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# Effect of tillage and herbicides on weeds and productivity of wheat under rice–wheat growing system

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**Abstract**

Field experiments were carried out to evaluate the effect of tillage and herbicides on weeds and wheat (*Triticum aestivum* L. emend. Fiori and Paol.) productivity under rice (*Oryza sativa* L.)–wheat growing system. *Rumex dentatus* was significantly higher (12.1 plants/m$^2$) under zero tillage (ZT) compared to conventional tillage (CT) (1.9 plants/m$^2$). CT favored *Phalaris minor*. The average *P. minor* dry-weight under ZT and CT was 234.7 and 386.5 g/m$^2$, respectively. This differential response reflected was due to variation in seed distribution during puddling performed for rice transplanting. The lower density of *R. dentatus* seeds led to its concentration in upper soil layer particularly on the surface, under ZT. Of the total seed found in upper 12.5 cm soil layer on the soil surface, about 0.02% and 1.24% were of *P. minor* and *R. dentatus*, respectively. Among the three tillage crop establishment methods, ZT and CT drill provided about 0.3 t/ha higher wheat grain yield over farmer's practice of CT-broadcast sowing. The reduced expenditure on tillage and higher yield, provided additional profit of about US \$ 161.3 ha$^{-1}$ for ZT over farmer's practice. In CT, the performance of sulfosulfuron at 25 g/ha, clodinafop at 60 g/ha and sulfosulfuron + metsulfuron at 25 + 1.6 g/ha was similar, where fields were dominated by *P. minor*. However, in ZT, overall tank mix application of sulfosulfuron + metsulfuron was the most effective treatment for control of the weed flora and improving wheat yield. Metsulfuron alone due to its effectiveness against broad-leaved weeds only was inferior. Considering the benefits of ZT in reducing the cost of cultivation and lowering the infestation of *P. minor*, this technology should be integrated with other weed control measures for economic and sustainable wheat production.


*Keywords:* Clodinafop; Metsulfuron; *Phalaris minor*; Puddling; *Rumex dentatus*; Seed distribution; Soil strength; Sulfosulfuron

## 1. Introduction

Rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L. emend. Fiori and Paol.) have been the staple food for a large population in Asia and their assured supply is essential for food security. As a system, rice–wheat occupies about 24 m ha area worldwide (Ladha et al., 2000) and in India it is the most popular and prevalent sequence covering about 10 m ha area (Timsina and Connor, 2001). These two crops meet about 80% of the carbohydrate food requirement of India. However, degradation of natural resources, factor productivity decline (Yadav, 1998) and weeds are some of the major concerns in the rice–wheat system and these factors cause significant annual regional productivity losses in wheat (Harrington et al., 1992).

Both grassy and broad-leaved weeds infest wheat. Among grassy weeds, *Phalaris minor* Retz. and among broad-leaved weeds *Rumex dentatus* L. are of major concern in irrigated wheat under rice–wheat system in India (Singh et al., 1995; Chhokar et al., 2006; Balyan and Malik, 2000). Both *P. minor* and *R. dentatus* are highly competitive weeds and can cause drastic yield reduction under heavy infestation. The yield reduction by weeds in wheat may be up to 80% depending upon weed type, density, timing of emergence, wheat density, wheat cultivar and soil and environmental factors (Afentouli and Eleftherohorinous, 1996; Chhokar and Malik, 2002; Cudney and Hill, 1979; Khera et al., 1995; Malik and Singh, 1995; Mehra and Gill, 1988). Besides reduction in yield and quality of wheat, heavy *Rumex* spp. populations can cause

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hindrance in combine harvesting (Chhokar, per. obs.) and heavy *P. minor* populations thus causing crop lodging. Resistance has evolved in *P. minor* (Malik and Singh, 1995; Chhokar and Malik, 2002) against isoproturon and as a result, it has emerged as a single weed species limiting wheat productivity in the North Western plains of India. For sustaining wheat productivity, its control is essential. For the control of isoproturon-resistant *P. minor*, clodinafop, fenoxaprop and sulfosulfuron have been found effective (Chhokar and Malik, 2002). Clodinafop and fenoxaprop control only grasses, whereas sulfosulfuron controls grasses and some of the broad-leaved weeds (Chhokar and Malik, 2002; Chhokar et al., 2006). In areas where the farmers are using graminicides like clodinafop and fenoxaprop, the broad-leaved weed flora particularly *Rumex* spp. has increased enormously. Under these conditions, broad-spectrum weed control is essential and for that combinations of herbicides are needed.

In India, rice is mainly grown as puddle transplant and wheat as conventional till involving 8–16 tractor operations with various implements (Chauhan et al., 2003; Sharma et al., 2002). Changes in soil structure during puddling in rice as well as rice straw residues forces farmers into multiple tillage operations for seedbed preparation for growing wheat. The intensive tillage performed combined with factor productivity decline and degradation of resources has contributed to an increased cost of cultivation. Adopting ZT technology in wheat reduces the expenditure on field preparation and saves more than 90% fuel and time as well as advances the sowing time compared to conventional tillage practices (Chauhan et al., 2003; Sharma et al., 2002). The advancement of sowing by adopting ZT can be a useful mean to increase yield of late sown wheat. The sowing of wheat in India is generally delayed when sown after either *Basmati* rice or two crops of rice (rice–rice–wheat) or after sugarcane or cotton harvesting. The extent of yield reductions in different zones in India vary with an average loss of about 26.8 kg/ha/day, when sowing is delayed (Tripathi et al., 2005). Although yield increase may not always accompany reduced tillage operations, but savings in fuel, equipment and labor costs along with its role in conservation of soil and water (Unger and Cassel, 1991) makes it a viable economic option.

