ management techniques generally showed an improvement over normal sowing methods. The highest yield for in-situ management techniques was in 2019-20 at 56.85 q/ha, compared to 54.90 q/ha for normal sowing. However, a decline in yield was noted for both methods in 2020-21 and 2021-22, with in-situ management techniques yielding 42.50 q/ha and normal sowing yielding 38.70 q/ha in 2021-22. Despite this decline, in-situ management techniques consistently outperformed normal sowing across the years, indicating its potential benefit in sustainable wheat production.

Economic impact: Sustainable practices consistently resulted in lower costs of cultivation compared to conventional methods in 2017-18, the cost of cultivation for the sustainable approach was Rs. 53,985/ha, compared to Rs. 57,226/ha for the conventional approach, resulting in a savings of Rs. 3,241/ha. This trend continued across the years, with the highest cost savings observed in 2020-21. Gross returns from sustainable practices were slightly lower or comparable to conventional methods in most years, in 2018-19, gross returns were Rs. 238,829/ha for sustainable methods and Rs. 241,681/ha for conventional methods. In 2022-23, net returns for sustainable practices were significantly higher at Rs. 188,038/ha compared to Rs. 168,913/ha for conventional methods. The B.C ratio, which measures the profitability of the cropping system, was consistently higher for sustainable practices and was 5.56 in compared to 5.21 in for conventional methods. This advantage was maintained over the years, with the largest difference observed in 2022-23 (4.51 for sustainable versus 3.93 for conventional).

Environmental impact: Paddy cultivation Sustainable practices i.e. cultivating SDV required fewer irrigations, with an average of 25 irrigations per year compared to 31 for conventional methods. This led to a substantial reduction in both total water use and water footprints per kilogram of yield (Table 3). The in-situ management of paddy stubble using methods viz. Happy Seeder/Super Seeder has proven to significantly reduce the emission of pollutants. The straw load from both short-duration varieties (SDV) and long-duration varieties (LDV) was measured, with SDV showing a lower straw load, which led to a reduced probability of emissions (Table 4). In the demonstration plot with SDV cultivation, considerable reductions in both particulate and gaseous emissions were observed when compared to the check plot with LDV. These findings highlight the potential for lower levels of harmful pollutants being released into the atmosphere through the use of sustainable practices. Over

Table 1. Demonstrations conducted

Year	SDV	In-situ management
2017-18	300	200
2018-19	300	200
2019-20	300	200
2020-21	300	300
2021-22	300	100
2022-23	300	100

Table 2. Impact on paddy yield

Year	Yield (q/ha)			
	SDV	LDV	HST	Normal sowing of wheat
2017-18	80.65	82.28	52.00	51.00
2018-19	78.65	80.41	56.25	55.00
2019-20	79.75	78.40	56.85	54.90
2020-21	78.15	82.35	49.50	49.00
2021-22	79.50	81.20	42.50	38.70
2022-23	76.38	68.90	55.47	53.28

Table 3. Economic analysis of sustainable and conventional paddy-wheat cropping system

Particular	Sustainable	Conventional	Change
2017-18			
Cost of cultivation (Rs/ha)	53985	57226	-3241
Gross returns (Rs/ha)	204905	207268	-2363
Net returns (Rs/ha)	150919	150041	877
B.C ratio	5.56	5.21	0.35
2018-19			
Cost of cultivation (Rs/ha)	62667	66346	-3679
Gross returns (Rs/ha)	238829	241681	-2852
Net returns (Rs/ha)	176161.5	175335	826
B.C ratio	5.60	5.30	0.30
2019-20			
Cost of cultivation (Rs/ha)	64619	67928	-3309
Gross returns (Rs/ha)	242590	239976	2613
Net returns (Rs/ha)	177971	172048	5922
B.C ratio	5.49	5.11	0.38
2020-21			
Cost of cultivation (Rs/ha)	71110	76407	-5297
Gross returns (Rs/ha)	242759	250604	-7845
Net returns (Rs/ha)	171649	174197	-2548
B.C ratio	5.27	5.02	0.25
2021-22			
Cost of cultivation (Rs/ha)	74450	80875	-6425
Gross returns (Rs/ha)	232211	235509	-3298
Net returns (Rs/ha)	157761	154634	3127
B.C ratio	4.19	3.68	0.51
2022-23			
Cost of cultivation (Rs/ha)	82690	86565	-3875
Gross returns (Rs/ha)	270728	255478	15250
Net returns (Rs/ha)	188038	168913	19125
B.C ratio	4.51	3.93	0.58

