EFFECT OF CROP ESTABLISHMENT METHODS ON CROP YIELD, WEED DYNAMICS, PROFITABILITY AND NUTRIENT UPTAKE UNDER RICE-WHEAT CROPPING SYSTEM OF INDO-GANGETIC PLAINS OF EASTERN INDIA

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ABSTRACT

The rice–wheat cropping system covering 13.5 million ha in the Indo-Gangetic Plains in South-Asia is vital for food security. Water, energy and labour scarcity, increasing cost of production, diminishing farm profit and the changing climate are major challenges faced by the farmers under intensive tillage based conventional practices. In a field study, we evaluated productivity, weed dynamics, nutrient uptake and economical profitability of four wheat establishment methods during two years. The wheat establishment methods included zero-till wheat (ZTW), happy seeder planted wheat (HSW), bed planted wheat (BPW) and conventional till wheat (CTW). The treatments were completely randomized and replicated five times. Wheat grain yield under HSW was 3.4% and 4.1% higher than BPW, 8.3% and 11.0% higher than ZTW and 20.8% and 24.5% higher than CTW in 2012-13 and 2013-14, respectively. Nutrient (N, P and K) uptake in wheat grain was also higher in HSW than in the other treatments. Weed density and biomass was the lowest under HSW followed by BPT, and the highest in CTW. The weed pressure was reduced in the second growing season compared to the first. Net profit and benefit cost ratio was highest under HSW and the lowest under CTW.

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Key words: *Crop establishment methods; Rice-wheat system; Economics; Weed dynamics; Yield*

Introduction

Rice–wheat cropping systems are critically important for global food security, providing the staple grain supply for about 8% of the world's population (Timsina and Connor 2001; Ladha *et al.* 2003). In South Asia, rice–wheat systems cover 13.5 million hectares with a marked concentration in India and the Indo-Gangetic Plains (IGP) (Timsina and Connor 2001). In the IGP wheat is grown in the cool and dry weather from November to March and rice is grown during the warm humid/semi-humid season from June to October. Rice–wheat systems encompass 23% of India's rice area and 40% of its wheat area, and rice and wheat together comprise 85% of India's cereal production (Timsina and Connor 2001).

The Green Revolution boosted the productivity of rice–wheat systems through the introduction of high-yielding varieties and complementary technologies like irrigation and fertilizer in a supportive policy environment. However, recent studies indicate that the productivity is plateauing and total factor productivity is declining because of fatigues in natural resources base and therefore, sustainability of this cropping system is at risk (Byerlee *et al.* 2003). Soil quality is governed primarily by the tillage practices used to fulfill the contrasting soil physical and hydrological requirements of the rice and wheat crop (Mohanty *et al.* 2007). Current crop cultivation practices in rice-wheat systems degrade the soil and water resources thereby threatening the sustainability of the system (Gupta *et al*. 2003; Ladha *et al*. 2003). The prevailing policy environment has encouraged inappropriate land and input use (Pingali and Shah 1999) and crop system constraints have encouraged unsuitable responses. Developing and disseminating agricultural technologies that can save resources reduce production costs and improve production while sustaining environmental quality is therefore becoming increasingly important (Gupta *et al*. 2002). Farmers of Indo-Gangetic Plains of Eastern India usually grow wheat after intensive dry tillage, planking and using seed-cum-fertilizer drills. The tillage operations are energy and input intensive, and also create problems in timeliness seeding of the succeeding crop (Bhushan *et al*. 2008; Jat *et al*. 2009). The tillage and crop establishment accounts to 25–30% cost of the total wheat production cost in rice–wheat cropping system of South Asia (Pathak *et al*. 2011), leading to lower benefit: cost ratios. Potential decline in productivity of wheat(4 to 38 percent) in this region, is reported through simulation studies under future climate scenarios with increased greenhouse gas emissions, resulting in increase in mean temperature during grain filling thereby decline in productivity (Haris *et al*. 2013).

