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Research Paper

Weed-management and wheat productivity in a conservation agriculture-based maize (*Zea mays*)–wheat (*Triticum aestivum*)–mungbean (*Vigna radiata*) system in north-western Indo-Gangetic plains of India

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ABSTRACT

In this study, a possible weed management has been envisaged in zero-till (ZT) and conventional till (CT) wheat [*Triticum aestivum* (L.) emend. Fiori & Paol.] with and without residue during 2013–14 and 2014–15 using residue, N and weed-control treatments. It was observed that ZT with 5 t/ha maize (*Zea mays* L.) residue retention (ZT + R) + 75% N + rest N-based on GreenSeeker (GS) caused a considerable reduction in the population of narrow-leaf, broad-leaf and total weeds compared to CT and ZT without residue. Pendimethalin (PMT) followed by sulfosulfuron (SSF) application significantly reduced the weeds population and dry weight than the unweeded control (UWC). Wheat yield attributes were higher in ZT with residue retention (ZT + R) than conventional-tilled treatments. Application of PMT @ 1 kg/ha followed by SSF 25 g/ha combined with ZT with 5 t/ha maize residue retention (ZT + R) + 75% N + rest N based on GreenSeeker (GS) resulting in higher wheat yield which was comparable with that in weed-free check (WFC). Zero tillage with or without residue reduced the nutrient uptake by weeds than the conventional tillage which led to the higher uptake of nutrients by crop in zero tillage condition over the years. The sum total amount of N, P and K removed by the crop was higher in ZT + R + 75% N + rest N based on GreenSeeker (GS) than CT-R + 100% N (farmer practice) to the tune of 23.8% and 34.6% in 2013–14 and 2014–15, respectively. The sequential application PMT and SSF had an edge over the ready-mix application of SSF+ metsulfuron methyl (MSM) in respect of nutrients uptake by crop which was due to the reduction in nutrients uptake by weeds by the former than the later. The treatment combination ZT + R + 75% N + rest N based on GreenSeeker (GS) and sequential application of PMT-SSF secured highest output energy than the CT–R + 100% N with UWC and ready-mix application of SSF + MSM. The interaction between tillage, residue and N management with weed control practices for net benefit: cost ratio revealed that irrespective of residue the zero tillage fetched the higher net benefit: cost than conventional tillage. The partial cost-benefit of sequential as well as ready-mix application of herbicide was on a par under both the tillage condition. Therefore, ZT + R + 75% N + rest N based on GreenSeeker (GS) and sequential application of PMT-SSF can be recommended for wheat production in north-western Indo-Gangetic plains of India.

Key words : Conservation agriculture, Economics, Pendimethalin, Weed management, Wheat, Zero tillage

There are several wheat-based cropping systems predominant in India. Among them maize-wheat is considered as one of the potential drivers of crop diversification under different situations (Jat *et al*., 2011). Zero till wheat is being introduced to avoid late planting and it ensures timely planting, better stand establishment and higher grain yield than conventional method. It also saves 30% on irrigation and land preparation costs (Zamir *et al*., 2010). However, previous crops, as well as weed infestation and weed-control measures can alter the direct effect of ZT on wheat yield. Minimum tillage systems are adopted worldwide because of savings in time and economic inputs. However, as tillage is reduced, weed control can become a limiting factor in crop production (Das, 2008). Moreover, changes in tillage practices can affect

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weed population dynamics, including weed seed distribution and abundance in soil seed bank (Mulugeta and Stoltenberg, 1997). In no-till systems, weed control is largely dependent on herbicides because of withdrawal of the tillage and chance of reduction of intercultural operation. In sub-tropical climate, winter cereals including wheat are often sown immediately after harvest of the rainy-season crop. In zero-tilled wheat, no use of ploughing and high soil moisture during sowing can hasten the weed flush than conventional-tilled wheat. The appropriate use of herbicides is more important than in traditional tillage systems mainly in years with a high yield potential (Young *et al*., 1994). In no-till systems, seeds of weeds and volunteer crops are frequently deposited in the first few centimeters of top soil. Appropriate weed-management strategies can reduce this weed pressure in wheat. The conventional use the same post-emergence herbicides can lead to poor management of early weed flush in wheat under zero-tilled condition and may aggravate the development in herbicide-resistant weeds in wheat. Despite the mentioned restrictions for weed development in no-till systems, it is essential to control weeds before direct sowing in order to minimize crop yield losses in these systems. An appropriate strategy, therefore, is needed to avoid high weed infestations and to prevent unacceptable competition with crop (Susha *et al*., 2014). Evaluation of suitable crop husbandry including zero-tillage with appropriate herbicides in wheat would be of paramount importance towards weed-management in wheat-based cropping system. The another aspect of present agriculture is the sustainability of cropping system. The energy consumption and energy-use efficiency provides a good indicator of the technological aspects of crop production system. It also provides the needful information about the environmental assessment of agriculture (Castoldi and Bechini, 2010), because it indicates intensity and saving in the fossil fuel in production system (Hülsbergen *et al*., 2001). About 25–30% of energy is required to field preparation and crop establishment (Tomar *et al.*, 2006). Farmers practice resort to as many as 5–6 tillage operations, including 3–4 disc harrowing and 2 cultivations followed by planking before sowing of wheat. As zero tillage eliminates the tillage operation it saves energy and reduces human drudgery. On the other, the weed-management in zero-tillage is mainly herbicide based (Das. 2008). Therefore, it is necessary to know the energy balance in different production system. Low labour, animal or equipment requirement is a major advantage of conservation tillage system because it allows elimination of several operations, depending on the conservation tillage systems used. Zero-tillage technology proved to be a wise choice, as it was reported to be economical as well as ecologically-viable as compared with conventional tillage due to savings in labour, fuel, repair and machinery overhead charges. But weeds increase cost of cultivation and deplete the resource base (Upadhyay *et al.,* 2012). In order to achieve enhanced crop production and higher benefits from applied inputs, weeds must be kept under check by any of the safe and effective mean. Thus, the objective of this study was to verify suitable tillage practices in combination with sequential application of pre- and post-emergence herbicides or application of mixture herbicides to reduce the weed dynamics, nutrient uptake by weeds and to know the energy balance and economic benefit of zero tillage over the conventional tillage.