Cost of cultivation varied from 53985 to 82690. Explain the reasons which facor responsible cots of input or labour

Table 4. Saving in water

Particular	Sustainable	Conventional	Diff
Irrigations (No)	25	31	-6
Total water use (000 litre/ha)	18685	22875	-4190
Water footprints (Litres/kg)	2459	3319	-860

the study period, these reductions translate into substantial avoided atmospheric pollution, contributing positively to environmental sustainability. With the continuous efforts, about 60 percent area was brought under the in-situ paddy residue management technologies. It is estimated that 6 thousand tonne straw burning per annum has been avoided resulted into the avoidance of large amount of pollutants avoidance in the project area. Previous studies also reported the similar findings (Singh *et al* 2022).

CONCLUSION

The implementation of the Farmer FIRST Programme in Punjab has demonstrated the effectiveness of sustainable agricultural practices, specifically the cultivation of short-duration varieties (SDV) of paddy and the in-situ management of paddy residue using techniques. SDV paddy yields remained relatively stable and competitive with long-duration varieties (LDV), while also offering significant benefits in terms of economic and environmental

Table 5. Impact on aatmospheric pollution

Pollutants		Emission factor for rice straw (g/kg dry mass of residue)	SDV (kg/ha)	LDV (kg/ha)	Probable pollution reduction (kg/ha)	Total avoided atmospheric pollution (ton)
Particulate emission	PM	9.64	75.67	98.04	-22.36	58.57
	PM_{10}	6.3	49.46	64.07	-14.62	38.28
	PM_{25}	5.75	45.14	58.48	-13.34	34.94
	BC	0.64	5.02	6.51	-1.48	3.89
	OC	2.2	17.27	22.37	-5.1	13.37
Gaseous emission	CO_2	1220.32	9579.51	12410.65	-2831.14	7414.54
	CO	101.29	795.13	1030.12	-234.99	615.43
	CH_4	9.6	75.36	97.63	-22.27	58.33
	VOC	7	54.95	71.19	-16.24	42.53
	NH_3	4.1	32.19	41.7	-9.51	24.91
	NO_x	1.95	15.31	19.83	-4.52	11.85
	SO_2	0.29	2.28	2.95	-0.67	1.76

Emission factors are calculated from the average of Andreae and Merlet (2001) and Zhang et al (2008) as given in Shrestha et al (2012) in the Emission Inventory Manual

sustainability. Despite occasional fluctuations, SDV consistently produced yields that were less variable than LDV, highlighting its reliability under varying conditions. Economically, the sustainable practices consistently resulted in lower costs of cultivation, higher net returns, and a more favourable benefit-cost (B.C) ratio compared to conventional methods. This economic advantage underscores the viability of adopting sustainable practices for long-term profitability. Environmentally, the sustainable practices significantly reduced water usage and pollutant emissions. The use of SDV and in-situ residue management led to fewer irrigations and a substantial reduction in total water use, thereby lowering the water footprint per kilogram of yield. Additionally, the adoption of in-situ residue management techniques reduced the emission of harmful pollutants, contributing positively to air quality and overall environmental health. In summary, the Farmer FIRST Programme has successfully demonstrated that sustainable agricultural practices not only maintain competitive yields but also enhance economic returns and mitigate environmental impacts.

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AUTHOR'S CONTRIBUTION

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