



# Advancing Sowing Time and Conservation Tillage - The Climate-Resilient Approach to Enhance the Productivity and Profitability of Wheat

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## Abstract

Field experiments consisting of two sowing time (early and timely), two tillage options (conventional tillage and conservation tillage) and ten genotypes were conducted with the aim to maximize the wheat productivity and profitability. The early sowing (second fortnight of October) produced 16.0% higher grain yield compared to timely sowing (mid-November) in northern Indian Plains. However, no significant yield differences were observed between conventional tillage (CT) and conservation tillage (CST) practices. Among genotypes, the better yielders were PBW 723, BISA 927 and HD 2967. The interaction of sowing time and genotype had a significant ( $p < 0.05$ ) effect on wheat yield. However, the interaction of genotype and tillage did not produce any significant response on wheat yield. The experiments conducted at farmer's fields also demonstrated similar performance of wheat under CT and CST systems but CST offered the savings of more than Rs. 3500 (US \$ 47) along with  $125 \text{ kg ha}^{-1}$  lesser  $\text{CO}_2$  emissions over CT due to reduction in fuel consumption associated with tillage and seed bed operations. At farmers field also, early sown wheat yielded 5.5% higher over wheat sown in November. The results of present studies show that early sowing of high yielding wheat genotypes under CST practice enhanced the productivity and profitability of wheat under rice-wheat cropping system along with lesser noxious impact on the environment. Amidst climate vagary and its menace on the agriculture, the adoption of climate-resilient management practices such as advancing the sowing time and conservation tillage can improve the productivity of long duration wheat cultivars in sub-tropical humid conditions besides lesser deleterious consequences on the environment.

**Keywords** Conservation tillage · crop residue · rice-wheat system · yield · Turbo Happy Seeder

## Introduction

Globally wheat, being a prime cereal food crop, contributes a production of 765.77 million tonnes (mt) from an area of 215.9 million hectares (m ha) in which Asia contributes 44.1 and 45.7%, respectively (FAOSTAT, 2021). Wheat in sequence with rice, a major cropping system providing the food security, covers about 13.5 m ha in South Asia (Ladha et al., 2003). To meet the demand of the rapidly growing population, researchers around the globe need to focus on

enhancing the productivity and production of these crops. However, rice-wheat system in the Indo-Gangetic Plains (IGP) of South Asia is facing several challenges such as yield stagnation, increased input cost and natural resource degradation along with adverse effects of climatic variability such as terminal heat stress (Michler et al., 2019; Kumar et al., 2021). Intensive tillage and residue burning are the practices which led to deterioration of soil quality, causing a serious threat to the sustainability of rice-wheat cropping system (Ghimire et al., 2012; Bhattacharyya et al., 2012; Gathala et al., 2013). The burning of crop residue causes loss of precious microbial population, soil organic carbon (SOC) and other nutrients along with adverse effect on soil physico-chemical and biological properties. Intensive tillage also degrades the SOC due to the enhanced oxidation. Bhattacharyya et al. (2000) reported that majority of Indian

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cultivated soils have SOC concentration less than  $5 \text{ g kg}^{-1}$  compared to uncultivated virgin soils having  $15\text{--}20 \text{ g kg}^{-1}$ . Conservation tillage (CST), an alternative crop production system having zero tillage (ZT) and at least 30% soil surface covered with crop residue, has the potential to address the issues of natural resource degradation, changing climate effects, and shortage of water, energy and labour along with enrichment of SOC. The integration of CST with crop diversification popularly known as conservation agriculture (CA) provides additional advantages and has been adopted globally on about 180.44 m ha under different cropping systems (Kassam et al., 2019).

In conventional tillage (CT) practice, farmers perform a large number of tillage operations in rice based cropping systems like rice-wheat. It consumes a huge amount of energy, labour and time, leading to increased cost of wheat cultivation with lesser farm profitability. The results of the numerous studies in rice-wheat system revealed that ZT with and without residue retention have advantages in terms of yield gain, resource-use efficiencies, reduced cost of cultivation and increased net-economic return along with reduced global warming potential (Aryal et al., 2015; Su et al., 2021). Moreover, CA-based cropping systems are found more adapted to extreme climatic conditions like terminal heat, water stress and help in arresting and reversing the soil degradation, thereby improving the productivity and sustainability of crops over CT system. In CA, ZT with residue retention facilitates the formation of continuous soil pores in the root zone, resulting in higher infiltration compared to CT system (McGarry et al., 2000; Gathala et al., 2011; Verhulst et al., 2011). In another study, O'Leary (1996) recorded the higher groundwater table after 10 years in area sown continuously under stubble-retained zero-tilled wheat-fallow conditions in Australia.

