Indian Journal of Agronomy **61** (1): 45–52 (March 2016)

Research Paper

Long-term impact of conventional and zero tillage on wheat (*Triticum aestivum*) in red and lateritic zone of West Bengal

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Received : August 2015; Revised accepted : January 2016

ABSTRACT

Farmers' participatory trials were conducted for 7 years during winter (*rabi*) seasons of 2004–05 to 2010–11, in red and lateritic zone of West Bengal, India, to evaluate the long-term effect of conventional (CT) and zero (ZT) tillage on yield and yield attributes, nutrient uptake, nutrient-use efficiency, economics of wheat [*Triticum aestivum* (L.) Emend. Fiori & Paol.]. The most influential climatic factor, best planting date for different cultivars and best cultivar corresponding to different tillage practices were also adjudged in this study. Zero tillage increased wheat yield on an average by 20.7%, net returns by ₹ 9,523/ha, N, P and K uptake by 16, 19.1 and 14.0% respectively, over CT. The most important contributing character to the total variability of wheat grain yield was number of spikes/m^2, which contributed 11.7 and 25.8% variation to the ZT and CT yield, respectively. Multiple regression coefficient analysis revealed that the influential climatic factor for ZT and CT wheat was minimum temperature and relative humidity, respectively. While evaluating performance of wheat cultivars under 2 tillage practices on different planting dates, 'PBW 343' and 'HD 2733' gave the maximum yield between 8 and 15 November, 'K 9107' and 'Swarna (L)' between 1 and 7 November with ZT method. In contrast, all the cultivars gave the maximum yield in CT within the first week of November, except 'PBW 343'. Interaction between tillage practice and wheat cultivar revealed that 'K 9107' and 'PBW 343' were most stable cultivar for this zone across tillage options. The lowest yield loss attributable to delay in planting was obtained in the cultivar 'Swarna (L)' (7.85 kg/ha/day) and 'K 9107' (7.21 kg/ha/day) for ZT and CT respectively, indicating higher stability of theses cultivars for late-sown condition in this region.

Key words *:* Conventional tillage, Nutrient-use efficiency, Uptake, Wheat, Yield, Zero tillage

Wheat is the second most important cereal crop in West Bengal and its average yield in different districts is about 2.3 t/ha. But the climatic potential yield is about 5–7 t/ha resulting in a yield gap of 45 to 66%, indicating a scope for improvement through proper crop management (Bhattacharyya *et al*., 2008). However, in the Red and Lateritic zone of Birbhum, West Bengal, wheat yield in the farmer's plot is 2.8 t/ha which is 45% less than the potential yield (Aggarwal *et al*., 2000). The major constraints for such yield gap delay in harvesting of winter rice, leading to delay in sowing of wheat; high soil moisture, short winter, low mechanization, imbalanced nutrient-use efficiency, poor land levelling, inadequate plant population, weed problem and high production cost. To tackle this problem of yield stagnation, an integrated approach was needed for improvement of the conventional production practices followed in the region to adopt to resource conserving technologies (RCTs) in order to enhance system yield, inputuse efficiency, and farm profitability on a sustainable basis.

To date, the RCT, that has been most successfully designed and tested in the Indo-Gangetic Plains is zero tillage (ZT) practice for wheat after rice with a tractor-drawn ZT seed-cum-fertilizer drill (Keil *et al*., 2015). Zero-tillage technique is an ecological approach for soil-surface management and seed-bed preparation, resulting in less input energy (Choudhary and Behera, 2013), less weed problem, better crop-residue management, enhances timeliness of wheat establishment and higher or equal yield (Jain *et al*., 2007). On-station and on-farm trials with zero till (ZT) wheat in the rice–wheat systems of the IGP have shown positive impacts on wheat crop-management, particularly through reduced input needs combined with potential yield increases (Sharma *et al*., 2012; Jat *et al*., 2014).

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Considering the above facts a research-cum-extension project was initiated in 2004–05 jointly by Government of West Bengal and Rice–Wheat–Consortium (RWC) of the IGP, for development, testing, refining and dissemination of RCTs. Under this project, the frontline demonstration on ZT wheat was compared with conventional tillage by means of a farmer participatory model involving farmers, researchers and extension workers from 2004–05 to 2008–09. Later on, this programme was continued under Cereal System Initiative for South Asia (CSISA) programme from 2009–10 to 2010–11. This paper summarises the results of these frontline demonstration programme in farmers' field of Birbhum district in order to find out the long-term effect of different tillage options on (*i*) yield and yield attributes, nutrient uptake, nutrient use efficiency and economics (*ii*) relation of weather parameters with wheat yield, and (*iii*) the most stable variety and their optimum planting date under different tillage systems.

