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Adoption and impact of technology in the rice-wheat system

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ABSTRACT

In this study the adoption, impact of varieties and resource management practices in selected states of India, viz. Punjab, Haryana and Uttar Pradesh has been examined during 2014–15. The economic surplus method was used to calculate impact of variety and technology. Result revealed that rate of varietal improvement and notification has increased for both rice and wheat, but there is varietal concentration. Top three varieties contributed more than three-fourths of total seed sale in the region. The estimated IRR was 38.8% and the ratio of net benefits to the cost was 17.31 which are slightly lower than the rates reported in the past. Nevertheless, these returns are quite high to justify higher allocation of public funds to agricultural research.

Key words: Economic surplus method, Rice-wheat system, Varietal development, Zero tillage

Evolution of the rice-wheat cropping system (RWS) in the Indo-Gangetic Plains in a way represents the path of agricultural development in South Asia. Although this system has been practiced since the 16th century, it spread widely with the expansion of canal and tubewell irrigation during the 1960s and 1970s. Availability of high-yielding varieties (HYVs) of rice and wheat has further expanded the area under RWS, ushering the Green Revolution. Eventually, the system emerged as one of the widest spread, intensively cultivated and extremely important for food security and agricultural prosperity of the region. It is estimated that RWS is followed on more than 14 mha of agricultural lands and nearly two-thirds of the existing cereal supplies of the region comes from this system.

Recent literature indicates that RWS in the Indo-Gangetic Plains is now facing a number of stresses. The growth in crop yields in the north-western plains of India (Punjab, Haryana and western Uttar Pradesh) with higher crop yields is decelerating, and the system intensification is putting pressure on land and water resources and environment. The immediate consequence of these changes is reported to be a threat to long-term sustainability of the system (Hobbs 2007, Reddy and Bantilan 2013, Reddy 2017). These undesirable trends are further compounded with the challenges of climate change, which may reduce the agricultural gross domestic product by 4–5% and crop yield to the extent of 30% (World Bank 2010). There is apprehension that food security of the region may be under pressure if these undesirable trends are not corrected in time through suitable technological and policy interventions.

Integration of research efforts of the CGIAR Centres and the national agricultural research systems in the region and mobilization of additional resources from international donors have been attempted through several programs and research consortia. In terms of research focus, major thrusts areas pursued were development of high yielding varieties of rice and wheat, tillage and crop residue management, weed control, reclamation of salt-affected lands and water and nutrient management. These programmes resulted into several important outcomes. In particular, resource conservation technologies like zero and reduced tillage made significant impact (Vijaylaxmi et al. 2007, Erenstein et al. 2008). Considerable work is in progress on water-saving methods of rice cultivation but these are yet to make some impact on farmers' fields. With this background present study took up following objectives to analyse adoption and impact of these plant varieties and resource management practices. The paper specifically deals with recent trends in the RWS, and adoption and economic impacts of new plant varieties and RCTs. Empirical evidences are however confined to the Indian region of RWS.

MATERIALS AND METHODS

The secondary data was compiled on various aspects like, area, production and yield of rice and wheat for IGP region. The data on area, production and yield were compiled from the Directorate of Economics and Statistics, Ministry of Agriculture. Multi stage stratified random sampling was

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used to collect sample. Primary data was collected from Punjab, Haryana and Uttar Pradesh with sample of 200 farmers for each state by using well prepared questionnaire during 2014–15. The sample comprises two districts of Punjab (Ludhiana and Amritsar) and 2 districts of Haryana (Karnal and Kaithal), and 3 districts of UP (Bulandshahar, Mirzapur and Chandauli). The farmers were selected randomly after stratification into different size of holdings. Economic surplus method is applied to estimate economic benefits of commodity research. The technologies considered here are perfect examples of commodity-specific research and therefore this method was applied for rice and wheat. The estimation of economic surplus needs information on market (demand, supply, production, prices etc.) parameters, reduction in the per unit cost of production and adoption level. Following (Alston *et al*. 1995), change in economic surplus is computed as:

$$DCS = PQ\ Z\ (1+.5\ Zh)$$
$$DPS = PQ\ (K-Z)\ (1+.5\ Zh)$$
$$DTS = D\ CS + D\ PS = PQ\ K\ (1+.5\ Zh)$$

where Z = K e / (e+ h), K is vertical shift in supply function as proportion of initial price, h is elasticity of demand (absolute), and e is elasticity of supply. DCS is change in the consumer surplus, DPS is the change in the Producer surplus, DTS is total surplus. P0 is Pre innovation price, Q0 is Pre innovation production, P1 is After innovation price, Q1 is After innovation production, Z is Relative reduction in price [–(P1-P0)/P0], Zn is Change in yield/ Elasticity of supply.