MATERIALS AND METHODS

A field experiment was carried out during the winter (*rabi*) seasons of 2013–14 and 2014–15 at the ICAR-Indian Agricultural Research Institute, New Delhi, on a split-plot design, comprising of 6 tillage, residues and N management in main plot and 4 weed-control treatments in subplot in wheat. The treatments were comprising conventional tillage without residue + 100% N (based on soil-test value) (CT-R + 100% N), conventional tillage + 5 t/ha maize residue incorporation + 100% N (CT + R + 100% N), conventional tillage + 5 t/ha maize residue incorporation + 75% N + rest N based on green seeker (CT + R + 75% N + GS), zero tillage without residue + 100% N (ZT-R + 100% N), zero tillage + 5 t/ha maize residue retention + 100% N (ZT + R + 100% N) and zero tillage + 5 t/ha maize residue retention + 75% N + rest N based on green seeker (ZT + R + 75% N + GS) in main plot and 4 weed-control treatments, viz. unweeded control (UWC), weed-free check (WFC), sulfosulfuron 75% WP + metsulfuron methyl 5% WP ready-mix herbicide @ 40 g/ha as post-emergence (SSF + MSM) and pendimethalin (1 kg/ha) as pre-emergence followed by sulfosulfuron (25 g/ha) post-emergence (PMT-SSF) in subplot. Soil was sandy loam, pH 7.9, organic C (0.60%), low in available nitrogen (220.6 kg/ha), medium in P (15.2 kg/ha) and K (260 kg/ha). In rainy season (*kharif*), maize crop was grown with the stipulated treatments and residue was applied in winter (*rabi*) season wheat. Maize crop performed well in rainy season and gave satisfactory yield. The plot was prepared according to requirement of main plots and then 4 subplots were made to accommodate the weed-control practices. Conventional tillage (CT) plots were ploughed by a tractor-drawn disc plough followed by planking. Previous season maize residue was retained on ZT with residue plots and ZT with no residue plot was left undisturbed. The weed-free check, the plots were maintained free of weeds through manual weeding as and when required. A pre-sowing irrigation was given to entire field to facilitate smooth germination of wheat. Wheat 'HD 2967' was sown by a happy seeder with a spacing 20 cm between rows with a 100 kg/ha seed rate. A dose of 150 kg N, 80 kg P_2O_5 and 60 kg K_2O/ha based on soil-test value was applied to wheat. Half dose of nitrogen was applied basal in 100% nitrogen treatment plots of conventional and zero tillage. Remaining half of nitrogen was applied in 2 equal split doses, 1 at crown-root-initiation stage that occurs around 21 days after planting and coincides with first irrigation and another at tillering stage (65 DAS) of wheat crop. In green seeker-based nitrogen-management plots, 75% of required nitrogen was applied basal and remaining nitrogen was applied at crown root initiation stage. Subsequently, GreenSeeker reading was taken and nitrogen was applied as and when required. In the experiment, a N-rich strip was established by applying 300 kg N/ha in split doses to ensure that nitrogen was not limiting. Nitrogen, P and K were applied in the forms of urea, single superphosphate and muriate of potash respectively. For sequential application of herbicides, pendimethalin @ 1 kg/ha and sulfosulfuron 25 g/ha were applied separately in the in the required amount with 400 litres water/ha before by knapsack sprayer. For ready-mix herbicide 'total' (sulfosulfuron 75% WP + metsulfuron methyl 5% WP) product basis, 40 g/ha was applied using a knapsack sprayer fitted with a flat-fan nozzle at 25 DAS. An area of 0.25 m^2 was selected randomly at 2 spots by throughing a quadrat of 0.5 m × 0.5 m, weed species were counted from that area, and density was expressed in number/m^2. The collected weeds were first sun-dried and then kept in an electric oven at 70< C till the weight became constant, and dry weight was expressed as g/m^2. The dried crop samples at harvest stage and weed samples at 70 DAS were used for nitrogen, phosphorus and potassium analysis following the standard methods. The uptake of nutrients were obtained by multiplying the nutrient concentration with their dry weight and expressed as kg/ha. As wide variation existed in data, number and dry weight of weeds were transformed through square-root [$\sqrt{(x+0.5)}$] method before analysis of variance. Wheat was harvested manually, but was threshed by a power-operated thresher. Data on grain yield were recorded from the net plot, whereas yield attributes from 5 randomly selected plants at harvesting. The cost of cultivation under various treatments was estimated on the basis of prevailing rates for inputs in New Delhi. The input costs of all the items like tillage operation, costs of seed, herbicide treatment application, chemical fertilizers, and the hiring charges of human labour and machines for land preparation, irrigation, fertilization, harvesting, and threshing. The benefit: cost ratios were calculated for each treatments applied in the system as the ratios of net returns to cost of cultivation.