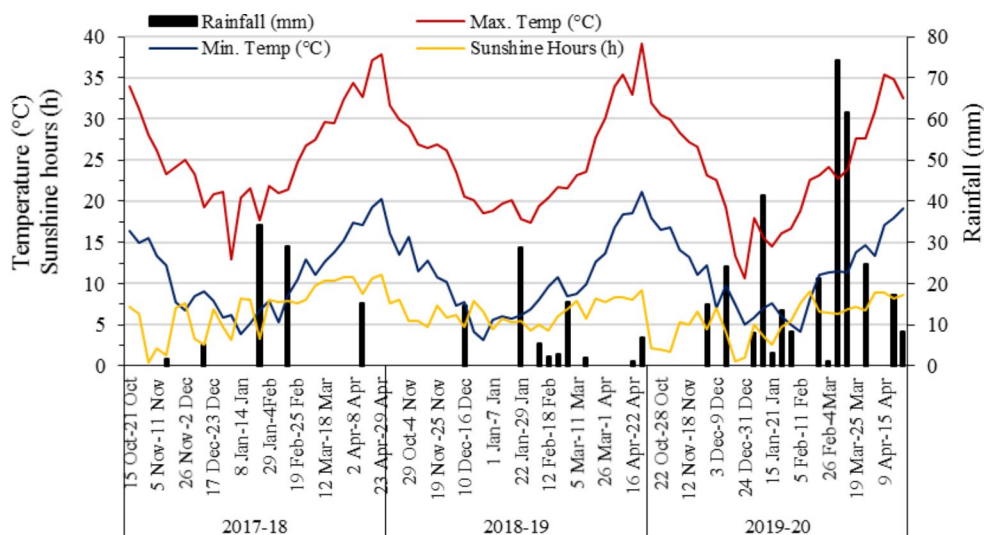
The layer of crop residues retained on the soil surface in no-till (NT) system reduces soil evaporation and water runoff (Zuazo & Pleguezuelo, 2008), fosters the build-up of organic matter in soils (Swanepoel et al., 2018), increases soil water retention capacity and mitigates drought effects (Lal, 1995; Scopel et al., 2004). In addition, residue cover reduces the rate of change in soil temperature (Ramakrishna et al., 2006; Muñoz-Romero et al., 2015; Shen et al., 2018), provides a buffer layer that can increase the crop adaptation to higher climatic variability and occurrence of extreme events (Page et al., 2020), and improves microbial populations/biological activity besides suppressing the weeds (Blevins et al., 1983; Unger, 1991; Chhokar et al., 2007; Sharma et al., 2008). Also, seeding winter wheat into standing stubble provides the protection against cold temperature due to trapped snow (Cox et al., 1986; Struthers & Greer, 2001) and in years having winter kill, NT yields higher than CT but in years with no winter injury, both the systems

provide the similar wheat yields. In some other conditions, such as winter crop in cold regions, it has been reported that leaving the soil surface bare or intermittent covering with residue increased the chance of yield gain compared to continuous soil cover. Also, NT had better performance than CA in winter wheat in northeast of China possibly due to adverse effect of soil cover on mean soil temperature (Shen et al., 2018) and thereby delaying the crop establishment and growth (Hatfield & Prueger, 2015; Muñoz-Romero et al., 2015; Page et al., 2020).