MATERIALS AND METHODS

The farmer's field trials were conducted in the wheat-growing villages under different blocks of Birbhum district, West Bengal, namely, Nalhati-I, Rampurhat I, Rampurhat II, Murarai I and Murarai II, located in the lower Gangetic Plain at 24.29^o N and 87.84^o E. The area falls under the hot, dry sub-humid zone, 60 m above mean sea-level. The soil of the experimental locations was very deep, well-drained, varying in texture from sandy loam, clay loam to clay. After manual harvesting of winter paddy, glyphosate @ 8–10 ml/litre water was applied in the field to control the mat of weed. The field was then divided into 2 subplots for 2 treatments, viz. CT and ZT, and same cultivars were used in both these tillage operations. In the CT, the land was ploughed twice with a cultivator before the pre-sowing irrigation. Seed and fertilizers were broadcast on the surface and mixed by 1 ploughing and 2 laddering. Zero tillage wheat was sown by a tractor-drawn zero-till-seed-cum-fertilizer drill. The machines opened a number (6-9) of narrow slits for placement of seed and fertilizer at the depth of 5 cm into the soil. The cultivars used by the farmers were: 'PBW 343', 'K 9107', 'HUW 468', 'UP 262', 'PBW 502', 'HD 2733' including a local cultivar 'Swarna' (L). Wheat seeds were sown during middle of November to end of December with recommended seed rate after treating with vitavax @ 2.5 g/kg. One-third of the recommended dose of nitrogen and full dose of P and K were applied basal and the remaining nitrogen was top-dressed in 2 equal splits– after first irrigation and at first node-formation stage. In both tillage practices, 2 irrigations were given, however, the average time of irrigation for CT and ZT were 22.5 h/ha and 19 h/ha, respectively. Both pre-emergence as well as post-emergence herbicides were applied as and when required in all the treatments. Other agronomic management practices followed were standard for the crop. Data on number of spike/m^2, number of grains/spike, 1,000-grains weight and biological and grain yields q/ha were recorded from each farmer's field plot at harvesting and analysed as per standard analysis of variance technique using SAS® version 9.3.

To estimate the yield loss due to delay in planting method given by Dhillon and Ortizz-Monasterio (1993), was adopted and the following regression was used:

$$Y_i = a + bPD_i + u$$

where Y_i is the yield in kg/ha for planting date i, PDi is the Julian date for the planting date *i*. The linear specification function provides an estimate of the yield reduction in absolute term due to delay in planting date, b, the slope of regression equation, is used to estimate the yield loss (kg/ha/day) due to delay in planting for a particular cultivar. In this regression analysis, yield data were considered for plating dates up to end of December because only few plantings were performed beyond December. Data from a different number of years were available for each cultivar and this was mentioned after the cultivar name in parenthesis in Table 4.

Sustainability index (Singh *et al*., 1990) of the treatments over 7 years of study was calculated as: SYI = $(\bar{Y}-\delta)/Y_{max}$, $\bar{Y}$ the average yield of a treatment, δ the treatment where standard deviation and Y_{max} maximum yield in the experiment over years.

At maturity, samples of wheat grain and straw were collected in the last 2 years, i.e. 2009–10 and 2010–11, oven-dried at 70°C to constant weight and ground to pass through a 0.5 mm sieve for chemical analysis. Nitrogen content in plant samples was determined by micro-Kjeldahl method (Jackson, 1973). The samples were digested in tri-acid mixture (HNO_3 : H_2SO_4 : $HClO_4$: 10 : 1: 4, by volume), and in the digest, P was measured by vanadomolybdate yellow colour method (Jackson, 1973), and K by flame photometer (Tandon, 1993). Uptake of N, P and K by crop was estimated by multiplying the dry-matter yields (after drying at 70^o C to constant weight) of each crop by plant nutrient concentration. The experimental data were analysed statistically in SAS® version 9.3 and interpreted accordingly. Cost of cultivation, gross returns, net returns, benefit: cost analysis were also derived on the basis of prevailing market prices of inputs and outputs for individual farmers' field and then averaged for a particular year.

RESULTS AND DISCUSSION

Yield attributes and grain yield

At the onset, farmers were tentative about the performance of the new technology (ZT) and only 2.13 ha can be brought under the programme. However, the farmers shifted to adopt the ZT technology after noticing the higher yield and economic advantages of cultivation. Since then, the acreage under ZT wheat in different blocks of Birbhum district increased from 5 ha in 2005–06 to 20 ha in 2007–08 (Table 1).

