Seeds, Water, and Markets to Increase Wheat Productivity in Bihar

by Avinash Kishore and Vartika Singh

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Abstract

Wheat yields are low and variable in the rice-wheat cropping systems in the lower Indo-Gangetic plains (IGP) covering Bihar and Eastern Uttar Pradesh (EUP) in India and the Terai areas of Nepal. Since wheat is the largest crop of the region and the most important source of calories after rice, its productivity plays a big role in ensuring food security and increasing farmers' income. This paper uses data from a recent large primary survey of a representative sample of 7,649 wheat growers from the region to identify four main reasons for the low productivity of wheat: 1) late sowing of the crop due mainly to the late transplantation and harvest of paddy; 2) insufficient irrigation of wheat; 3) persistent use of old seed varieties, and 4) poor incentives for input intensification due to low price realization by farmers. We argue that the high cost of diesel-powered irrigation is a major reason for the late transplantation of paddy and under-irrigation of wheat. A concerted approach that includes a) public investments in the electrification of irrigation and rationalization of electricity subsidies, b) incentives to promote private sector participation in input markets to accelerate the adoption of improved seeds, c) scaling up of institutional innovations (like FPOs) to aggregate marketable surpluses of smallholder farmers, and d) the creation of competitive agricultural markets to ensure better price realization is required to increase wheat yields and farmers' incomes from wheat production.

Keywords: Irrigation, Yields, South-Asia, Seeds, Markets, Procurement

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1. Introduction

Wheat is an important crop for Bihar and Eastern Uttar Pradesh (EUP) both for the income security of farmers and the food security of the households. It is the second-largest crop in the region after rice in terms of area, production, and value of output. Farmers in Bihar cultivate wheat on more than 2 million ha of land and produce 5-6 million tons of it every year. Wheat occupies 28% of the gross cropped area of Bihar and 70% of the sown area in the Rabi season. The Situation Assessment Survey of Farmers 2012-13 (SASF) by the National Statistical Organization (NSO) shows that 5.73 million of the 7.09 million farmers (81%) in Bihar cultivated wheat.[1] Wheat contributes 13-14% of the total value of the agricultural output of the state compared to 9-10% value share at the all India level (Central Statistical Office, 2018).

Wheat is also critical for the food security of Bihar as it is the main staple along with rice. Almost all households (>93%) in the state consume wheat and per capita consumption is 4.55 kg/month - second only to rice (4.72 kg/month). Urban households in Bihar consume more wheat (5.32 kg/month) than rice (4.92 kg/month), but in rural areas, where 89% of the state's population lives, the consumption of rice is marginally higher. The total consumption of wheat in the state is growing while the total consumption of rice is declining with a rise in incomes (Table 1).

Table 1. Total Household Consumption of Rice and Wheat in Bihar in 2004-05 and 2011-12

Staple	Thousand Tonnes	
	2004-05	**2011-12**
Rice & rice products	7669	6467
Wheat & wheat products	5895	6128

Source: Authors' calculation using NSS-CES Data from 61st and 68th rounds

Despite its importance to the state's agrarian economy and food security, wheat yield and the gross value of output per hectare are lowest in Bihar among all major wheat-producing states of India[2] (see columns 2 and 3 in Table 2) while the cost of production (INR/tonne) is high

[1] 5.34 million of these farmers grow both rice and wheat. 5.90 million farmers grew paddy in that crop year.
[2] Bihar (6.2%), Gujarat (2.8%), Haryana (11.4%), Madhya Pradesh (16.4%), Punjab (17.5%), Rajasthan (9.7%), and Uttar Pradesh (31.1%) are the major wheat growing states of India. Together, they account for more than

(INR 10630/tonne vs. INR 9600/tonne for India) and the net profit (INR per hectare) from wheat cultivation is the lowest (CACP, 2020). The low yield of wheat is one of the main reasons for its high cost of production (as measured in INR per tonne) and the low profits from its cultivation in Bihar.

Table 2. Wheat yield, the value of output and production cost and profits in major wheat growing states of India in 2018-19

(1)	(2)	(3)	(4)	(5)	(6)
States	**Yield (tonnes/ha)**	**Gross Value of Output (INR/ha)**	**Production Cost (INR/ha)**	**Production Cost (INR/tonne)**	**Profits (INR/ha)**
Bihar	2.76	58958	31264	10630	27694
Gujarat	-	64567	33872	12040	30695
Haryana	4.59	99655	37114	8500	62541
Madhya Pradesh	2.99	72122	31707	9280	40415
Punjab	4.99	96121	33714	7140	62407
Rajasthan	33.4	88317	47282	997	41035
Uttar Pradesh	32.7	75950	39273	1033	36677
India	33.6	77673	36924	960	40749

Source: CACP (2020)

Wheat yields are low in Bihar not only compared to the other states of India, but also in comparison to the potential yield and the realized yields in farmers' fields in the state (Table 3). Potential yield is the yield achieved in frontline demonstrations (FLD) where best scientific and management practices are followed while realized yield is the yield obtained using improved technology under farmers' practices. The CACP got data on the potential and the realized yields of wheat from the Indian Council of Agriculture Research (ICAR) research institutes conducting FLDs (Commission for Agricultural Costs and Prices (CACP), 2020). The average productivity of wheat in Bihar needs to increase by 48% to reach the potential yield and by 24% to reach the highest realized yields in the state. Wheat yields are not only low in Bihar, but they are also unstable. In the ten years from 2009-10 to 2018-19, average wheat yield in Bihar has ranged from .8 tonnes/ha in 2014-15 to 2.9 tonnes/ha in

95% of the total wheat produced in the country. Numbers in parenthesis indicated the share of each state in the total wheat produced in India.

2018-19 (Directorate of Economics and Statistics, multiple years) often due to varying climatic conditions (Kiel et al., 2020).

Table 3. Potential and Average Yield of Wheat (tonne/ha) in the Major Wheat Growing States of India

State	Potential Yield (tonnes/ha)	Realized Yield (tonnes/ha)	State Average Yield (tonnes/ha)
Bihar	4.11	3.44	2.78
Haryana	5.15	4.95	4.62
Madhya Pradesh	4.98	4.16	2.99
Punjab	5.32	5.18	4.99
Rajasthan	5.05	4.55	3.34
Uttar Pradesh	4.83	4.24	3.27
India	4.53	3.96	3.36

Source: CACP (2020)

This paper uses data from a primary survey of a representative sample of 5,793 wheat growers in Bihar and 1,855 in the neighbouring districts of EUP in 2017-18 to identify major reasons for low wheat yields. We focus on four major reasons for low productivity:

1. First, irrigation is expensive in Bihar because it is dependent primarily on diesel pumps. Farmers wait for rains to transplant paddy, rather than using irrigation. This waiting leads to the late transplantation and harvest of paddy which also delays the sowing of wheat exposing it to terminal heat in its critical growth phase.
2. Second, farmers also under-irrigate wheat (water application < reference evapotranspiration) because irrigation is expensive resulting in yield losses.
3. Third, a large number of wheat growers in Bihar continue to use very old varieties of seeds with low yield potential.
4. Finally, these farmers do not get remunerative prices for wheat. Low and uncertain output prices reduce farmers' incentives for input intensification.

The rest of the paper is organized as follows. Section 2 describes the primary data used for our analysis. We discuss the impact of the high cost of diesel-powered irrigation on delays in the sowing of wheat and the under-application of irrigation in section 3. Section 4 shows the persistent use of old seed varieties, its correlation with lower yields, and suggests an innovative approach to accelerate the adoption of newer varieties of seeds. Section 5 draws attention to the problem of poor price realization of wheat in Bihar and argues that improving price realization of wheat will incentivize farmers to intensify input use and realize higher yields. Section 6 concludes the paper.

2. Data

2.1. The Landscape Diagnostic Survey (LDS) of Wheat Production Practices and Yield

We rely mainly on the LDS data in this paper. The 'landscape diagnostic survey data of wheat production practices and yield' collected primary data from a representative sample of randomly selected 7,648 wheat growers from 1,766 villages spread across 40 districts of Bihar and EUP in 2018-19 (Table 4) (CIMMYT, 2018). More details on LDS can be found in Singh et.al., (2020). For the largest plot on which the farmer cultivated wheat, the LDS collected data on input use (seeds, fertilizers, water), cultivation practices (method of land preparation, timing, and method of sowing the seeds, frequency of irrigations, weed control, etc.), sales of produce, and the output market price realized. The LDS also has data on soil quality and the location of the largest plot of land. Farmer-reported wheat yields were validated by conducting crop-cutting experiments on more than 300 plots.