The conservation agriculture (CA) based resource conservation technologies (RCTs), practiced over 125 million hectare (m ha) area worldwide have proven to be energy and input efficient, improve production and income, and address the emerging environment and soil health problems (Saharawat *et al*. 2010; Gathala *et al*. 2011). The RCTs involve zero or minimum tillage with direct seeding using a seed-cum-fertilizer drill, bed planting, and Happy Seeder innovations in residue management to avoid straw burning, and crop diversification (Gupta and Sayre, 2007). Farm mechanization plays a vital role for the success of CA-based RCTs in different agro-ecologies and socioeconomic farming groups. It ensures timeliness, precision, and quality of field operations; reduces production cost; saves labor; reduces weather risk in the changing climatic scenarios; improves productivity, environmental quality, sustainability, and generates rural employment on on-farm and off-farm activities (Ladha *et al*. 2009).

Soil cover with crop residues is an essential part of the CA-based cropping systems. The crop residues improve soil health and moisture conservation, but also pose problems for weed seed germination by obstructing sunlight. The germination response of weeds to residue depends on the quantity, position (vertical and below- or above-ground weed seeds), allelopathic potential of the residues, and weed biology (Chauhan *et al*. 2006). Therefore, an experiment was established to evaluate different crop establishment methods for wheat crop in term of wheat and rice yield, weed dynamics, nutrient uptake and profitability for long term sustainability of rice-wheat rotation on clay loam soil of eastern India.

Materials and methods

The experiment was conducted at the research farm (25˚34'6.33"N, 83˚59'0.18" E and 63 m above sea level) of the Farm Science Centre, Buxar of ICAR Research Complex for Eastern Region, Bihar, India during 2012-13 to 2013-14. Prior to experimental establishment, the field was under puddled transplanting rice and conventional till wheat system from 2006. The soil of the experimental site was clay loam in texture, slightly alkaline in reaction (pH 7.6) with 0.43% organic carbon (Walkley and Black 1934), 128 kg ha^{-1} alkaline $KMnO_4$oxdizable N (Subbiah and Asija 1956), 17.2 kg ha^{-1} Olsen-P and 168.3 kg ha^{-1} ammonium acetate extractable-K.

The climate of the area is semi-arid subtropical, characterized by very hot summers and cool winters. The hottest months are May and June, when the maximum temperature reaches 45–46 ◦C, whereas during December and January, the coldest months of the year, the temperature often drops below 5 ◦C. The average annual rainfall is 1100 mm, 65–82% of which is received through the northwest monsoons during July to October. In the 2012-13 growing season total rainfall was 935.6 mm and 1018.5 mm, in 2013-14. The distribution of rainfall was more uniform from June to October during both years, during which 96 and 88% of the rainfall occurred during 2012-13 and 2013-14, respectively. In January of 2013 the wheat crop received 25 mm of rainfall while in 2014 it received 60.5 mm in January and 58.5 mm in February. The weekly mean maximum temperature ranged from 21 to 43°C with an average of 31.2 during

2012-13, and 21 to 43°C with an average of 31.2°C during 2013-14. The weekly mean minimum temperature ranged from 4 to 35°C with an average of 18.4°C during both years.