Globally, the importance of optimum sowing time for higher yield without any extra cost has been well proven (Balwinder-Singh et al., 2015, 2016). The optimum sowing time varies depending upon the varieties as well as growing conditions of the region. After the green revolution, the sowing time of dwarf wheat was shifted to the first fortnight of November in India. Based on the large number of coordinated trials on sowing time and genotypes in India over the years and locations, it was found that any delay in wheat sowing beyond November reduced the yield at the rate of  $27.6\text{--}32.0 \text{ kg ha}^{-1} \text{ day}^{-1}$  in northern Indian Plains (Tripathi et al., 2005). The results of these studies conducted at multi-locations over the years also revealed no yield advantage in early sown (last week of October) wheat over timely sowing (November) under CT due to lack of suitable genotypes for these conditions. However, for the past 10–15 years, efforts have been made to break the yield barriers by increasing the crop biomass and grain filling duration with the aim to increase the sink size. In the past two decades, the probable incidence of terminal heat stress increased due to rise in temperature during the grain filling period (February and March), leading to yield decline in wheat. Also, delayed harvesting of previous crop causes shorter growing period of wheat resulting in coincidence of grain filling stage and high temperature (terminal heat), thereby declining the yield. One of the ways to mitigate the adverse effect of terminal heat is through the application of light irrigations but generally, farmers avoid it due to fear of lodging. Under such circumstances, early sowing of wheat and adoption of CA are more practicable approaches to escape the terminal heat stress (Jat et al., 2018; Kumar et al., 2018; Dubey et al., 2020). Conservation agriculture helps through better soil moisture regime and lesser risk of lodging as a result of improved water infiltration and better crop anchorage. The newly developed high yielding wheat genotypes also require alteration in agronomic management for the yield maximization and the most basic and important factor is optimization of sowing time.

Generally, the response of wheat genotypes is expected to vary due to alteration in micro-climate with the adoption of CA as a result of ZT and surface residue cover. Therefore, specific genotypes may be needed for NT system with

**Fig. 1** Mean weekly maximum temperature, minimum temperature, sunshine hours and rainfall during the experimental years



or without surface residue retention (Chevalier & Ciha, 1986; Tillman et al., 1991; Yang & Baker, 1991; Chhokar et al., 2018; Yadav et al., 2019). The researchers (Chevalier & Ciha, 1986; Hall & Cholick, 1989; Tillman et al., 1991; Yang & Baker, 1991; Watt et al., 2005; Trethowan et al., 2005; Sagar et al., 2014; Yadav et al., 2017) highlighted that genotype and tillage/environment ( $G \times T/E$ ) interactions had significant effect on wheat yield, which indicates the importance of selecting the suitable genotypes for NT system. In contrary, some researchers found lack of genotype  $\times$  tillage ( $G \times T$ ) interaction effect on yield (Francis et al., 1984; Ullrich & Muir, 1986; Cox, 1991; Chhokar et al., 2018).

In addition to yield, tillage and crop establishment methods also account for a major part of total crop production cost (Erenstein & Laxmi, 2008; Gathala et al., 2011). The adoption of CA fully or partially in the form of ZT and CST significantly diminishes the tillage and crop establishment costs (79–95%) over CT based system (Gathala et al., 2011). The adoption of CA or CST based wheat under rice–wheat system can facilitate the early planting along with immediate yield benefit and reduced production cost in the regions where rice is harvested late (Chhokar et al., 2007; Saharawat et al., 2010). However, adoption of CA and CST practices at farmers' fields has been slow due to lack of CA compatible seeding machines and inadequate screening of region-specific wheat cultivars suited for CST conditions. Also, there are limited number of agronomical-economics studies on these practices at farmers' field to convince the farmers to shift from traditional methods of wheat cultivation. Moreover, globally little work has been done on the identification of suitable wheat genotypes for CST system. Considering these points in mind, the present study was undertaken to explore the possibilities of improving the wheat productivity and profitability through integrated

approach of adjusting the sowing time, tillage method and screening of suitable genotypes under irrigated conditions of rice-wheat cropping system in northern Indian plains.

## Materials and Methods

### Experimental site Details

Field experiments were conducted at research farm (29°42'21.5" N, 76°59'32.6" E) of ICAR–Indian Institute of Wheat and Barley Research (IIWBR), Karnal during 2018–19 and 2019–20 to maximize the wheat productivity by identifying the suitable combination of wheat genotype, tillage option and sowing time under rice-wheat system. At experimental site, the soil varied from sandy loam to clay loam in texture, alkaline in reaction (pH 7.35), low in available N ( $132.3 \text{ kg ha}^{-1}$ ), low in organic carbon (0.37%) and medium in phosphorus ( $15.4 \text{ kg ha}^{-1}$ ) and potash ( $168.2 \text{ kg ha}^{-1}$ ). To validate the experimental results, similar experiments were conducted at farmers' fields around Karnal district of Haryana, India. The seasonal weather data during the growth period of wheat crop (October to April) in the experimental years (2017–18, 2018–19 and 2019–20) are shown in Fig. 1. The occurrence of maximum temperature  $> 25^\circ\text{C}$  was observed during the end of February in 2017-18 whereas it was witnessed in second fortnight of March during 2018-19 and 2019-20. There was comparatively more rainfall during 2019-20. The details of the experiments and crop management approaches are described in the subsequent sections.