RESULTS AND DISCUSSION

Weed population and dry weight

Dominant weed flora in wheat comprised *Chenopodium album* L., *Melilotus indica* L., *Coronopus didymus* (L.) Smith., *Fumaria parviflora* (L.) Wt. & Arn., *Anagallis arvensis* L. among broad-leaf weeds; *Phalaris minor* Retz., *Avena sterilis* ssp *ludoviciana* (Dur.) Nym. among grasses. Differences in density of broad-leaf weeds at 70 DAS due to tillage, residue, nitrogen and weed-management practices across the years were non-significant (Table 1). Among the different tillage, residues and N-management practices, CT-R + 100% N was not found effective in reducing the population of broad-leaf weeds, as these treatments caused significantly more population of broad-leaf weeds than the ZT-R + 100% N and ZT + R + 100% N and ZT + R + 75% N + GS at 70 DAS.

The treatment ZT + R + 75% N + GS significantly reduced the population of broad-leaf weeds compared to CT-R + 100% N and CT + R + 75% N + GS at 70 DAS; however, it remained at par with remaining tillage, residue and N-management practices. The UWC treatments caused significantly more density of broad-leaf weeds compared to remaining weed control treatments at 70 DAS in both the years. Among the herbicidal treatments, PMT-SSF and SSF + MSM were at par for controlling of broad-leaf weeds, but in general the density of total broad-leaf weeds was less in PMT-SSF. Data pertaining to pooled analysis showed that the lowest number of broad-leaf weeds were in ZT + R + 75% N + GS which was significantly lower than CT-R + 100% N and remained at par with rest of the tillage, residue, and nitrogen management treatments.

The weed-control practices significantly reduced the population of weeds than UWC. Differences in density of narrow leaf weeds at 70 DAS due to tillage, residue, nitrogen and weed management practices across the years were significant (Table 1). At 70 DAS, the lowest narrow-leaf weeds population was in ZT + R + 75% N + GS and it was on a par with remaining tillage, residue, N-management treatments. But in the second year, ZT + R + 75% N + GS significantly reduced the density of narrow-leaf weeds population than CT-R + 100% N. Pooled data also showed that zero-tilled with residue treatments were superior to conventional-tilled treatments for reducing the narrow-leaf weeds, indicating the smothering effect residue laden plots on weed growth (Susha *et al*., 2014). Weed-control treatments were found to reduce the narrow-leaved weeds density than UWC in both the years. Among the herbicidal treatments, PMT-SSF and SSF + MSM were at par for controlling of narrow-leaf weeds (Das and Yaduraju, 2012). A significant year-wise variation of data in respect to total weed population was observed due to tillage, residues, N and weed-management practices (Table 1). The CT-R + 100% N was not found effective in reducing the total population of weeds, as these treatments caused significantly more population of total weeds compared to the ZT + R + 75% N + GS in both the years. Herbicidal treatment significantly reduced the total weeds population than UWC in both years (Das *et al.,* 2010). The lowest total weed density was observed in the application of PMT-SSF, excluding WFC. Pooled analyzed data showed that the lowest number of total weeds population were in ZT + R + 75% N + GS which was significantly lower than CT-R + 100% N and ZT-R + 100% N and remained at par with rest of the tillage, residue, and nitrogen-management treatments. In the entire situation, zero-tilled with residue treatments had lower weed density. This indicated possible smothering effect of residues on weeds. Although the different herbicidal application, i.e sequential application of pre- and post-emergence and ready-mix application of post-emergence herbicides proved at par in respect to reduction weed density, but sequential application pendimethalin as pre-emergence followed by sulfosulfuron as post-emergence had an edge over the one time application of post-emergence herbicides. This might be due to, pre-emergence application of pendimethalin suppressed the initial flush of weeds and it was compounded with subsequent post-emergence application of sulfosulfuron which might have controlled the second flush of weeds. That ultimately led to better weed control across all the tillage practices. The year-wise variation due to tillage, residue and N-management practices at 70 DAS in respect of dry-matter accumulation by broad-leaf weeds were non-significant (Table 2). The pooled data of both the years data showed that ZT + R + 75% N + GS significantly reduced the dry weight of broad-leaf weeds than CT-R + 100% N and CT + R + 75% N + GS. Application of PMT-SSF and SSF + MSM significantly reduced the dry weight of broad-leaf weeds. Among the herbicidal treatments, the effect of application of PMT-SSF marginally reduced the broad-leaf weed dry weight than SSF + MSM. Dry-matter accumulation by narrow-leaf weeds significantly differed year-wise due to tillage, residue and N management practices at 70 DAS (Table 2). The lower narrow-leaf weeds dry weight was obtained in the second year than that of the first year. Pooled data showed that the treatment ZT + R + 75% N + GS significantly reduced the dry weight of narrow-leaf weeds than CT-R + 100% N and ZT-R + 100% N. Application of PMT-SSF and SSF + MSM significantly reduced the dry weight of narrow-leaf weeds than the UWC in both years. Among the herbicidal treatments, the effect of PMT-SSF and SSF + MSM was at