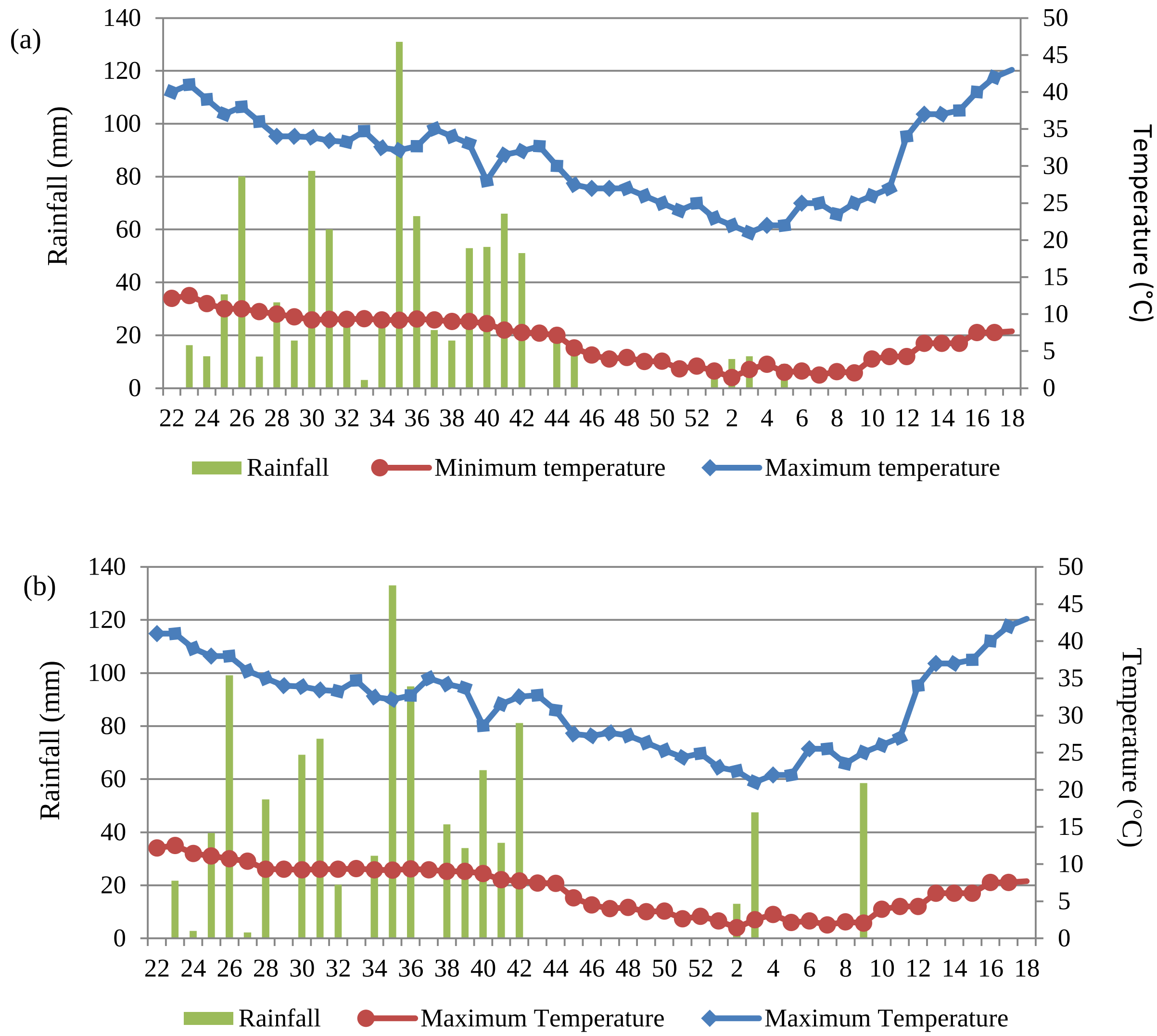

Fig 1. Weekly maximum temperature, minimum temperature and rainfall at the experimental site for (a) 2012-13 and (b) 2013-14.

The four treatments consisted of zero till wheat, Happy Seeder sown wheat, furrow irrigated raised bed planted wheat, and conventional till wheat in a rice–wheat rotation. Each treatment was evaluated in a randomized complete block design with five replications. Each experimental plot measured 10.0 m × 7.5 m (75 m^2).

T1.Zero-till seeding of wheat (ZTW): The wheat crop was seeded in ZT plots at 20 cm row spacing using ZT seed-cum-fertilizer drill.

T2. Wheat sown by Happy Seeder (HSW): The wheat crop was seeded in HS plot at 20 cm row spacing using a Happy Seeder machine along with fertilizer placement in single operation.

T3. Wheat on raised beds (BPW): Soil was tilled using two harrowings and three ploughings (using a field cultivator) followed by one field leveling (using a wooden plank). The raised bed was prepared using a tractor-drawn bed planter along with seeding and fertilizer placement in single operation. The beds were 50 cm wide at the top, 10cm in height, and separated by furrows 25 cm wide. Three rows of wheat were seeded on each bed at 20 cm row to row spacing.

