# Ex-ante Impact of Direct Seeding of Rice as an Alternative to Transplanting Rice in the Indo-Gangetic Plain

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## ABSTRACT

*This study assessed the economic impacts of direct seeding of rice as an alternative crop establishment method for farmers in rice-wheat systems in Uttarakhand, Uttar Pradesh, and Bihar, India. Specifically, it examined the changes in farmers' inputs (labor and materials) and level of productivity and incomes between direct-seeded (DSR) and transplanted (TPR) rice, and measured the economic returns on investment in direct seeding. Analyses included comparison of means, cost and return, and economic surplus framework.*

*The average yield of DSR across sample farms in all three states was 5 percent lower than that of TPR. On the other hand, wheat yield increased by 9 percent after adopting DSR. The net present values (NPVs) of direct seeding in rice-wheat systems in Uttarakhand, Uttar Pradesh, and Bihar were USD 41 million, USD 32 million, and USD 44 million, respectively. The corresponding benefit-cost ratios were estimated at 46, 36, and 50. The NPVs of direct seeding in rice production alone in Uttarakhand, Uttar Pradesh, and Bihar were USD 33 million, USD 23 million, and USD 31 million, respectively. Hence, the greater proportion of benefits from DSR adoption was derived from the change in rice production. In sum, DSR is a profitable option in rice-wheat systems and is appropriate for diffusion.*

**Keywords**: direct seeding, direct-seeded rice, cost-reducing, northern India
**JEL classification**: Q16

## INTRODUCTION

The Indo-Gangetic Plain (IGP) is the rice and wheat bowl of India and its neighboring South Asian countries. Its contribution to food and livelihood security is largely attributed to its fertile soil, relatively well-developed irrigation infrastructure, and the availability of farm machinery (Gautam 2008). Nevertheless, given India's large (1.13 billion) and growing (1.4% per annum) population, increasing rice production has been a major challenge. Labor and water scarcity, reflected in rising production costs, constrain the achievement of this objective. Direct seeding, a crop management technology, is one approach to overcoming these constraints. Instead of transplanting rice from a nursery to the field, seeds are sown directly in the field. Direct seeding has been proposed as an alternative to transplanting as it allows quicker land preparation and saves approximately 20 percent of labor cost and 30 percent of water cost during crop establishment (Lee et al. 2002; Swiss Agency for Development and Cooperation [SDC] 2008).

Direct seeding of rice is gaining popularity among farmers in Asia in response to these productivity constraints (Johnson et al. 2003). For example, in the Mekong Delta of Vietnam, the area planted to modern rice varieties using direct seeding has increased markedly during the past four decades because of crop intensification and shortage of family and hired labor (Nguyen and Xuan 2002). Labor scarcity has also led to the spread of direct seeding in Thailand (Pandey and Velasco 2004), Korea (Lee et al. 2002), China (Tang 2002), India (Hobbs et al. 2002), Bangladesh, and the Philippines (Mazid et al. 2002; de Dios et al. 2005). Balasubramanian and Hill (2002) reported a number of benefits of direct seeding. These include faster and easier planting of rice, reduced labor needs, less drudgery, earlier crop maturity (by 7–10 days), more efficient water use and higher tolerance to water deficit, lower methane emission, and higher profit in areas with an assured water supply. Balasubramanian and Hill (2002) emphasized that, despite the reductions in labor and associated costs for crop establishment, however, other technologies are essential to overcoming constraints such as lodging of the mature rice crop imposed by direct seeding. The interaction of crop establishment, water management, and weed control in relation to crop lodging in both dry- and wet-seeded rice must be addressed. In Malaysia, 92 percent of the farmers in the Muda irrigation area reported that yield of direct-seeded rice was superior to that of transplanted crops, with significant cost reductions. Direct seeding has enabled Muda farmers to save 29 percent of the total cost of a transplanted crop (Ho and Romli 2002).

In the Indian IGP, transplanting remains the most common method of crop establishment in irrigated areas. Rice productivity growth in these areas has been marginal; a big gap exists between potential and realized productivity due to delayed planting (G.B. PUAT 2005). In addition, inefficient use and increasing scarcity of water and labor threaten the productivity and sustainability of the rice-wheat systems in the IGP (Jackson 2009). Appropriate technology options are needed to tackle these constraints.

A multi-year project by the Irrigated Rice Research Consortium (IRRC) of the International Rice Research Institute (IRRI) introduced direct-seeded rice (DSR) to farmers in Uttarakhand, Uttar Pradesh, and Bihar as an alternative to transplanting rice. It aimed to help the farmers address increasing labor costs (especially during crop establishment) and augment their income by lowering production cost in the wet season (*kharif*) and increasing wheat yield in winter (*rabi*). It expected to gain an understanding of the benefits and constraints of direct seeding and to identify technical options to overcome these constraints. Conducted from 2000 to 2007, the project received a total investment of USD 1.89 million from IRRC and its partners (Table 1).

Technology options for wet and dry direct seeding were developed and validated in India by setting up on-station experiments and small-scale on-farm trials in 2000 (V.P. Singh et al. 2010). Farmers' trials were conducted in the states of Uttarakhand, Uttar Pradesh, and Bihar; they involved a range of agroecosystems in the IGP and an extensive community of farming stakeholders, ranging from mechanized farms in Uttarakhand to smallholder farms (≤ 0.5 ha) that rely on manual labor in Bihar (Johnson et al. 2006). Annual farmers' fairs, dissemination of leaflets on weed management, and workshops of researchers and farmer-leaders were done to introduce farmers to direct-seeding and to expand their awareness of it.