**Table 1** Calculation of fuel cost associated with different farm implements used in the present study

Name of the implement	Working width (m)	Speed of operation (km h <sup>-1</sup> )	Fuel consumption (L ha <sup>-1</sup> )	Fuel cost (Rs. ha <sup>-1</sup> )
Disc harrow	2.21	7.5–9.0	7.58*	491
Spring-tyne cultivator	2.17	7.5–9.0	7.03	455
Rotary tiller	1.45	3.0–3.5	17.20	1113
Planker	3.5	7.5–9.0	2.60	168
Turbo Happy Seeder	2.25	3.0–3.5	13.75**	890

\*First pass, \*\*CA plot

## Experimental Design, Treatments and Crop Management

Field experiments were conducted in a split-split plot design with three replications during *Rabi* seasons of 2018-19 and 2019-20. The main plots comprised two sowing time i.e. early (second fortnight of October) and timely (mid-November), whereas, subplots consisted of two tillage options i.e. conventional tillage (CT) and conservation tillage (CST) and sub-sub plots had ten genotypes as listed in Table 1. In all the treatments, seed rate of 100 kg ha<sup>-1</sup> and recommended dose of fertilizer (150 kg N+60 kg P<sub>2</sub>O<sub>5</sub>+40 kg K<sub>2</sub>O ha<sup>-1</sup>) were used. The irrigation was applied according to the recommended package of practices for wheat in this zone.

Preceding wheat, coarse rice (HKR-47) was grown under puddle transplanted (wet tillage) conditions with recommended agronomic practices. The non-selective herbicide glyphosate at the rate of 1000 g ha<sup>-1</sup> was sprayed about 4–5 days before sowing of the wheat crop in CST plots. The early and timely wheat sowing was done using Turbo Happy Seeder (THS) on 22<sup>nd</sup> October and 15<sup>th</sup> November during the first year and on 22<sup>nd</sup> October and 19<sup>th</sup> November during the second year, respectively. The CT plots were prepared using cross disc harrowing followed by cross spring-tyne cultivator and then pulverizing the soil with rotary tiller. It was then followed by leveling the seedbed with planker. In CST plots, no tillage was performed and direct seeding of wheat was done using THS.

The observations of yield and yield attributes were recorded during the crop growth period in all the treatments. The effective tillers were counted about a fortnight before harvesting in one running meter at two places in each plot and converted to per square metre. The crop in individual plot was manually harvested and threshing was done by small plot thresher. After recording the yield, a random sample was taken from each treatment to measure the weight of 1000 grains. The wheat yields were calculated based on net plot area, leaving the border rows.

## Demonstrations at Farmers' Field

### Comparative Performance of Tillage and Sowing Time Options after Rice at Farmers' Field

Besides the experiments conducted at research farm, the demonstrations were also conducted at farmers' field (village Taraori, Rambha and Baragaon of Karnal district, Haryana, India), where two tillage options (CT and CST) and two sowing time (early and timely) were tried in the large area. One acre area was divided in two equal parts having CT and CST options. The demonstrations at farmers' field were conducted for three consecutive *Rabi* seasons of 2017-18, 2018-19 and 2019-20. The yield of trial laid out during 2019-20 could not be recorded due to Covid-19 pandemic.

For CST plots, full residue of previous rice crop was spread uniformly after combine harvesting. In CT plots, residue was removed and field was well prepared using cross harrowing and cross tilling with cultivator followed by cross planking. The sowing in both tillage conditions was done with THS using high yielding wheat cultivars either HD 2967 or PBW 723. All the recommended package of practices were followed. From each block, three samples each having a size of 4.5 m<sup>2</sup> (4 rows and 5 m length) were taken for recording the grain yield.