T4. Conventional till wheat (CTW): The conventional farmer practice for soil tillage involved two harrowings, three ploughings (using a field cultivator), and one field leveling (using a wooden plank). The wheat was seeded in rows 20 cm apart using a seed-cum-fertilizer drill.

Wheat (HD 2733) was seeded at 110 kg seed ha^{-1} at 20 cm row spacing in T1, T2 and T4, and a seed rate of 100 kg ha^{-1} was used in furrow irrigated raised bed planted wheat (T3). Seeding of wheat was done on the same day in all the treatments of both years.

Wheat was harvested manually with partial residue retention (20 cm high anchored wheat stubbles in all the treatments) except T4. Wheat, all plots received 120 kg N, 26 kg P, and 50 kg K ha^{-1}. Half the N and all of P and K were applied as basal at sowing of wheat. To wheat, remaining half N was top dressed in two equal split doses; the first split before 1st post-sowing irrigation at crown root initiation stage and the second before 3rd irrigation at pre-flowering stage.

Initial plant population of wheat was determined by counting the number of plants in 1 m at three locations within each plot and expressed as plants m^{-2}. Plant height of five randomly selected plants in each individual plot was measured using a meter scale from base of plant (soil surface) to apex. For biomass, plants were cut close to ground in 0.5 m transects at five random places within each plot. Samples were first dried in sun and then oven dried at 65°C until constant weight was achieved and expressed as m^{-2}. Yield attributing parameters, i.e. number of spikes counts were done in the same manner as the initial plant population, the spike length of ten randomly selected plants in each plot was measured from base of the spike to tip. The mean spike length was computed and expressed in cm. Number of grains per spike was counted in ten randomly selected plants from each plot and averaged to obtain the number of grains per spike. 1000 grains from the each plot were counted and their weight was recorded (at 14% moisture). Grain yield was taken from a 5 m × 2 m(10m^2) area for ZTW, HSW and CTW, and 5 m × 2.25 m (11.25 m^2)for BPT (3 beds of 75 cm) in the center of each plot and expressed in kg ha^{-1} at 12% moisture. The grain samples were subjected to analysis of N content through alkaline permanganate stem distillation micro kjeldahl method, phosphorus content through colourimetry using vanado molybdophosphoric acid yellow colour method and potassium content through flame photometrically (Jacson, 1973). Weed count, for estimating weed density at 30 and 60 days after sowing (DAS) in wheat, was recorded using a quadrat (0.5 m × 0.5 m) placed randomly at four spots in each plot. To record weed dry weight, weeds were cut at ground level, washed with tap water, sun dried, hot-air oven-dried at 75°C for 48 h, and then weighed.

Cost of cultivation under different treatments was estimated on the basis of approved market rates for inputs (costs of seed, fertilizers, chemicals) and the hiring charges of human labor (minimum wage rate by Govt. of India) and machines for land preparation and seeding, irrigation, fertilizer application, plant protection, harvesting, and threshing, and the time (h) required per ha to complete an individual field operation. Gross returns were calculated on the basis of support price offered by Commission for Agricultural Costs and Prices, Government of India for wheat (Rs 1350/q and 1400/q during 2013 and 2014, respectively). Net returns were calculated as the difference between gross income and total cost of cultivation.

All data on weed density and weed dry matter values, yield and yield parameters of wheat, and economics were analyzed as per the methodology of Gomez and Gomez (1984). Treatments were compared by computing the ‘‘F-test’’. The significant differences between treatments were compared pair wise by critical difference at 5% level of probability.

Results

Wheat growth attributes were significantly influenced by crop establishment methods (Table 1). Plant density was the highest in HSW and the lowest in CTW, while BPW and ZTW had intermediate plant density in both growing seasons. Plant density varied from 115 plants m^{-2} (CTW in 2012-13) to 144 plants m^{-2} (HSW in 2013-14). Plant density under HSW was 21% and 23% higher over CTW during 2012-13 and 2013-14, respectively

Plant height varied from 81 to 92 cm (Table 1). CTW had the lowest plant height in both growing seasons. In 2012-13, this treatment had significantly lower plant height than all other treatments, but in 2013-14 the difference was only significant compared to HSW, which had the highest plants. Biomass was the highest with HSW and was statistically higher than all other treatments during both growing seasons except BPW in 2013-14. Biomass was lowest under CTW (813 and 817 g) during the experimentation.