The intricacy of rice production systems requires that farmers have substantial knowledge so they can decide on and apply the best technology options in any particular situation (Johnson and Mortimer 2008). Thus, since 2005 the project had been conducting activities with farmers' groups to validate direct-seeding practices in farmers' fields and to explore the information needs of farmers to effectively support their decision making (V.P. Singh et al. 2010).

The study also measured the economic impact of DSR in the three states in the Indian IGP. Specifically, it examined the changes in inputs (labor and materials) used and level of productivity and incomes between direct-seeded and transplanted rice and the economic returns on investment in direct seeding. Approaches for wide-scale adoption of direct seeding were recommended.

## RESEARCH APPROACH AND METHODS

### Study Areas

Uttarakhand, previously known as Uttaranchal, is a state located in northern India. It borders Tibet to the north, Nepal to the east, and the states of Himachal Pradesh and Uttar Pradesh (of which it formed a part before 2000)

**Table 1. Annual project cost (USD 000) in Uttarakhand, Uttar Pradesh, and Bihar, by source of funds, India, 2000-2007**

| Year | Source of Funds | | | | Project Cost by State | | |
|---|---|---|---|---|---|---|---|
| | IRRC[a] | NRI-IRRI[b] | NARES[c] | Total | Uttarakhand | Uttar Pradeshh | Bihar |
| 2000 | | 200 | 50 | 250 | 83 | 83 | 83 |
| 2001 | | 200 | 50 | 250 | 83 | 83 | 83 |
| 2002 | | 200 | 50 | 250 | 83 | 83 | 83 |
| 2003 | | 200 | 50 | 250 | 83 | 83 | 83 |
| 2004 | | 200 | 50 | 250 | 83 | 83 | 83 |
| 2005 | 30 | 200 | 50 | 280 | 93 | 93 | 93 |
| 2006 | 30 | 100 | 50 | 280 | 60 | 60 | 60 |
| 2007 | 30 | 100 | 50 | 280 | 60 | 60 | 60 |
| Subtotal | 90 | 1,400 | 400 | 1,890 | 630 | 630 | 630 |
| 2008–2029 | | | 1,100 | 1,100 | 367 | 367 | 367 |
| Total | 90 | 1,400 | 1,500 | 2,990 | 997 | 997 | 997 |

*Note:* [a] Irrigated Rice Research Consortium; [b] Natural Resources Institute – International Rice Research Institute; [c] National Agricultural Research and Extension Systems in the west and south, respectively (Figure 1). Rice yield in Uttarakhand increased at an average of 0.4 percent from 2000 to 2006 despite the reduction in both area harvested (2%) and production (1%) (Table 2).

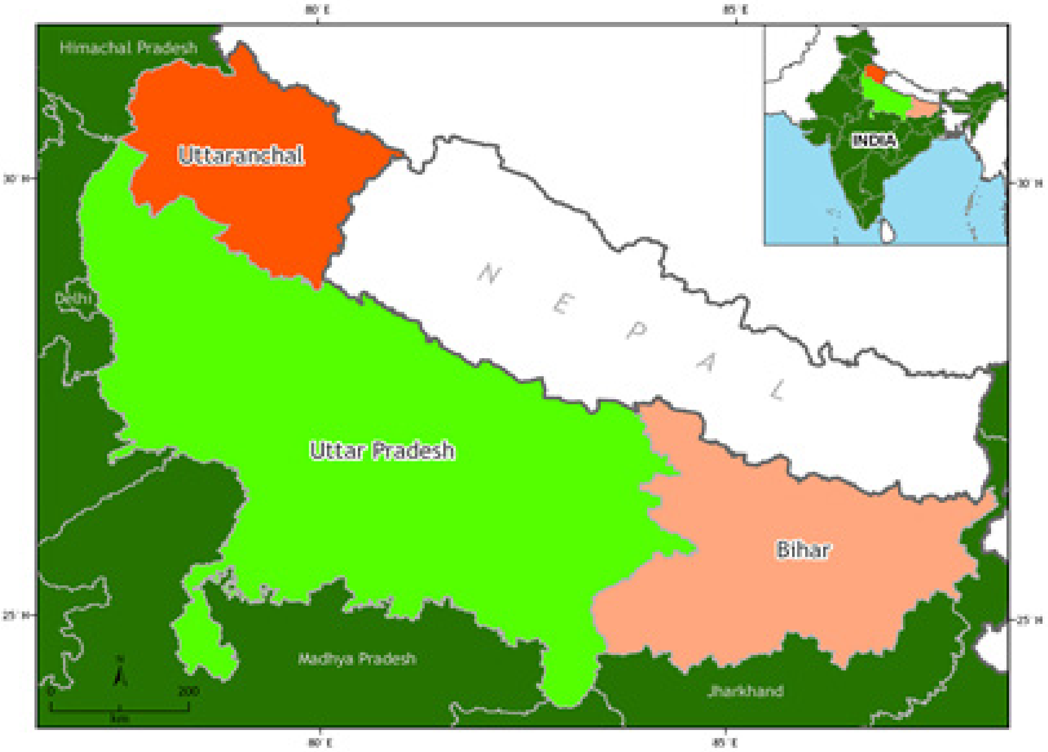
Uttar Pradesh, also located in northern India, is the country's most populous state, with a population of over 190 million people. With an area of 243,286 square kilometers (km$^2$), Uttar Pradesh covers a large part of the highly fertile and densely populated upper Gangetic plain (Figure 1). Increases in area harvested (1%) and production (2%) from 2000 to 2006 resulted in a 0.1-percent increase in yield in Uttar Pradesh (Table 2).