Table 4. The LDS Sample in Bihar and EUP

Sampling Units	Bihar	EUP
Number of farmers	5,793	1,855
Villages	1,304	462
Blocks	314	101
Districts	31	9

Source: Singh.et.al., 2020

2.2. Farm enterprise characteristics

87% of all farmers in the LDS had landholdings smaller than 2 hectares and 64.7% owned less than 1 hectare of land as can be seen in Table 5. LDS collected detailed data on inputs and cultivation practices used in the largest wheat plot of farmers. The average size of the largest plot was 0.25 ha and 81% of these plots were cultivated by the landowners while nearly 19% of them were operated by tenants. Nearly 60% of the respondents belonged to ‘other backward castes’ (or OBC) group while 13% of them were Dalits (scheduled caste) and 24% were from the ‘general caste’.

Groundwater is the predominant source of irrigation for the farmers in the sample. Only 8% of farmers relied exclusively on surface water for irrigating their wheat crop. Canals, rivers, and ponds were the common sources for surface water for irrigation. 89% of all farmers in the LDS relied on diesel as the source of energy for groundwater irrigation. Only 16.8% of groundwater irrigators in Bihar and 21.2% in EUP irrigated with electric pumps. Nearly one third of these farmers reported using both electric and diesel pumps for irrigation. The frequent use of diesel pumps by electric pump users suggests unreliable electric power supply in the study area.

Almost all of wheat growers in Bihar and EUP apply nitrogen and phosphorous fertilizers. Application of Potash, though recommended for wheat (Fishman et al. 2016), is not as widespread. Only 62% farmers applied any Potash or complex fertilizers, like NPK, that contain potassium. 19.5% farmers in the LDS applied FYM. Zinc deficiency is also common in the region, but very few farmers (11.5%) apply zinc to wheat. Most farmers apply Zn to paddy in the paddy-wheat cropping systems.

Table 5. Characteristics of sampled farmers in the LDS

Farmer Characteristics	**Mean**
Holding size (ha)	1.21 (2.14)
Size of the largest plot (ha)	0.25 (0.27)
% of Marginal farmers (landholding <1 ha)	64.70
% of Small farmers (landholding < 2ha)	86.82
% of largest plots under tenant cultivation	18.82
Social Categories of farmers	
Scheduled Castes (%)	12.88
OBC (%)	59.17
General (%)	24.20
Others including STs (%)	3.75
Farmers exclusively using surface irrigation (%)	8.03
Farmers using groundwater irrigation (%)	91.07

Source of energy for groundwater irrigation	
Only diesel	82.14
Only electricity	12.22
Both diesel & electricity	5.64
Fertilizer use in Wheat	
Farmers who applied Urea (%)	99.57
Farmers who applied Phosphate (%)	96.39
Farmers who applied Potash (%)	62.30
Farmers who applied Zinc (%)	11.5
Farmers who applied farmyard manure (%)	19.46
Total Farmers in the sample	**7648**

Source: Authors' calculations using LDS data

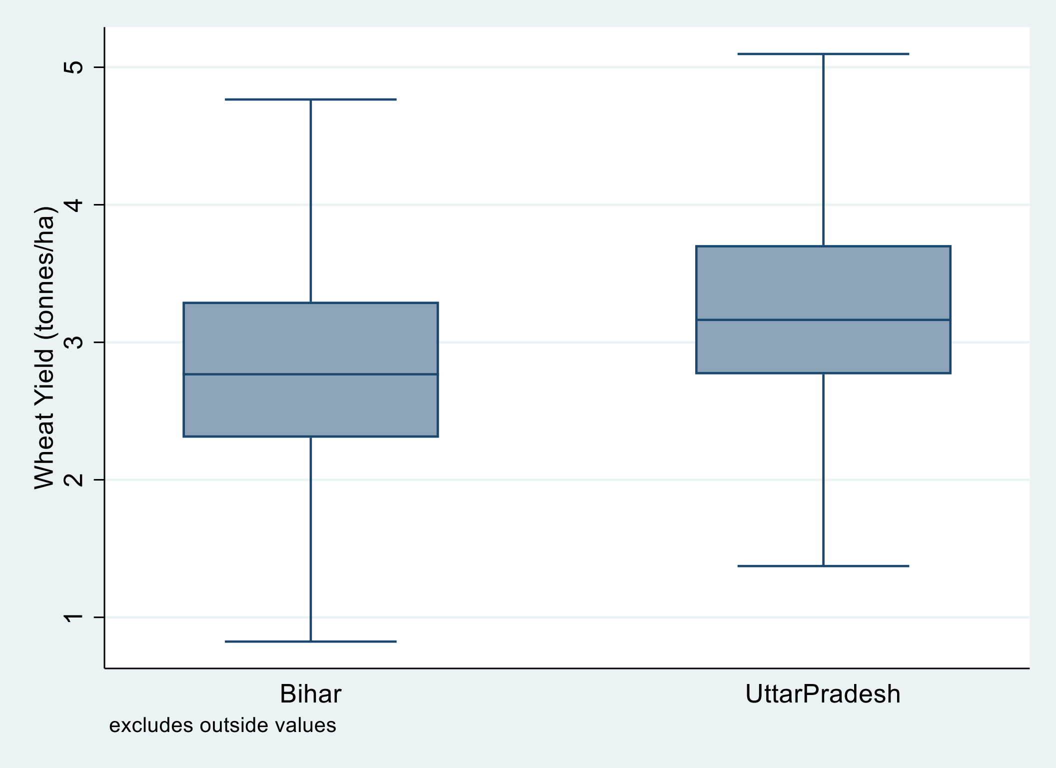
3. Results

3.1. Low wheat yields in Bihar and EUP

The LDS shows that wheat yields are low in both Bihar and EUP (Figure 1). The median yield was 2.8 tonnes/ha in Bihar and 3.1 tonnes/ha in EUP[3] compared to the national average yield of 3.4 tonnes/ha. Even the 75th percentile of wheat yield in Bihar is lower than the average all-India yield.

Figure 1. Wheat yields (tonnes/ha) in Bihar and EUP in 2017-18

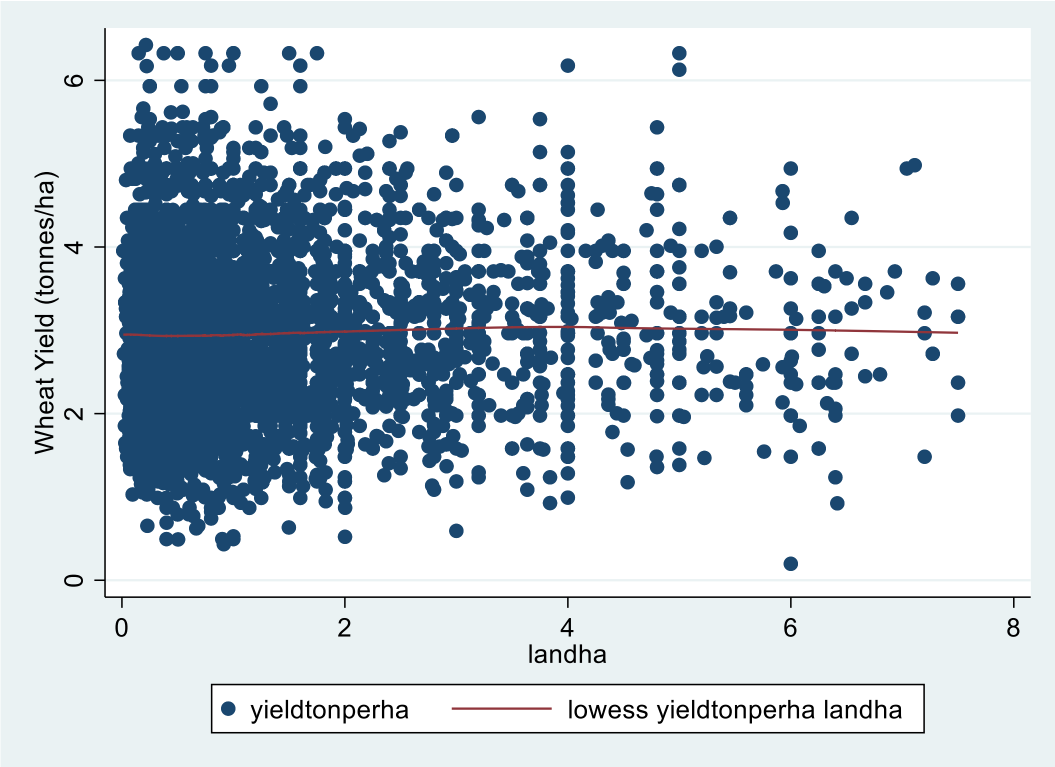
[3] The average yields were marginally higher at 2.9 tonnes/ha and 3.3 tonnes/ha for Bihar and UP respectively.



