Implications of Monsoon Cropping Decisions on Wheat Sowing Dates in Bihar, Eastern Indo-Gangetic Plains

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Abstract

India is the second largest producer of wheat globally. However terminal heat stress during the grain filling period negatively impacts its yield potential. Increasing temperatures have intensified observed yield gaps and this trend is expected to continue. One way to mitigate this negative effect is by sowing wheat earlier, thereby shielding it from heat stress. But farming households in the eastern Indo-Gangetic Plains (IGP) seldom sow wheat on time. This delay is often attributed to the rice-wheat crop rotation system practiced across the IGP where rice is planted during monsoon followed by wheat in winter. However, there is very little understanding of factors that influence monsoon cropping decisions in the IGP. This study investigates the socio-economic, biophysical, perceptual, and management factors influencing rice and wheat sowing date decisions in Arrah District, Bihar, India. The study is based on data collected from 355 farmers across 10 villages in Arrah. We found irrigation type, delay in monsoon onset dates, and soil type to be the major factors constraining timely sowing of rice and subsequently delaying wheat sow dates. Particularly, farmers who had access to borewell preponed rice sowing dates by a few weeks when compared to farmers who relied only on canal irrigation. These results suggest that in addition to climate variability, structural constraints also affect rice sowing dates. To ensure timely sowing and enable adaptation to increasing temperatures, therefore, policy interventions must also address the structural constraints that affect farmer decision making.

Keywords: rice, wheat , warming temperature, rainfall pattern, sow date, Indo-gangetic plains, adaptation

Introduction

Drained by the rivers Indus, Ganga and Brahmaputra, the Indo-Gangetic plains (IGP) encompass the northern region of the Indian subcontinent. The IGP is characterized by rich alluvial deposits, making it highly suitable for agriculture.

Following the Green revolution in early 1960s, Rice-Wheat annual crop rotation system became one of the dominant cropping systems in the region (Kataki et al, 2001). India is the second largest producer of rice and wheat (Singh 2018), however several studies corroborate a plateauing trend in the rice and wheat yields as a result of existing abiotic stressors and increasing climate variability (Pathak et al., 2003, Ray et al., 2012). This is especially true with wheat where research indicates a 5% decline in wheat yields as a result of warming temperatures and yield gaps are predicted to grow by 30% in the near future (Ortiz et al., 2008, Lobell et al., 2008).

Wheat is highly sensitive to high temperatures. Warmer temperatures have an intense negative impact on the grain-filling period (Lobell et al., 2012) thereby reducing the yield potential (Asseng et al., 2011). Yield gaps are much higher in the eastern IGP states such as parts of Uttar Pradesh (UP) and Bihar (Alwin Keil et al.2017) when compared to western IGP regions. Therefore, it is crucial to investigate possible factors influencing the observed yield gaps in the eastern IGP.

One strategy proposed to increase wheat yields in the eastern-IGP states is to prepone wheat sowing dates such that the crop matures before the terminal heat stress (Jain et al., 2017). To gain maximum yield, studies have shown 15th November to be the ideal sowing date for wheat (Ortiz-Monasterio R et al., 1994). Although, Punjab, Haryana and the western parts of UP sow wheat on time, the eastern IGP states such as Bihar and the eastern parts of UP delay sowing wheat crops by almost a month (Lobell et al., 2012, Chakraborty et al., 2017). Studies show that with every one-day delay in wheat sowing date there is roughly 0.8–1.5% loss in wheat yields (Lobell et al., 2012, Randhawa et al 1981). Therefore, regions that sow wheat later than the optimal date are projected to suffer more yield loss than the areas that sow wheat on time (Naresh Kumar et al., 2014).

The Indian Agricultural Research Institute predicts a 6 - 23% wheat yield decline in India by 2050 under the current warming scenarios (Naresh Kumar et al., 2014). In case of rice yields analyzed between 1961 - 2008, around 36% of the land under rice cultivation in India has observed a yield stagnation (Ray et al., 2012). These trends in yield slowdown foreshadows the future of food security of the country and questions the livelihood of millions of people engaged in the agricultural sector.

Studies suggest delay in rice nursery establishment and transplantation dates during the monsoon season (Kharif) to be a major factor affecting timely sowing of wheat during winter (Rabi) (Chatterjee et al., 2016). Further, the time involved in residual removal post paddy harvest and conventional tillage may also detain wheat sowing dates (Balwinder et al., 2015, Chakraborty et al., 2017). In addition to early sowing of wheat (Chakraborty et al., 2017), several research findings also propose zero-till or reduced-till management for wheat, where the seeds are sown directly into the soil using drill seeders. This method bypasses the conventional tillage and field preparation time, thereby preponing wheat sowing dates by 2 - 4 weeks (Lobell et al., 2012). Additionally, uncertainties associated with monsoon onset dates, extreme rainfall events, and poor irrigational infrastructure could also affect rice sowing dates (Auffhamme et al., 2012) thereby impacting wheat sow dates.

Despite numerous studies that corroborate early sowing as one of the key factors in explaining wheat yield gaps, (Jain et al., 2017) most farming communities in Bihar and parts of Uttar Pradesh seldom adhere to the recommended sowing schedule (Chakraborty et al., 2017). Thus, there is a lack of comprehensive research on why farmers in eastern IGP sow wheat later than the optimal time. A thorough understanding of these factors will aid in promoting effective adaptation and mitigation strategies towards combating the negative effects of climate change on crop yields.

Against this background, our study attempts to investigate various factors that influence a farmer's decision towards resolving the sow dates of both, rice and wheat in Bihar, India. Information pertaining to weather perception, socio-economic fabric, bio-physical factors, rice and wheat sowing dates, common stressors, access to irrigation facilities and local adaptation techniques were collected. Specifically, we were interested in addressing the following question:

1. How do farmers perceive rainfall variability and how does this affect cropping decisions?
2. Which socio-economic, biophysical, perceptual and management factors are associated with late sowing dates for Rice?
3. How do monsoon cropping decisions affect Wheat sowing dates?

Results from this study will help us better understand key factors associated with the observed heterogeneity in terms of sowing dates of wheat and rice among the different farming communities in Bihar. Further, the outcomes from this analysis would shed light on the implications of rice sow date decisions on the winter crop. Finally, findings from this analysis can help in devising operative interventions that would help farmers is closing yield gaps and subsequently increase the efficiency of rice-wheat cropping systems in the IGP.

2. Study Area and Methodology

2.1 Study Area

To operationalize this study, we carried out household survey across 10 villages in Arrah district, Bihar, India. Besides Bihar being a good representative state of the eastern- IGP (Figure 1) we also selected these villages based on a previous study that showed late monsoon cropping to be associated with wheat sow dates (Newport et al., 2019). Therefore, we wanted to understand major factors that influenced rice sowing dates in this region. More than 50% of Arrah's population depends on rural agricultural land (Directorate of Census Operations, Bihar 2011) to sustain their livelihoods, with major production seen in fruits, vegetables, rice and wheat. The 10 villages surveyed in this study are namely, Amrai Navada, Baligaon, Karisath, Kusuma, Ichari, Balbandh, Berat, Barni, Tulsi and Haradia.