Bihar, located in eastern India, is the 12th largest state in terms of area (99,200 km$^2$). Lying midway between humid West Bengal in the east and subhumid Uttar Pradesh in the west, Bihar has a transitional position in terms of climate, economy, and culture. It is bounded by Nepal in the north and by Jharkhand in the south. Rice production in Bihar increased at an average of 5 percent from 2000 to 2006 despite a 1-percent decrease in area harvested, which led to a 5-percent increase in yield.

## Data Collection

Focus group discussions and pretesting of questionnaires were conducted before the surveys were undertaken in Uttarakhand, Uttar Pradesh, and Bihar states, where project on-farm activities on direct-seeded rice were done. Farm-level data were obtained from the input-output surveys. The input-output aspects of production included farmers' inputs (e.g., fertilizers, pesticides, labor) and yield, which are directly affected by farmers' current practices. Farm-level data on *kharif* (wet season) 2006

**Figure 1. Study area for direct-seeded rice, India**



*Source*: Geographic Information Systems, IRRI (2008)

**Table 2. Rice area, production, and yield in Uttarakhand, Uttar Pradesh, and Bihar, India, 2000-2006**

| Year | Uttarakhand | | | Uttar Pradesh | | | Bihar | | |
|---|---|---|---|---|---|---|---|---|---|
| | Area (000 ha) | Prod'n (000 tons) | Yield (t/ha) | Area (000 ha) | Prod'n (000 tons) | Yield (t/ha) | Area (000 ha) | Prod'n (000 tons) | Yield (t/ha) |
| 2000 | 313 | 932 | 2.98 | 5,907 | 17,519 | 2.97 | 3,656 | 8164 | 2.23 |
| 2001 | 299 | 922 | 3.08 | 6,071 | 19,284 | 3.18 | 3,552 | 7804 | 2.20 |
| 2002 | 283 | 725 | 2.56 | 5,213 | 14,392 | 3.28 | 3,585 | 7628 | 2.13 |
| 2003 | 293 | 854 | 2.91 | 5,952 | 19,528 | 2.76 | 3,578 | 8172 | 2.28 |
| 2004 | 306 | 858 | 2.80 | 5,339 | 14,333 | 2.68 | 3,123 | 3708 | 1.19 |
| 2005 | 302 | 885 | 2.93 | 5,578 | 16,701 | 2.99 | 3,252 | 5243 | 1.61 |
| 2006 | 281 | 834 | 2.97 | 5,921 | 16,686 | 2.82 | 3,357 | 7484 | 2.23 |
| Average | 297 | 858 | 2.89 | 5,712 | 16,920 | 2.95 | 3,443 | 6886 | 1.98 |

*Source*: Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India

rice production were collected from February to June 2007.

A multistage sampling technique was employed; 'with' and 'without DSR' groupings were used to compare yields, incomes, labor inputs, irrigation costs, chemical costs, and other input costs between direct-seeded and transplanted farms in the three states. A total of 100 farmers were interviewed: 40 each in Uttarakhand and Uttar Pradesh (composed of 20 DSR and 20 TPR for each state), and 20 farmers who planted both direct-seeded rice and transplanted rice in Bihar. Thus, 60 respondents represented the DSR group and another 60 respondents, the TPR group. The market-level data, which included production data in each state and the world price of paddy rice, were obtained from IRRI Rice Facts (IRRI 2009).

## Data Analyses

Experimental and quasi-experimental designs using statistical techniques have been increasingly used over the past decade because of their relatively strong counterfactual treatment and high internal validity. Moreover, experimental designs depend on random choice of project participants, control groups, and/or on data collected from the same households over time (panel data) to more precisely estimate the magnitude of impact of a project. As such, they can largely overcome the problematic issues of selection bias and explicitly account for unobservable differences in the control and treatment groups such as differences in managerial skills.

However, experimental designs must be a priori planned and implemented as part of the project; they require a relatively large dataset. In the case at hand, experimental designs were not an integrated part of the project and the dataset is very small, so a much more simplified approach was used. Specifically, cost and return analyses were used to calculate the profits accruing to 'with' (DSR) and 'without' (TPR) farmer groupings. A test of means was used to determine the statistical significance of farm-level variables between the two groups. Economic evaluation of direct-seeding impacts was made using an economic surplus framework. Although data collection and analysis were undertaken after the completion of the IRRI project, adoption of DSR technologies was still at a very early stage then. Hence, the adoption profile was based on approximations rather than on quantified adoption levels. In this regard, analysis used to measure the impact of direct seeding of rice as an alternative to transplanting rice could be considered as a forecasting exercise.

Given this simplified approach, the results must be interpreted with caution since the available dataset does not allow for analysis of non-observable differences such as differences in farmers' management skills. Moreover, given the timing of this analysis, sustainability and/or scaling were not considered.