Tillage influences soil bulk density, penetration resistance, aggregate mean weight diameter and surface roughness (Carman, 1996). Therefore, the changes in mechanical characteristics of the seedbed due to tillage can influence the crop and weed emergence. Tillage affects weed seed distribution in soil profile (Pareja et al., 1985; Yenish et al., 1992, 1996) and the differential distribution of the seed in soil profile has the potential to change weed population dynamics (Buhler, 1991, 1995, 1997; Froud-Williams et al., 1983; Harper, 1957). It also affects soil properties, such as organic matter, microbial populations, soil moisture, temperature and pH (Blevins et al., 1983), which can affect herbicide activity by influencing herbicide adsorption, movement, persistence and efficacy.

As the ZT wheat area is likely to increase in India and a shift from an intensive tillage system to reduced tillage system can cause major changes in weed population dynamics (Buhler, 1995), ultimately affecting the herbicide efficacy due to change in microclimate and weed flora. The present study was carried out with the aim to determine the effect of tillage and herbicides in wheat on weeds and wheat productivity in a rice–wheat growing system.

## 2. Materials and methods

Studies were conducted at the research farm of the Directorate of Wheat Research, Karnal, Haryana, India (Latitude 29°43′N, Longitude 76°58′E at an elevation of 245 m above mean sea level) and at farmer's fields around Karnal.

### 2.1. Herbicide performance under CT and ZT wheat

Two field experiments were conducted, one in CT and another in ZT for evaluation of the herbicides performance. The soil of the experimental field was sandy loam with pH of 8.5 and organic matter content of 0.35%.

Under the CT system, wheat cultivar (PBW 343) was sown (20 cm row spacing) with seed cum-fertilizer drill using seed rate of 100 kg/ha on 28 November 2002 and 12 November 2003. For field preparation, 4, 2 and 3 passes of harrow, cultivator and plank were performed, respectively. During both the years, grassy weed *P. minor* was dominant and during second year low infestation of broad-leaved weeds, *Melilotus alba, Medicago denticulata* and *Coronopus didymus* were also observed. Six weed control treatments i.e. sulfosulfuron (Leader 75 WG) 25 g a.i./ha, sulfosulfuron + metsulfuron (25 + 1.6 and 30 + 2.0 g a.i./ha), metsulfuron (Algrip 20 WP) 4 g a.i./ha and clodinafop (Topik 15 WP) 60 g a.i./ha and untreated control were evaluated (Table 1) in a randomized block design with three replicates. Fertilization (150 kg N, 60 kg $P_2O_5$, 40 kg $K_2O$) and irrigations (six) were done according to recommended practice for wheat.

In the second experiment, efficacy of sulfosulfuron 25 g, sulfosulfuron + metsulfuron (25 + 1.6 g/ha), metsulfuron 4 g and clodinafop 60 g/ha were examined under zero tillage sown wheat under rice–wheat system. After manual rice harvesting (harvested close to the ground), pre-sowing irrigation was given and at optimum soil moisture, wheat seeding was done using ZT machine (having inverted T-type slit openers) on 18 November 2002 and 14 November 2003. Except sowing in untilled conditions, the practices were similar to that of CT wheat as mentioned earlier. This experiment was also conducted in randomized block design with three replicates. The main weeds infesting were *P. minor*, *R. dentatus*, *M. alba*, *M. denticulata* and *C. didymus. P. minor* was the major during both the years, whereas, *R. dentatus* was dominant among broad-leaved weeds during 2002–2003.

Table 1
Evaluation of herbicides against weeds in CT wheat

| Herbicide | Dose/ha (g a.i.) | *P. minor* dry wt. ($g/m^2$) | | Broad-leaved weeds dry wt. ($g/m^2$) | Grain yield (t/ha) | |
|---|---|---|---|---|---|---|
| | | 2002–2003 | 2003–2004 | 2003–2004 | 2002–2003 | 2003–2004 |
| Clodinafop | 60 | 4.4 | 1.0 | 40.3 | 4.50 | 6.21 |
| Sulfosulfuron + S[a] | 25 | 10.8 | 1.3 | 18.0 | 4.42 | 6.39 |
| Metsulfuron + S[b] | 4 | 301 | 443.3 | 0.2 | 2.83 | 2.36 |
| Sulfosulfuron + metsulfuron + S[a] | 25 + 1.6 | 10 | 2.3 | 5.7 | 4.36 | 6.35 |
| Sulfosulfuron + metsulfuron + S[a] | 30 + 2 | 5 | 0.7 | 2.3 | 4.45 | 6.44 |
| Weedy check | | 347.2 | 466.7 | 2.7 | 2.78 | 2.03 |
| LSD at 5% | | 23.5 | 51.5 | 5.8 | 0.32 | 0.43 |

[a]Cationic surfactant (polyethylene amine) was used at 1250 ml/ha.
[b]Cationic surfactant was used at 625 ml/ha.