There are two major sources of irrigation facility available to farmers in this region. First, surface water irrigation sources such as canals, ponds, and streams. Second, groundwater irrigation such as tubewells/borewells which are normally run on diesel or electricity. Canal irrigation is one of the cheapest options, however they are often poorly maintained and unreliable. Contrarily, groundwater resources ensure timely availability however, there is are costly. Farmers who own tubewells incur an initial cost of installation and pumping while farmers who rent tubewells bare the hourly renting charges.

Traditionally, in most parts of India, rice cultivation takes place in two stages (Farooq et.al, 2001). At first, a nursery is established were the rice seedlings sprout and are grown for over 3-4 weeks then they are transplanted into the actual field where they grow until harvest. Farmers generally leave the field fallow for a few weeks post rice harvest, during which they prepare the plot for the winter crop (Figure 5). This serial system of crop cultivation indicates that wheat sowing dates besides being influenced by resource availability during winter, is also impacted by the nursery establishment period, rice transplantation dates and fallow period duration.

2.1 Data Collection and Statistical Analysis

At first questions for the household survey were designed by keeping the independent and dependent variables in mind (Table 1). Questions ranged from being open ended to having multiple options. Further, the survey was translated into the local language-Hindi and was piloted in a village which was not a part of the study area. This step helped us understand if the questionnaire was worded and translated well. On an average 30 - 35 farmers were interviewed per village. To capture the heterogeneity among the farming communities with-in the villages in terms of resource availability and socio-economic status, we sampled individuals using a stratified random sampling technique. The different stratum was identified based on the operational landholding size of the farmers. Studies have shown landholding size to be a good indicator of socio-economic status and crop management decisions in India (Jain et al. 2015). Thus, we interviewed farmers belonging to marginal (< 2 acre), small (2-5 acre), medium (5-10 acre), semi-medium (10-25 acre), and large (> 25 acre) landholding categories. The villages were mostly compact in structure, with people belonging to similar socio-economic status usually clustered spatially (Moser, D.,1963). In India, the villagers are mostly aware of the general distribution of the other farmers with in the village. At first, we inquired about the local village demography from a randomly picked farmer, and cross confirmed the initial data with another farmer. Finally, with the help of online maps we traversed through the village and randomly picked households for the survey and interviewed the household member in charge of agricultural decision-making.

To avoid over-representation of farmers with multiple plots, regressions were run using data from the farmer's largest plot. We used linear regressions to identify factors influencing the dependent variables (e.g. sowing date, wheat sowing dates). We ensured that all our continuous covariates had a linear relationship with our dependent variables.

Specifically, we ran six regressions to address our objectives, Regression in table 2 shows factors influencing timely rice nursery establishment date. Some of the independent variables included in the model are – rice duration, irrigation type, profit and weather perception and education level. Rice duration was included in the analysis to understand how varying rice varieties such as long, medium and short duration affected nursery establishment date. We were also interested in understanding how access to different types of irrigation facility influenced the nursey dates. Further, farmers across the 10 villages had a varying perception on profitability of rice and wheat. To see if perceptual factors influenced nursery dates we included this variable in the model. From our field observation we saw socio-economic status of a framer had an impact on rice and wheat sowing decisions. Therefore, to understand how this factor influenced nursery sow dates we included educational level and wealth index. Next, we were interested in looking at factors that influenced rice sowing dates. Table 3 shows a list of the independent variables that were significant in explaining rice sow dates. In addition to the independent variables used in the first regression we also included factors such as soil type, topography of the fields and nursery duration in weeks. Transplanting rice into individual plots depends on the length of the nursery period thus, we included this variable. Unlike nurseries where all the rice saplings are grown together in a single plot, during the transplantation stage rice saplings are transferred into new fields. Therefore, it is important to look at plot level characteristic such as soil type and topography. These geographic features could either aid or hinder time sowing of rice. Further, Regression in table 4 shows factors that were significant in explain farmers' choice of rice variety. Rice duration is a good indicator of different rice varieties grown by farmers in this region. The choice of rice variety depends on factors such as profit and weather perception, irrigation type, soil type and socio- economic status thus, these variables were included in the regression analysis.

In table 5 we look at factors influencing the length of the fallow period duration. Fallow period duration is influenced by rice harvest dates, preceding cropping decision, land preparation mechanisms and resource availability. Therefore, we regressed variables such as rice harvest dates, wheat sowing techniques, soil type, topography and wealth over the dependent variable. Further, we looked at how various factors influencing rice crop affect wheat sow dates. Consequently, we regressed variables such as rice sowing dates, rice duration, soil type, topography and perceptual factors against Wheat sow dates (table 6). Finally, results in table 7 indicates factors that are significant in explaining wheat duration/wheat variety. We included variables describing field characteristics such as soil type and topography as well drained field saw an earlier wheat sow date. For the above regressions the total number of observations varied with the number of non-responses for one or more independent/dependent variables considered in the model.

3. Results

3.1. Perception of change in rainfall patterns and famer level intervention

The average age of farmers interviewed across the 10 villages was 53 years. Most farmers interviewed were actively engaged in the agricultural sector for over a decade. When asked if they perceived any changes in the rainfall pattern over the past 10 years, farmers reported that they observed a delay in monsoon onset dates and that the amount of precipitation had also significantly reduced. These responses were in agreement with the finding from the Indian Meteorological Department (IMD) that reported a rainfall deficit in many districts across Bihar. Generally, the long-term average of annual precipitation in Bihar is 1027.6 mm. However, between 2006-2017 the average precipitation reduced to 912 mm. Last year the government of Bihar declared 33 districts to be drought-hit, making it the second consecutive declaration of a drought year in this state.

Despite perceiving variability in the monsoon onset dates and severe rainfall deficit over the years, farmers in this region do not have any farm level intervention in place. 62% of the farmers reported that they either delayed sowing rice or tried arranging for more irrigation facilities such as renting or installing new borewells and 28% of the farmers did not make any changes with respect to changing rainfall patterns. Finally, less than 4% of the farmers reported switching to different rice varieties or crops as an adaptation mechanism to the changing rainfall patterns.

3. 2. Factors Influencing Timely Rice Nursery Establishment and Transplantation Dates

Farmers in this region perceive June 14th to be the ideal date for establishing nurseries and July 14th to be the ideal rice transplantation date. However, from our survey we found that 53% of the farmers established their nurseries late, and 72% of the farmers transplanted rice saplings later than the ideal date. On comparing socio-economic, bio-physical, perceptional and management factors to nursery establishment date (NED), we found access to irrigation as a major driving factor that influenced NED. Farmers who had access to both canal infrastructure and borewell irrigation established nurseries 14 days earlier ($p < 0.001$) than farmers who relied only on canal irrigation. Similarly, farmers who owned tubewells were able to establish nurseries 12 days earlier ($p < 0.001$) and farmers who rented tubewells were able to establish nurseries 16 days early ($p < 0.001$).

Further, we compared factors influencing transplantation dates and found irrigation type, soil type, profit perception and nursery duration to be highly associated with late rice sowing/transplantation. Farmers who had access to both canals and tubewells were able to transplant rice 15 days earlier ($p < 0.001$), farmers who owned tubewells were able to transplant rice 13 days earlier ($p < 0.001$), and farmers who rented tubewells were able to transplant rice 16 days earlier ($p < 0.001$) than farmers who had access only to canal irrigation systems. Additionally, farmers who had fields with sandy loam transplanted rice 8.5 days earlier ($p <0.001$) than fields with loamy soil. Interestingly, we found that farmers who perceived both Kharif and Rabi crop to be equally profitable advanced rice sowing dates by 7 – 11 days when compared to farmers who either perceived Kharif or Rabi crop to be more profitable. Finally, it is also observed that farmers who had a long nursery period (with every 1 week) transplanted later by 2.2 days ($p = 0.039$) days.