RESULTS AND DISCUSSION

Agricultural development: The share of agriculture in the state gross domestic product is higher than the national average of 14% in 2011. In Punjab, agriculture's share is as high as 30% and it is 27% in UP. In terms of area, these four states contribute nearly 30 mha to the total land area of 140 mha. The RWS area in India is about 10 mha and nearly half of this is in Uttar Pradesh. Adding Bihar, the two states occupy nearly 70% of the total RWS area. However, crop productivity is low and combined yield of rice and wheat is 3–5 tonnes/ha in these states. This is against more than 8 tonnes/ha in Haryana and Punjab. Thus RWS in India can easily be characterized into the high productivity region of Punjab and Haryana and the low productivity region of UP, Bihar and other eastern region. The eastern region is primarily rice growing region with high rainfall and yield is now picking up. Another significant characteristic of agriculture in the low productivity region is that it is primarily smallholder agriculture. The current official statistics indicate that average size of holding is less than one ha in UP and Bihar, whereas it is 1.6 ha in Haryana and more than 3.9 ha in Punjab, because of outmigration of population and changes in agrarian structure through consolidation of holdings and reverse tenancy. Infrastructure development like irrigation, and input use also echo these two diverse development trends.

The sources of growth in output also show a distinct pattern. The growth in the total factor productivity (TFP) contributed about one-third to output growth in the Trans-Gangetic Plains of Punjab and Haryana, and the rest was contributed by the growth in inputs and area since 1980s. This trend was observed a bit later in the 1990s in UP and Bihar. The decomposition of growth in TFP showed that investment in agricultural R&D was the major source of growth in TFP (Kumar 2004). This implies that, when the hope of output growth in future is pinned on the productivity growth, agricultural R&D should be targeted to provide technological solutions for binding system constraints.

Crop productivity trends: There has been a slowdown in the yields growth for both the crops in Haryana and Punjab. The yield growth was even negative for rice in Haryana mainly because of expansion of area under basmati varieties of rice. Rice yield accelerated in both the states in 2000s due to spread of high yielding superfine varieties. In 1990s, the yield growth was comparatively better in UP and Bihar, even comparable to that in 1980s, except rice in UP, mainly due to spread of the green revolution technologies in these states. Wheat yield became stagnant in the last decade in all the four states, except UP where it is growing at an annual growth of 1.4% (Table 1).

Except Punjab and Haryana, where yield gap is almost non-existent, rice yield can be increased up to one-third of the current yield levels in the eastern part of IGP. The same holds true for wheat yield. UP and Bihar covering most of the IGP area have the high yield gap, and therefore efforts to large scale transfer of technology along with assured input supply will result into substantial yield gains. These efforts should be complemented with development of market infrastructure in the region.

Variety development: There is increase in the number

Table 1 Growth rate of rice and wheat (1980 to 2013-14)

	Punjab	Haryana	UP	Bihar	All India
Rice area growth					
1980-1990	5.39	2.40	0.03	0.25	0.41
1990-2000	2.48	6.12	0.81	0.14	0.68
2000-2014	1.00	3.52	0.15	-1.03	-0.02
Rice yield growth					
1980-1990	1.28	-0.15	5.65	3.87	3.19
1990-2000	0.02	-1.64	2.21	4.76	1.34
2000-2014	0.29	0.84	1.67	2.50	1.96
Wheat area growth					
1980-1990	1.26	1.94	0.86	2.32	0.46
1990-2000	0.27	2.24	0.91	0.95	1.72
2000-2014	0.29	0.96	0.62	0.18	1.43
Wheat yield growth					
1980-1990	3.00	4.06	2.87	2.50	3.10
1990-2000	1.98	1.51	2.24	2.56	1.83
2000-2014	0.97	1.47	1.44	1.55	1.35

of superfine rice varieties during the last two decades or so. The varieties developed for irrigated conditions can be grown in RWS and their share in the total varieties developed during the last decade is 29.5% for rice and 40% for wheat. The share of private sector in total seed sale of rice varied from 48% in UP to 81% in Punjab. In the case of wheat, the private share is comparatively low and it varies from 25% in Bihar to 59% in Haryana. It is interesting to note that most of the farmers use quality seed and the share of farm-saved seed ranged between 15-27 %. Most of the farmers buy seed from private dealers, who also sell seed produced by public agencies. The proportion of farmers buying seed from the public agencies is comparatively higher in Punjab and Haryana. Thus private dealers could play an important role in popularization of improved varieties and increasing farmers' access to quality.

The share of top one variety is up to 32-59% in wheat, which further rises to more than two-thirds if the share of top two varieties is taken. The share of top three wheat varieties was as high as 76% in Haryana, 83% in Punjab and 87% in UP. The share of top three varieties of rice varied from 36% in Haryana to 56% in UP. The share of top one variety was much smaller (14 - 36 %) in rice as compared to wheat. The high varietal diversity in rice is expected because of varietal choice available to farmers, especially for grain quality, and wide variation in the production environment (Table 2).

Another notable trend in the varietal concentration is that the share of new varieties, released after 2000, is rather low for both rice and wheat. This is more so for the states of UP and Bihar where production environment is less favourable because of erratic weather and low irrigation intensity. This is in spite of the fact that number of varieties released after 2000 for the irrigated conditions is quite high (nearly 75%). Therefore, it would be worthwhile to revisit the variety evaluation criteria and release only those varieties having significant superiority in all agronomic and economic parameters.