Cationic surfactant (polyethylene amine) from Monsanto India Ltd. was used at 1250 ml/ha with sulfosulfuron and sulfosulfuron + metsulfuron treatments, whereas with metsulfuron, the cationic surfactant was used at 625 ml/ha. The herbicide spray was done between 31 and 35 DAS with knap sack sprayer fitted with flat fan nozzles using 350 l water/ha. Dry weight of grassy and broad-leaved weeds were recorded 120 DAS and for that weeds were cut at ground level, sun dried followed by oven drying at $70 \pm 5\,^{\circ}C$ for 48 h and then weighed. Grain yield was recorded from net plot area and expressed in t/ha. Differences among treatment means were determined using ANOVA and when the $F$ test was significant means were compared with LSD test at 5% level of significance.

### 2.2. Effect of tillage on wheat productivity and weeds

The effect of tillage in wheat under rice–wheat system on wheat productivity, economics and weeds, evaluation of various tillage crop establishment methods (TCE) was conducted on farmer's fields during three consecutive crop seasons (2001–2002 to 2003–2004). Wheat cv. PBW 343 was sown under ZT and CT with similar package of practices as mentioned earlier.

The productivity and economics of wheat under three TCE methods were evaluated at eight locations, each having an area of about $4000\,m^2$. Each field was divided into three equal parts for sowing under ZT, CT-drill and farmers practice of broadcast sowing. Sowing under ZT was done with zero till drill in a single operation, sowing in CT drill was done by same drill after conventional field preparation (four passes of harrow, two passes of cultivator and three passes of plank) and for broadcast sowing after field preparation broadcasting of seed and fertilizer was followed by two passes of cultivator and one pass of plank. The total field operations in farmer practice were 12. The diesel consumption for different sowing methods was recorded. The expenditure for three TCE methods was also calculated based on the hiring rate (single pass of harrow = US \$13.89 $ha^{-1}$, cultivator = US \$13.89 $ha^{-1}$, CT drill = US \$16.67 $ha^{-1}$, planker = US \$5.56 $ha^{-1}$, ZT drill = US \$19.44 $ha^{-1}$) prevalent in Karnal district (Haryana). For control of complex weed flora, sulfosulfuron + metsulfuron 25 + 2 g/ha mixture was applied at around 30–35 DAS. Finally the yield was recorded and net profit over farmer's practice was also worked out. The price of wheat grain and straw taken was US \$16.67 and 2.22 $t^{-1}$, respectively.

To examine the effect of tillage on weeds, sowing of wheat was done under ZT and CT in 1 acre field ($4000\,m^2$ area each) divided in two equal parts at 42 farmer's field. The significant population of *P. minor* was observed in 15 fields and *R. dentatus* in 10 fields. Fields dominated by *P. minor* were sprayed with clodinafop 60 g/ha followed by metsulfuron 4 g/ha. An area of $3 \times 3\,m^2$ was left untreated with clodinafop at three places each in ZT and CT to know the tillage effect on *P. minor*.

Ten fields having *R. dentatus* were uniformly treated with clodinafop 60 g/ha and then followed by metsulfuron 4 g/ha. Three quadrats ($3 \times 3\,m^2$) were left metsulfuron untreated in each tillage options. The *P. minor* dry weight and *R. dentatus* populations were recorded at 120 DAS under ZT and CT from each quadrat.

Based on the data of different field observations, average and $\pm$SEM were worked out for treatment comparison as per the procedure mentioned in Panse and Sukhatame (1995). Fischer paired $t$-test was used for comparing the significance of two treatment means. The soil strength (kp) was also recorded for ZT and CT using recording penetrometer. The observations were taken at 24 spots for each tillage and averaged (Fig. 4).

### 2.3. Effect of puddling on weed seed distribution in the soil

To study the distribution pattern of *P. minor* and *R. dentatus* seeds in the soil profile due to puddling, two sets of experiments were conducted to simulate the field conditions. General observations on seed density and seed weight (saturated and oven dry) of *P. minor* and *R. dentatus* were recorded. Cleaned seeds were used for hectoliter weight (bulk density/test weight) determination and for which a specially DWR designed hectoliter weight instrument was used, which indicates the weight/volume (kg/hectoliter):

(i) In the first set, pits of 50 cm × 50 cm × 25 cm size ($l \times b \times h$) were dug. The dug soil from the pit was mixed with seeds of *R. dentatus* and *P. minor* at 5 g/kg air dry soil and six pits for each weed were used. Seed mix soil was filled to about 15-cm height of each pit. Thereafter, each pit was filled with water for soaking of seeds for 2 days and afterwards puddling was done using *khurfi* (hand held tyne) followed by stirring with a wooden peg in the standing water of 7–10 cm. The puddled soil was allowed to settle and after drying of water, samples from various depths, at 2.5 cm intervals up to 12.5 cm, were collected using Auger of 5.5 cm diameter. Three samples per pit were taken and composited for each depth for seed retrieval after thorough washing in water on a 0.4 mm sieve. Seeds of both weeds present just on the surface were also counted separately before sampling and finally added for 0–2.5 cm depth.

(ii) In the second set, pots (20 cm diameter) of 20 kg soil capacity were used. Pots were filled with 10 kg soil after uniform mixing of *P. minor* and *R. dentatus* seeds weeds (50 g/pot). Five pots were maintained for each weed. After 2 days of soaking, puddling was done as mentioned in the pit experimentation. The pots were left for settling of seed and soil and after water from pots evaporated, soil from the pots was removed at field capacity. Seed retrieval from various depths was done after removing the intact soil from the pots and cutting the columns for viz. 0–2.5, 2.5–5.0, 5.0–7.5,7.5–10.0 and 10–12.5 cm depth intervals. The seeds were recovered for various depths by washing on a 0.2 mm sieve. Weed seeds from various depths including on surface were counted and percentage distribution was calculated based on total seeds recovered in 12.5 cm soil layer. The seed distribution in both the sets was averaged.