### Fuel Cost Calculation

The cost of fuel accounted for field preparation and sowing operations in both tillage systems were calculated based on the large data collected on fuel consumption during the field trials on commonly used farm implements in our previous studies (Chauhan et al., 2000; Sharma et al., 2002). The details of such calculations are given in Table 1. In all experiments conducted at research farm and farmers' field, tractor with rated power of 45–55 hp was used for field preparation as well as for sowing operation. During the second pass of harrowing, fuel consumption (L ha<sup>-1</sup>) was taken as 90% of the value accounted during the first pass of harrowing (as given in Table 1) due to higher soil strength and comparatively more energy requirement in initial opening of the soil. During the field operation with harrow, cultivator and

planker, tractor was operated in high gear (7.5–9.0 km h<sup>-1</sup>). In preparing the seedbed with rotary tiller and during sowing operation with THS, tractor was operated in low gear (3.0–3.5 km h<sup>-1</sup>). The fuel consumption (L ha<sup>-1</sup>) in sowing operation with THS under CT plots is comparatively low and it was taken as 90% of fuel consumption under CA plots (as given in Table 1). The fuel cost was calculated based on the price of diesel (Rs. 64.73 L<sup>-1</sup>) in Karnal as on 15<sup>th</sup> November 2019.

## Data Analysis

The data of yield and yield attributes were subjected to analysis of variance (ANOVA) for determining the differences among the treatment means and when the F test was significant, the means were compared with Fisher's protected least significant difference (LSD) test at 5% level of significance ( $\alpha=0.05$ ). Based on the data of different field observations, average and SE  $\pm$  m were also worked out in different demonstrations. "Fischer's paired t-test" was used for comparing the significance of two treatment means. The data were pooled where the results were similar in the experimentation over the years.

## Results and Discussion

### Effect of Sowing Time, Tillage and Genotypes on Wheat Grain Yield

The effect of sowing time, tillage and genotype on yield and yield attributes of wheat is presented in Table 2. It is evident from the pooled results that early sowing of wheat i.e. on 22<sup>nd</sup> October produced 16.0, 12.0 and 12.1% higher grain yield, biomass and thousand grains weight, respectively, over timely sowing around 15<sup>th</sup> November. The mean grain yield recorded under early and timely sown conditions was 68.65 and 59.17 q ha<sup>-1</sup>, respectively. The early sowing of wheat allows proper filling and development of grains prior to the exposure of crop to terminal heat stress, which otherwise cause shortening the heading and maturity duration (Jat et al., 2018; Padovan et al., 2020). In early sowing, anthesis and filling stages of wheat are advanced, thereby allowing the grains filling under optimum temperature for a longer period. Streck (2005) observed the shortening of grain filling period by 2.8 days for every 1 °C increase in temperature above the optimum growing temperature of wheat. Though grain filling rate hastens at increased temperature but it is not equally compensated against the reduced grain filling period, thereby resulting in improper filling and shrinkage of grains. The present study also showed the bolder wheat grains under early sowing (45.99 g per 1000

grains) compared to the timely sown condition (40.98 g per 1000 grains). Thus, early sowing of wheat offers advantages to high yielding wheat varieties of longer duration in terms of minimizing the gap between potential and actual yield, and developing bolder grains which are also suitable for seed production program. Kajla et al. (2015) also reported that high yielding varieties (PBW-343 and DBW-17) have flexibility, adaptability and well suited to timely as well as early sowing time. In another study from China, Dong et al. (2022) found similar grain yield of wheat sown between 8 and 22 October but it decreased when sowing was delayed beyond 22 October. The effect of tillage was found non-significant and wheat yield was similar under CST (63.82 q ha<sup>-1</sup>) and CT (63.99 q ha<sup>-1</sup>) systems. Laik et al. (2014) reported 46–54% higher grain yield of wheat crop with inclusion of all components of CA along with the best management practices as compared to CT farmers' practice. Similarly, Chaki et al. (2021) reported 5.6% increase in system productivity of rice-wheat cropping system but it was concluded that major advantage of CA on yield in rice-wheat cropping system can be realized in fine-textured soil. In present study, the genotypic differences were significant. Among ten genotypes, significantly higher grain yields were recorded with PBW 723 and BISA 927 compared to rest of the eight genotypes. The two other genotypes, which yielded higher than 65 q ha<sup>-1</sup>, were HD 2967 and BISA 921.