Source: Authors' calculations using LDS data

Wheat yields are low in the region across all landholding size categories. This is evident from the slope of the line in Figure 2 that displays the smoothed values of a kernel-weighted local polynomial regression of yield against the holding size with confidence bands shown as the shaded area around the line.

Figure 2. Distribution of wheat yields across landholding size of farmers



Source: Authors' calculations using LDS data

4.2. Reason for low yields of wheat

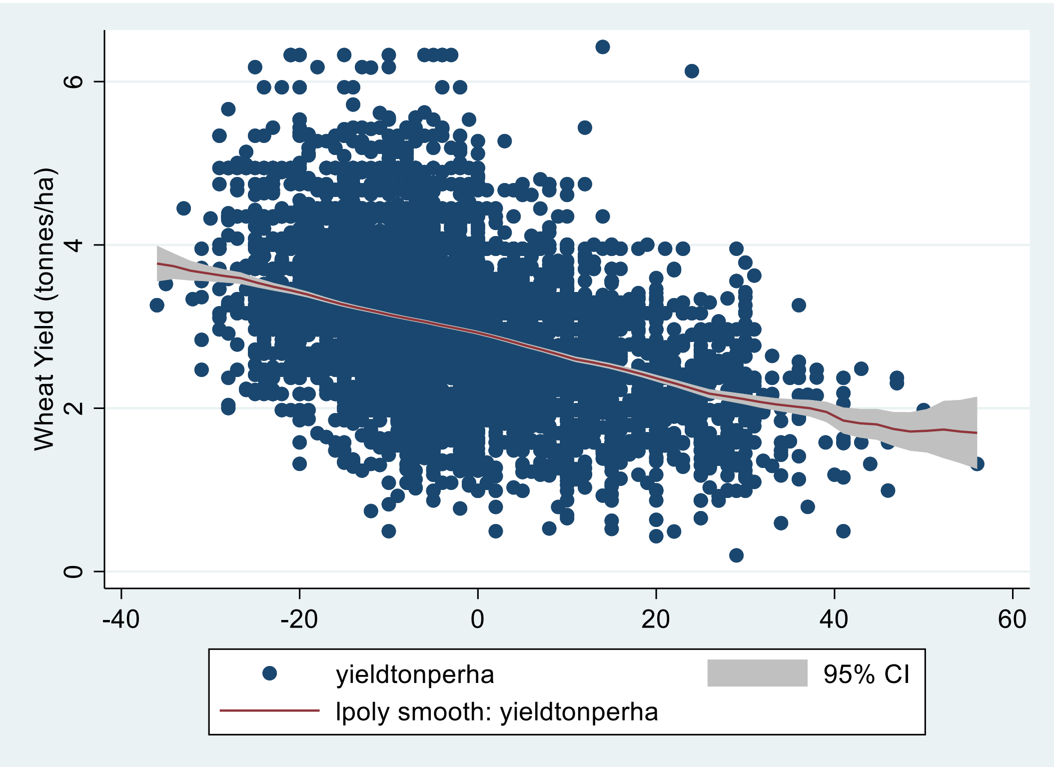
4.2.1. Late sowing of wheat

The LDS data shows that in Rabi 2017-18, 88% of the 5793 farmers in Bihar sowed wheat after 15th November, and 35% of them sowed it after November 30th. The earliest sowing of wheat in the LDS sample took place on 25th October 2017 and farmers reported sowing wheat as late as on 25th January 2018. Figure 3 shows a scatterplot of wheat yields against the date of sowing and smoothed values of a kernel-weighted local polynomial regression between the two variables. The X-axis in the figure shows the time of sowing as the number of days from 30th November. Negative values on the X-axis mean that the sowing occurred before 30th November. Both the scatterplot and the fitted non-parametric line show that late sowing of wheat is associated with a significant decline in its yields (Figure 3).

Heat stress is a major reason for wheat yield depressions across the IGP (Kiel et al., 2020; Jain et al., 2017; Lobell et al., 2008). In particular, extreme temperatures above 34° reduce crop growth and growing season duration (Barlow et al., 2015). In wheat, a rise in maximum temperature shortens the duration of the grain-filling period which results in reduced grain yield. Earlier in the growing season, heat stress during flowering can cause anther and pollen sterility that limits embryo development thereby creating sink limitations and low harvest indices (Al-Khatib and Paulsen, 1984). Ortiz et al. 1994 found yield losses of 0.7% daily if wheat is sown past an optimum time window based on the cultivars' maturity rating. Solutions to terminal heat stress largely come from earlier sowing (Lobell et al., 2013). Early sowing shifts the development of wheat to earlier in the year such that the crop has a greater chance of completing its growth cycle before the onset of terminal heat stress.

The LDS data also shows that the date of sowing is a strong predictor of the crop duration. It alone explains 65% of the variation in the crop duration in the LDS sample (see column 2 in Table 6). When we control for the location (district) of the farmer, the date of sowing explains 71% of the variation in the crop duration (column 3 in Table 6). Every day's delay in the sowing of wheat after 30th November is associated with a 0.8-0.9-day shorter growing period. Park et al. (2018) also find that late sown wheat in Bihar and Nepal Terai has a shorter growth period.

Figure 3. Wheat yields against the date of sowing



Source: Authors' calculations using LDS data

Table 6. Correlation between crop duration and the date of sowing of wheat

VARIABLES	(2) cropdays	(1) cropdays
daysafter30nov	-0.862***	-0.810***
	(0.00738)	(0.00836)
Constant	137.0***	134.9***
	(0.0868)	(0.458)
Observations	7,344	7,344
R-squared	**0.650**	**0.715**
District FE	NO	YES

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The LDS asked farmers the reasons for the late sowing of wheat. Nearly 80% of farmers who sowed wheat after 30th November cited the late harvest of paddy as a major reason for the delay. Farmers reported wet soil at the time of sowing or the lack of moisture as other major reasons for the delay (Table 7).

Table 7. Reasons for delay in sowing of wheat in 2017-18

Reasons for the late sowing of wheat	**Frequency**	**Percentage**
Late harvest of rice	1858	79.0
Land wet for ploughing	894	38.0
Dry soil at sowing	319	13.6
Labor Shortage	268	11.4
Unavailability of equipment for tilling	93	4.0
Unavailability of seed	59	2.5
Number of farmers who sowed wheat after 30th November	2351	100

Source: Authors' calculation using the LDS data

Could it be that the farmers in Bihar and EUP do not realize the negative impact of late sowing of wheat on crop yields? In a survey of 256 farmers in the Arrah district of Bihar, Newport et al. (2020) found that most farmers realize there are benefits to sowing earlier. 77% of the farmers in their survey responded that they were aware that high temperatures in March reduce wheat yields and two-thirds (66%) of the respondents also reported that the temperatures during the growing seasons had increased over the last ten years. Late sowing of wheat persists despite the general awareness of its negative effects on yield.

4.2.2. The high cost of irrigation is a major reason for delays in the rice-wheat cropping system in Bihar

Late transplantation of paddy is a major reason for its late harvest. Even when the onset of monsoon is late, farmers in Bihar wait for rains rather than using irrigation to transplant paddy on time. They do so because irrigation is expensive in the state. LDS did not collect information on the cost of irrigation, but data from a representative sample of paddy and wheat growers in India, collected every season by the Commission of Agricultural Costs and Prices (CACP) shows that the hourly cost of groundwater irrigation of paddy and wheat is the highest in Bihar (Table 8) even when the average depth to groundwater is relatively shallow in the state compared to many other parts of India (MI Census, 2017).