## Evaluation Framework

The economic benefits of the direct-seeding project were estimated over a period of 30 years (2000–2029). It was assumed that direct seeding will be continuously practiced by farmers as an alternative crop establishment method during this period. Shortage in labor and water availability was expected to worsen over time; this highlights the importance of direct seeding as a way of reducing dependence on these major inputs, a benefit that is expected to convince more farmers to adopt the technology. The differences in yields of DSR and TPR farms were also incorporated in the framework. The research benefits and costs were discounted using a 5-percent rate. A possible increase in wheat yields resulting from DSR in the *kharif* season was included in the estimation of the net present values (NPVs), benefit-cost ratios (BCRs), and internal rates of return (IRRs).

The NPVs and BCRs of direct seeding, by state and in total, were used in the evaluation. NPV is the difference between the cash flows generated from an investment and the initial amount of investment. An NPV greater than 0 indicates a positive return, while a negative NPV implies a loss. The BCR indicates the proportion of expected benefits from a project relative to its costs. A BCR greater than 1 indicates that the project generates benefits greater than what was spent.

Data required for the analysis included an estimate of the farm-level changes in the quantity of output produced and/or cost of production, market-level data (Table 3), the adoption profile, and project-level data (time, duration, investment).

Annual benefits and costs were expressed on a per hectare basis to deal with variations in farm sizes among the three states. The real prices of inputs and the rice price were assumed to be constant. While the nominal price of grains reached record levels in 2008, the long-term real price of rice was assumed to be in the order of USD 350 per ton.

For the purposes of this analysis, the yield change that is negative was estimated using the equation:

$$E(Y) = \frac{(Y_{SDSR} - Y_{STPR})}{Y_{STATE}} \qquad (1)$$

**Table 3. Rice and wheat production by state and world price, 2006**

| State | Area (000 ha) | Production (000 tons) | Yield (tons/ha) | Price (USD/ton) |
|---|---|---|---|---|
| **Rice** | | | | 305* |
| Uttarakhand | 281 | 834 | 2.94 | |
| Uttar Pradesh | 5,921 | 16,686 | 2.82 | |
| Bihar | 3,357 | 7,484 | 2.23 | |
| **Wheat** | | | | 217 |
| Uttarakhand | 391 | 801 | 2.05 | |
| Uttar Pradesh | 9,198 | 25,027 | 2.72 | |
| Bihar | 2,050 | 3,911 | 1.91 | |

*Source*: For area, production, and yield, Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India; For prices, The Pink Sheet, World Bank.

* rough paddy

where $E(Y)$ = yield change; $Y_{SDSR}$ = yield of DSR from the surveys; $Y_{STPR}$ = yield of TPR from the surveys; and $Y_{STATE}$ = average yield by state (from secondary data).

It should be noted that the average yield for all states was less than half the yield obtained from the survey areas. Hence, using the state yield data as the denominator in Equation 1 gave a yield loss that was almost twice as high as it would be if the survey yield data were used. This approach was undertaken to obtain a conservative measure of benefits.

### Adoption Profile

Asia has about 29 million hectares (ha) of direct-seeded rice area, approximately 21 percent of the total rice area in the region (Pandey and Velasco 2004). In Vietnam's Mekong River Delta in the south, which accounts for 52 percent of the country's rice area, about half of the rice area is irrigated and the crop is mainly direct-seeded (Azmi et al. 2005). At the end of the 1990s, rice cultivation in Thailand covered about 10 million ha; the majority of the rainfed rice area was dry direct-seeded while the irrigated areas in the Central Plain were largely wet-seeded (Azmi et al. 2005).

In the analysis, DSR adoption was assumed to have started in 2008, a year after the project ended. The maximum adoption level was subjectively and conservatively assumed at 10 percent and projected to be achieved in 2025. This means that 10 percent of the total area currently planted to TPR will eventually be planted to DSR (Figure 2). A conservative adoption level was assumed since direct seeding is a relatively complex technology (involving mechanization, weed management, and crop agronomy).

## RESULTS AND DISCUSSION

### Basic Socioeconomic Profile of Respondents

The DSR and TPR farmers in all three states had an average age of 51 years (Table 4). They averaged 10–14 years of education, meaning they reached a secondary or tertiary level. Household size ranged from 4 to 6 members.

Farmer-respondents from Uttar Pradesh had significantly larger farms than those from Uttarakhand and Bihar (Table 4). On average, DSR farmers in all three states had slightly larger farms than TPR farmers. They also had TPR plots, which were significantly larger than their DSR plots. The smaller areas allocated to DSR were assumed to be due, at least in part, to farmers' risk management in dealing with a relatively new technology. In Bihar,