During the household survey, farmers across the 10 villages mentioned lack of irrigation, delay in rainfall, and high temperatures to be some of the challenges associated with early sowing of rice and nursery establishment. Therefore, we find that the results from the regression analysis to be in accordance with observations made on the field.

3.3. Factors Influencing Rice Duration

Based on maturity period, paddy is classified into three different categories. Short duration rice varieties take around 95-110 days to mature while medium duration matures between 120-140 days and long duration rice variety takes more than 160 days. In our study area farmers grew rice varieties that matured between 57 – 170 days, however on an average farmer grew medium duration rice crops. Rajendra Swetha, Ruplai, Sonam, Kajal and Moti Super are some of the common rice varieties grown in this region. The above-mentioned varieties belong to the short-medium and long duration categories. From our regression results we found the factors that most influenced rice duration were irrigation access and soil type. Farmers with own and rented tubewells saw a shorter rice duration that matured 10 days earlier ($p < 0.001$) than farmers who had access only to canal irrigation systems. Rice crops that were planted in plots with loamy ($p < 0.001$) and mixed soil type ($p = 0.006$) matured 11 days later than plots with sandy loam.

3.4. Factors Influencing Fallow Period Duration

Fallow period is the transitional time between rice harvest and wheat sowing dates. During this phase the farmers leave the field fallow and make preparation for the next crop. Most farmers across our study area had an average fallow period of 17 days. We regressed our independent variables over the fallow period duration to understand factors that influenced this time. Regression results show rice harvest date, wealth and rented tubewells to be significantly associated with fallow period duration. We see that farmers who rented tubewells had a longer fallow period by 5 days ($p = 0.024$) when compared to farmers who had access only to canal irrigation. The other types of irrigation facility were not significantly different from the intercept. Further, farmers who harvested the rice crop 1 day earlier saw a shorter fallow period by 0.6 days ($p < 0.001$). Additionally, wealthier farmers had a shorter fallow period by 1.5 days ($p = 0.011$). However, we see that the other variables such as topography and soil type did not have a significant association towards explaining the fallow period duration.

3.5. Factors Influencing Wheat Sowing Dates

In 2018 around 98% of the farmers across the study site sowed wheat crop much later than the optimal wheat sowing date. Some of the challenges associated with early sowing of wheat as reported by the farmers were lack of irrigation, shortage of tillage machines, water logging and standing of rice crop from the previous seasons. To understand the factors that underpin this delay we ran a regression with wheat sowing date was the dependent variable. We found irrigation type, rice harvest dates and wealth variables to be significantly associated with wheat sowing dates. Farmers who rented tubewells for irrigation delayed their wheat sowing dates by 5 days ($p = 0.029$) and farmers who had access only to irrigation resources such as small creeks and ponds delayed wheat sowing by 12 days ($p = 0.05$), when compared to farmers who had access to only canal irrigation systems. Further, with every 1-day delay in the rice harvest dates, wheat sow dates were delayed by 0.33 days ($p < 0.001$). Finally, we see that wealthier farmers advanced their wheat sowing dates by 1.26 days ($p = 0.04$).

3.6. Factors Influencing Wheat Duration

Unlike rice, the classification of wheat variety is highly diversified and is based on factors such as the crops` performance towards biotic and abiotic stressors, geographic attributes, tillage mechanism, grain quality and other agroeconomic conditions (ICAR Report). However, among different scenarios wheat yield is found to be positively associated with the length of the grain filling period (Monpara et al., 2011). Hence, wheat duration could potentially act as an indicator showcasing the farmer choice of wheat. The wheat variety grown in this region matured between 95 to 145 days with an average maturity of 117.4 days. HD2969, PBW154, SRI303 were some of the common varieties grown in this region. Factors that mostly influenced wheat duration/wheat variety were nursery establishment dates, rice harvest dates, irrigation type and soil type. From the regression table we see that early nursery establishment dates reduced the wheat duration by 0.29 days ($p < 0.001$). Further, delay in rice harvests saw an increase in the duration by 0.1 day ($p = 0.025$). Also, farmers who had their own tubewells saw a longer wheat duration by 5.4 days ($p = 0.032$). Finally, farmers who had mixed soil type in their plot had a shorter wheat duration by 8 day ($p = 0.021$)

4. Discussion

In this study we were interested in looking at factors that influenced rice and wheat sowing dates among farming communities across 10 villages in Arrah District, Bihar, India. Specifically, we wanted to investigate which of the socio-economic, bio-physical, perceptional (climate and profit) and management factors drove sowing dates the most. Further, we wanted to analyze how farming decisions made during the Kharif season impacted the sowing dates of wheat during Rabi.

From the results we see that although climate perception was not significant in explaining rice sowing dates, farmers in this region perceived irregularities in the monsoon patterns and consider it to be a major factor influencing rice sow dates. To cope with climate variability, farmers in this region either delayed rice sowing dates or attempted to gain additional irrigation facilities. However, besides delaying sow dates, farmers did not have any interventions to mitigate this negative affect.

We found irrigation type, profit perception and soil type as the major factors that influenced timely sowing of rice and nursery establishment dates. Farmers who had access to tubewells advanced their nursery establishment and rice sowing dates by 2 weeks when compared to farmers who had access only to canal infrastructure. We hypothesize that the reason early sowing of rice and nursery establishment is associated with groundwater irrigation is due to it being more reliable when compared to canals. Canal irrigation system have limited access and are highly unreliable, as water replenishment in these systems depends on the monsoon onset and amount of precipitation (Kazmi et al. 2012). Therefore, farmers who relied only on canals saw a delay in rice sow dates.

Some of the common soil type found across the 10 villages are Clay, Sandy loam and Loamy soil respectively. The regression analysis shows that plots with sandy loam have earlier rice transplantation dates by ~8 days when compared to plots with loamy soil. Seasonal waterlogging is a major concern in many parts of Bihar (Bhattacharya et al.,1992) which occurs due to heavy downpour during the Kharif season coupled with the absence of a robust drainage systems. Plots with loamy soil have a higher water retention capacity when compared to sandy loam, thus are prone to moderate to severe flooding (Chowdary et,al., 2008). Therefore, we hypothesize that farmers with loamy soil type delayed rice transplantation because they were waiting for optimal water drainage.

Rice duration is a good indicator for understanding different rice varieties the farmers choose to grow. From our results, we see that most farmers in this region grew short to medium duration rice varieties. Irrigation facility and soil type played a crucial role in explaining the rice variety planted in the fields. The average rice duration ranged between 116 – 128 days for farmers who had access to borewells and canals respectively. We hypothesize two reasons for the observed results. First, the median rice duration remained the same between surface and ground water irrigation (120 days); we thus hypothesize that farmers who had access to tubewells were able to sow the rice crop early and harvested the crop 10 days in advance when compared to farmers who had access to only to canal irrigation. Second, we believe that farmers who perceived both crop types and only Rabi to be more profitable than Kharif crop tend to plant shorter duration rice variety. Farmers who perceived Rabi to be more profitable may plant shorter duration rice as this enables them to sow wheat earlier. This reasoning is further supported by the results seen from Table 4 where farmers who perceived both Kharif and Rabi to be equally profitable advance rice sowing dates by ~8 days.