The number of spikes per m^2 was significantly influenced by treatment (Table 1). The HSW produced highest number of spikes over all the treatments except BPW, while CTW produced the lowest number of spikes during both growing seasons. The HSW recorded significantly higher spike length compared to BPW, ZTW and CTW (Table 2). The BPW was the next best treatment in respect to length of spike and was at par to ZTW. Shortest length of spike was recorded under CTW. The number of grains per spike varied from 36 to 45 and was highest under HSW followed by BPW and ZTW. A lower number of grains per spike was registered with CTW. The 1000 grain weight was also influenced by treatments in both growing seasons and was the lowest with CTW and the highest under HSW (Table 2).

Crop establishment method significantly affected wheat grain yield in both growing seasons (Table 2). Wheat yield was the highest under HSW followed by BPW, the lowest being under CTW. Grain yield under HSW was 3.4 and 4.1% higher than under BPW, 8.3 and 11.0% higher than under ZTW and 20.8 and 24.46% higher than under CTW in 2012-13 and 2013-14, respectively.

The nutrients (N, P and K) uptake by grain was affected by wheat establishment method (Table 3). It varied from 60.5 to 85.6 kg/ha nitrogen, 8.9 to 12.9 kg/ha phosphorus and 18.9 to 27.5 kg/ha potassium. HSW recorded higher uptake of N, P and K by grain than other crop establishment methods. The lowest nutrient uptake was associated with CTW.

Nine weed species were identified and grouped in to grassy (*Phalaris minor, Avena ludoviciana and Cynodon dactylon*), sedges (*Cyperus rotundus*) and broad leaved weeds (*Rumex retroflexus, Chenopodium album, Mililotus alba, Anagalis arvensis* and *Vicia sativa*). *Phalaris minor* in grassy and *Chenopodium album* and *Rumex retroflexus* in broad leaved weeds were dominant weed species in all crop establishment methods (Fig. 2). Density of grasses, sedges and broad-leaved weeds was significantly influenced by crop establishment method and weed density was higher in the first than in the second growing season in all treatments at both stages, except the density of *Cynodon dactylon, Rumex retroflexus, Chenopodium album.* Density of all weed species was higher in CTW over other treatments. HSW was best crop establishment methods to reduce the density of all the weed species at both the stages followed by BPW (Fig. 2).

Total weed density at 30 DAS was 29 to 16% lower in all the treatments during the second growing season compared to the first one (Table 4). Total weed density at 60 DAS was 8.2%, 7.1% and 2.9% higher in the second growing season in HSW, BPW and CTW, respectively while it was 4% lower in ZTW compared to the first growing season. Total weed density was the lowest HSW, followed by BPW and ZTW at both the stages of observations in both growing seasons. CTW registered higher density of weed flora. Similarly total weed dry weight was the lowest in HSW and the highest in CTW (Table 4).

The maximum cost of wheat production was recorded under CTW followed by BPW and HSW, whereas the minimum cost of production was observed with ZTW (Table 5). Gross return and net return of wheat were significantly influenced by crop establishment method. Gross return was higher with HSW followed by BPW. The gross return was lowest in CTW. The net return form wheat production across treatments and years ranged from 385.5 to 675.8 USD. In general, the net return was higher in HSW and lower in CTW.

Discussion

The higher plant density in HSW followed by BPW and ZTW is ascribed to right placement of seed and fertilizer, and the favorable environment provided by the residue cover for seed germination and protection from the abiotic and biotic stresses (Singh et al., 2013) The higher plant height and biomass with HSW might be due to more and uniform residue retention on soil surface reduce evaporative losses, buffer the soil moisture and temperature as well as canopy temperature. Higher plant density, and minimum weed pressure are another reason. Plant height and biomass was lower under CTW due to higher weed incidence, which resulted in greater competition for nutrient, waster, space and light (Jat et al., 2009).