### 2.4. Statistical analyses

Differences among treatment means were determined using ANOVA and when the $F$ test was significant means were compared with LSD test at 5% level of significance. Based on the data of different field observations, average and ±SEM were worked out. "Fischer's paired $t$-test" was used for comparing the significance of two treatment means as mentioned in Panse and Sukhatame (1995).

## 3. Results and discussion

### 3.1. Herbicide performance under conventional till wheat

The dominant weed during the field study was *P. minor* and only during 2003–2004, minor infestations of broad-leaved weeds i.e. *M. denticulata*, *M. alba, C. didymus* and *R. dentatus* were observed. Since, the broad-leaved weed infestation during 2002–2003 was negligible their dry weight was not recorded. The lowest wheat grain yield of 2.78 and 2.03 t/ha was recorded under weedy check, during first and second year, respectively, due to severe weed competition (Table 1). All the herbicide treatments except metsulfuron 4 g/ha provided significantly higher grain yield compared to weedy check. Metsulfuron was effective against broad-leaved weeds only. Sulfosulfuron 25 g, clodinafop 60 g and sulfosulfuron + metsulfuron 25 + 1.6 and 30 + 2 g/ha provided effective control of *P. minor*. The efficacy of sulfosulfuron + metsulfuron at both the doses (25 + 1.6 and 30 + 2 g/ha) was statistically similar with regard to weed control and grain yield. Since, *P. minor* was the single dominant weed with negligible presence of broad-leaved weeds, the yield obtained with the application of clodinafop, sulfosulfuron and sulfosulfuron + metsulfuron was statistically similar. Wheat grain yield improvement of >56.8% was recorded with the use of sulfosulfuron, sulfosulfuron + metsulfuron and clodinafop. Clodinafop had no effect on broad-leaved weeds and recorded significantly higher dry weight (40.3 $g/m^2$) compared to sulfosulfuron + metsulfuron, sulfosulfuron, metsulfuron and untreated check. The lower dry weight of broad-leaved weeds under weedy check was due to the strong competition offered by *P. minor* (466.7 $g/m^2$).

### 3.2. Herbicide performance under zero till wheat

Four herbicide treatments (clodinafop 60 g, sulfosulfuron 25 g, metsulfuron 4 g, sulfosulfuron + metsulfuron 25 + 1.6 g/ha) were also evaluated under ZT sown wheat during two consecutive seasons i.e. 2002–2003 and 2003–2004 (Fig. 1). The major weed flora of zero till sown wheat was *P. minor, R. dentatus, M. denticulata*, *M. alba* and *C. didymus.* The effective control of *P. minor* was observed with the application of clodinafop 60 g and sulfosulfuron 25 g/ha alone or in combination with metsulfuron 1.6 g/ha. Metsulfuron and clodinafop were effective against broad-leaved and grassy weeds, respectively, whereas, sulfosulfuron besides controlling grassy weeds also controlled many broad-leaved weeds (Chhokar and Malik, 2002). However, during first year its poor response was observed against broad-leaved weeds (4.88 t/ha) due to heavy infestation of *R. dentatus.* Sulfosulfuron was ineffective in controlling *R. dentatus.* The lowest wheat grain yield of 1.23 and 3.39 t/ha, during first and second year, respectively, were recorded (Fig. 1) in metsulfuron methyl treatment due to severe competition from grassy weeds (6.25 and 2.72 t/ha). This herbicide provided effective control of broad-leaved weeds only and had no effect on *P. minor*. Similarly, due to narrow weed control spectrum (grass only), the grain yield levels were low with clodinafop 60 g/ha (1.88 and 4.90 t/ha). Whereas, the highest yields were recorded with sulfosulfuron + metsulfuron during both the crop seasons due to control of complex weed flora. The yield differences between this combination and other three herbicide treatments

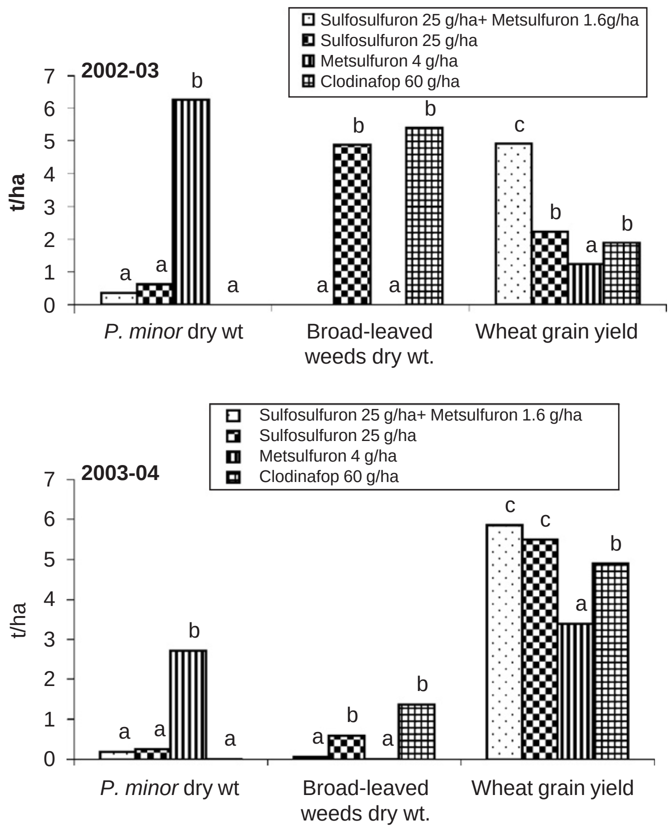


Fig. 1. Effect of herbicides on weeds (*P. minor* and broad-leaved) and wheat productivity in ZT during 2002–2003 and 2003–2004. The column bars having same letter are not significantly different.