To understand the influence of management factors on wheat sow dates we looked at various factors that were significant in explaining the fallow period duration. The average fallow period was ~17 days long, and farmers utilize this time to prepare the field for the Rabi crop by removing rice residues. A study conducted by Newport et al., 2019 mentions that farmers in this region irrigate the plots before sowing wheat, this helps in loosening the soil and makes it easier for tilling.

From our regression analysis we see that when compared to canal access, farmers who rented tubewells had a 4 day longer fallow period. Here, we hypothesize that farmers renting tubewells were waiting to gain access to canal irrigation in order to reduce the overhead cost incurred while renting tubewells. Further, rice harvest dates were also associated with fallow period duration; for every one-day earlier rice harvest date the fallow period reduced by 0.6 day. Finally, it was interesting to note that wealthier farmers had a shorter fallow period duration by 1.5 days, as wealthy farmer might have had the agency to arrange for resources that aided in advancing wheat sow dates.

Nighty eight percent of the farmers in our study site planted wheat later than the ideal sow date. From Table 6 we see irrigation type, rice harvest dates and wealth to be significantly associated with wheat sow dates. Here again, we see that farmers relying on rented tubewells planted wheat crops 5 days later than farmers who had access to only to canal irrigation. Similar to fallow period, we hypothesize that farmers renting tubewells waited for some time to gain access to canal water. Also harvesting rice later delayed wheat sowing dates, this is due to the delay associated with clearing the rice residue post monsoon harvest. Finally, wealthier farmers also had earlier wheat sowing dates. This is supported by farmers responding that access to tillage machines was one of the challenges for sowing wheat early (Figure 3).

Finally, we were interested in understanding if monsoon cropping decisions had an impact on wheat variety. The wheat varieties in this region on an average matured by 117 days. From our results in Table 7 we see that nursery establishment date and wheat duration are inversely related. With every one-day delay in nursery establishment date the farmers opted for a shorter duration wheat variety. This could be a possible adaptation mechanism employed by the farmers to shield the wheat crop from the terminal heat stress. Also, farmers with their own borewells had longer wheat duration varieties, indicating that reliable access to water helped farmers grow longer wheat varieties which are often associated with higher yields (Tiwari, 2007).

From the above results and discussion, we see that monsoon onset delays, irrigation infrastructure and drainage systems played an important role in resolving the sowing dates of rice and wheat. Although farmers perceived variability in rainfall patterns to be crucial in major agricultural decision making, they seldom had any interventions in place to mitigate its negative effect. Studies have shown that one possible reason associated with the absence of an intervention is that farmers did not perceive climate variability as an immediate threat (Newport et al., 2019). Therefore, future research should examine potential reasons associated with the lack of adaptation mechanisms. Further, expanding the study over a larger geographic area could give us a holistic understanding of various factors that underpin the observed delay in different part of the eastern IGP. Additionally, it will be interesting to look at market dynamics over time and examine its impact on the rice and wheat varieties the farmer decides to grow. Finally, looking at how various sowing techniques such as direct seedling in the case of rice and zero till in the case of wheat impact wheat and rice sowing date will be an interesting comparison to the traditional rice cultivation technique.

5. Conclusion

To address the growing wheat yield gaps observed in the eastern IGP, it is crucial to understand factors that influence rice sowing dates. Previous studies have shown that wheat sowing dates primarily depend on rice sowing decisions made during the monsoon season (Newport et al. 2019). In order to examine factors influencing rice sowing dates, we conducted household surveys with 355 farmers across 10 villages in Arrah District, Bihar. Information pertaining to socio-economic status, perception of profit and climate variability, bio-physical properties of the field, and management factors were collected. We examined how these factors influenced rice and wheat sowing dates. We found irrigation type, delay in monsoon onset dates, and soil type to be the major factors that influenced rice sowing dates. Farmers who had access only to canal irrigation infrastructure had the maximum delay in rice sowing dates; this is likely because of the unreliability of water from canals as opposed to borewells. We found that farmers who had access to borewell planted rice 2 weeks earlier when compared to farmers relying only on canal irrigation. Therefore, if most farmers had access to good irrigation infrastructure, rice sowing dates could be advanced, thereby advancing wheat sowing dates. We also saw that soil type had and impact on rice transplantation dates. Although, it is impossible to control for the soil type found in each plot, there is a lot of scope for improvement with respect to maintaining a robust drainage system. We see that tackling waterlogging alone could advance rice sowing dates by 8.5 days. Finally, the results depict that 98% of the farmers delayed wheat sowing dates in 2018. Lack of irrigation, waterlogging, lack of tillage machines and standing rice crop were reported to be some of the challenges associated with early sowing of wheat. Our regression results also indicate that rice harvest dates impacted both the length of the fallow period and wheat sow dates. In summary, there are two important takeaways from this study. First, as a result of the rice - wheat crop rotation system, factors constraining timely sowing of rice impacted the fallow period duration and subsequently wheat sowing dates. Second, in order to advance wheat sowing date to match the ideal sowing date, rice must be sown earlier. We find that with proper irrigation infrastructure and drainage systems, farmers can potentially advance rice sowing by 1-2 weeks.