### Effect of Sowing Time and Genotype Interaction on Wheat Grain Yield

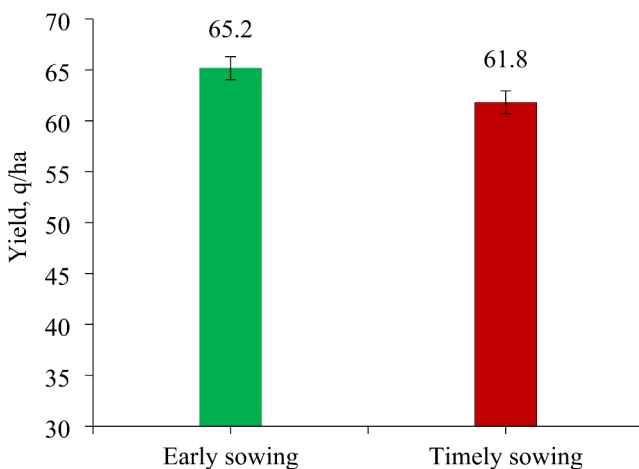
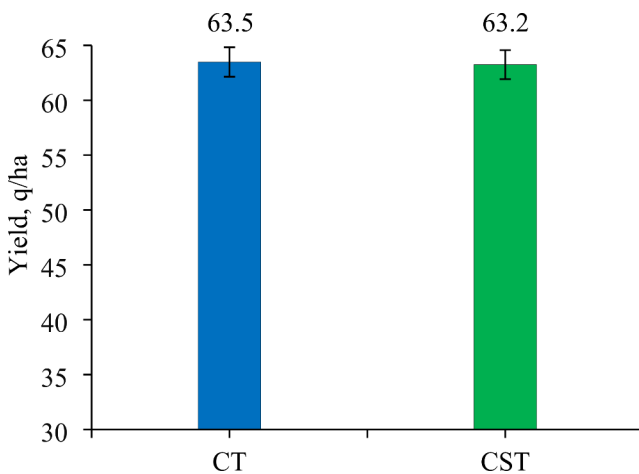
Among the various treatments effects, only the interaction effect of sowing time and genotype on wheat grain yield was significant and the results are given in Table 3. The performance of high yielding longer duration varieties can suffer drastically if sowing is not done at proper time. Under the early sowing condition, variety BISA 927 performed superior over other test entries with a mean yield of 73.56 q ha<sup>-1</sup>. However, the shift in sowing time from early to timely condition brought PBW 723 as top performer with a mean yield of 64.66 q ha<sup>-1</sup>. It can be understood that a top performer wheat variety under early sowing may suffer yield lag under delayed sown condition as a result of reduced grain filling period. Therefore, sowing time is equally important like selection of suitable wheat variety for getting the higher productivity. The results of present study are in-line with the findings of Coventry et al. (1993), Murungu & Madanzi (2010), Yusuf et al. (2019) and Ali et al. (2021), who found significant effect of the sowing time and genotype interaction on wheat grain yield. It is interesting to see that under timely sown conditions, the most of the genotypes had lower grain yield during 2018-19 over