Table 8. Cost (INR/hour) of groundwater irrigation of rice and wheat 2016-17[4]

Crop	Bihar	Rest of India
Paddy	81.60 [n = 1287]	47.31 [n = 12,213]
Wheat	88.02 [n = 1124]	59.60 [n = 5861]

Source: Authors' calculations using the CACP data

Irrigation is expensive in Bihar because it is dependent almost entirely on diesel pumps and diesel is costly. The Minor Irrigation Census 2013-14 (2017) shows that 95% of the 0.64 million irrigation pump-sets in the state are powered by diesel. More recent data from the Economic Survey of Bihar (2019) shows that there were 0.18 million electric pumps in the state in 2017-18, the year LDS was carried out, and it went up to 0.23 million in 2018-19. Of the 5,255 farmers from the LDS sample in Bihar who irrigated with groundwater, 83% relied exclusively on diesel pumps and another 5.8% used both diesel and electric pumps. Less than 10% of groundwater irrigators in the sub-sample from Bihar (and 16.04% in the EUP sub-sample) relied exclusively on electric pumps in 2017-18.

89% of farmers in the LDS sample used diesel pumps for irrigation. A 5 horsepower (hp) diesel pump uses 1 litre of diesel/hour of irrigation costing INR 76.10 in the survey year (2017-18)—excluding the cost of procuring it from the nearest gas station. This effectively translates into an energy cost of more than INR 20/kWh. In comparison, the average power purchase cost for the distribution companies (DISCOMS) in Bihar is INR 4.20/kWh and the average cost of supply (including the high transmission & distribution losses) is INR

[4] Ideally, one should compare of cost of irrigation in INR/m^3 and not INR/hour because pumps sizes and discharge rates may be very different across different parts of India. However, we do not have reliable data on pump discharge data by states.

7.35/kWh (BERC, 2020)[5]. The subsidized rate of electricity for irrigation in Bihar is INR 84/hp/month for unmetered connections and only 0.65/kWh for metered connections (South/North Bihar Power Distribution Company Limited, 2020)[6]. Electric pumps are also more energy-efficient and have higher water discharge rates per unit of energy used (Martin et al. 2011). Therefore, the effective difference in the cost of water pumped between diesel and electric pumps, measured in INR/m^3, is even higher.

Furthermore, more than 90% of groundwater irrigators in Bihar do not own pumps. They rent pump-sets from their neighbours in informal oligopolistic water markets (Shah 2007; Shah et al. 2009). The LDS did not collect data on pump rental rates, but the CACP data shows that the average pump rental rate in Bihar in 2016-17 was INR 111/hour. When irrigation is expensive, waiting for rains is perceived as a more sense sensible strategy to farmers than irrigating their land to transplant paddy on time. Even in severe drought year like 2010, when the average rainfall in Bihar was only 79%of its long-term mean (India Water Portal 2012), farmers, on average, provided only 24 hours of irrigation per ha of paddy which translates into irrigation depth of around 120-144 millimetre only (authors estimates using the CACP data and average hourly discharge rate of 50-60 m^3/hour) resulting in a sharp decline in the average crop yield to 1.1 tonnes/ha [compared to 2.1 tonnes/ha in 2011-12 when the monsoon rainfall was normal].

The number of farmers in Bihar who irrigate paddy and the total hours of irrigation per ha of the crop has increased over the years (Figures 4a and 4b), but under-irrigation persists resulting in late transplantation of paddy and its low and unstable yields. Late transplantation of paddy also delays its harvest and sowing of wheat that follows the paddy. 93% percent of farmers in Bihar who grow wheat in the Rabi season, cultivate paddy before it (SASF 2012-13). Therefore, late transplantation and harvest of paddy affect almost the entire wheat area of the state.

[5] https://berc.co.in/orders/tariff/transmission/2222-press-release-of-tariff-order-fy-2019-23 [viewed on 25th January 2021]

[6] https://www.nbpdcl.co.in/(S(ghwvhpkdldjt13bq0ywvqsxn))/Tariff_Regulation_PDF/174/K.%207912/TARIFF%20SCHEDULE%20IN%20HINDI%20FOR%20FY%202020-21%20%20WITH%20CURRENT%20DSUBSIDY%20(1)%20FINAL%2031.03.2020.PDF [viewed on 25th January 2021. The information on this page is in the Hindi language.]

Figure 4a. The Percentage of Paddy Plots that were Irrigated in Bihar [2000-01 to 2016-17]

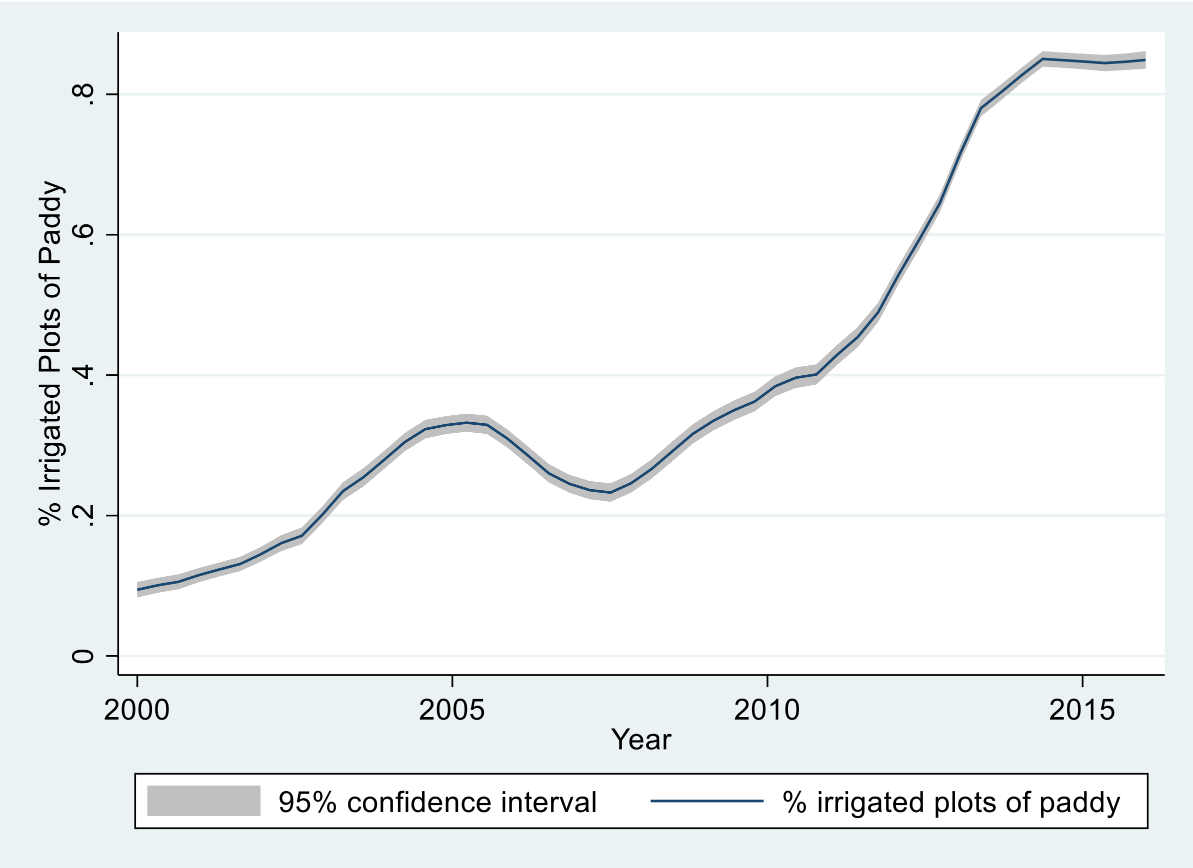
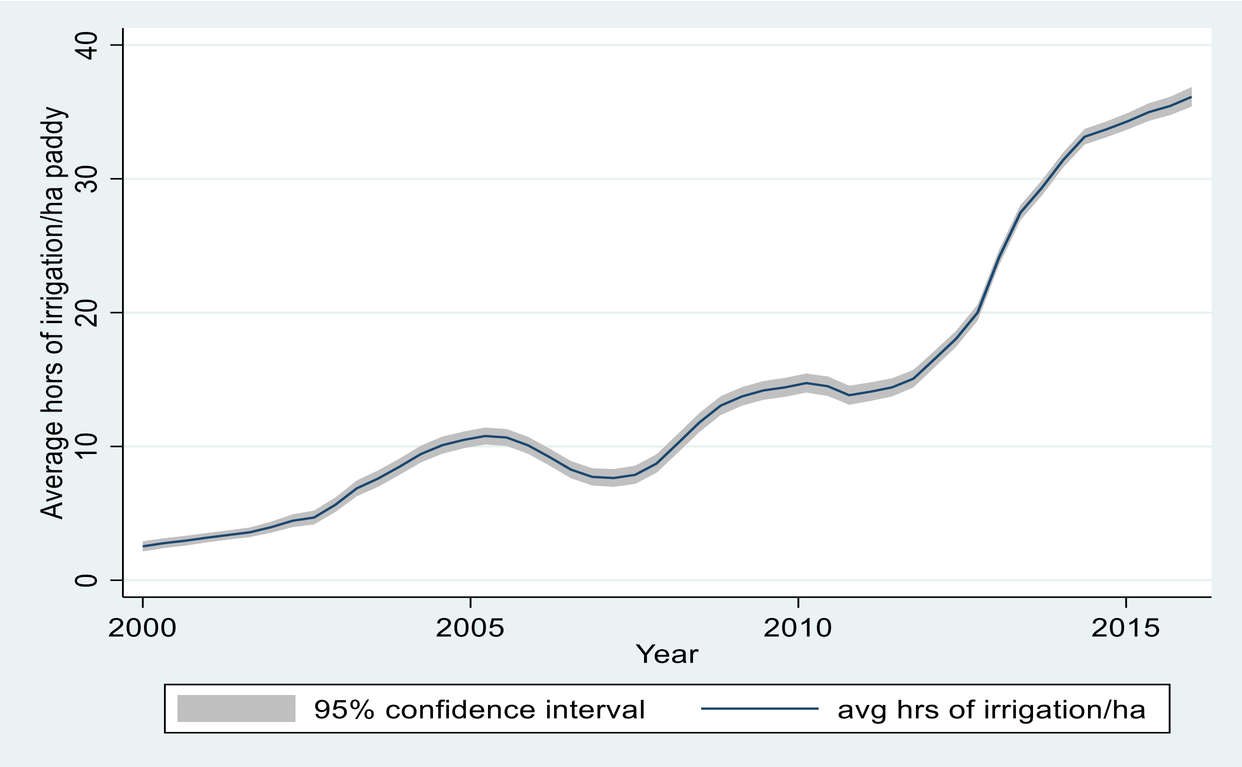