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Figures and Tables

Figures

Figure 1: Shows the geographical extent of the study area

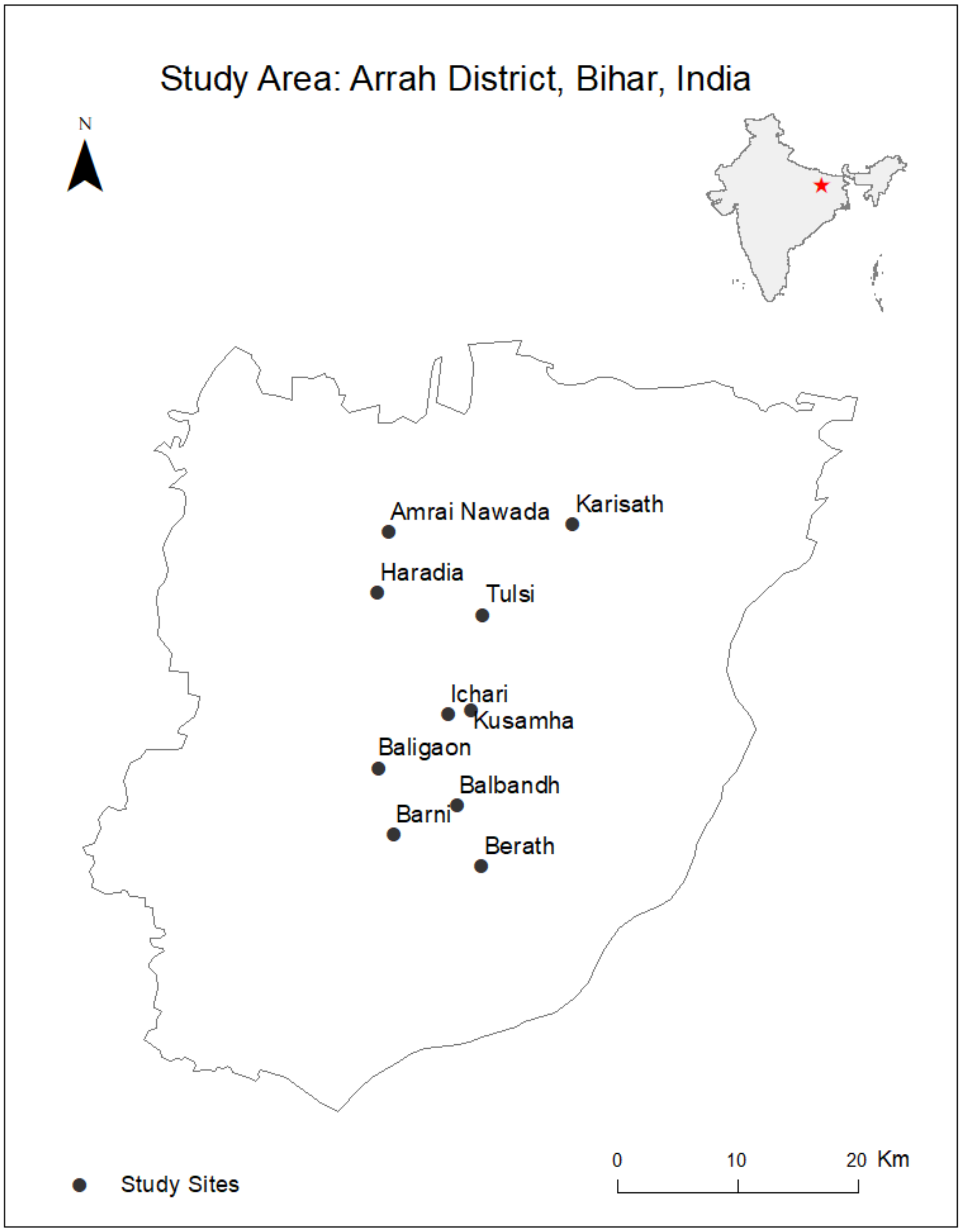

Figure 2: Farmers' responses to variability in rainfall pattern over the last 10 years (A). Farmer level interventions adopted to mitigate the negative effects of rainfall variability (B).

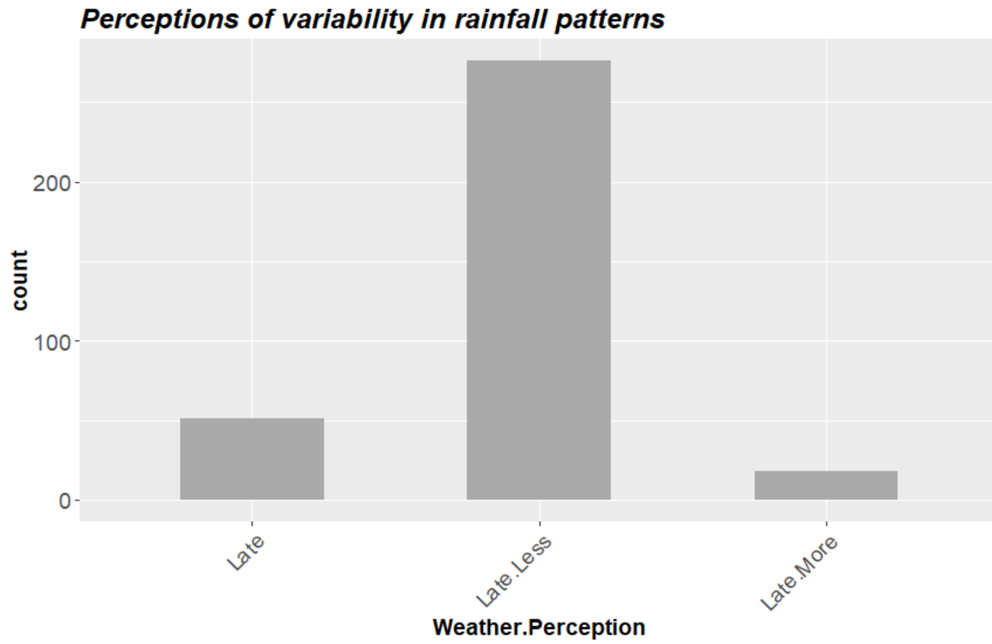

Figure (2.A)

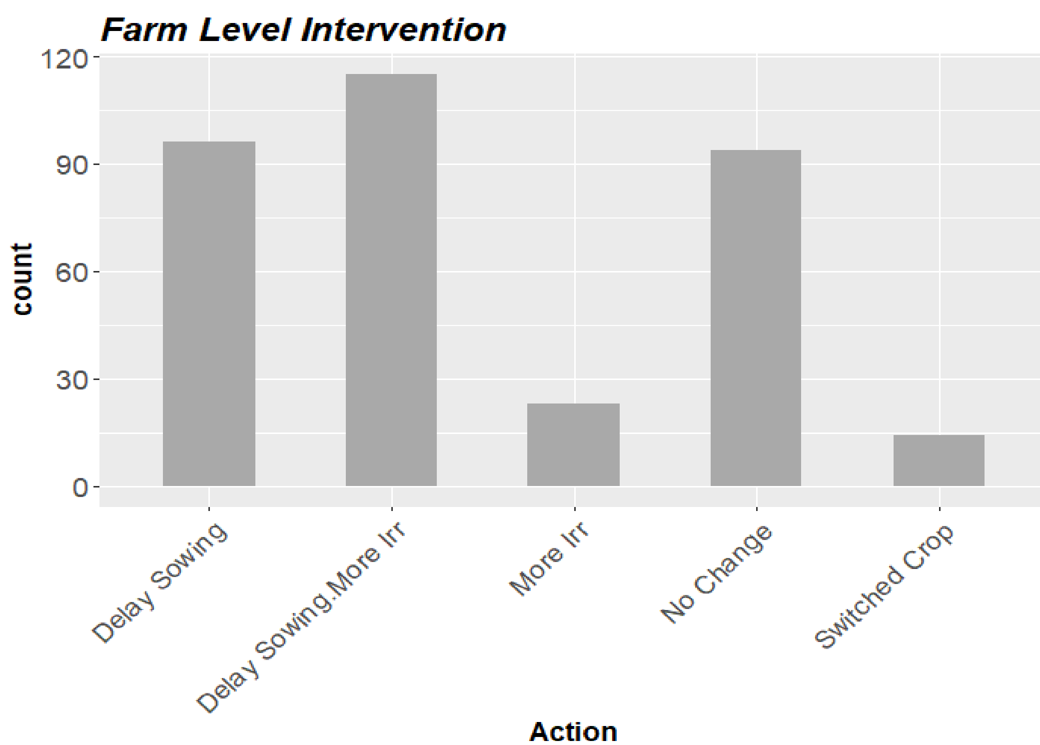

Figure (2.B)

Figure 3: Challenges associated with early nursery establishment (3.A) and timely rice transplantation (3.B)