**Table 2** Effect of sowing time, tillage and genotypes on wheat grain yield and yield attributes

	2018-19					2019-20					Pooled					
	Tillers m <sup>-2</sup>	Biomass (q ha <sup>-1</sup> )	Yield (q ha <sup>-1</sup> )	1000 grains wt. (g)	Tillers m <sup>-2</sup>	Biomass (q ha <sup>-1</sup> )	Yield (q ha <sup>-1</sup> )	1000 grains wt. (g)	Tillers m <sup>-2</sup>	Biomass (q ha <sup>-1</sup> )	Yield (q ha <sup>-1</sup> )	1000 grains wt. (g)	Tillers m <sup>-2</sup>	Biomass (q ha <sup>-1</sup> )	Yield (q ha <sup>-1</sup> )	1000 grains wt. (g)
<b>Sowing time (A)</b>																
Early	430.1	170.79	71.52	45.18	404.5	170.06	65.78	46.67	417.3	170.42	68.65	45.93				
Timely	444.9	145.07	58.32	39.88	491.5	159.19	60.02	42.08	468.2	152.13	59.17	40.98				
LSD (0.05)	NS	6.89	1.84	0.69	NS	1.75	4.81	1.76	NS	2.48	1.53	0.93				
<b>Tillage (B)</b>																
CST	426.8	154.28	64.68	42.80	445.2	166.33	62.96	44.76	436.0	160.31	63.82	43.78				
CT	448.2	161.57	65.16	42.26	450.8	162.92	62.83	43.99	449.5	162.25	63.99	43.12				
LSD (0.05)	NS	5.47	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.40				
<b>Genotype (C)</b>																
HD 3316	424.6	158.80	59.65	40.79	445.8	166.27	61.65	42.10	435.2	162.53	60.65	41.44				
HD 3317	392.1	153.36	63.21	45.97	405.0	163.10	60.60	48.07	398.6	158.23	61.91	47.02				
BISA 913	493.3	151.62	60.22	36.76	488.5	149.90	56.06	40.03	490.9	150.76	58.14	38.40				
BISA 916	532.3	153.59	60.32	36.46	497.7	170.63	62.59	40.82	515.0	162.11	61.46	38.64				
BISA 921	448.5	158.10	68.27	48.33	464.0	159.13	63.82	50.82	456.3	158.61	66.04	49.58				
BISA 927	393.8	163.08	67.51	44.11	411.3	172.72	67.27	45.67	402.5	167.90	67.39	44.89				
HD 2967	426.5	158.45	65.29	41.23	429.0	166.07	65.52	43.44	427.7	162.26	65.41	42.34				
PBW 723	429.4	167.59	71.26	44.59	437.9	160.12	66.05	44.73	433.6	163.86	68.66	44.66				
MPO 1215	420.8	152.78	66.82	45.04	493.5	173.91	62.60	45.74	457.2	163.34	64.71	45.39				
UAS 415	413.5	161.92	66.64	42.03	407.3	164.38	62.79	42.32	410.4	163.15	64.71	42.17				
LSD (0.05)	51.6	5.79	1.94	1.48	44.3	5.64	2.56	1.24	32.2	3.38	1.47	0.97				
<b>Interaction</b>																
A*B	NS	NS	NS	0.92	19.4	NS	NS	NS	NS	NS	NS	0.56				
A*C	NS	NS	2.75	2.09	62.7	7.97	3.62	1.76	45.5	4.78	2.08	1.37				
B*C	NS	NS	NS	NS	NS	7.97	NS	NS	NS	4.78	NS	NS				
A*B*C	NS	11.58	NS	NS	NS	11.28	NS	NS	NS	6.76	NS	NS				

**Table 3** Interaction effect of sowing time and genotypes on wheat grain yield ( $\text{q ha}^{-1}$ )

Genotype	2018-19		2019-20		Pooled	
	Early	Timely	Early	Timely	Early	Timely
HD 3316	63.95	55.34	66.58	56.73	65.27	56.04
HD 3317	70.65	55.77	67.77	53.43	69.21	54.60
BISA 913	68.15	52.29	58.40	53.73	63.27	53.01
BISA 916	64.03	56.61	64.35	60.83	64.19	58.72
BISA 921	74.58	61.95	66.63	61.01	70.60	61.48
BISA 927	77.08	57.95	70.04	64.50	73.56	61.23
HD 2967	73.25	57.33	68.13	62.92	70.69	60.13
PBW 723	78.14	64.37	67.17	64.94	72.65	64.66
MPO 1215	71.99	61.65	64.08	61.11	68.04	61.38
UAS 415	73.36	59.92	64.63	60.95	68.99	60.43
LSD=0.05 for Sowing time $\times$ Genotype	2.75		3.62		2.08	

**Fig. 2** Effect of sowing time on wheat productivity ( $n=18$ )**Fig. 3** Effect of tillage on wheat productivity ( $n=20$ )

2019-20, which might be due to lesser sunshine hours during February, ultimately affecting the photosynthesis process of plants (Fig. 1).

### Validation of Sowing Time and Tillage Effects on Wheat Productivity at Farmers' Field

To validate and demonstrate the effects of sowing time and tillage methods on wheat productivity, trials were conducted at farmers' field around Karnal during *Rabi* seasons of 2017-18, 2018-19 and 2019-20. The trials on sowing time were conducted at 18 farmers' fields and results are presented in Fig. 2. It is clear that early sowing of high yielding varieties (HD 2967, PBW 723) produced 5.5% higher grain yield over timely sowing, having a mean yield of  $61.8 \text{ q ha}^{-1}$ . Thus, simply advancing the sowing time of long duration high yielding wheat genotypes, yield can be improved. The results of the trials conducted on tillage methods at 20 farmers' field are demonstrated in Fig. 3. It is evident from the results that wheat performed equally good under CST as with CT, without any significant difference in the mean wheat grain yield. This represents huge opportunity with twin benefits of enabling the farmers for advanced seeding of wheat in critical window period and recycling of crop residue back to soil by eliminating the residue burning and its associated destructive effects on the natural resources. Moreover, the long-term adoption of conservation tillage and residue recycling would be helpful in improving the soil physico-chemical and biological properties. Thus, advancing the wheat sowing under CST would improve the crop productivity and quality of natural resources in addition to lesser tillage cost (as discussed in the next section). In this direction, future research efforts of the breeding program on developing new wheat cultivars suited to ZT or CA conditions would be helpful in improving the wheat productivity and bringing the more area under CA.