Figure 4b. Average hours of irrigation/ha to paddy plots in Bihar [2000-01 to 2016-17]



Source: Authors' calculations using CACP data

4.2.3. The high cost of irrigation also leads to deficit irrigation of wheat

Late transplanting and harvesting of paddy and the resulting delay in sowing of wheat is not the only channel through which the high cost of irrigation affects wheat yields in Bihar. It also affects wheat yields directly as it forces farmers to practice deficit irrigation where they apply water below full crop-water requirements (Fereres and Soriano 2007).

LDS collected data on the frequency of irrigation application to wheat. 65.40% of all farmers in Bihar irrigated wheat only once or twice and only 5% of them provided four or more irrigations to their largest wheat plot (Table 9). Wheat is sensitive to water stress and therefore needs frequent irrigation for optimal growth and yield (Alderfasi and Nielsen 2001). Under normal conditions, 4-6 irrigations are recommended for optimal wheat production in India (Singh 1991). Reduced irrigation increases water use efficiency (WUE) of wheat (Xue et al. 2006) but if the crop is overstressed, reduced photosynthesis and accelerated leaf senescence may reduce yield (Kobata et al. 1992).

Table 9. Frequency of irrigation to the wheat crop in Bihar in 2017-18

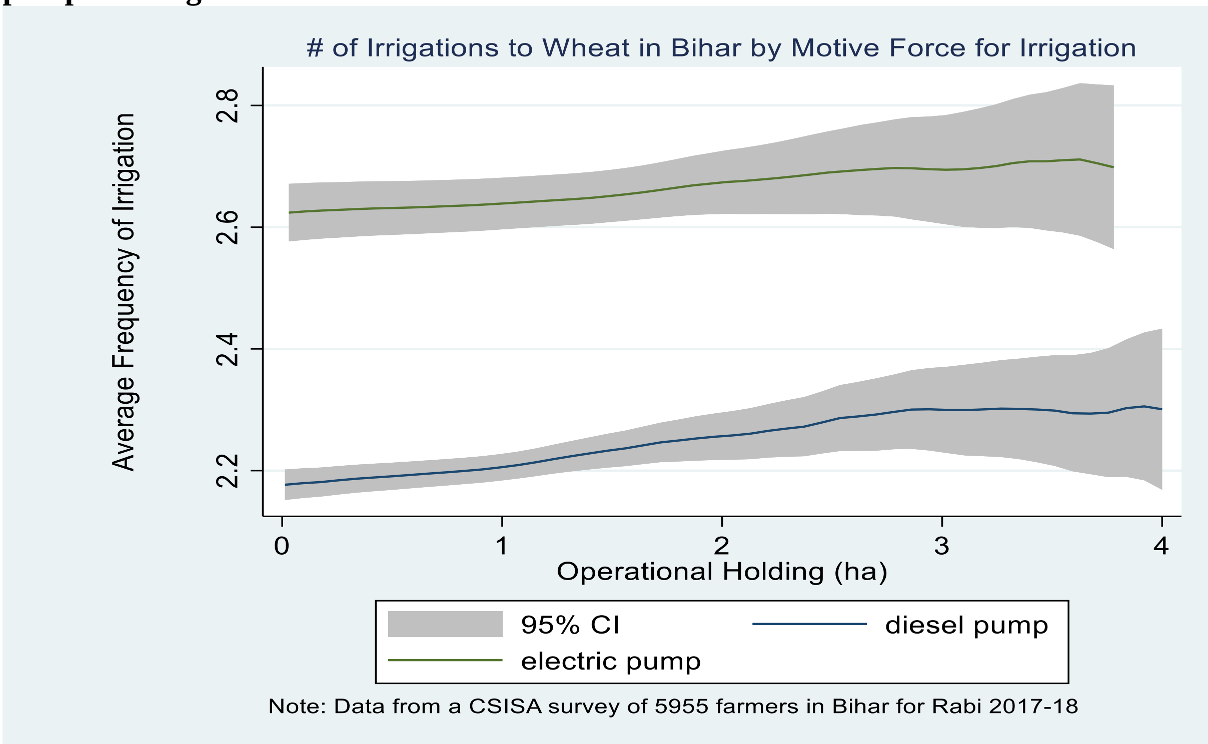
# Irrigations	# Farmers	% of Farmers
1	811	14.06
2	2,961	51.34

3	1,706	29.58
4	281	4.87
5	8	0.14

Source: Authors' calculations using LDS data

Farmers with access to electric pumps apply a significantly higher number of irrigations to their wheat across all landholding sizes (Figure 5). Figure 5 also shows that for both diesel and electric pump users, the irrigation frequency increases very modestly with the increase in holding size.