**Figure 2. Adoption profile of direct-seeding in the Indo-Gangetic plain, 2000-2029**

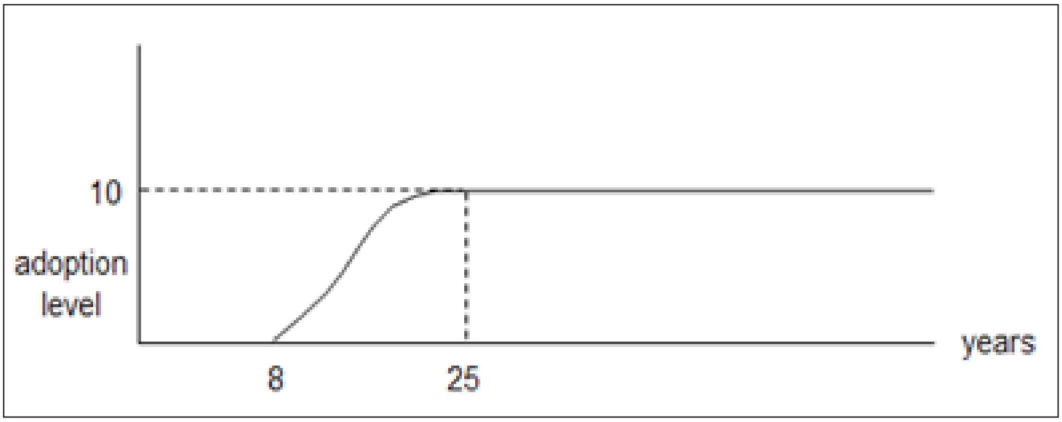


**Table 4. Basic socioeconomic profile of respondents**

| Item | Uttarakhand | | Uttar Pradesh | | Bihar | Three states | |
|---|---|---|---|---|---|---|---|
| | DSR[a] | TPR[b] | DSR[a] | TPR[b] | DSR[a]/TPR[b] | DSR[a] | TPR[b] |
| Sample size | 20 | 20 | 20 | 20 | 20 | 60 | 60 |
| Average age (years) | 55 | 53 | 49 | 49 | 49 | 51 | 50 |
| Years of education | 10 | 13 | 14 | 11 | 10 | 11 | 11 |
| Household size | 6 | 5 | 4 | 5 | 4 | 5 | 5 |
| Farm size (ha) | 7.32 | 5.13 | 9.02 | 9.46 | 3.92 | 6.75 | 6.17 |
| DSR plots | 0.94 | 0 | 2.33 | 0 | 0.20 | 1.16 | 0.07 |
| TPR plots | 6.38 | 5.13 | 6.65 | 9.46 | 3.72 | 5.58 | 6.10 |
| Unplanted | 0 | 0 | 0.04 | 0 | 0 | 0.01 | 0 |

*Note*: [a] DSR (direct-seeded rice) respondents (with both DSR and TPR plots); [b] TPR (transplanted rice) respondents

the area planted to DSR was only 5 percent of the average farm size. Most of the farmers interviewed owned the land they cultivated.

## Impact of Direct Seeding at the Farm Level

### *Input use*

A major benefit of direct-seeded rice is lower input costs, particularly those of labor and some materials.

#### *Labor cost*

In all three states, the labor costs of DSR for land preparation, crop establishment, fertilizer application, and irrigation were lower than those of TPR (Table 5). The highest difference in labor cost was in crop establishment. On average, the DSR labor cost for crop establishment was USD 40/ha lower than TPR's. This reduced need for labor not only saves time and money of farmers but also allows greater flexibility so that farmers can attend to crop establishment activities in TPR farms. Labor costs for land preparation (USD 16/ha), irrigation (USD 12/ha), seedbed preparation and care (USD 14/ha), and fertilizer application (USD 5/ha) were also lower for DSR than TPR (Table 5). On the other hand, DSR incurred higher costs for herbicide application and manual weeding than TPR. This concurs with the findings of Pandey and Velasco (2002). The cost difference was USD 8/ha and USD 12/ha, respectively.

In Uttar Pradesh and Bihar, labor costs for all farm activities were significantly lower for DSR than for TPR, except for fertilizer application in Uttar Pradesh and manual weeding in Bihar (Table 5). In Uttarakhand, the DSR labor costs for seedbed preparation and care, land preparation, crop establishment, irrigation, and fertilizer application were significantly lower than TPR's. On the other hand, labor costs for manual weeding and herbicide application were significantly higher for DSR than TPR .

#### *Material cost*

Seed cost among DSR farms in Uttarakhand, Uttar Pradesh, and Bihar was higher than in TPR farms by USD 7/ha, USD 2/ha, and USD 3/ha, respectively (Table 5). Higher expenditures on seeds were expected because higher seeding rates are required for direct seeding relative

**Table 5. Differences in cost of materials, labor, fuel and rent, and yields by method of crop establishment in the rice-wheat cropping system, by state**