Table 1. Effect of tillage, residue, nitrogen and weed-management practices on total broad-leaf, total narrow-leaf and total weed population at 70 days after sowing (DAS) (pooled data of 2 years)

Treatment	Total broad-leaf weed population (Nos./m^2)	Total narrow-leaf population (Nos./m^2)	Total weed population (Nos./m^2)
First year	1.04 (49.9)	1.60 (77)	1.88 (90.2)
Second year	1.08 (52.0)	0.99 (47.8)	1.37 (65.8)
SEm±	0.06	0.06	0.06
CD (P=0.05)	0.18	0.18	0.20
Tillage, residue and nitrogen management (M)			
CT-R + 100% N	1.40 (22.4)	1.58 (25.2)	2.04 (32.6)
CT+R + 100% N	1.04 (16.6)	1.24 (19.6)	1.47 (23.5)
CT + R + 75% N + GS	1.03 (16.4)	1.23 (19.7)	1.51 (24.1)
ZT-R + 100% N	1.16 (17.1)	1.47 (23.5)	1.87 (29.9)
ZT + R + 100% N	0.98 (15.7)	1.21 (19.4)	1.51 (24.1)
ZT + R + 75% N + GS	0.78 (12.3)	10.5 (18.4)	1.36 (22.8)
SEm±	0.11	0.10	0.11
CD (P=0.05)	0.33	0.31	0.34
Weed management (W)			
UWC	2.44 (58.6)	2.45 (58.9)	3.68 (88.3)
WFC	0	0	0
SSF + MSM	0.88 (21.3)	1.48 (35.4)	1.48 (35.4)
PMT-SSF	0.86 (20.6)	1.26 (30.2)	1.35 (32.3)
SEm±	0.09	0.14	0.10
CD (P=0.05)	0.25	0.40	0.28

Details of treatments are given under Materials and Methods

Data were transformed through square-root $\sqrt{(x+0.5)}$ method; Figures in the parentheses are original values par. Total dry-matter accumulation by weed differs non-significantly year-wise due to tillage, residue and N-management practices at 70 DAS. The pooled data showed that ZT + R + 75% N + GS significantly reduced the total dry weight weeds than CT + R + 75% N + GS. Application of PMT-SSF and SSF + MSM significantly reduced the total dry weight of weeds than the UWC in both years. Such results might have accentuated from considerable reductions in the populations and dry weights of *C. album* and *M. indica* under those treatments compared to that of weedy check. The broad-spectrum activity and persistence nature of sequential application of herbicides also played a role. Some of the weeds infesting this cropping system are present in much greater density under the conventional system. This may be due to the higher soil disturbance under conventional systems. In no-till systems, the occurrence of perennial weeds is more feasible, and changes in the temperature and light incidence on the soil surface influence dormancy of some weed species. The weed-suppressive effects of maize-crop residue have resulted in greater reduction of weeds in zero-tillage with residue (Christoffoleti *et al*., 2007). Zero-till with crop-residue management is an important multi-tactic approach to manage weed population dynamics in crop rotations. Retention of crop residue on the soil surface under no-till systems can suppress weed-seedling emergence, delay the time of emergence, and allow the crop to gain an advantage over weeds, and reduce the need for control.

Wheat yield attributes and yield

Due to greater suppression of weeds compared to weedy check, the negative effect of weeds on ear-bearing tillers, wheat grains/spike, weight of spike and 1,000-grain weight and yield was reduced in the sequential and ready-mix application of herbicides in wheat (Table 3).