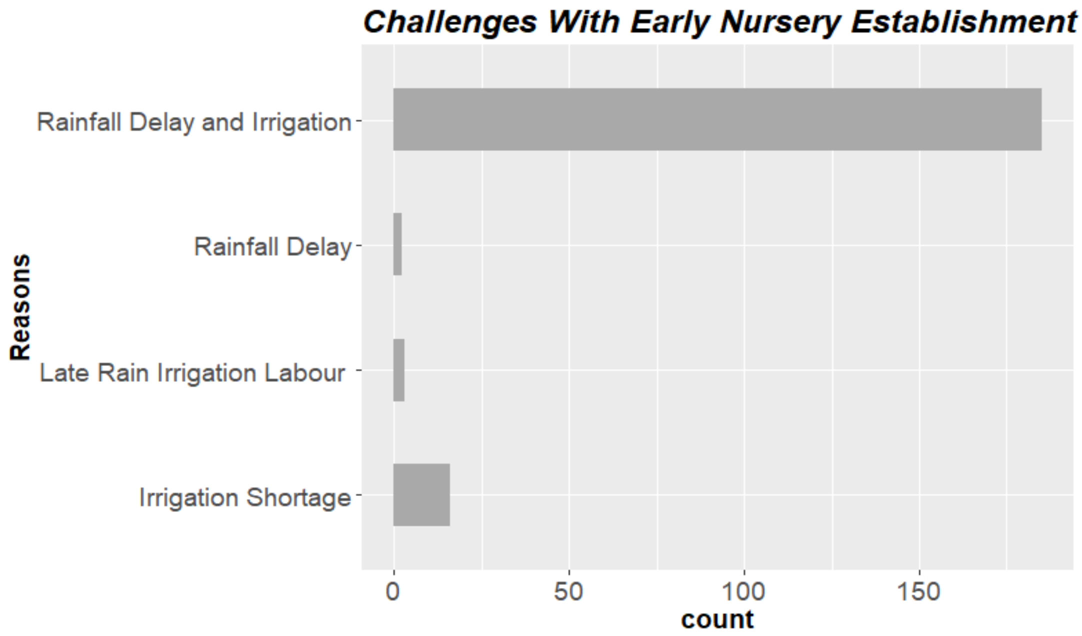

Figure (3.A)

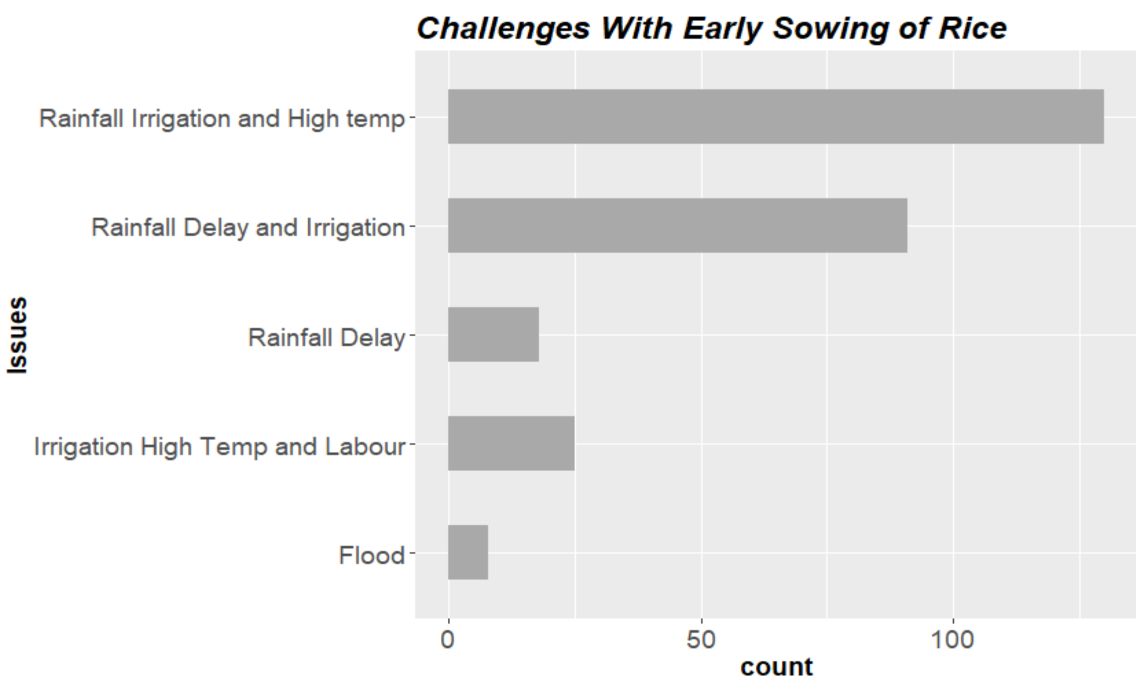

Figure (3.B)