The ZT increased the spikes/m^2, grains/spike, 1,000-grain weight and grain yield over CT in all the years. Segregated over the years, the yield and yield attributes were significantly higher under ZT than CT except number of spikes/m^2. Amongst different yield attributes, grains/spike varied most, being was 6.21–21.4% higher under ZT over CT, while the 1,000-grain weight (g) was 1.78–18.32% higher across years (Table 1). The highest grain yield over the years was recorded under ZT during 2010–11, while the highest yield increment under ZT over CT was obtained during 2004–05. This higher yield under ZT was owing to increase in yield-attributing characters. There was average gain of 487 kg/ha or 20.7% wheat yield un-

Table 1. Grain yield and yield attributes obtained during wheat growing cycle (2004–2011)

Growing season/ (Area ha)	Treatment	Spike/m^2	Grains/spike	1,000-grain weight (g)	Yield (t/ha)	Harvest index
	ZT (n = 16)	172 ± 28.60	45.41 ± 7.19	40.84 ± 2.76	2.75 ± 0.10	0.37 ± 0.020
	CT (n = 16)	173 ± 31.95	38.23 ± 7.02	39.00 ± 4.29	2.12 ± 0.25	0.33 ± 0.037
2004–05 (2.13 ha)	ZT–CT (%)	-0.884	18.6	4.72	29.6	12.12
	SEm±	10.40	2.44	1.24	0.065	0.00143
	CD (P=0.05)	NS	4.96	2.52	0.132	0.0032
	ZT (n = 28)	197 ± 22.31	37.60 ± 5.31	39.49 ± 5.29	2.67 ± 0.24	0.29 ± 0.033
	CT (n = 28)	191 ± 21.91	33.24 ± 4.38	36.30 ± 7.39	2.27 ± 0.25	0.27 ± 0.042
2005–06 (5.00 ha)	ZT–CT (%)	3.00	13.1	8.81	17.44	7.41
	SEm±	5.28	1.16	1.54	0.058	0.0006
	CD (P=0.05)	10.55	2.32	3.06	0.117	0.0013
	ZT (n = 74)	165 ± 34.22	52.53 ± 8.86	42.94 ± 3.23	2.73 ± 0.38	0.37 ± 0.024
	CT (n = 74)	167 ± 33.73	43.21 ± 7.98	42.19 ± 3.43	2.24 ± 0.27	0.35 ± 0.027
2006–07 (13.07 ha)	ZT–CT (%)	-1.23	21.4	1.78	21.60	5.71
	SEm±	5.34	1.32	0.52	0.052	0.0017
	CD (P=0.05)	NS	2.62	1.03	0.103	0.0036
	ZT (n = 150)	189 ± 37.96	33.69 ± 5.89	38.68 ± 5.76	2.79 ± 0.72	0.33 ± 0.019
	CT (n = 150)	183 ± 38.16	31.23 ± 5.90	37.02 ± 5.33	2.38 ± 0.56	0.32 ± 0.022
2007–08 (20.0 ha)	ZT–CT (%)	3.62	7.20	4.46	17.19	3.13
	SEm±	4.96	0.77	0.72	0.084	0.0010
	CD (P=0.05)	NS	1.51	1.42	0.165	0.0022
	ZT (n = 95)	210 ± 20.01	39.34 ± 2.81	33.57 ± 2.02	2.89 ± 0.28	0.38 ± 0.033
	CT (n = 95)	206 ± 17.03	34.51 ± 2.35	26.36 ± 2.20	2.36 ± 0.19	0.35 ± 0.038
2008–09 (12.7 ha)	ZT–CT (%)	1.87	14.0	18.32	22.27	8.57
	SEm±	3.26	0.45	0.37	0.042	0.0029
	CD (P=0.05)	6.45	0.90	0.73	0.083	0.0063
	ZT (n = 134)	214 ± 17.15	35.39 ± 3.99	36.42 ± 4.61	2.97 ± 0.33	0.43 ± 0.023
	CT (n = 134)	207 ± 14.76	31.42 ± 3.08	31.43 ± 5.87	2.41 ± 0.27	0.40 ± 0.024
2009–10 (17.3 ha)	ZT–CT (%)	3.64	12.64	15.87	23.11	7.50
	SEm±	2.17	0.48	0.71	0.041	0.0034
	CD(P=0.05)	4.27	0.95	1.41	0.081	0.0073
	ZT (n = 80)	244 ± 48.65	38.06 ± 4.28	33.53 ± 2.33	3.06 ± 0.45	0.45 ± 0.027
	CT (n = 80)	239 ± 53.40	35.84 ± 4.41	31.90 ± 2.53	2.67 ± 0.38	0.43 ± 0.025
2010–11 (10.5 ha)	ZT–CT (%)	2.06	6.21	5.11	14.68	4.65
	SEm±	10.89	0.93	0.52	0.089	0.0033
	CD (P=0.05)	NS	1.84	1.03	0.177	0.0119
	ZT (pooled)	199 ± 26.9	40.29 ± 6.54	37.92 ± 3.59	2.84 ± 0.14	0.37 ± 0.06
	CT (pooled)	195 ± 24.6	35.38 ± 4.24	24.89 ± 5.33	2.35 ± 0.17	0.35 ± 0.05
Mean	ZT–CT (%)	1.83%	13.8%	8.71%	20.7%	6.94 %
	SEm±	13.75	2.95	2.43	0.084	0.0017
	CD (P=0.05)	NS	NS	NS	2.35	NS
Sustainability index	ZT	–	–	–	0.499	–
	CT	–	–	–	0.418	–