(sulfosulfuron, clodinafop, metsulfuron) were more during first year due to more *R. dentatus* infestation. The presence of this weed resulted in yield loss of 54.6% and 6.2% in sulfosulfuron 25 g/ha compared to sulfosulfuron + metsulfuron, during first and second year, respectively. The advantage of sulfosulfuron + metsulfuron over sulfosulfuron and clodinafop will be in situations having the infestation of broad-leaved weeds, especially the *Rumex* spp.

This study suggests that a field having mixed infestation of weeds needs a combination of herbicides. A combination of two or more herbicides besides broadening the weed control also helps in reducing the cost of weed control. The effectiveness of grass herbicides are generally reduced when mixed with broad-leaved herbicides (Vidrine, 1989; Holshouser and Coble, 1990; Grichar, 1991; Vidrine et al., 1995; Damalas and Eleftherohorinos, 2001). About 80% of the interactions that has been observed in species of the family Poaceae (grasses) refer to cases of antagonism (Zhang et al., 1995). Whereas synergism/compatibility has been found to occur more frequently in mixtures where the companion herbicides belong to the same chemical groups (Damalas, 2004). Sulfosulfuron + metsulfuron are compatible but tank mix application of clodinafop with either 2,4-D or metsulfuron is antagonistic (Mathiassen and Kudsk, 1998) and needs sequential application. On the basis of these studies sulfosulfuron + metsulfuron was found to be the most effective treatment in controlling complex weed flora in wheat thereby improving wheat yields.

### 3.3. Effect of puddling on weed seed distribution

One thousand seed weight of *P. minor* and *R. dentatus* on oven dry weight basis was 1.91 and 2.46 g, respectively, and saturated weight was 2.53 and 5.06 g, respectively (Table 2). The depth from which *P. minor* and *Rumex* spp. can germinate has been reported as 10 cm (Chhokar et al., 1999) and 4 cm (Dhawan, 2005), respectively. after conventional field preparation. So, the 12.5 cm soil depth was taken for seed distribution in soil profile after puddling.

The percentage of seeds found on the surface was 0.02% and 1.24%, respectively, for *P. minor* and *R. dentatus*. In the top 2.5 cm soil layer, the percentage of the total seed present in upper 12.5 cm soil depth was 29.3% and 33.6% for *P. minor* and *R. dentatus*, respectively (Fig. 2). The higher *R. dentatus* concentration in the upper soil layer particularly on the surface after puddling was due to its lower seed density of 16.17 kg/hectolitre compared to 61.31 kg/hectolitre for *P. minor* (Table 2). *R. dentatus* seeds with perianth tend to float leading to higher seeds in the surface layer. The lowest seed distribution percentage was recorded in 10.0–12.5 cm soil layer for both weeds.

### 3.4. Effect of tillage on weeds and wheat productivity

The effect of tillage in wheat under rice–wheat system was examined and based on the average of 15 fields observations (Fig. 3), the *P. minor* dry weight was lower in ZT (234.7 g/m$^2$) compared to CT (386.5 g/m$^2$). The lower dry weight in ZT was due to lesser emergence owing to higher soil strength (Fig. 4). Soil strength was higher up to

Table 2
Bulk density and seed weight of *Rumex dentatus* and *P. minor*

| Particular | *Rumex dentatus* | *P. minor* |
|---|---|---|
| Bulk density (kg/hectolitre) | 16.17 | 61.31 |
| 1000 Seed weight (g) dry basis | 2.459 (1.06[a]) | 1.91 |
| 1000 Seed weight (g) saturated basis | 5.057 | 2.53 |

[a]Seeds without perianth.

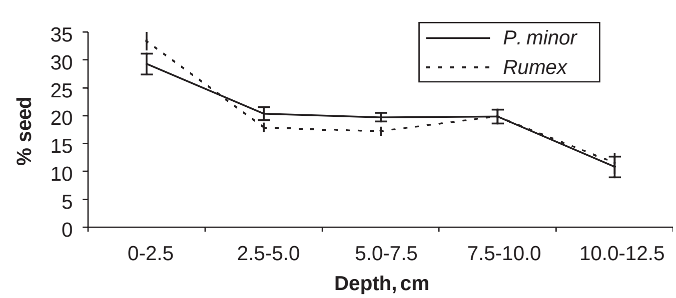


Fig. 2. Effect of puddling on seed distribution of *P. minor* and *R. dentatus*. Vertical bars represent ±SEM.

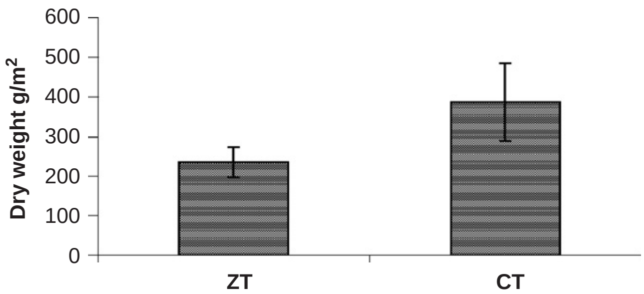


Fig. 3. Effect of tillage on *P. minor* dry weight (average of 15 field observations). Vertical bars represent ±SEM. Means are significantly different at $P = 0.10$ using "Fisher's paired *t*-test".