| Item | Direct-seeded Rice vs. Transplanted Rice | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Uttarakhand | | Uttar Pradesh | | Bihar | | All States | |
| | **Difference** | ***p*-value** | **Difference** | ***p*-value** | **Difference** | ***p*-value** | **Difference** | ***p*-value** |
| Rice | | | | | | | | |
| Material cost | | | | | | | | |
| Seed cost | 6.74 | 0.00 | 2.15 | 0.00 | 2.74 | 0.00 | 3.88 | 0.00 |
| Seedbed material cost | −2.07 | 0.00 | −6.27 | 0.00 | −3.10 | 0.00 | −3.82 | 0.00 |
| Herbicide | 26.48 | 0.00 | 29.72 | 0.00 | 23.38 | 0.00 | 26.52 | 0.00 |
| Total cost (USD/ha) | 8.13 | | 16.70 | | 1.27 | | 8.70 | |
| Fuel cost and rent | | | | | | | | |
| Land preparation | −19.00 | 0.01 | −21.01 | 0.00 | −9.49 | 0.00 | −16.50 | 0.00 |
| Irrigation | −15.52 | 0.03 | −17.63 | 0.00 | −4.63 | 0.21 | −11.05 | 0.02 |
| Total cost (USD/ha) | −34.52 | | −38.64 | | −14.13 | | −27.55 | |
| Labor | | | | | | | | |
| Seedbed preparation and care | −15.22 | 0.00 | −9.07 | 0.00 | −19.03 | 0.00 | −14.44 | 0.00 |
| Land preparation | | | | | | | | |
| Seedbed | −8.11 | 0.00 | −7.60 | 0.02 | −12.54 | 0.00 | −9.42 | 0.00 |
| Main field | −21.03 | 0.01 | −14.54 | 0.00 | −11.73 | 0.00 | −15.77 | 0.00 |
| Crop establishment | −43.14 | 0.00 | −41.84 | 0.00 | −33.62 | 0.00 | −39.54 | 0.00 |
| Herbicide application | 6.60 | 0.02 | 8.63 | 0.00 | 8.77 | 0.03 | 8.00 | 0.00 |
| Manual weeding | 19.96 | 0.01 | 15.48 | 0.02 | 5.36 | 0.63 | 11.81 | 0.03 |
| Irrigation | −20.19 | 0.00 | −10.41 | 0.01 | −6.12 | 0.01 | −12.24 | 0.00 |
| Total cost (USD/ha) | −81.12 | | −59.35 | | −74.28 | | −71.51 | |
| Change in costs (USD/ha) | −84.49 | | −72.39 | | −60.76 | | −72.55 | |
| Yield (tons/ha) | −.0.17 | 0.37 | −0.22 | 0.57 | −0.31 | 0.00 | 0.23 | 0.003 |
| Wheat: Yield (tons/ha) | 0.22 | 0.25 | 0.31 | 0.05 | 0.50 | 0.00 | 0.36 | 0.004 |

*Note*: All monetary values are in 2006 prices; Exchange rate: USD 1 = 40 Indian Rupee (INR)
Not statistically significant items (fertilizer application in Uttarakhand and manual weeding and irrigation in Bihar) were excluded in the computation of change in cost.
Data on wheat yield were taken from farmers' fields, 2004–2005, in Uttarakhand and Uttar Pradesh, and 2003–2004 in Bihar

to transplanting. The highest cost difference between DSR and TPR in material cost was for herbicides. In all three states, the average expenditure on herbicides was higher by USD 27/ha among DSR farms than TPR farms (Table 5). The higher cost for herbicides in DSR came from the combined effect of applying more herbicides and the higher cost per unit of herbicides suitable for DSR. Farmers who practiced direct seeding were more reliant on herbicides simply because they cannot rely on flooding to suppress weeds during the crucial initial period of crop establishment (Johnson 2006). On the other hand, expenditures on fertilizers, fuel, and rent in land preparation and irrigation were lower for DSR than TPR. Fertilizer costs incurred in DSR in Uttarakhand, Uttar Pradesh, and Bihar were lower by USD 23/ha, USD 9/ha, and USD 22/ha, respectively, than in TPR (Table 5). This was because TPR farmers were inclined to use more fertilizers as a treatment or preventive measure against transplanting shock. It can also be attributed to the hesitation of DSR farmers to spend more on fertilizers since they were still in the trial stage of technology adoption.

Rent and fuel costs for land preparation and irrigation, on the average, were also lower in DSR than TPR in all three states by USD 17/ha and USD 13/ha, respectively (Table 5). Specifically, the cost differences for land preparation in Uttarakhand, Uttar Pradesh, and Bihar were USD 19/ha, USD 21/ha, and USD 10/ha, respectively (Table 5). For irrigation, they were USD 16/ha, USD 18/ha, and USD 5/ha, respectively.

### *Yield*

The average yield of DSR (4.8 tons/ha) in all three states was 5 percent lower than that of TPR (5.05 tons/ha). The yield difference for each state was 0.17 ton/ha in Uttarrakhand, 0.22 ton/ha in Uttar Pradesh, and 0.31 ton/ha in Bihar (Table 5). Previous studies had found that DSR may obtain a lower yield due to the unstable establishment of rice seedlings and slow growth during the early growing stage (Kimio et al. 1999). Yield in direct seeding can be also reduced by weed problems. Yield losses (due to weeds) largely depend on season, weed species, weed density, rice cultivar, and growth rate and density of weeds and rice (Azmi et al. 2005). Another factor affecting yield in direct seeding is seed rate. A seed rate higher than the recommended rate can result in lower yield of DSR since it may lead to nitrogen deficiency, thus reducing tillering and increasing the proportion of ineffective tillers, to attacks of brown plant hoppers, and to crop lodging (RWC Tech Bulletin 2006). However, yield of DSR is not always lower than that of TPR. In the rice-wheat systems in India, rice yields of wet- or dry-seeded crops have been higher than those of transplanted crops, provided weeds are adequately controlled (Johnson et al. 2003).

An indirect positive effect of growing DSR in the wet season (*kharif*) is the corresponding higher yield of wheat in the next winter cropping season (*rabi*). Wheat yields were significantly higher in Uttarakhand, Uttar Pradesh, and Bihar by 0.22 ton/ha, 0.31 ton/ha, and 0.50 ton/ha when wheat was preceded by DSR (Table 5). This concurs with the studies of V.P. Singh et al. (2008), Yadav et al. (2008), and Sinha et al. (2008). Higher wheat yield resulting from DSR in the *kharif* season is due to the shorter time it takes for DSR to reach maturity. This allows for on-time planting of wheat, thus saving farmers from a 1 percent (or more) reduction in yield per day (Hobbs 2001).