Recent technological interventions: The successful interventions include improved varieties of rice and wheat, and zero and reduced tillage in wheat. The yield potential on research stations is also higher by about one tonne. After taking into consideration the yield gap, rice varieties have a yield advantage up to one tonne per hectare but wheat varieties have a moderate yield advantage about half a tonne per hectare. The varieties which were released after or picking adoption in 2000 were taken for impact assessment. Another important technological intervention in IGP is the introduction of zero-tillage for wheat which occupied substantial wheat area. The main advantage of this technology is cost reduction due to no or reduced tillage and saving of irrigation water in wheat. Incorporation of paddy stubbles also enriches soil, resulting moderate yield gains in some locations. The spread of these technologies is quite significant in terms of area coverage. However, most of the adoption area is limited to Punjab, Haryana and west UP. The efforts are in progress to demonstrate and encourage adoption of these technologies in the eastern IGP.

Table 2 Variety concentration and share of new varieties in commercial seed sale of rice and wheat, 2014-15

Particulars	Punjab	Haryana	UP	Bihar
Rice				
Total seed sale ('000 q)	226	166	35	232
Share of private seed (%)	81	67	48	58
Share (%) of new varieties released after 2000	70	45	46	40
Share of top one variety (%)	21	14	20	36
Share of top two varieties (%)	38	26	40	45
Share of top three varieties (%)	53	36	56	53
Wheat				
Total seed sale ('000 q)	1259	1157	1031	672
Share of private seed (%)	48	59	52	25
Share (%) of new varieties released after 2000	35	63	41	27
Share of top one variety (%)	59	32	34	47
Share of top two varieties (%)	77	60	66	63
Share of top three varieties (%)	83	76	87	76

Source: Based on seed sale data compiled from respective state governments

Technology adoption: After adjustment of farmer-to-farmer spread of seed, these data give variety shares in crop acreage. These data were adjusted with information on the spread of varieties obtained through farm survey in Punjab, Haryana and UP. After estimating the present adoption level, it was necessary to compute the future adoption path, which also requires an assessment of ceiling level of adoption. Basmati rice varieties and zero-tillage have nearly reached the maximum adoption level which was used for computing the adoption path. Information for wheat varieties was rather difficult and the maximum adoption was assessed based on the area covered by the varieties which are likely to be replaced by the new varieties.

Assessing the economic impact: This change in the cost is realized due to cost savings in zero-tillage in wheat and reduction in yield losses due to various stresses for wheat and rice (common) varieties. In case of basmati rice variety, per unit cost of production decreased because of higher yield of new varieties (Pusa 1121, CSR 30) over the traditional basmati, or improved basmati bred earlier like Pusa Basmati 1. Economic surplus with close economy was applied for wheat variety and zero-tillage, while the open economy model was used for basmati rice as nearly half of total basmati rice production in India is exported. These

Table 3 Parameters for estimation of economic benefits and the rate of returns

Parameter	Zero-tillage	Wheat variety	Basmati rice variety	Common rice variety
Yield advantage (%)	6	11.7	25	18.8
Ceiling level of adoption (%)	25	61	60	29
Price (₹/tonne, 2012)	11,200	11,200	28,829	12,500
Production (million tonnes)	29.8	64.8	7.79	35.46
Research cost (million ₹ 1999)			2741	
R&D lag (years)			10	
Net present value (₹ billion)			169	
IRR (%)			38 %	

economic benefits can be compared against the research cost, which is arrived based on the research expenditure incurred by the states of Punjab, Haryana, Bihar and UP. These aggregate research expenditures were adjusted by the shares spent on crop research, assuming that SAUs in RWS system spend nearly half of the crop research expenditure, or 35% of the total expenditure on these crops. In addition, there are some ICAR institutes working in the region and considering their budget, 15% of ICAR expenditure was also taken as research cost. This may be slight over estimation of the research cost but this can be justified as all crop and resource management research target crop productivity of these two important crops in the region.

The technological interventions are likely to generate economic benefits (NPV) of ₹ 169 billion over 20 years at 2012 prices (Table 3). More than two thirds of the aggregate benefits were generated by wheat and common rice varieties due to their larger adoption, and most of the aggregate benefits were shared by the consumers. The estimated internal rate of return is 38% and the ratio of net benefits to the cost is 16.65. In addition, there are environmental benefits of saving of fuel and low carbon emission in the zero-tillage, incorporation of plant residue in reduced tillage and water saving in zero-tillage and shorter duration of basmati rice varieties.

The results confirm the trend of slowing down of productivity growth of rice and wheat in IGP except for rice and Punjab and Haryana where the growth has accelerated due to significant increase in the productivity of superfine rice. The rate of varietal improvement and notification has increased for both the crops, but there is varietal concentration in both the crops. For example, top three varieties contributed more than three-fourths of total seed sale for wheat in the region. Private sector supply an increasing proportion of quality seed and the share of farm-saved seed is reduced to less than one-fifth. The zero tillage in wheat and crop variety improvement are the major technological interventions in the system, which have generated the returns to the order of ₹ 169 billion since 2000. The estimated IRR is 38% and the ratio of net benefits to the cost is 16.6%, which are slightly lower than the rates reported in the past.

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