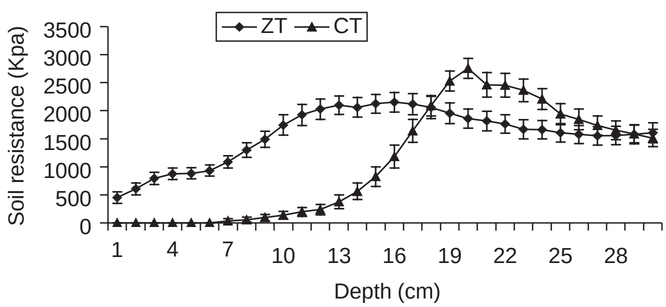


Fig. 4. Soil strength under ZT and CT. Vertical bars represent ±SEM.

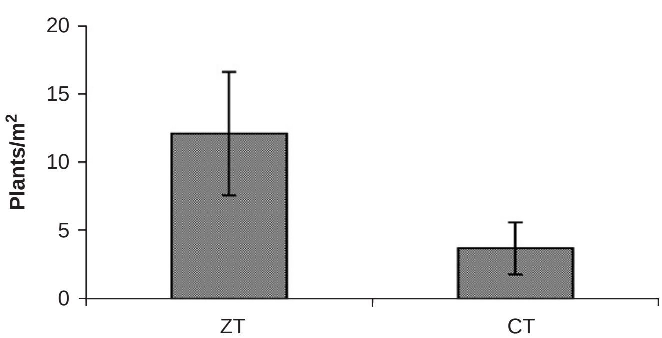


Fig. 5. Effect of tillage on *R. dentatus* population (average of 10 field observations). Vertical bars represent ±SEM. Means are significantly different at $P = 0.05$ using "Fisher's paired *t*-test".

17 cm under ZT and thereafter it was more for CT. Soil strength was very less up to 10 cm in CT and *P. minor* seeds are capable of germination up to 10 cm soil depth (Chhokar et al., 1999). Peak soil strength for CT was observed at 20 cm and it might be due to creation of hard pan by tillage operation.

The reverse was observed with regard to *R. dentatus.* Its population was significantly higher ($P = 0.05$) under ZT (Fig. 5). The higher population was due to the presence of more seeds in the surface layer after puddling. The higher concentration in the upper soil layer combined with its preference for higher soil moisture and lesser emergence depth (Dhawan, 2005) caused the higher emergence under ZT. Germination of *Rumex* was totally inhibited at osmotic stress higher than 0.5 mPa (Dhawan, 2005). In ZT, moisture remains higher than CT. In CT, the upper soil layers dry very fast leading to lesser soil moisture and ultimately lesser weed emergence before first irrigation. Leslie (1965) also reported the influence of soil moisture and structure on the emergence of crop and weeds.

The differential weed seedling recruitment in response to tillage system has been reported earlier (Moyer et al., 1994; Buhler and Daniel, 1988; Buhler and Mester, 1991). Buhler and Daniel (1988) reported lower *Abutilon theophrasti* Medik and higher *Setaria fabri* Herrm. seedling recruitment under no till systems. Tillage besides changing the physical and chemical environment of the seed also exposes weed seeds to light (Scopel et al., 1994), which in turn influences the germination. If no-till in wheat in conjunction with no-till in previous crop is adopted then this double no-till system may enhance the natural loss of weed seeds by maintaining seeds on the soil surface through exposure to environment extremes and predation (Sagar and Mortimer, 1976; Roberts, 1981; Anderson, 2005). However, Mohler (1993) reported that weed seedling emergence may be greater for some weeds with no-till compared to tilled system in the first year after seed rain as observed with *Aegilops cylindrica*. This differential response may be due to seeds enclosed within spikelet thereby protecting from environmental conditions on the soil surface. This might have happened in the present case of *R. dentatus* where seed is covered with perianth and might protect it from environmental variation on the surface and causing higher infestation under ZT. However, if seed formation is prevented then weed population in no-till will reduce fast than in tilled system. This is in general due to rapid loss of viability on the soil surface compared to seeds buried in the soil.

Therefore, continuous ZT adoption will help in reducing the more problematic weed *P. minor* but will increase the population of *R. dentatus*. However, *Rumex* spp. can be easily controlled with metsulfuron, chlorsulfuron, 2,4-D or carfentrazone in wheat (Balyan and Malik, 2000; Singh et al., 2004). A major concern in India is *P. minor* infestation, which has also evolved herbicide resistance (Chhokar and Malik, 2002; Malik and Singh, 1995). The present study suggests that *P. minor* can be effectively managed through integration of herbicides with ZT under rice–wheat system. As the population of *P. minor* will be less under ZT and further, if encouraged to germinate through presowing irrigation and killed with non-selective herbicides (like glyphosate/paraquat) followed by seeding under ZT conditions. The subsequent populations will be less due to minimum disturbance of soil. An integrated approach consisting of ZT with slightly advanced sowing (last week of October) with higher seed rate and narrow row spacing of competitive cultivars can drastically reduce *P. minor* population (Chhokar and Malik, 1999). Further if ZT is practised with residue retention then weed infestation will be lesser. This is because crop residues alter environmental conditions related to weed seed germination, physically impede seedling growth, or inhibit germination