## Effect of Tillage Methods on Fuel Cost and Environment

In trials on tillage methods at farmers' field, wheat was directly sown using THS in the presence of full rice residue under CST whereas under CT, wheat was sown after preparing the field with traditional practice as described in section 2.3.1. The fuel cost associated with field preparation and sowing operations under CT and CST plots was computed to be Rs. 3925 and 890 ha<sup>-1</sup>, respectively. It needs to be understood that just the elimination of tillage with CST, Rs. 3035 per hectare can be saved along with other potential benefit of mitigating > 125.2 kg CO<sub>2</sub> ha<sup>-1</sup> as compared to CT. It represents a huge advantage in terms of savings on tillage cost and improved environment coupled with sustainable crop production system. Besides this tillage cost saving, reduced tillage operations in CST can also help in advancing the sowing time particularly when harvesting of previous long duration crops like fine rice cultivars is delayed which prevails in majority of the area under eastern IGP.

It can be understood that use of THS provides the opportunity of directly seeding the wheat after combine harvesting of rice crop and can advance the wheat sowing provided that pre-sowing irrigation has been applied to the rice crop well in advance. Moreover, if adoption of CST or CA wheat is extended to whole rice-wheat system, a significant boost in the productivity and profitability can be realized along with improved soil and environmental conditions. The other workers also reported that if CA is extended to entire wheat growing area (around 30 m ha), diesel fuel to the tune to 1200 mega litres can be saved every year along with other environmental benefits (Sepat et al., 2013; Akbarnia & Farhani, 2014; Sidhu et al., 2015). So, there is enormous untapped potential to improve the overall crop productivity, system profitability as well as soil and environmental sustainability through the large-scale adoption of CA in integration with best management practices in wheat based cropping systems. However, it is evident that presently, the world is facing a temperature rise of 1.2 °C with reference to global temperature in the pre-industrial period of 1850–1900 and last seven years (2014–2020) have been the hottest seven years with top year as 2016 having 1 °C rise in the global temperature compared to 20<sup>th</sup> century (Lenssen et al., 2019; GISS, 2020; Anonymous, 2021a). According to the estimates considering the current policies and 2030 targets, the world would face a global warming of nearly 2.4 °C (1.9–3.0 °C) since pre-industrial times by 2100 (Anonymous, 2021b). Therefore, alteration in sowing time and other climate-resilient agronomical measures would be required to sustain the crop productivity in future considering the projections of global temperature rise.

## Conclusions

The results suggests that adoption of CST-based wheat establishment along with the early sowing and suitable genotype can enhance the net-return of farmers over the intensive CT practices in rice–wheat system. The early sowing of wheat (second fortnight of October) was found to have significant grain yield improvement over timely sowing (mid-November) and it bridges the gap between actual and potential yield of new high yielding long duration wheat cultivars which otherwise may suffer from terminal heat stress under delayed sowing conditions. The similar wheat yield can be realized under CST as with CT but with higher profitability due to the savings of more than Rs. 3000 on elimination of multiple tillage operations. It also reduces CO<sub>2</sub> release by 125 kg ha<sup>-1</sup> in addition to providing the opportunity of *in-situ* crop residue management. Besides these immediate benefits, if CST or CA is practiced over the years continuously then NT and residue retention will increase the C and N stocks (Lal, 1995; Campbell et al., 1996; Bayer et al., 2000), thereby improving the soil health. Thus, advancing the sowing time of long duration high yielding wheat cultivars under long-term CST or CA practice in sub-tropic humid conditions would be effective to improve the crop productivity, profitability, and soil and environmental sustainability amidst the challenges of climate change and degrading natural resources.

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## Declarations

**Conflict of Interest** The authors declare no conflicts of interest.

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