der ZT over CT in each year from 2004–05 to 2010–11 across different locations of Birbhum district, ranging from 14.68% (390 kg/ha) in 2010–11 to 29.6% (630 kg/ ha) in 2004–05. The increased yield under ZT might be attributed to proper placement of seed and fertilizer at proper depth and consequently good germination and better crop establishment, all of which attributed to better input efficiency and better crop growth converting into yield. Keil *et al*. (2015) also reported that ZT practices led to a robust yield gain over conventional tillage wheat across different agro-ecological zones of IGP, India, amounting to 498 kg/ha (19%) on average. From the long-term monitoring of wheat yield in Birbhum district over 7 years, it was observed that ZT was more sustainable with sustainable index (SI) of 0.499 than CT (SI, 0.418) (Table 1). This might be owing to consistent higher grain yield obtained under ZT than CT across the years. Regression drawn between grain yield and different yield attributes and spike/m^2, grains/spike and 1,000-grain weight showed significant relation with grain yield under both the tillage operations (Table 2). According to the results, the most important contributing character to the total variability of wheat grain yield was spike/m^2, which contributed 11.7 and 25.8% variation to the ZT and CT yield, respectively.

Wheat yield–weather response and stability

The minimum and maximum temperatures (°C) and relative humidity (RH) (%) had prominent and inverse relationship on the yield of both ZT and CT (Fig. 1). The minimum and maximum temperatures and relative humidity were the lowest during 2010–11 which might have contributed towards the highest grain yield under both ZT and CT over all the years. Indeed a recent study (Barlow *et al.*, 2015) on effect of temperature extremes and heat, in wheat revealed that excessive heat can cause reduction in grain number and duration of grain-filling period leading to reduction in yield potential. The lowest yield across the years was recorded during 2005–06 which might be attributed to high rainfall during this year. However, the effect of rainfall on wheat yield did not reflect any trend since wheat is cultivated in this area is largely under irrigated condition. Indeed Stepwise Multiple Regression Coefficient Analysis (Table 3) revealed that the minimum temperature was the most important climatic factor for ZT followed by relative humidity and total rainfall. However, for CT the most important climatic factor was relative humidity followed by maximum and minimum temperatures (Table 3).

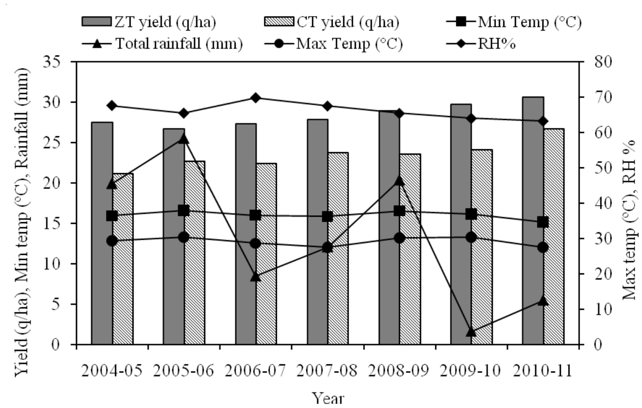

Fig. 1. Relationship between zero tillage and conventional tillage yield with average weather parameters during seven years of wheat-growing season (November–April)