All the yield attributing characters were higher in ZT + R + 75% N + GS which was significant with CT-R + 100% N. Wheat yield (Table 4) differed significantly between tillage and weed control measures in both the years. Weed-free check was comparable with sequential application of pendimethalin 1 kg/ha as pre-emergence followed by sulfosulfuron 25 g/ha as post-emergence and resulted in significantly higher yield than unweeded control (Table 4). The grain yield of wheat and yield attributes differed significantly due to tillage and weed control measures.

ZT + R had significantly higher number of ear bearing tillers, wheat grains/ear and 1,000-grain weight compared to CT and zero-tillage without residue resulting in higher grain yield. The differences for number of wheat grains/ear, 1,000-grain weight, grain yield and biological yield

Table 2. Total broad-leaved, total narrow-leaved and total weed dry-weight at 70 days after sowing (DAS) as influenced by tillage, residue, nitrogen and weed-management practices (pooled data of 2 years)

Treatment	Total broad-leaf weed dry weight (g/m^2)	Total narrow-leaf weed dry weight (g/m^2)	Total weed dry weight (g/m^2)
First year	1.04 (49.9)	1.60 (77)	2.43 (116.8)
Second year	1.08 (52.0)	0.99 (47.8)	2.70 (129.4)
SEm±	0.06	0.06	0.21
CD (P=0.05)	0.18	0.18	0.67
Tillage, residue and nitrogen management (M)			
CT-R + 100% N	1.40 (22.4)	1.58 (25.2)	2.74 (43.9)
CT + R + 100% N	1.04 (16.6)	1.23 (19.6)	2.33 (37.2)
CT + R + 75% N + GS	1.03 (16.4)	1.23 (19.7)	3.07 (49.1)
ZT-R + 100% N	1.16 (18.5)	1.47 (23.5)	2.67 (42.8)
ZT + R + 100% N	0.98 (15.7)	1.21 (19.4)	2.87 (45.9)
ZT + R + 75% N + GS	0.77 (12.3)	0.93 (17.0)	1.71 (27.3)
SEm±	0.11	0.10	0.38
CD (P=0.05)	0.33	0.31	1.20
Weed management (W)			
UWC	2.44 (58.6)	2.45 (58.9)	5.57 (133.65)
WFC	0	0	0
SSF + MSM	0.88 (21.3)	1.48 (35.4)	2.51 (60.25)
PMT-SSF	0.86 (20.6)	1.26 (30.2)	2.18 (52.3)
SEm±	0.09	0.14	0.27
CD (P=0.05)	0.25	0.40	0.77

Details of treatments are given under Materials and Methods
Data were transformed through square-root method; Figures in the parentheses are original values

were significant. This was, probably, due to compensatory effects between yield components during growth and development of crop, and to a lower number of weeds/m^2 (broad-leaved, grasses and total) at heading stage of wheat. A significant effect on wheat yield was observed in both the years and weed-free check being comparable with sequential application of pendimethalin 1 kg/ha as pre-emergence, followed by sulfosulfuron 25 g/ha as post-emergence resulted in significantly higher yield than unweeded control (Table 5). Wheat yield was influenced by

Table 3. Influenced of tillage, residue, nitrogen and weed-management practices on yield attributes of wheat (pooled of 2 years)

Treatment	Ear-bearing tillers/m^2	Grains/ spike	Weight/spike (g)	1,000-grain weight (g)
First year	280	33.3	2.39	42.1
Second year	322	43.2	3.11	40.6
SEm±	9.6	0.3	0.05	0.17
CD (P=0.05)	30.4	0.9	0.14	0.52
Tillage, residue, nitrogen management (M)				
CT-R + 100% N	273	35.2	2.43	40.1
CT + R + 100% N	284	35.9	2.55	41.1
CT + R + 75% N + GS	321	38.1	2.76	41.7
ZT-R + 100% N	320	38.0	2.79	40.6
ZT + R + 100% N	324	40.3	2.90	42.0
ZT + R + 75% N + GS	354	41.7	3.08	42.6
SEm±	7.6	0.5	0.08	0.3
CD (P=0.05)	22.7	1.6	0.25	0.9
Weed management (W)				
UWC	269	36.1	2.56	38.9
WFC	329	39.8	2.90	42.4
SSF + MSM	303	37.8	2.74	41.8
PMT-SSF	305	39.2	2.79	42.2
SEm±	8.2	0.3	0.06	0.2
CD (P=0.05)	24.5	0.8	0.16	0.5

Table 4. Grain, straw and biological yields, harvest index and net benefit: cost of wheat as influenced by tillage, residue, nitrogen and weed management practices (pooled of 2 years)