Table 3
Comparative performance of ZT and CT over farmer's practice of wheat sowing

| Tillage crop establishment | Wheat yield (t/ha) Mean±SE | Tillage expenditure on hire basis (US \$/ha)[a] | Diesel consumption (l/ha) | Additional profit over farmers practice (US \$/ha) |
|---|---|---|---|---|
| Zero tillage | 5.25±1.68 | 19.5 | 6.1 | 161.3 |
| Conventional tillage-drill (10)[b] | 5.24±1.53 | 116.7 | 59.0 | 80.9 |
| Farmers practice (12)[b] | 4.93±1.74 | 135.6 | 70.8 | |

Additional profit was worked out over farmer's practice considering the expenditure on hire basis.
[a]One US \$ = Rs. 45 (Indian rupees).
[b]Number of field operations.

and growth by allelopathy (Crutchfield et al., 1986). Wicks et al. (1994) found that each 1000 kg/ha of winter wheat residue on the soil surface reduced 14% weed seedling establishment. Such an integrated approach, consisting of multi-tactic can offer a viable solution if the choice for selective herbicides is restricted.

Compared to farmers practice of broadcast sowing (4.93 t/ha), ZT and CT had higher wheat yield (Table 3). The expenditure on tillage crop establishment on hire basis was higher for farmer's practice (US \$135.6 $ha^{-1}$) and for ZT and CT were US \$19.5 and US \$116.7 $ha^{-1}$, respectively. The fuel consumption was 6.1, 59 and 70.8 l diesel/ha for ZT, CT and farmers practice, respectively. Profit gain over farmer's practice under ZT and CT was US \$161.3 and US \$80.9 $ha^{-1}$, respectively.

This study has shown the effect of tillage on weeds. The differential distribution of weed seeds during puddling for rice transplanting as well as changes in microclimate (soil structure, moisture, diurnal temperature fluctuations and light exposure) due to tillage in wheat can influence the weed seedling recruitment. ZT wheat had lower *P. minor* infestation under rice–wheat system and this grassy weed is the main threat to the sustainability of wheat production. Further besides helping in the management of *P. minor,* ZT also reduces the cost of cultivation. Therefore ZT in conjunction with other weed control measure can offer a more economic and sustainable options of wheat cultivation.

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## References

Afentouli, C.G., Efleftherohorinous, I.G., 1996. Littleseed canarygrass (*Phalaris minor*) and short spiked canarygrass (*Phalaris brachystachys*) interference in wheat and barley. Weed Sci. 44, 560–565.

Anderson, R.L., 2005. A multi-tactic approach to manage weed population dynamics in crop rotations. Agron. J. 97, 1579–1583.

Balyan, R.S., Malik, R.K., 2000. New herbicides for Jungali Palak (*Rumex retroflexus* L.). Indian J. Weed Sci. 32, 86–88.

Blevins, R.L., Smith, M.S., Thomas, G.W., Frye, W.W., 1983. Influence of conservation tillage on soil properties. J. Soil Water Conserv. 38, 301–307.

Buhler, D.D., 1991. Influence of tillage systems on weed population dynamics and control in the northern corn belt of the United States. Adv. Agron. (India) 1, 51–60.

Buhler, D.D., 1995. Influence of tillage systems on weed population dynamics and management in corn and soybeans in central USA. Crop Sci. 35, 1247–1258.

Buhler, D.D., 1997. Effects of tillage and light environment on emergence of 13 annual weeds. Weed Technol. 11, 496–501.

Buhler, D.D., Daniel, T.C., 1988. Influence of tillage systems on gaint foxtail (*Setaria faberi*) and velvetleaf (*Abutilon theophrasti*) density and control in corn (*Zea mays*). Weed Sci. 36, 642–647.

Buhler, D.D., Mester, T.C., 1991. Effect of tillage systems on the emergence depth of gaint (*Setarai faberi*) and green foxtail (*Setaria viridis*). Weed Sci. 39, 200–203.

Carman, K., 1996. Effect of different tillage systems on soil properties and wheat yield in middle Anatolia. Soil Till. Res. 40, 204–207.

Chauhan, D.S., Sharma, R.K., Chhokar, R.S., 2003. Comparative performance of tillage options in wheat (*Triticum aestivum*) productivity and weed management. Indian J. Agric. Sci. 73 (7), 402–406.

Chhokar, R.S., Malik, R.K., 1999. Effect of temperature on the germination of *Phalaris minor* Retz. Indian J. Weed Sci. 31, 73–74.

Chhokar, R.S., Malik, R.K., 2002. Isoproturon resistant *Phalaris minor* and its response to alternate herbicides. Weed Technol. 16, 116–123.

Chhokar, R.S., Malik, R.K., Balyan, R.S., 1999. Effect of moisture stress and seeding depth on germination of littleseed canarygrass (*Phalaris minor* Retz.). Indian J. Weed Sci. 31, 78–79.

Chhokar, R.S., Sharma, R.K., Chauhan, D.S., Mongia, A.D., 2006. Evaluation of herbicides against *Phalaris minor* in wheat in northwestern plains. Weed Res. 46, 40–49.

Crutchfield, D.A., Wicks, G.A., Burnside, O.C., 1986. Effect of winter wheat (*Triticum aestivum*) straw mulch level on weed control. Weed Sci. 34, 110–114.