Grain yields of different wheat cultivars pooled over 7 years across locations are presented in Fig 2. The most frequent varieties used over 7 years were ‘K 9107’, local cultivar ‘Swarna’ (L) and ‘PBW 343’. The pooled data revealed significant interaction between tillage practice and wheat cultivar, where ‘K 9107’ and ‘PBW 343’ performed better and recorded stable yield over years, while ‘HUW 468’ gave the lowest yield both under ZT and CT. However, the grain yield increase in ZT over CT for different cultivars was in the order ‘Rajlaxmi’ (29.33%) > ‘UP 262’ (23.52%) > ‘K 9107’ (22.26%)> ‘HUW 468’ (19.7%)> ‘PBW 343’ (19.4%), ‘HD 2733’ (18.2%)>

Table 2. Relationship between yield attributes and grain yield of wheat under zero tillage and conventional tillage practices

Variable	Regression equation	R^2
Zero tillage (n=469)		
Spikes/m^2 vs grain yield	Y = 0.315 X + 15.541	0.117**
Grains/spike vs grain yield	Y = 0.098 X + 22.413	0.074**
1,000-grain weight vs grain yield	Y = 0.213 X + 20.439	0.056*
Conventional tillage (n =469)		
Spikes/m^2 vs grain yield	Y = 0.058 X + 12.393	0.258**
Grains/spike vs grain yield	Y = 0.0154 X + 19.242	0.039**
1,000-grain weight vs grain yield	Y = 0.107 X + 21.134	0.031*

*P=0.01; **P=o.05

'Swarna (L)' (17.8%)> 'PBW 502' (14.9%).

Planting time and tillage effects on wheat yield

The pooled data of wheat grain yield of various cultivars across locations and years showed significant interactions among tillage practices, varieties and planting dates (Fig. 3 a, b). Five cultivars which were widely grown in various years were selected for this study. The highest yield under ZT for the cultivars 'PBW 343' and 'HD 2733' were obtained when planted during 8–15 November, while for 'K 9107' and 'Swarna' (L) this could be obtained if sown during 1–7 November. Among different cultivars the yield of 'HUW 468' was the lowest under both ZT and CT; however it should be sown during 16–22 November under ZT for its potential yield. In contrast with zero tillage all the varieties recorded the highest yield in CT when planted within the first week of November except 'PBW 343' for which the planting date should be 16–22 November. The slope of the lines (Fig. 3 a, b) were derived from linear regression and lowest values was obtained for 'Swarna' (L) (–0.499) under ZT and 'K 9107' (–0.794) under CT which indicates higher stability of these cultivars for late-sown condition in this Red and Laterite zone.

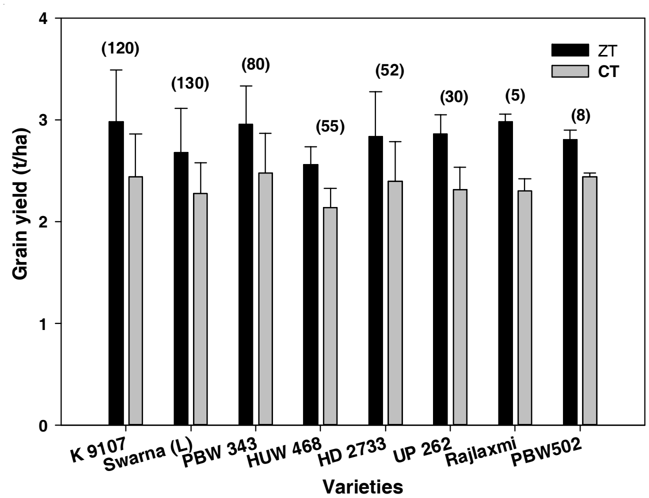

Fig. 2. Performance of different wheat varieties under zero tillage and conventional tillage method. The values above each column indicate the number of trials conducted in farmer's fields with the particular cultivars.

Wheat yield lose due to delay in planting

The grain yields of all the 5 cultivars were decreased due to delay in plating time (Table 4). Under ZT the highest yield loss (kg/ha/day) was observed in 'PBW 343' followed by that in 'HD 2733' and 'HUW 468', while under

Table 3. Multiple regression equations between weather parameters and zero tillage and conventional tillage yield over 7 years

Equation for ZT	R^2	Individual contribution	Equation for CT	R^2	Individual contribution
			Weather parameters		
ZTY = 34.937 – 0.203 max temp	0.051	5.10	CTY = 40.831 – 0.594 max temp	0.190	19.0
ZTY = 58.431 + 0.947 max temp – 3.60 min temp	0.495	44.4	CTY = 57.251 + 0.275 max temp – 2.607 min temp	0.345	15.5
ZTY = 47.104 + 0.738 max temp – 2.461 min temp – 0.063 total rainfall	0.583	8.80	CTY = 45.782 + 0.064 max temp – 1.453 min temp – 0.064 total rainfall	0.405	6.00
ZTY = 64.067 – 0.062 max temp – 0.414 min temp – 0.067 total rainfall – 0.399 relative humidity	0.857	27.4	CTY = 74.718 – 1.302 max temp + 2.038 min temp – 0.071 total rainfall – 0.680 relative humidity	0.939	53.4