Yield attributing characters are the function of growth and development that developed during vegetative phase of the plant. Higher value of spikes m^{-2}, spike length and grains per spike in HSW over BPW and ZTW are perhaps due to better partitioning of photosynthates from source to sink as a result of better growth which was obtained owing to favorable growing condition in this crop treatment. Lower spikes m^{-2}, spike length and grains per spike under CTW might be due to lower plant density and biomass production. Yield of wheat was higher during second season in all the treatments as ascribed to crop received the rainfall in January and February which provide the better environment to produced more number of shoots and biomass. Higher wheat yields in HSW and BPW are ascribed to more productive tillers, biomass, higher yield attributes, enhanced fertilizer and water use efficiencies and to a significant reduction in weed population; particularly population density of *Phalaris. minor, Cyperus rotundus* and *Chenopodium album*. Similar results were also reported by Erenstein et al. (2008).

Nutrient content in wheat grain was increase during second growing season might be due to decomposition of residue improve the fertility level of the soil resulting more uptake of nutrient. HSW recorded higher content of N, P and K in grain over other treatments. Probable reason for higher nutrient content in grain are residue on soil surface preserve the plant nutrient as well as improve physical, chemical and biological properties of soil. Continuous adoption of intensive tillage practices in CTW destroyed the soil properties resulting lower the content of nutrients.

Density of *Phalaris minor, Cyperus rotundus* and *Chenopodium album* was lower at both the stages in HSW might be due to high residue over the surface and minimum disturbance of soil. Chokkar et. al. (2007) reported that density of weed especially *Phalaris minor* was higher in

CTW. Density of weed flora and dry weight lover under HSW ascribed to residue cover on the surface and minimum disturbance of soil reduced the germination. Singh et al (2013) reported that the happy seeder reduced the weed population 28% over conventional tillage. Better plant density also reduced the weed density. More tillage practice under CTW provides the environment for more weed germination. Erenstein et al. (2008) also reported that conservation tillage reduced the germination and poor stunted growth of *P. minor*.

The short term positive effects of reduced/zero tillage and improved management practices observed on yield were translated into more favourable economics. Tillage and crop establishment methods account for a major part of total crop production costs. Higher cost of production in HSW as ascribed to no tillage cost, lover establishment cost, less use of fuel and labor. CTW had higher cost of production due to more tillage and establishment cost, higher fuel and labor use. The higher Net Benefit from HSW and BPW is ascribed to higher grain yield, low cost of production, reduced weed growth and population, enhanced fertilizer and water-use efficiency (Ozpinar, 2006; Erenstein et al., 2008). The higher BCR from HSW and BPW is ascribed to higher grain yield, and lower cost of production than CT. The lower BCR under CTW might be due to higher cultivation cost in addition to provision of favorable environment for weeds which heavily dominated the wheat crop causing reduction in grain yield compared to HSW/BPW (Chhokar et al., 2007). The higher net return and benefit cost ratio in HSW plot was due to higher production of grain yield over other methods.

Conclusion

On the basis of two year study showed that HSW and BPW are more economical than CTW. HSP was superior to other crop establishment methods when taking into account, yield, weed control, profitability and its effect on nutrient content in crop.

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Table 1. Effect of crop establishment methods on growth of wheat

Treatment	Plants m^{-2} at 20 DAS		Plant height (cm)		Biomass (g m^{-2})		Spikes m^{-2}	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
ZTW	125	128	88	88	836	849	319	354
HSW	139	144	92	92	894	905	381	384
BPW	131	133	90	90	850	884	370	379
CTW	115	117	81	86	813	817	311	317
LSD (P=0.05)	6	7	5	5	39	53	20	21

ZTW: zero till wheat, HSW: happy seeder planted wheat, BPW: bed planted wheat, CTW: conventional till wheat, DAS: days after sowing, LSD: least significant difference at P=0.05