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Biomass yield (t/ha)	Harvest index	Net benefit: cost
First year	5.16	7.86	13.02	0.40	2.05
Second year	4.39	7.46	11.85	0.38	1.57
SEm±	0.08	0.09	0.11	0.01	0.03
CD (P=0.05)	0.23	0.27	0.31	0.02	0.10
Tillage, residue, nitrogen management (M)					
CT-R + 100% N	4.48	7.21	11.69	0.38	1.82
CT + R + 100% N	4.63	7.42	12.05	0.39	1.50
CT + R + 75% N + GS	4.91	7.79	12.70	0.39	1.66
ZT-R + 100% N	4.51	7.33	11.84	0.38	2.08
ZT + R + 100% N	5.00	8.00	13.00	0.38	1.85
ZT + R + 75% N + GS	5.11	8.20	13.31	0.39	1.95
SEm±	0.14	0.16	0.18	0.01	0.06
CD (P=0.05)	0.40	0.46	0.54	0.02	0.17
Weed-management (W)					
UWC	4.06	7.35	11.41	0.36	1.65
WFC	5.16	7.79	12.95	0.40	1.82
SSF + MSM	4.91	7.67	12.58	0.39	1.90
PMT-SSF	4.97	7.82	12.78	0.39	1.87
SEm±	0.07	0.14	0.16	0.01	0.03
CD (P=0.05)	0.20	0.40	0.45	0.02	0.10

growing season rainfall, and it was found to be higher in the first year than in second year. The yield and yield attributes differed significantly due to tillage and weed-control measures. Zero-tillage with residue retention had significantly greater number of wheat grains/spike, and 1,000-grain weight resulting in higher grain yield (Singh *et al.,* 2003). This might have resulted from greater photosynthesis, and hence better translocation of photosynthates, besides larger sink and stronger reproductive phase, as reflected in the greater number of effective tillers/m^2 row, grains/ear and 1,000-grain weight. Also there may be a positive impact on soil water balance resulting from crop residue on the soil surface under no-till management. Residue from maize was simulated to be especially effective in suppressing soil evaporation. This might have resulted in enhanced soil-water retention, increased deep water percolation, and increased wheat yields. Soil organic carbon is increased and soil-erosion potential is reduced in reduced tillage and intensified cropping. Ram *et al*. (2012) observed higher bulk density and cumulative infiltration in no-tillage compared with conventional tillage. Fischer *et al*. (2002) reported that within the maize–wheat rotation, ZT + R was clearly superior to the other tillage-residue combinations and during dry periods, showed less wilting. The use of surface residue coverage is an integral part of any successful CT system. Pooled data showed that the net benefit: cost ratios were significantly higher in ZT-R + 100% N treatment than all the conventional-tilled treatment in both years. The residue addition of residue in both the tillage system reduced the net benefit: cost ratio because of the cost of residue but residue addition gave higher yield. The treatment ZT + R + 75% N + GS was next best treatment in terms of net benefit: cost because of the saving in the nitrogen and higher yield. Among the weed-management practices, the benefit: cost ratios were higher in SSF + MSM treatment than all the remaining treatment in both the years and was significantly higher than the UWC. Among herbicidal treatments, SSF + MSM fetched higher net benefit: cost ratios but it was on a par with PMT-SSF. Reduction in yield in UWC and higher cost involved in the manual weeding WFC led to the reduction in the net benefit: cost ratio (Chander *et al*., 2013).

Nutrients uptake by weeds

The highest nutrient uptake by weeds was in CT-R + 100% N and the least was in ZT + R + 75% N + GS in both the years (Fig. 1a). Residue retention in zero tillage had considerable influence on the nutrients uptake by weeds because of reduction in weed dry weights. The ZT + R + 75% N + GS caused reduction in 19.2% N, 14.3% P, 17.4% K in the first year than CT-R + 100% N, and in the second year it was in tune of 34.2% N, 32.2% P and 31.1% K. The highest uptake of nutrients, i.e 17.2 kg N, 5.3 kg P, 16.8 kg K in 2013–14 and 19.1 kg N, 3.5 kg P and 9.5 kg K was under unweeded control treatment due to more weed density and more weed dry weight. All the weed-control practices significantly reduced the nutrient uptake by weeds than UWC (Fig. 1b). Both the sequential as well as ready-mix application of herbicides were on at par in terms of nutrients uptake by weeds. Different herbicidal treatments significantly reduced nutrient uptake by weeds over weedy check because of better weed control. Upasani *et al.* (2013) also reported low nutrient uptake under different weed-management practices.

All tillage, residue, N and weed management caused significant influence on N, P and K uptake by wheat in both the years. The highest nitrogen uptake (151.9 kg/ha in 2013–14 and 141.2 kg/ha in 2014–15) by wheat grain was recorded with ZT + R + 75% N + GS, which was considerably higher than the conventional till treatments (Fig. 2a).