Figure 5. Number of irrigations to wheat crop by farmers who use diesel and electric pump for irrigation



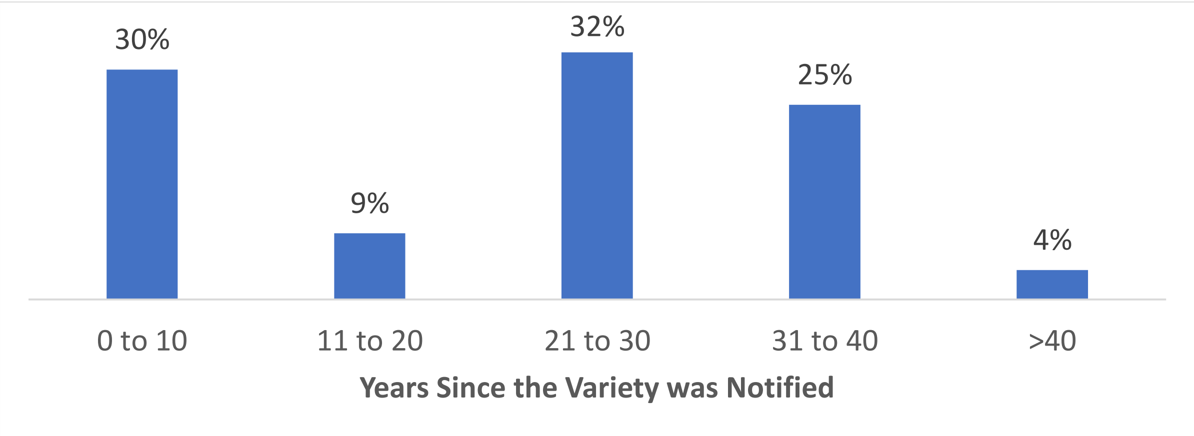
Source: Authors' calculations using LDS data

The LDS did not collect data on the hours of irrigation farmers apply. The CACP data, however, shows that farmers in Bihar, on average, apply only about 45 hours of irrigation per ha of wheat compared to 92 hours/ha of irrigation across other major wheat growing states of India. The MI Census data shows that the average pump size or the hourly discharge rate of wells is not higher in Bihar compared to the rest of India. The lower hours of irrigation per ha of wheat in Bihar, therefore, is a sign of lower water application rates. Furthermore, like most other parts of India, there is very little rain during the Rabi season in Bihar (Zakwan et al. 2019). Under-application of water, therefore, leads to moisture stress and yield loss.

4.2.4. Use of old varieties of seeds

The Indian Council of Agricultural Research (ICAR) and the State Agricultural Universities (SAUs) have released several new and improved varieties of wheat seeds over the last 20 years. These newer varieties have higher yield potential[7]. The state government also provides a subsidy of INR 500/- per quintal or 50% of the cost, whichever is less, on the purchase of certified wheat seeds of varieties that were notified less than 10 years ago to promote the adoption of newer varieties. Despite the rapid development of new seeds and incentives by state governments to accelerate their adoption, old and very old seed varieties continue to dominate the cropped area in Bihar and EUP. 70% of farmers in our sample used varieties that were older than 10 years and more than 60% of farmers used varieties that were developed before the year 2000 (Figure 6). Two other independent studies on varietal adoption in Bihar, by CIMMYT and IFPRI & ICAR, also show the dominance of old varieties of wheat in Bihar. Both these studies estimate that the average age of wheat varieties grown in Bihar was around 28-30 years (Ray and Maredia 2016; Negi et. al. 2020).

Figure 6. Percent of Farmers using wheat varieties of different vintages



Source: Authors' calculations using LDS data
Note: All percentage figures are rounded to the nearest whole number. N = 6871 farmers. The total sample size is 7648, but we could not find the year of official release the varieties of seeds used by 777 farmers in the sample.

Table 10 shows the results of a linear probability model of farmer characteristics associated with the use of wheat varieties notified after 2000. Use of newer seed varieties is not influenced by land holding size and proximity to markets also does not significantly affect the choice of varieties. Farmers who rely on diesel pumps for irrigating wheat are significantly

[7] https://www.bausabour.ac.in/varieties-developed.aspx

less likely to use newer varieties. These farmers also apply less water to their crops. This association between expensive irrigation and the use of older seed varieties may be there because new varieties probably give better returns only when adequate irrigation is applied. Farmers who under-irrigate their crops also skimp on other complementary inputs. Access to affordable irrigation is, therefore, critical to the success of better seeds and input intensification in rice-wheat systems.

Table 10. Factors associated with a higher probability of using newer varieties of wheat seeds

VARIABLES	(1) Probability of Using seeds released after 2000
Landholding size (ha)	0.00370
	(0.00323)
Distance to markets	0.00117
	(0.00118)
Uses diesel pump	-0.0268*
	(0.0145)
Constant	0.298***
	(0.0354)
District Dummies	YES
Observations	7,648
R-squared	0.222

*** p<0.01, ** p<0.05, * p<0.1

3.3. The effect of irrigation frequency, time of sowing, and seed type on wheat yields

We estimate a simple production function using the LDS data to test the effect of the frequency of irrigation, time of sowing, and the use of old or new seed varieties on wheat yields. The rich LDS data allows us to control for the texture of the soil (light, medium, or heavy), its perceived quality (low, medium, high), the drainage (lowland, medium land, upland, or very low land), kilograms of different fertilizers applied to the crop, and the application of farm-yard manure (a dummy variable). We use district fixed effects in this regression to control for fixed observable and unobservable characteristics of the location that are not explicitly controlled for in the model.

Table 11 shows the results of this regression. The landholding size of the farmer is not significantly correlated with the crop yield on the largest plot of land. Late sown wheat has lower yields even after we control for the frequency of irrigation, soil quality, plot location (upland, midland, or lowland), and use of fertilizers and manures. Each day of delay in sowing after 30th November is associated with a reduction in yield by 20 kg/ha which is very similar in magnitude to Ortiz et al. (1994) who found yield losses of 0.7% daily if wheat is sown past an optimum time window based on the cultivars' maturity rating. 18% of all farmers in the LDS sowed wheat on or after 10th December resulting in yield loss of 0.2 tonnes/ha or more compared to the farmers who sowed wheat in November itself.

Applying one more irrigation to wheat leads to an increase in yield by 0.45 tonnes/ha. The average yield in our sample is 3.0 tonnes/ha. So, one more irrigation is associated with a 15% increase in yield. The average farmer in our sample sold wheat at INR 1400/quintal in 2018. At this price of wheat, the marginal value product of one more irrigation is INR 6365/ha. According to the CACP data, a pump renter in Bihar paid INR 111/hour for irrigation. If we assume that each irrigation requires 10 hours of pumping per acre of wheat, the marginal returns from one more irrigation were more than twice as high as its marginal cost (INR 2718/ha). Increased irrigation is often associated with an increase in the use of other inputs like fertilizers and labor for water application, weeding, and harvesting. The increase in net returns from additional irrigation will, therefore, be lower than the simple difference between the MVP of increased yield and the marginal cost of irrigation. Even if we were to account for the associated increase in the cost of other inputs, the incremental gains from one or two more irrigations will be significant.

There can be two reasons why most farmers in Bihar and EUP do not apply the third or the fourth irrigation despite promising returns. First, they are credit constrained and the shortage of working capital prevents them from applying more water even if the returns significantly exceed the cost (Bubb, Kaur, and Mullainathan, 2018). Nearly half of the farmers in Bihar and EUP do not have access to institutional credit and interest rates are very high for loans from informal sources ranging from 36-39% per year (Kumar et al., 2020). A second reason could be that they are uncertain of the potentially higher returns of additional irrigation. Depending on the reasons for under irrigation, timely access to loans at reasonable interest rates and extension efforts to show the gains from more frequent watering may encourage farmers to provide adequate irrigation to their wheat crop.

The use of older varieties of seeds, i.e. varieties released before 2000, was associated with an average yield penalty of 0.22 tonnes/ha. In this case, too, the benefits of using modern varieties seem to exceed their additional cost. It is important to point out here that while the varietal replacement is slow in Bihar, the seed replacement rate has risen sharply from 8% in 2000 to 34.8% in 2011[8]. Farmers buy seeds regularly, but they continue to buy older varieties. Improving the availability of improved seeds with adequate extension support may increase the adoption of improved varieties and improve farmer welfare (deBrauw, Kramer and Murphy, 2020).