Table 4. Regression equations between Julian dates for the planting dates and yield of different varieties to estimate the yield loss due to delay in planting

Varieties	Treatments	Equation	R^2	*P*	Yield loss (kg/ha/day)
'K 9107' (6 years)	ZT	6476 – 10.56x	0.835	0.011	10.56
	CT	4876 – 7.210x	0.788	0.018	7.210
'PBW 343' (7 years)	ZT	9936 – 20.34x	0.986	<0.001	20.34
	CT	9427 – 20.096x	0.990	<0.001	20.09
'HUW 468' (5 years)	ZT	6281 – 11.028x	0.880	0.006	11.03
	CT	5943 – 12.056x	0.954	0.001	12.06
'Swarna' (L) (7 years)	ZT	5449 – 7.848x	0.856	0.003	7.850
	CT	9937 – 22.172	0.946	<0.001	22.17
'HD 2733' (5 years)	ZT	9465 – 19.409x	0.984	<0.001	19.41
	CT	8503 – 17.420x	0.842	0.004	17.42

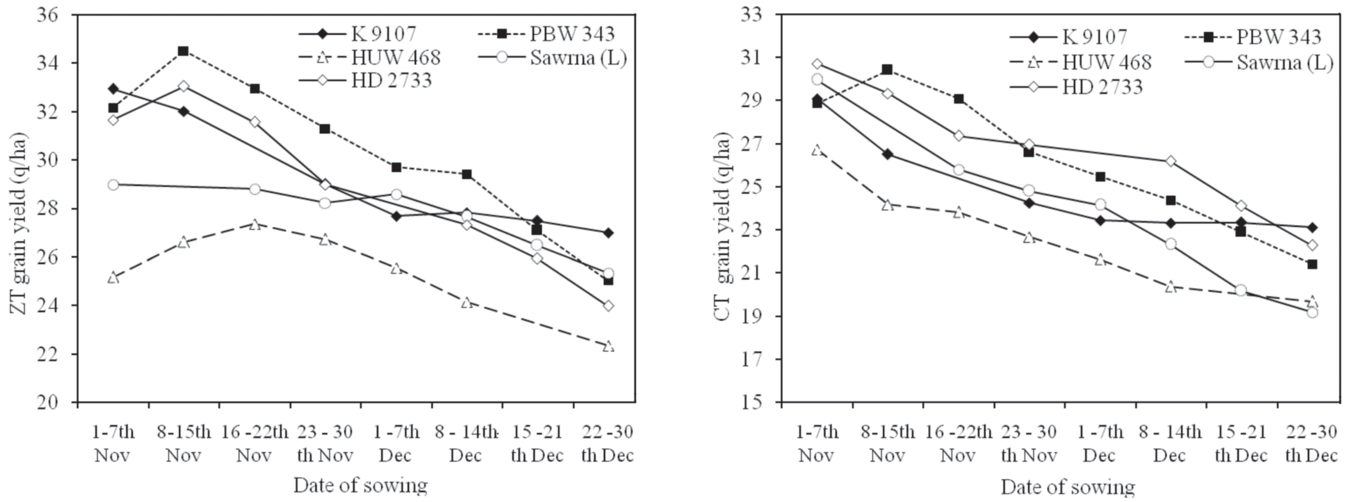

Fig. 3 (a, b). Effect of planting dates and tillage practices on yield of different wheat cultivars

CT the highest yield loss was observed for the cultivar 'Swarna' (L) followed by 'PBW 343' and 'HD 2733'. However, the cultivar 'Swarna' (L) under ZT and 'K 9107' under CT recorded the least decline in yield of 7.85 and 7.21 kg/ha/day respectively. Earlier studies have also reported that wheat sown after middle of November reduced potential yield to the tune of 1–1.5%/day due to terminal heat (Oriz-Monasterio *et al.*, 1994) and lower use efficiency of inputs applied. Interestingly, the yield losses in all the cultivars except 'Swarna' (L) and 'HUW 468' were higher under ZT option than CT. Thus it can be concluded that higher yield of wheat with ZT can be assured when planting is done within the first fortnight of November.