Figure 4: Challenges associate with early wheat sowing date

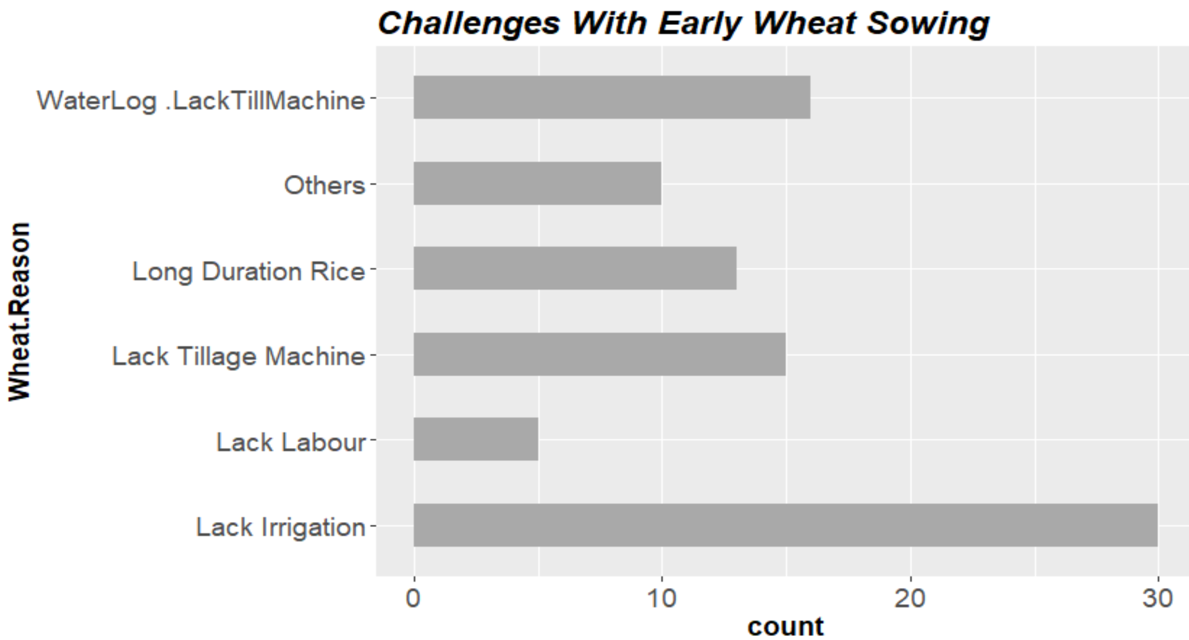

Figure 4

Figure 5: Schematic representation of Rice – Wheat crop rotation system

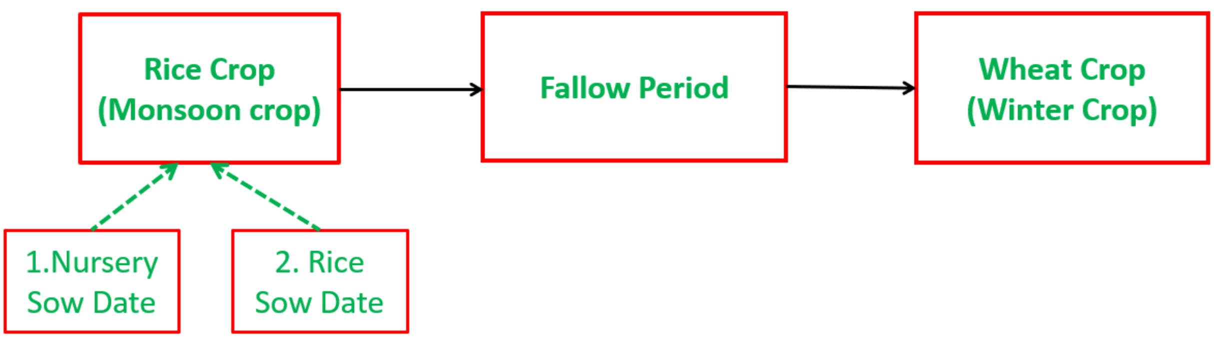

Figure 5

Tables

Table 1: Summary statistics for all variables included in regressions

Nursery Establishment Date N = 341	Mean = June 13 Range = May 3 to July 19
Nursery Duration (Variable named Nur Week Final) N = 336	Mean = 4.2 weeks Range = 3 to 8 weeks
Rice Transplantation/Sowing Date (Rice Trans Date) N = 347	Mean = July 22 Range = June 12 to August 29
Rice Duration N = 352	Mean = 120 Range = 57 to 170
Rice Harvest Date N = 353	Mean = November 22 Range = September 30 to December 21
Fallow Period N = 314	Mean = 17 days Range = 0 to 82 days
Wheat Sow Date N = 350	Mean = December 7 Range = November 5 to January 1
Wheat Duration N = 344	Mean = 117 Range = 95 to 145
Irrigation Type for Monsoon (Irr.type) N = 344	100% of farmers have irrigation; 11.8 % are canal irrigated, 38.2% rent water from another farmer’s bore well, 30.4% use water from their own bore well, 15.9% use both canal and borewells for irrigation, 4.6% use other irrigation types such as ponds and streams
Irrigation type for Winter (Winter.Irrigation) N = 348	100% of farmers have irrigation; 10.6 % are canal irrigated, 39.25% rent water from another farmer’s bore well, 35.54% use water from their own bore well, 14.3% use both canal and borewells for irrigation, 1.4% use other irrigation types such as ponds and streams
Maximum Education Level N =354	13.1% had no schooling, 30.2% went to primary school, 30% graduated from the 10^{th} standard, 15.4% graduated from the 12^{th} standard,10% earned a B.A./B.Sc and 2% earned a master’s degree.
Age N = 354	Mean = 53 Range = 22 to 90
Wealth Index N = 355	Mean = -0.90 Range = 0.93 to -2.31 Derived by performing PCA on all durable goods (e.g. bikes, television, etc.) that a landowner owns
Soil Type N = 344	2% of farmers had dark clay soil (Kewal), 23% had sandy loam soil(Baluwai), 69.2% had loamy soil and 5% had other soil types.

Topography (variable name topo.type) N = 348	4% have lowland topography, 87.1% have midland topography, 4.5% have upland topography and 4.8% had a combination of the above topography
Rainfall perception over the past 10 years (Variable named as Weather. Precipitation) N = 340	15.2% reported delay in monsoon onset; 80.8% reported delay in monsoon onset and lesser precipitation and 4% reported delay in monsoon onset dates with heavy downpour
Profit perception N = 351	76.3% of farmers reported Kharif crop to be more profitable, 17.09% perceived Rabi crop to be more profitable and 7% of the farmers perceived both to be profitable
Area of the largest plot (Acre) N = 349	Mean = 0.5 acre Range = 0.13 to 3 Acre
Wheat Sowing Technique N= 351	85.7% broadcasted wheat, 11.9% used Zero Till and 9% used other techniques such as drill

Table 2: Regressing various socio-economic, biophysical, perceptional, and management factors on nursery establishment date. Reference levels is canal for irrigation type. Significance is indicated by p values in bold font.

	Nursery Establishment Date		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	161.43	147.80 – 175.07	**<0.001**
Rice Duration	0.11	0.03 – 0.20	**0.008**
Irr.typeCanal and Tubewell	-13.83	-18.43 – -9.24	**<0.001**
Irr.typeOthers	-8.93	-15.96 – -1.90	**0.013**
Irr.typeOwn Tubewell	-12.36	-16.57 – -8.14	**<0.001**
Irr.typeRented Tubewell	-16.32	-20.59 – -12.05	**<0.001**
profit.percepKharif	3.25	-1.80 – 8.30	0.208
profit.percepRabi	4.44	-1.29 – 10.17	0.130
Weather.PerceptionLate.Less	-1.77	-5.30 – 1.77	0.329
Weather.PerceptionLate.More	-4.78	-10.88 – 1.33	0.126
Education Level	-0.12	-1.01 – 0.77	0.796
WI	0.74	-0.59 – 2.07	0.276
as numeric(Age)	0.02	-0.07 – 0.12	0.630
Observations	322		
R^2 / adjusted R^2	0.224 / 0.194		

Table 3: Regression of various socio-economic, biophysical, perceptional, and management factors on rice transplantation date. Reference levels are canal for irrigation type, Baluwai (Sandy Loam) for soil type and Kharif and Rabi both profitable for-profit perceptions. Significance is indicated by p values in bold font.

	Rice Trans Date		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	191.46	170.00 – 212.92	**<0.001**
Irr.typeCanal and Tubewell	-14.76	-20.41 – -9.11	**<0.001**
Irr.typeOthers	-9.88	-18.06 – -1.70	**0.019**
Irr.typeOwn Tubewell	-13.38	-18.68 – -8.09	**<0.001**
Irr.typeRented Tubewell	-16.43	-21.72 – -11.13	**<0.001**
Soil.TypeDoumat	8.49	4.61 – 12.38	**<0.001**
Soil.TypeKewal	-1.61	-14.16 – 10.94	0.802
Soil.TypeMixed	8.58	1.03 – 16.13	**0.027**
profit.percepKharif	6.85	0.49 – 13.21	**0.036**
profit.percepRabi	11.03	3.67 – 18.40	**0.004**
Area	-2.71	-6.96 – 1.54	0.212
Topo.TypeMedium.Land	2.67	-6.88 – 12.21	0.585
Topo.TypeMixed.Type	-4.03	-16.06 – 8.00	0.512
Topo.TypeUp.land	2.91	-8.77 – 14.60	0.625
Rice Duration	0.02	-0.09 – 0.12	0.771
Nur Week Final	2.24	0.12 – 4.37	**0.039**
Education Level	0.53	-0.55 – 1.62	0.334
Weather.PerceptionLate.Less	-1.19	-5.59 – 3.22	0.598
Weather.PerceptionLate.More	-3.23	-11.25 – 4.80	0.431
WI	1.05	-0.63 – 2.74	0.221
as numeric(Age)	0.00	-0.12 – 0.13	0.976
Observations	306		
R^2 / adjusted R^2	0.261 / 0.209		

Table 4: Influence of socio-economic, biophysical, perceptional, and management factors on rice duration. Reference levels are canal for irrigation type and Baluwai (Sandy Loam) for soil type. Significance is indicated by p values in bold font.