### *Production costs and gross and net incomes*

In all three states, TPR farmers got higher yields so their gross income was also higher by USD 69.85/ha (*p*=.006) than that of DSR farmers. However, the total costs incurred by

TPR farmers were higher by USD 124.54/ha (*p*=.001). On the other hand, although DSR farmers got relatively lower yields, the reduction in total cost was large enough to result in a net income higher by USD 54.70/ha (*p*=.035) than that of TPR farmers.

## Economic Evaluation of the Impact of Direct-Seeding of Rice

Table 5 summarizes farm-level changes in quantity of output and production costs. In terms of output, the yield obtained by DSR farmers in the three states was 0.23 ton/ha lower than that by TPR farmers. As regards cost of production, DSR farmers compared with TPR farmers had (a) higher expenditures on seeds and herbicides; (b) lower expenses on fertilizer, fuel, and rent cost for both land preparation and irrigation; (c) lower labor costs for seedbed preparation and care, land preparation, crop establishment, fertilizer application, and irrigation; and (d) higher labor costs for herbicide application and manual weeding (Table 5). In sum, the cost of production in Uttarakhand, Uttar Pradesh, and Bihar was lower in DSR than TPR by USD 118/ha, USD 81/ha, and USD 86/ha, respectively (Table 5).

Table 3 shows the market-level data on rice in Uttarakhand, Uttar Pradesh, and Bihar used in the analysis. Among the three states, Uttarakhand has the smallest area, which corresponds to just approximately 5 percent and 8 percent of the total area devoted to rice in Uttar Pradesh and Bihar, respectively. Although Uttarakhand has the smallest area, it had the highest average yield (3 tons/ha).

Table 1 shows the total project cost from 2000 to 2007, estimated at USD (2006) 1.89 million or an expenditure of USD (2006) 0.63 million each for Uttarakhand, Uttar Pradesh, and Bihar. Fund contributors included the IRRC, Natural Resources Institute (NRI), IRRI, and national agricultural research and extension system (NARES). NARES continued to support the promotion of DSR beyond 2007, allocating USD 50,000 each year for all three states.

It is too early to know with any degree of certainty what the adoption profile will be; however, even if maximum adoption is only 10 percent and it would take 25 years to reach that level, the returns on investment to the project in rice-wheat systems in Uttarakhand, Uttar Pradesh, and Bihar at a discount rate of 5 percent would still be USD 41 million, USD 32 million, and USD 44 million, respectively, or a total of USD 117 million (Table 6). The corresponding BCRs were estimated at 46, 36, and 50, respectively, with an average of 44. These values suggest that every dollar spent on the direct-seeding project in Uttarakhand, Uttar Pradesh, and Bihar generates a corresponding benefit of USD 46, USD 36, and USD 50, respectively (Table 6).

In rice production alone, returns to the project in Uttarakhand, Uttar Pradesh, and Bihar at a discount rate of 5 percent are USD 36 million, USD 23 million, and USD 31 million, respectively, giving a total of USD 88 million (Table 6). The corresponding BCRs were estimated at 39, 26, and 33, with an average of 34. The project would thus more than pay for itself even at just a maximum adoption of 10 percent.

## Sensitivity Analysis

### *Maximum adoption of 20 percent*

In the base case, maximum adoption was subjectively and conservatively assumed at 10 percent and would be achieved by 2025. However, the adoption level could be higher than 10 percent. Thus, if the adoption level is 20 percent by 2025, the returns to the project in Uttarakhand, Uttar Pradesh, and Bihar would more than double: USD 83 million, USD 65 million, and USD 90 million, giving a total of

**Table 6. Results of the analysis at 5% discount rate by state, *kharif* season**

| State | Investment Criterion | | | |
|---|---|---|---|---|
| | Present Value of Benefits (USD 000) | Cost (USD 000) | NPV (USD 000) | BCR |
| Rice-Wheat | | | | |
| Uttarakhand | 41,595 | 902 | 40,693 | 46 |
| Uttar Pradesh | 32,524 | 902 | 31,622 | 36 |
| Bihar | 45,213 | 902 | 44,311 | 50 |
| All states | 119,332 | 2,706 | 116,626 | 44 |
| Rice | | | | |
| Uttarakhand | 34,831 | 902 | 33,930 | 39 |
| Uttar Pradesh | 23,440 | 902 | 22,539 | 26 |
| Bihar | 32,227 | 902 | 31,325 | 36 |
| All states | 90,498 | 2,706 | 87,793 | 33 |

*Note:* NPV refers to net present value; BCR refers to benefit-cost ratio

USD 238 million (Table 7). The corresponding BCRs are 93, 73, and 101, with an average of 89.

### *Maximum adoption of 10 percent but achieved four years earlier*

Assuming that maximum adoption remains at 10 percent but is achieved four years earlier (in 2021 rather than 2025), the NPVs at a discount rate of 5 percent in Uttarakhand, Uttar Pradesh, and Bihar would be USD 68 million, USD 53 million, and USD 73 million, giving a total of USD 194 million (Table 7). The corresponding BCRs are 76, 59, and 82, with an average of 73 (Table 7).