Table 11. Correlates of high wheat productivity in Bihar and EUP

VARIABLES	(1) **Production (tonnes)**	(2) **Yield (tonnes/hectare)**
Plotsize (hectare)	2.679***	
	(0.1898)	
Operational Holding	0.0278*	0.00291
	(0.0166)	(0.00447)
Sowing date (days after 30th Nov)	-0.00411***	-0.0175***
	(0.000420)	(0.000754)
Frequency of irrigations	0.109***	0.455***
	(0.00648)	(0.0115)
Used seed variety notified before 2000 [1: Yes; 0: No]	-0.0436***	-0.221***
	(0.0116)	(0.0167)
Used Farmyard Manure [1: Yes]	-0.00137	0.0378*
	(0.00971)	(0.0206)
Total Urea (kg)	0.00114	0.000380
	(0.000772)	(0.000249)
Total DAP (kg)	0.000236	0.00038
	(0.000764)	(0.000526)
Total MoP (kg)	0.00860**	0.00153
	(0.00356)	(0.000971)
Drainage [Reference: lowlands]		
2.Medium land	0.0243**	0.102***
	(0.0102)	(0.0233)
3.Upland	0.0262**	0.116***
	(0.0132)	(0.0314)
4.Very Low land	0.0371	0.103
	(0.0399)	(0.0826)
Perceived soil quality [Reference: High]		
Low	-0.0859***	-0.281***
	(0.0213)	(0.0482)
Medium	-0.0521***	-0.163***

[8] https://seednet.gov.in/PDFFILES/SRR-13.pdf

	(0.0134)	(0.0268)
Soil texture [Reference: Heavy soil]		
Light Soil	-0.00509	-0.0169
	(0.0148)	(0.0356)
Medium Soil	-0.0162	-0.0526**
	(0.0128)	(0.0262)
Constant	-0.308***	1.930***
	(0.0522)	(0.0685)
District FE	**YES**	**YES**
Observations	7,621	7,621
R-squared	0.907	0.447

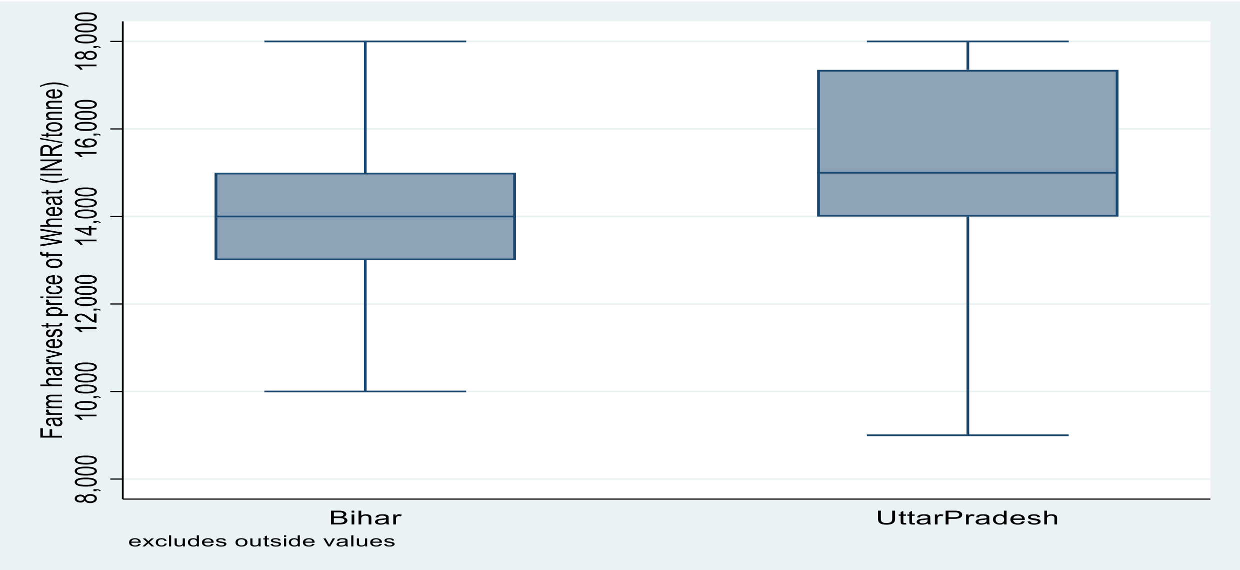
Standard errors clustered at district level in parentheses

*** p<0.01, ** p<0.05, * p<0.1

3.4. Poor price realization dampens incentives for input intensification

Farmers in Bihar and EUP get low prices for their wheat crop. Figure 7a shows that in 2017-18, the median farmer in the LDS sample got only INR 140 per tonne of wheat in Bihar and INR 150 per tonne in EUP at the time of harvest (Figure 6a)—19% and 13% below the minimum support price (MSP) of INR 173.5 per tonne announced for that year.

Figure 7a. Farm-harvest price of wheat (INR per tonne) in Bihar and Uttar Pradesh in 2017-18



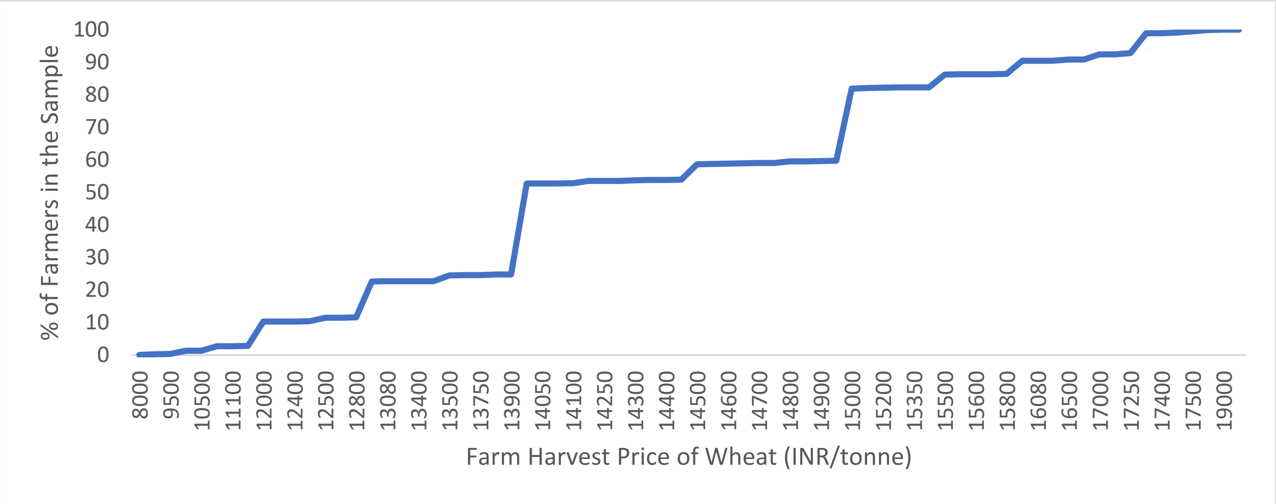
Source: Authors' calculations using LDS data

If we look at the complete distribution of the farm harvest prices, we find that more than 90% of the farmers in our sample sold wheat at prices below the minimum support price (Figure

7b). There is very little public procurement of wheat at MSP from the region. For example, less than 10,000 tonnes of the 6.1 million tonnes of wheat produced in Bihar in 2017-18 was procured at MSP (CACP, 2018)[9].

Poor price realization diminishes farmers' incentives for input intensification. Farmers would irrigate more and will be willing to spend more on other yield-enhancing inputs if they get better prices for their produce. Increasing the public procurement of wheat is a strategy that states like Haryana, Madhya Pradesh, and Punjab use to guarantee higher price of wheat for their farmers. Higher and more predictable output prices encourage input intensification by farmers and result in higher crop yields (Hazrana, Kishore, and Roy, 2020**)**. However, a public procurement led strategy can also delink crop production from crop demand and can lock agriculture into long-term dependence on price subsidies for a long period as has happened in Punjab, Haryana, and Western Uttar Pradesh (Pingali et al., 2019). We briefly discuss other market-led strategies to improve farmers' price realization in the next section of the paper.

Figure 7b. The cumulative distribution of farm-harvest prices (FHP) of wheat (INR/tonne) in 2017-18



Source: Authors' calculations using LDS data

[9] Procurement was low in EUP also, as is evident from average price realizations in the LDS sample, but we do not have sub-state level data. The estimate of wheat production is taken from the 'Five-year Series Data from 2014-15 to 2018-19' on area, production, and yield (APY) published by the Directorate of Economics and Statistics, Ministry of Agriculture and Farmers' Welfare, Government of India available at: https://eands.dacnet.nic.in/APY_96_To_06.htm

4. Policy strategies to promote sustainable intensification of rice-wheat cropping system in Bihar

The LDS data shows that late sowing of wheat (due to late transplantation and harvest of paddy), deficit irrigation, and the use of old varieties of seeds are three major reasons for the low productivity of wheat in Bihar and EUP. Poor price realization by farmers dampens their incentives for input intensification. There is also suggestive evidence that farmers are not adopting inputs (like improved seeds) or under-applying them (e.g., irrigation) even when the returns from doing so may exceed the cost. Credit constraints and lack of awareness may be the reasons for the sub-optimal use of inputs in wheat cultivation.