Phosphorus and potassium uptake by crop also showed the similar trends in both the years. Zero tillage with resi-

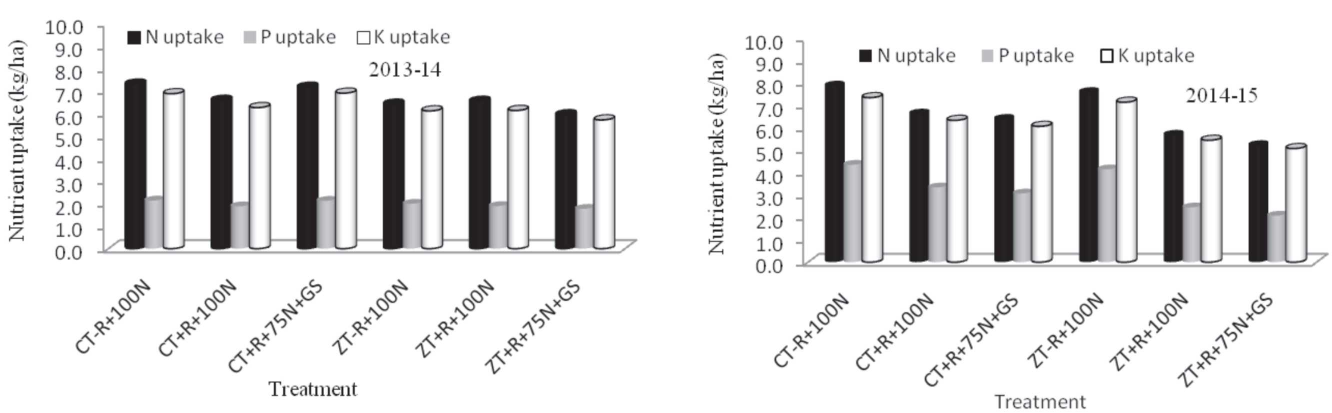


Fig. 1a. Nutrients uptake by weeds as affected by different tillage, residue and N-management treatments

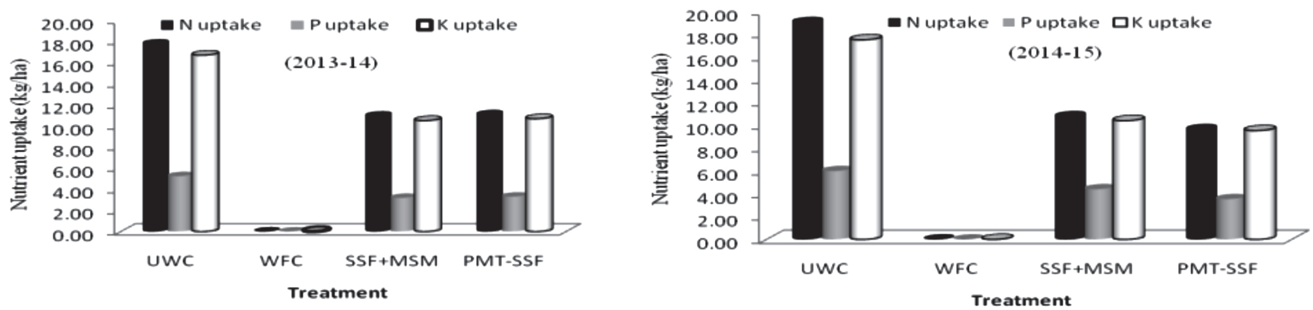
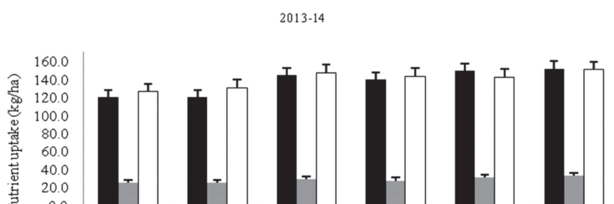
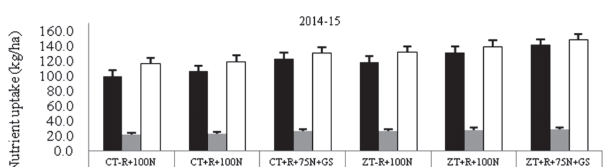


Fig. 1b. Effect of different weed-management practices on nutrient uptake by weeds

due caused higher nutrient uptake than the without residue treatment. Among the weed-control measures, WFC and PMT-SSF were at par in respect of N, P and K uptake by wheat (Fig. 2b). The herbicidal treatment PMT-SSF was better than SSF + MSM in this regards and both sequential as well as ready-mix application of herbicides caused significant increase in nutrients by crop than UWC. Better spreading of roots under zero tillage with residue led to higher nutrients uptake by crop. On the other hand, higher crop-weed competition, low yield under unweeded control resulted in the lowest nutrient uptake by wheat (Kumar and Das, 2008). Application of herbicides reduced weed population and dry weight which ultimately increased uptake of nutrients by crop (Bharat and Kachroo, 2007).