Table 2. Effect of crop establishment methods on yield attributes of wheat

Treatment	Spike length (cm)		Grains spike^{-1}		1000 grain weight (g)		Grain yield (Mg ha^{-1})	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
ZTW	8.5	8.4	41	40	38	38	3.99	4.12
HSW	9.5	9.5	43	45	43	41	4.35	4.63
BPW	8.8	8.9	42	42	40	40	4.20	4.44
CTW	7.5	7.5	36	36	37	36	3.61	3.72
LSD (P=0.05)	0.5	0.5	2	3	2	2	0.19	0.25

ZTW: zero till wheat, HSW: happy seeder planted wheat, BPW: bed planted wheat, CTW: conventional till wheat, LSD: least significant difference at P=0.05

Table 3. Effect of crop establishment methods on nutrient uptake by grain.

Treatments	N uptake by grain (kg ha^{-1})		P uptake by grain (kg ha^{-1})		K uptake by grain(kg ha^{-1})	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
ZTW	69.7	72.8	10.3	10.6	20.8	21.3
HSW	79.6	85.6	12.1	12.9	25.7	27.5
BPW	74.9	79.9	11.1	12.2	23.5	25.1
CTW	60.5	62.7	8.9	9.4	18.9	19.5
LSD (P=0.05)	3.7	4.2	0.8	0.7	1.3	1.8

ZTW: zero till wheat, HSW: happy seeder planted wheat, BPW: bed planted wheat, CTW: conventional till wheat, LSD: least significant difference at P=0.05

Table 4. Total weed density and weed dry weight in wheat.

Treatments	Total weed density (No. m^{-2})				Total weed dry weight (g m^{-2})			
	2013		2014		2013		2014	
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
ZTW	99.0	89.6	74.3	85.6	20.9	28.8	15.2	28.1
HSW	53.2	43.6	37.3	47.5	11.4	14.2	7.9	15.7
BPW	78.8	86.1	66.3	92.7	16.6	27.8	13.6	30.3
CTW	136.1	132.2	114.2	136.1	28.4	43.0	23.3	44.7
LSD (P=0.05)	10.4	2.5	6.0	6.4	2.2	0.8	1.6	2.0

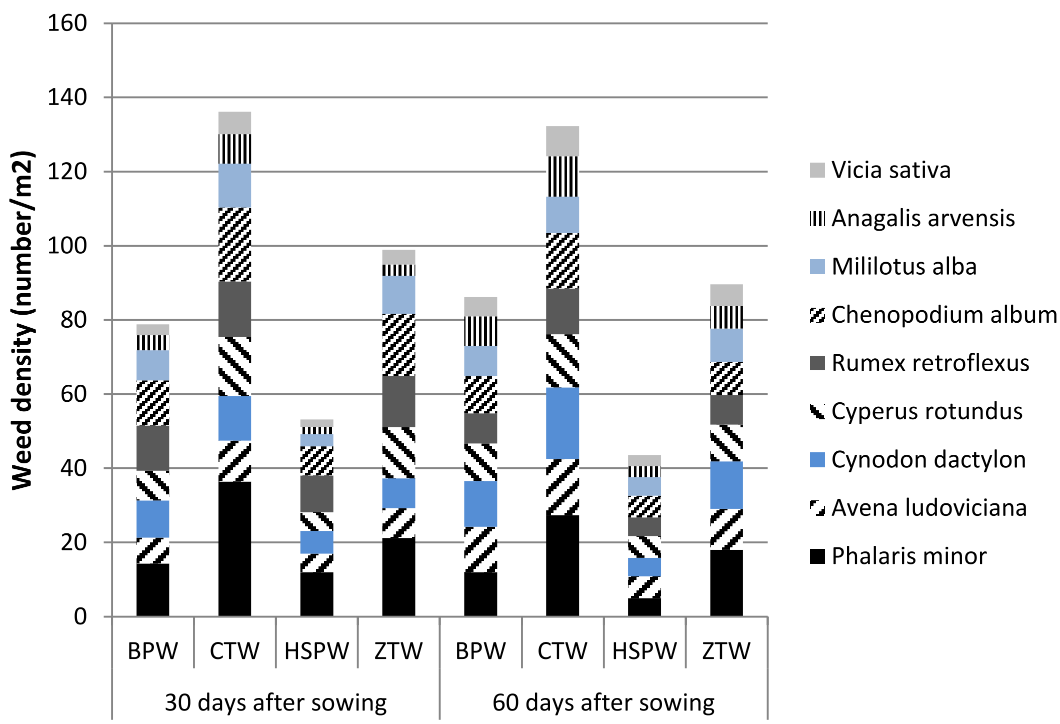
ZTW: zero till wheat, HSW: happy seeder planted wheat, BPW: bed planted wheat, CTW: conventional till wheat, DAS: days after sowing, LSD: least significant difference at P=0.05