### *Attribution of benefits to IRRC and partners*

The benefits of direct seeding to the IRRC and its partners were attributed using the cost-share approach. This approach, which considers the share of total expenditure invested in the project, is appropriate when the activity is necessary but not sufficient to change the practice or behavior (Templeton 2009). The project contributed to the development of direct-seeding practices in northern India, where complementary activities were also carried out by the Indian Council of Agricultural Research (ICAR) and Rice-Wheat Consortium (RWC). Only 40 percent of the benefits were credited to the IRRC and its partners. When the 40-percent contribution is applied to the estimated benefits attributable to the IRRC and its partners, the realized benefits for Uttarakhand, Uttar Pradesh, and Bihar were estimated at USD 0.048 million, USD 0.013 million, and USD 0.091 million, respectively (Table 8). The projected benefits are USD 16.2 million, USD 13 million, and USD 17.6 million, respectively. The total benefits were estimated at USD 16.3 million for Uttarakhand, USD 13 million for Uttar Pradesh, and USD 17.7 million for Bihar.

## CONCLUSION

The benefits of DSR at the farm-level in terms of reducing expenditures on labor and other input costs and in increasing net incomes of farmers in the rice-wheat systems are comparable with the estimated benefits of DSR in previous studies (Pandey and Velasco 2004; S.P. Singh et al 2008). In areas where there is a labor shortage, DSR is an advantageous option because it reduces labor inputs for crop

**Table 7. Sensitivity analysis in rice-wheat systems at a discount rate of 5%**

| Sensitivity Analysis/State | Investment Criterion | | | |
|---|---|---|---|---|
| | Present Value of Benefits (USD 000) | Cost (USD 000) | NPV (USD 000) | BCR |
| Maximum adoption of 20% | | | | |
| Uttarakhand | 83,828 | 902 | 82,926 | 93 |
| Uttar Pradesh | 65,397 | 902 | 64,495 | 73 |
| Bihar | 91,094 | 902 | 90,192 | 101 |
| All states | 240,318 | 2,706 | 237,613 | 89 |
| Maximum adoption of 10% achieved 4 years earlier | | | | |
| Uttarakhand | 68,389 | 902 | 67,487 | 76 |
| Uttar Pradesh | 53,469 | 902 | 52,567 | 59 |
| Bihar | 74,343 | 902 | 73,441 | 82 |
| All states | 196,201 | 2,706 | 193,496 | 73 |

**Table 8. Estimates of benefits (USD 000) attributable to the IRRC and its partners under 40% contribution assumption at a discount rate of 5% (in rice-wheat systems)**

| Description | Uttarakhand | Uttar Pradesh | Bihar | All states |
|---|---|---|---|---|
| Total benefits | | | | |
| Realized present value of benefits (2000–2009) | 121 | (33) | 228 | 316 |
| Projected present value of benefits (2010–2029) | 40,572 | 31,655 | 44,083 | 116,310526 |
| Total present value of benefits (2000–2029) | 40,693 | 31,622 | 44,311 | 116,626 |
| Benefits attributable to IRRI-IRRC | | | | |
| Realized present value of benefits (2000–2009) | 48 | (13) | 91 | 126 |
| Projected present value of benefits (2010–2029) | 16,229 | 12,66204 | 17,633 | 46,524 |
| Total present value of benefits (2000–2029) | 16,277 | 12,649,100 | 17,724 | 46,650 |

establishment, land preparation, and irrigation. The advantage of DSR technology can be maximized in areas where irrigation water is scarce. This implies that farmer adoption of DSR would be higher in areas where the availability of irrigation water has gone down significantly or reached critical levels. On the policy aspect, DSR could be an option to address water and labor shortages in rice production.

However, DSR has the disadvantage of possibly reducing yield, as seen in this study. This can affect the self-sufficiency objective of the area, particularly considering the global decrease in paddy production and the increasing wholesale and retail prices of rice. Thus, further studies need to be undertaken on the farms that encountered yield reductions as well as those that experienced higher yields with DSR. It will be useful to identify the factors that affected either yield reduction or increase. Being able to sustain higher yields in DSR would generate bigger benefits to rice farmers in the area.

DSR was found to be a cost-reducing technology and farmers are aware of this benefit. Farmers, however, are risk-averse and usually look at production on a per-crop basis rather than long-term (Rogers 1995). Yield variability thus affects their decision on whether or not to adopt a technology. In this study, some farmers were willing to adopt the technology even if the DSR yields were lower since the lower production costs in *kharif* and higher wheat yield in *rabi* resulted in a higher net income.

Nevertheless, direct seeding is viable for farmer adoption. One reason why some farmers had not tried it was lack of knowledge about the technology. Wider dissemination of information materials would enable more farmers to be aware of the benefits of DSR technology. Training in rice management practices using optimum inputs (e.g., quality seeds and appropriate quantity and type of herbicides) and proper weed management in DSR will be useful in promoting this technology as an alternative crop establishment method.

The benefits of DSR at the project-level imply that it is worth investing on a direct-seeding project. On the other hand, while the estimated net benefits of DSR appear to be high, they are total benefits over a 30-year period and represent less than 1 percent of the present value of the total production of rice and wheat in Uttarakhand, Uttar Pradesh, and Bihar over the same time period.

Nevertheless, the study shows the economic relevance of DSR to farmers as an alternative planting method to transplanting. DSR is appropriate for adoption and profitable in rice-wheat systems. The technology is seen as not only improving the livelihood of farmers but also as an important component of conservation agriculture, wherein limited resources are efficiently used for sustainability.

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