Nutrient uptake and nutrient-use efficiency

Across locations and years, the variability of N, P and

Table 5. Economic analysis in zero tillage (ZT) system and conventional tillage (CT) system over 5 years (2006–07 to 2010–11)

Growing season	Treatment	Cost of cultivation (₹/ha)	Savings in ZT over CS (₹/ha)	Gross returns (₹/ha)	Price of wheat grain (₹/kg)	Net Profit (₹/ha)	Benefit: cost ratio
2006–07	ZT	7,215	3,532	23,128	8.5	15,913	2.206
	CT	10,747	–	19,015	8.5	8,268	0.769
	SEm±	–	–	443.7	–	443.7	0.056
	CD (P=0.05)	–	–	876.4	–	876.4	0.109
2007–08	ZT	9,690	4,755	25,115	9.0	15,425	1.592
	CT	14,445	–	21,430	9.0	6985	0.484
	SEm±	–	–	753.2	–	753.2	0.069
	CD (P=0.05)	–	–	1,484	–	1,483.9	0.137
2008–09	ZT	10,899	4,852	27,436	9.5	16,537	1.517
	CT	15,750	–	22,442	9.5	6,692	0.425
	SEm±	–	–	397.9	–	397.9	0.033
	CD (P=0.05)	–	–	787.5	–	787.5	0.0657
2009–10	ZT	12,931	5,363	32,094	10.8	19,163	1.482
	CT	18,357	–	26,074	10.8	7,717	0.420
	SEm±	–	–	442.9	–	442.9	0.031
	CD (P=0.05)	–	–	873.1	–	873.1	0.061
2010–11	ZT	13,270	5,630	35,187	11.5	21,917	1.652
	CT	18,900	–	30,682	11.5	11,782	0.623
	SEm±	–	–	651.0	–	651.0	0.043
	CD (P=0.05)	–	–	2,037	–	2,036.9	0.136
Pooled mean	ZT	10,801	4,826	28,592	–	17,791	1.692
	CT	15,640	–	23,929	–	8,289	0.542
	SEm±	1,845.6	–	3,015	–	1,522.9	0.148
	CD (P=0.05)	4,256	–	NS	–	3,511.8	0.3422

K uptake by ZT and CT wheat is shown in Fig. 4a. The total above-ground N, P and K accumulation was 115–196, 11.5–27.9 and 77–138 kg/ha, respectively, under ZT, while under CT these was 94–173, 10.4–26.1 and 56–132 kg/ha respectively. However, the average N, P and K uptake was 16.7, 19.1 and 14.0% higher respectively, under ZT than the CT. The higher uptake of these nutrients in ZT than CT could be attributed to better root growth and biomass production resulting from positive physiological and metabolic activities (Lupwayi *et al.*, 2006) and greater accumulation of nutrients in surface. Precisely, the higher N uptake in ZT may be due to the increased soil organic matter and subsequent N mineralization. On the other hand, solubilization of native phosphorus by the organic acids produced during decomposition of stubbles under ZT could be the reason for higher P availability and uptake; besides stubble decomposition might have released some amount of K in addition to lead to greater uptake of K under ZT than CT.

The internal nutrient-use efficiency is the ratio of grain yield by total nutrient uptake (grain + straw), which was determined for 2009–10 to 2010–11 and presented in Fig. 4 b, c, d. The average internal nutrient efficiencies (IEs) for the ZT were 19.6, 159 and 28.3 kg grain/kg plant N, P and K respectively. On the other hand, the corresponding values for CT were 19.05, 158 and 26.8 kg grain/kg plant N, P, K respectively. T-test indicated that the IEN ($P <$ 0.001) and IEK ($P < 0.001$) values were significantly higher under ZT than CT, while there was no significant difference for IEP ($P = 0.512$). The higher IEN and IEK in