Table 5. Effect of crop establishment methods on economics of wheat.

Treatments	Cost of production (Rs)		Gross return (Rs)		Net return (Rs)		BCR	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
ZTW	23546	24046	53858	57655	30313	33609	2.29	2.40
HSW	24446	24946	58707	64840	34261	39894	2.40	2.60
BPW	25504	26004	56732	62218	31229	36214	2.22	2.39
CTW	26404	26904	48773	52080	22369	25176	1.85	1.94
LSD(P=0.05)	-	-	2502	3483	2502	3483	0.10	0.13

ZTW: zero till wheat, HSW: happy seeder planted wheat, BPW: bed planted wheat, CTW: conventional till wheat, LSD: least significant difference at P=0.05

(a)



(b)

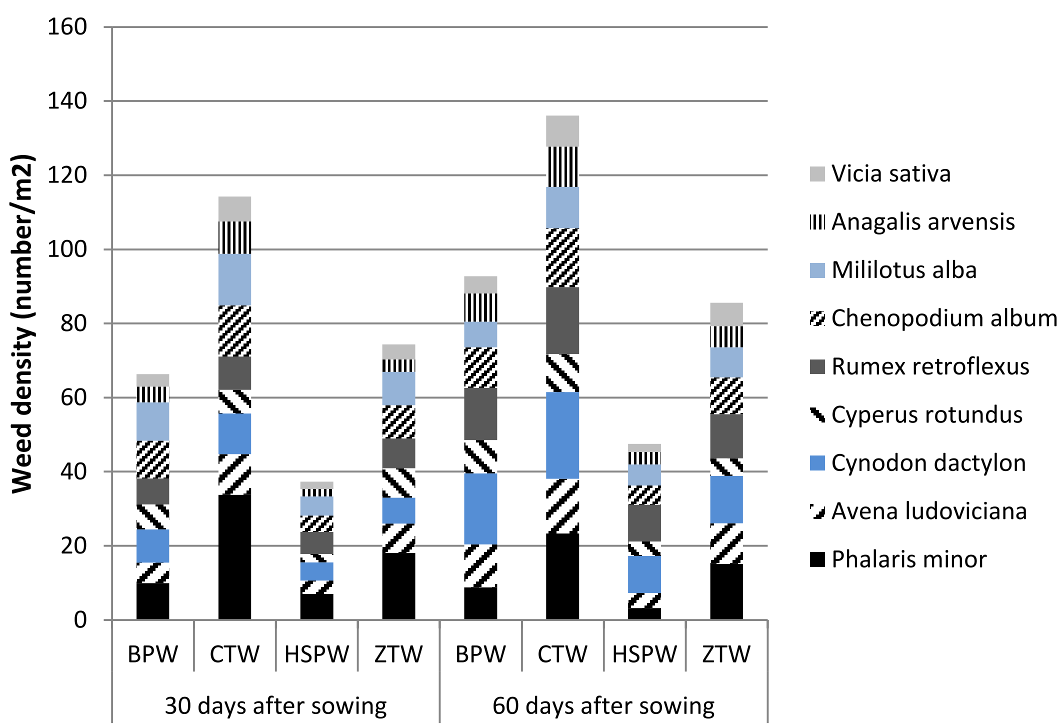


Figure 2. Weed density of nine evaluated species as affected by management practice and sampling date in (a) 2012-13 and (b) 2013-14.