Given our findings, we recommend a three-pronged action by the Government of Bihar to increase the productivity and profitability of the rice-wheat cropping system in the state.

4.1. Ensure affordable access to irrigation for everyone

The Living Standards Measurement Survey (LSMS) conducted by the World Bank showed that 80% of the sample villages had irrigated lands in Bihar and EUP even in 1997-98 (Anderson, 2007). More recently, the Situation Assessment Survey of Farmers, conducted by the National Statistical Organization (NSSO) in 2012-13 also shows that almost all farmers and villages in the survey had access to irrigation. Both LSMS and SASF covered a representative sample of farmers in Bihar and EUP. In the LDS sample too, only 26 of the 5793 (<0.5%) farmers in the sample did not have access to irrigation. We conclude that farmers in Bihar generally lack *affordable* access to irrigation and steps to promote that will be useful to encourage agricultural intensification in Bihar.

Irrigated agriculture in Bihar relies predominantly on groundwater. 93% (5,247 of 5,669 respondents) of farmers in the LDS used groundwater for irrigation. Electrification of irrigation wells can help reduce the cost of pumping groundwater. The recent improvements in rural electrification and power supply conditions in the state offer an opportunity for rapid electrification of irrigation. Government of Bihar declared universal electrification on 25th October 2018. All 45,103 villages in the state are now connected to the power grid. The increase in access to electricity has been accompanied by a significant improvement in the quality and the duration of the power supply. The total energy sold to consumers has increased nearly three times—from 8.2 billion units in 2013-14 to 23 billion units in 2019-20.

This sharp increase in electricity consumption is visible even from the space in the night light images of Bihar (Sudarshan, 2019).

The improvement in the power supply is benefiting the agriculture sector too. The lower operating cost of electric pumps will reduce the cost of irrigation for farmers in Bihar if the power supply is reliable and of good quality. The state government has also launched a program for feeder segregation with the establishment of 296 new power substations and 1312 dedicated feeders for farm connections to transmit electricity from generating stations or substations to distribution points on the pattern of the Jyotigram Yojana (JGY) in Gujarat (Shah and Verma, 2008). Separate feeders and the investment in new supply lines will help improve the quality and reliability of power supply, reduce technical losses, and allow more reliable accounting of energy consumption by farmers. Government of Bihar is heavily subsidizing electricity tariffs for irrigation connections. Pump owners with an unmetered connection pay INR 84/hp/month for electricity and those with a metered connection pay INR 0.65/kWh of electricity when the average cost of supplying electricity to farmers is estimated to be INR 7.36/kWh in the state (see footnotes 5 & 6 for references). Thus, farmers in Bihar get more than 90% subsidy on electricity used for irrigation.

Such high subsidy will be a drain on the exchequer and it will encourage wasteful use of water and electricity in agriculture. Furthermore, less than 10% of all farmers in Bihar own pump-sets. The other 90% rent pumps from their neighbors. Low power tariffs won't benefit water buyers much if the water markets are not competitive. Cheap electricity, by itself, won't make water markets competitive. Markets will be competitive if more farmers can switch from diesel to electric pumps. With such high subsidies, power utilities in Bihar will try to limit selling power to the farmers by limiting the hours of power supply and rationing new connections like power utilities in many other states of India do (Sidhu, Kandlikar and Ramankutty, 2020). Water markets will be less competitive if getting new electricity connections for irrigation is difficult and the power supply is restricted to only a few hours/day. These restrictions will act as barriers to entry in the water markets leading to local monopolies or oligopolies that favor those who already own electric pump-sets. The pump-owners may corner a disproportionate share of the electricity subsidy while the are water buyers will continue to pay high prices for groundwater irrigation.

State governments in India are notoriously late in paying the subsidies they owe to the utilities creating working capital problems for them (Pargal and Banerjee, 2014). If this continues, the cash-strapped utilities in Bihar will also struggle to maintain the quality and reliability of the power supply. Farmers in Bihar are investing huge amounts of money to switch from diesel to electric pumps. If we assume that each electric installation costs farmers INR 20,000, farmers in Bihar have invested more than INR 4 billion over the last 5 years to electrify more than 0.2 million wells. All this investment will become unproductive if the quality of the power supply falters.

Instead of high tariff subsidies on the price of electricity, the state government should use its resources to provide capital subsidy and affordable loans to farmers for electric pumps, tube-wells, and electricity connections. The government should also make it easier for farmers to secure new electricity connections. Reducing cost and administrative barriers to new pump connections will make water markets more competitive and ensure that all farmers in the state benefit from electrification, not only a few pump-owners. Irrigation with electric pumps, even with a reasonable tariff rate for electricity, would still be significantly cheaper than irrigation using diesel as the source of energy. Furthermore, if farmers pay the full cost of electricity, they will be more likely to demand quality service from the utilities and the utilities would also see farmers as their clients and not their beneficiaries.

4.2. Accelerate the adoption of improved seeds

Varietal replacement is slow even for irrigated crops in Bihar and EUP despite subsidy schemes to promote the adoption of newer varieties, with the exception of maize. The dominance of private companies in the maize seeds market is one of the reasons for the rapid penetration of new hybrid seeds in the state. Hybrid seed markets are more lucrative to them as the margins are higher and farmers have to buy new seeds every year. IARI-PUSA has tried collaborations with small and medium seed companies and start-up firms to accelerate the adoption of new rice and wheat seeds developed by the institute with remarkable success (Kishore, Singh and Gupta ,2020). The profit motive and a wider reach among farmers allow private seed companies to popularize new varieties faster than the government extension system. We recommend the government of Bihar to the public-private participation (PPP) model for dissemination of seed varieties. Instead of charging royalties or license fees from private partners, the state government may even use seed subsidies to pay cash rewards to companies that reach more farmers to accelerate the adoption of newer seed varieties.

The government should target the promotion of early sowing of paddy to villages with higher levels of electrification of irrigation wells. Farmers with electric pumps are more likely to adopt early transplantation and switch to newer seed varieties.

4.3. Ensure better price realization of crops for farmers in Bihar and EUP Programs to improve farmers' access to inputs like electrification of irrigation and PPP to accelerate varietal turnover should be combined with efforts to increase farmers' price realization for wheat (and paddy). In a recent study on first sale of produce by farmers in Bihar (and Odisha and Punjab), Chatterjee et al. (2020) find that farmers' price realization does not increase if they undertake simple post-harvest processes like cleaning or grading of their produce. Drying has a small positive effect (1.5% higher) on price realized. Further, farmers who wait longer after the harvest sell their crops also do not get higher prices in Bihar. The average price realized does, however, go up with the increase in the volume of sales. A farmer who sells twice as much receives a 2.4–2.5% higher price on an average in Bihar. Therefore, initiatives for the aggregation of small and marginal farmers' produce by forming farmers' groups or producer companies will help.

Increasing the public procurement of wheat (and rice) is another option to ensure that farmers get remunerative prices and do not face price uncertainty. Bihar accounts for 6% of the marketable surplus of wheat (CACP, 2020) but a negligible share of the grain procured at MSP. Higher and assured prices will increase farmers' incentives to intensify wheat cultivation, resulting in higher productivity and profits (Mythili, 2012; Hazrana, Kishore, and Roy 2020). However, a public procurement led strategy can create excessive dependence on subsidies and delink production from demand resulting in the excess production of wheat that does not have a market. Creating more competitive agricultural wholesale markets and linking farmers or farmer groups directly to these markets may be a more sustainable way to increase farmgate prices of wheat (and other food grains).

5. Conclusion

Our analysis shows that increasing wheat productivity in Bihar and EUP requires looking at the rice-wheat cropping system together. A concerted approach that includes a) public investments in the electrification of irrigation and rationalization of irrigation subsidies to ensure widespread access to affordable irrigation, b) incentives to promote private sector participation in input markets to accelerate the adoption of improved seeds, c) scaling up of institutional innovations (likes FPOs) to aggregate marketable surpluses of smallholder farmers, and d) the creation of competitive agricultural markets to ensure better price realization is required to increase wheat yields and farmers' incomes from wheat production.

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