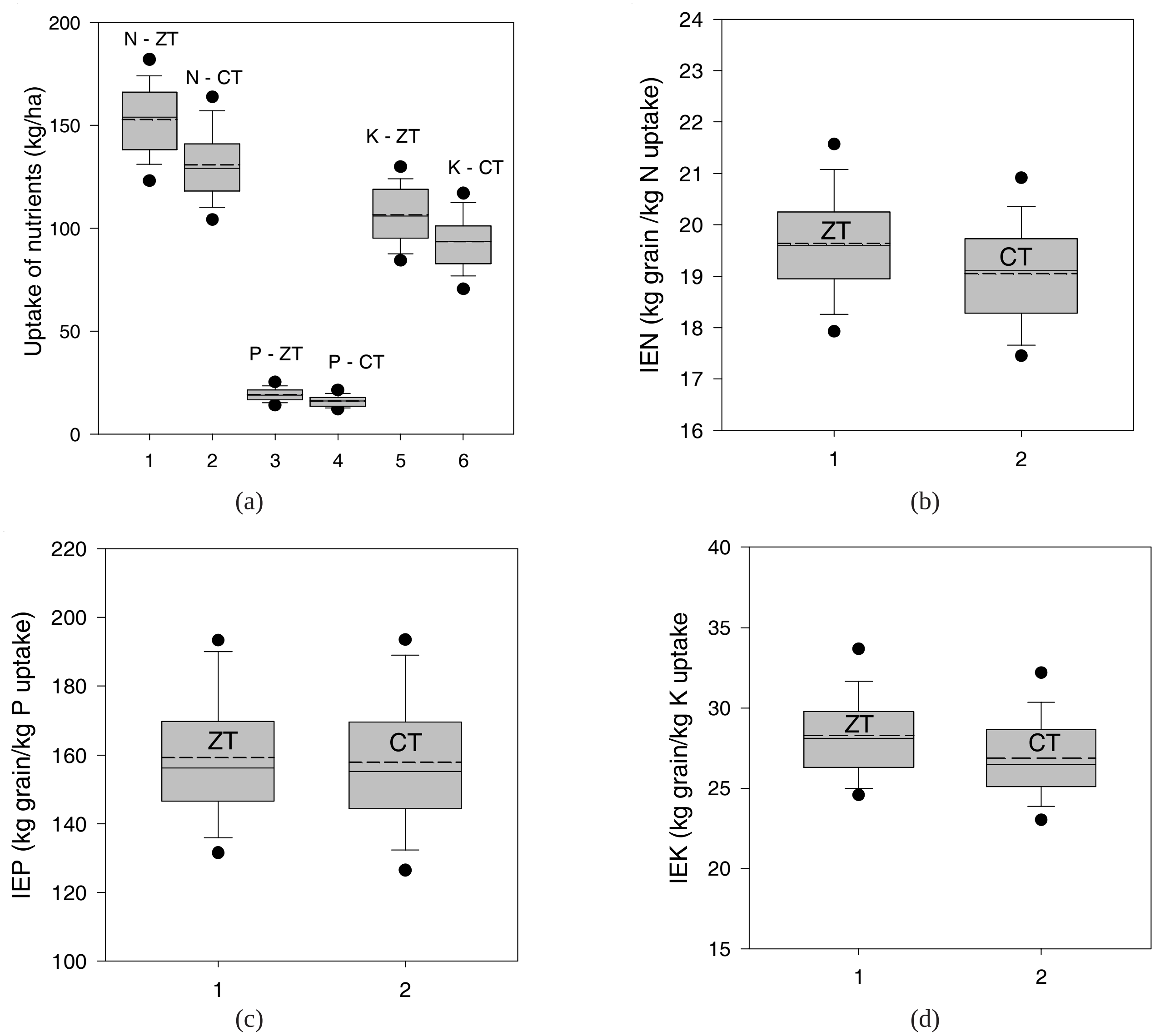

Fig. 4 (a, b, c and d). Uptake and internal nutrient efficiency (IES) of nutrients (2009–10 and 2010–11) under different tillage options. The error bars represent 5 to 95 percentile of the data, and the dotted line represents the mean (ZT, zero tillage; CT, conventional tillage

ZT could be ascribed to mineralization of plant residues left and subsequent higher uptake of nutrients by larger root biomass than under CT.

Cost savings and profitability

The average cost of cultivation across the last 5 years under ZT was significantly lower than CT, which resulted an average savings of ₹4,826/ha (Table 5). Pooled data revealed that adoption of ZT fetched significantly higher average net returns and benefit: cost ratio than CT, while the gross returns under ZT were higher but insignificant. This higher economic profit under ZT might be attributed to higher yield, lower cost of cultivation per kg grain and higher financial water productivity. Erenstein *et al*. (2008) and Jat *et al*. (2014) also reported lower cost of production and higher net returns in ZT than in CT.

Thus, it may be concluded from 7 years of study that a shift from conventional to zero tillage system may break the yield barrier of wheat in the Red and Lateritic zone of West Bengal by enhancing the yield and yield attributes, nutrient uptake and nutrient-use efficiency. The combined effect of yield increase with cost saving in zero tillage produced higher returns to the adopters. However, selection of suitable cultivar and planting date are the pre-requisites to fetch maximum benefit from this technology.

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