	Rice Duration		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	114.91	95.93 – 133.90	**<0.001**
Irr.typeCanal and Tubewell	0.19	-5.93 – 6.30	0.953
Irr.typeOthers	2.74	-6.11 – 11.60	0.544
Irr.typeOwn Tubewell	-9.70	-15.32 – -4.08	**0.001**
Irr.typeRented Tubewell	-9.66	-15.27 – -4.05	**0.001**
Soil.TypeDoumat	11.22	7.22 – 15.22	**<0.001**
Soil.TypeKewal	11.68	-1.83 – 25.20	0.091
Soil.TypeMixed	11.33	3.27 – 19.40	**0.006**
Topo.TypeMedium.Land	-0.18	-10.49 – 10.13	0.972
Topo.TypeMixed.Type	-6.68	-19.63 – 6.27	0.313
Topo.TypeUp.land	-3.86	-16.46 – 8.74	0.549
Nur Week Final	-0.29	-2.59 – 2.01	0.804
Education Level	-0.22	-1.38 – 0.95	0.718
Weather.PerceptionLate.Less	-1.66	-6.40 – 3.09	0.494
Weather.PerceptionLate.More	-3.52	-12.18 – 5.14	0.426
WI	0.51	-1.31 – 2.34	0.581
as numeric(Age)	0.13	-0.01 – 0.26	0.070
profit.percepKharif	1.22	-5.66 – 8.10	0.729
profit.percepRabi	0.26	-7.71 – 8.22	0.950
Observations	306		
R^2 / adjusted R^2	0.247 / 0.200		

Table 5: Influence of socio-economic, biophysical, perceptional, and management factors on fallow period duration. Reference levels are Canal for Irrigation type. Significance is indicated by p values in bold font.

	Fallow Period		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	226.52	198.55 – 254.49	**<0.001**
Winter.IrrigationCanal and Tubewell	1.39	-3.29 – 6.07	0.560
Winter.IrrigationOthers	9.71	-2.85 – 22.27	0.131
Winter.IrrigationOwn Tubewell	3.57	-0.58 – 7.72	0.093
Winter.IrrigationRented Tubewell	4.91	0.66 – 9.15	**0.024**
Rice Harvest Date	-0.68	-0.75 – -0.60	**<0.001**
Wheat Duration	-0.01	-0.10 – 0.08	0.823
Soil.TypeDoumat	1.39	-1.41 – 4.18	0.332
Soil.TypeKewal	6.52	-3.39 – 16.42	0.198
Soil.TypeMixed	0.82	-4.59 – 6.22	0.767
Topo.TypeMedium.Land	2.45	-3.39 – 8.28	0.412
Topo.TypeMixed.Type	4.09	-3.79 – 11.98	0.310
Topo.TypeUp.land	5.11	-2.51 – 12.73	0.190
profit.percepKharif	0.78	-4.03 – 5.60	0.750
profit.percepRabi	0.58	-4.80 – 5.96	0.833
Weather.PerceptionLate.Less	-1.55	-4.69 – 1.59	0.334
Weather.PerceptionLate.More	1.63	-4.02 – 7.29	0.572
Wheat.Sowing.MethodW.Broadcast	4.61	-3.83 – 13.05	0.285
Wheat.Sowing.MethodW.ZT	3.46	-5.55 – 12.47	0.452
Education Level	0.19	-0.61 – 0.98	0.642
as numeric(Age)	-0.02	-0.11 – 0.07	0.611
WI	-1.56	-2.76 – -0.37	**0.011**
Area	-2.08	-5.55 – 1.38	0.240
Observations	304		
R^2 / adjusted R^2	0.550 / 0.515		

Table 6: Influence of various socio-economic, biophysical, perceptional, and management factors on wheat sow date. Reference levels are Canal for Irrigation type. Significance is indicated by p values in bold font.

	Wheat Sow Dates		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	228.36	198.59 – 258.12	**<0.001**
Winter.IrrigationCanal and Tubewell	2.01	-2.71 – 6.73	0.405
Winter.IrrigationOthers	11.38	0.07 – 22.70	**0.050**
Winter.IrrigationOwn Tubewell	3.09	-1.10 – 7.29	0.150
Winter.IrrigationRented Tubewell	4.95	0.53 – 9.38	**0.029**
Rice Trans Date	-0.00	-0.09 – 0.08	0.951
Rice Harvest Date	0.33	0.26 – 0.41	**<0.001**
WI	-1.26	-2.46 – -0.06	**0.040**
Rice Duration	-0.04	-0.11 – 0.04	0.333
Wheat.Sowing.MethodW.Broadcast	3.53	-4.30 – 11.36	0.378
Wheat.Sowing.MethodW.ZT	2.68	-5.79 – 11.15	0.536
Soil.TypeDoumat	1.98	-0.95 – 4.91	0.186
Soil.TypeKewal	8.23	-0.92 – 17.38	0.079
Soil.TypeMixed	1.93	-3.58 – 7.43	0.493
profit.percepKharif	0.71	-3.92 – 5.34	0.763
profit.percepRabi	0.90	-4.43 – 6.23	0.740
Education Level	0.36	-0.43 – 1.14	0.373
Weather.PerceptionLate.Less	-1.42	-4.58 – 1.74	0.379
Weather.PerceptionLate.More	2.00	-3.59 – 7.59	0.483
as numeric(Age)	-0.01	-0.10 – 0.08	0.789
Observations	318		
R^2 / adjusted R^2	0.303 / 0.259		

Table 7: Influence of various socio-economic, biophysical, perceptional, and management factors on wheat duration. Reference levels are Canal for Irrigation type, Baluwai (Sandy Loam) soil type and Kharif and Rabi both profitable for-profit perception. Significance is indicated by p values in bold font.

	Wheat Duration		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	137.81	98.88 – 176.73	**<0.001**
Nursery Establishment Date	-0.29	-0.42 – -0.17	**<0.001**
Rice Harvest Date	0.11	0.01 – 0.20	**0.025**
Winter.IrrigationCanal and Tubewell	0.71	-4.98 – 6.40	0.807
Winter.IrrigationOthers	9.70	-5.76 – 25.16	0.220
Winter.IrrigationOwn Tubewell	5.47	0.48 – 10.46	**0.032**
Winter.IrrigationRented Tubewell	1.85	-3.41 – 7.11	0.491
Soil.TypeDoumat	-2.35	-5.81 – 1.10	0.183
Soil.TypeKewal	7.40	-4.73 – 19.54	0.233
Soil.TypeMixed	-7.83	-14.46 – -1.21	**0.021**
Topo.TypeMedium.Land	-0.64	-8.11 – 6.82	0.866
Topo.TypeMixed.Type	-2.35	-12.03 – 7.33	0.635
Topo.TypeUp.land	-3.21	-12.76 – 6.34	0.511
Wheat.Sowing.MethodW.Broadcast	-2.91	-14.13 – 8.31	0.612
Wheat.Sowing.MethodW.ZT	-1.67	-13.55 – 10.22	0.784
profit.percepKharif	-2.86	-8.59 – 2.87	0.328
profit.percepRabi	-2.93	-9.43 – 3.57	0.378
Weather.PerceptionLate.Less	0.87	-3.00 – 4.74	0.660
Weather.PerceptionLate.More	1.07	-5.75 – 7.90	0.758
WI	0.42	-1.03 – 1.87	0.573
as numeric(Age)	-0.03	-0.14 – 0.08	0.552
Education Level	-0.29	-1.26 – 0.69	0.566
Observations	310		
R^2 / adjusted R^2	0.207 / 0.149		

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