	CT-R+100N	CT+R+100N	CT+R+75N+GS	ZT-R+100N	ZT+R+100N	ZT+R+75N+GS
N uptake	120.3	120.3	144.9	139.7	149.4	151.9
P uptake	24.8	25.1	28.9	27.6	30.8	33.0
K uptake	126.0	130.5	146.8	142.9	142.3	150.5

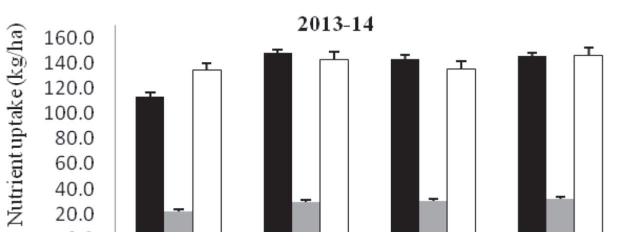


	CT-R+100N	CT+R+100N	CT+R+75N+GS	ZT-R+100N	ZT+R+100N	ZT+R+75N+GS
N uptake	99.1	105.7	122.9	117.8	131.1	141.2
P uptake	21.3	22.0	25.8	26.0	27.8	28.4
K uptake	115.9	119.0	130.7	131.8	139.1	148.5

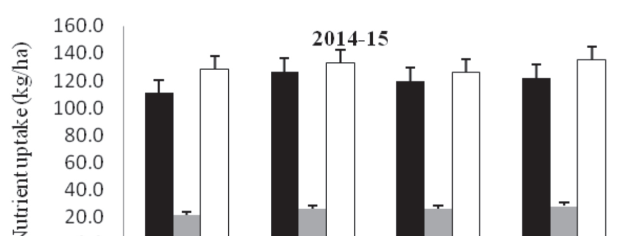
Fig. 2a. Nutrients uptake by crop as influenced by tillage, residue and N-management treatments

Output energy

The total output energy in wheat under various tillage, residue and N-management treatments was minimum with CT-R + 100% N and maximum with ZT + R + 75% N + GS (Fig. 3) because in zero-tillage required less input energy than conventional-tilled treatments. Among tillage, residue and N-management treatments with-residue consumed higher energy than without residue. The pooled value of output energy was higher with ZT + R + 75% N + GS, being significantly higher than all the conventional-tilled treatments. When comparison can be done with all the residue retention and residue-incorporation treatments, it showed that zero-tilled with residue-retention treatment gave higher output energy than the conventional-tilled with residue incorporation. Less use of N based on



	UWC	WFC	SSF+MSM	PMT-SSF
N uptake	113.7	148.1	143.5	145.6
P uptake	21.9	29.8	30.0	31.7
K uptake	134.3	143.1	135.8	146.1



	UWC	WFC	SSF+MSM	PMT-SSF
N uptake	110.7	126.3	119.8	121.8
P uptake	21.3	25.7	25.9	27.9
K uptake	128.4	133.2	126.0	135.7

Fig. 2b. Effect of weed-management practices on nutrients uptake by crops

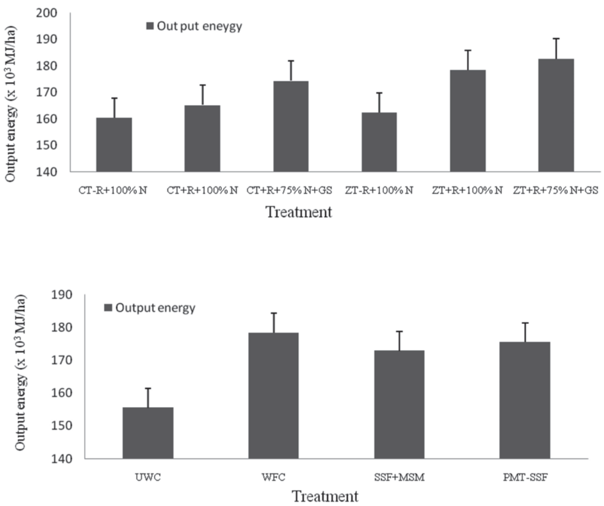


Fig. 3. Pooled output energy (× 10^3 MJ/ha) as influenced by tillage, residue, N and weed-management practices

GreenSeeker also reduced the energy requirement and had more energy output. The total output energy in wheat was lower with UWC in both the years as compared to the remaining weed-control practices. The output energy of wheat due to different weed-control practices was higher with WFC which was significantly higher than UWC, but remained at par with all herbicidal treatments. Among herbicidal treatments, PMT-SSF gave higher gross output energy in wheat than SSF + MSM. The positive interactive effect of zero tillage with PMT-SSF herbicides gave higher grain and biomass yield and led to increase in output energy.

Thus, the results show that the ZT with 5 t/ha maize residue retention (ZT + R) + 75% N + rest N based on GreenSeeker (GS) resulted in significant reductions in weed growth (population and dry weight) and caused a considerable increase in the productivity and nutrients uptake by wheat. The sequential application of pendimethalin 1 kg/ha as pre-emergence followed by sulfosulfuron 25 g/ha resulted in better weed suppression and was superior to other weed-control treatments. The effect of this treatment was more pronounced under ZT+R compared to other tillage treatments. Therefore, a combination of ZT with 5 t/ha maize residue retention (ZT+R) +75% N + rest N based on GreenSeeker (GS) and sequential application of pendimethalin 1 kg/ha as pre-emergence, followed by sulfosulfuron 25 g/ha can be recommended for better weed control and high wheat productivity in North-Western Indo-Gangetic plains of India.

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