Cudney, D.W., Hill, J.E., 1979. The response of wheat grown with three population levels of canarygrass to various herbicide treatments. In: Proceedings of the West. Soc. Weed Sci. (Dept. Bot. Plant Sci., University California, River Side, CA, 92521, USA), vol. 32, pp. 55–56.

Damalas, C.A., 2004. Herbicide tank mixtures: common interactions. Int. J. Agric. Biol. 6, 209–212.

Damalas, C.A., Eleftherohorinos, I.G., 2001. Dicamba and atrazine antagonism on sulfonylurea herbicides used for johnsongrass (*Sorghum halepense*) control in corn (*Zea mays*). Weed Technol. 15, 62–67.

Dhawan, R.S., 2005. Studies on germination and emergence of *Rumex maritimus*. Indian J. Weed Sci. 37, 144–146.

Froud-Williams, R.J., Chancellor, R.J., Drennan, D.S.H., 1983. Influence of cultivation regime upon buried weed seeds in arable cropping systems. J. Appl. Ecol. 20, 199–208.

Grichar, W.J., 1991. Sethoxydim and broadleaf herbicide interactions effects on annual grass control in peanuts (*Archis hypogeae*). Weed Technol. 5, 321–324.

Harper, J.C., 1957. The ecological significance of dormancy and its importance in weed control. Int. Conf. Plant Prot. Hamburg 1, 415–420.

Harrington, L.W., Morris, M., Hobbs, P.R., Singh, V.P., Sharma, H.C., Singh, R.P., Chaudhary, M.K., Dhiman, S.D., 1992. Wheat and rice in Karnal and Kurukshetra districts, Haryana, India. Exploratory Survey Report. Hisar, New Delhi, India Mexico and Philippines : CCS Haryana Agricultural University, Indian Council of Agricultural Research, Centro Internacional de Mejoramiento de Maizy Trigo, and International Rice Research Institute, pp. 40–42.

Holshouser, D.L., Coble, H.D., 1990. Compatibility of sethoxydim with five post-emergence broadleaf herbicides. Weed Technol. 4, 128–133.

Khera, K.L., Sandhu, B.S., Aujla, T.S., Singh, C.B., Kumar, K., 1995. Performance of wheat (*Triticum aestivum*) in relation to small canarygrass (*Phalaris minor*) under different levels of irrigation, nitrogen and weed population. Indian J. Agric. Sci. 65, 717–722.

Ladha, J.K., Fischer, K.S., Hossain, M., Hobbs, P.R., Hardy, B. (Eds.), 2000. Improving the productivity and sustainability of rice-wheat systems of the Indo-Gangetic Plains: A synthesis of NARS-IRRI partnership research. IRRI Discussion Paper Series No. 40. International Rice Research Institute, Makati City, Philippines.

Leslie, J.K., 1965. Factors responsible for failure in the establishment of summer grasses of the black earth's of the Darling Downs, Queensland. J. Agric. Anim. Sci. 22, 17–38.

Malik, R.K., Singh, S., 1995. Littleseed canarygrass (*Phalaris minor* Retz.) resistance to isoproturon in India. Weed Technol. 9, 419–425.

Mathiassen, S.K., Kudsk, P., 1998. Influence of broadleaved weed herbicides on the activity of fenoxaprop-p-ethyl. Weed Res. 38, 283–289.

Mehra, S.P., Gill, H.S., 1988. Effect of temperature on germination of *Phalaris minor* Retz. and its competition in wheat. J. Res. Punjab Agric. Univ. 25, 529–533.

Mohler, C.L., 1993. A model of the effects of tillage on emergence of weed seedlings. Ecol. Appl. 3, 53–73.

Moyer, J.R., Roman, E.S., Lindwall, C.W., Blackshaw, R.E., 1994. Weed management in conservation tillage systems for wheat production in North and South America. Crop Prot. 13, 243–259.

Panse, V.G., Sukhatame, P.V., 1995. Statistical Methods for Agricultural Workers. ICAR, New Delhi, India.

Pareja, M.R., Staniforth, D.W., Pareja, G.P., 1985. Distribution of weed seeds among soil structural units. Weed Sci. 33, 182–189.

Roberts, H.A., 1981. Seed banks in soils. Adv. Appl. Biol. 6, 1–55.

Sagar, G.R., Mortimer, A.M., 1976. An approach to the study of the population dynamics of plants with special reference to weeds. Adv. Appl. Biol. 1, 1–47.

Scopel, A.L., Ballare, C.L., Radosevich, S.R., 1994. Photostimulation of seed germination during soil tillage. New Phytol. 126, 145–152.

Sharma, R.K., Chhokar, R.S., Chauhan, D.S., 2002. Zero tillage technology in rice–wheat system: retrospect and prospects. Indian Fmg 54 (4), 12–17.

Singh, G., Singh, V.P., Singh, M., 2004. Effect of carfentrazone-ethyl on nongrassy weeds and wheat yield. Indian J. Weed Sci. 36, 19–20.

Singh, S., Malik, R.K., Balyan, R.S., Singh, S., 1995. Distribution of weed flora of wheat in Haryana. Indian J. Weed Sci. 27, 114–121.

Timsina, J., Connor, D.J., 2001. Productivity and management of rice–wheat cropping systems: issues and challenges. Field Crops Res. 69, 93–132.

Tripathi, S.C., Mongia, A.D., Sharma, R.K., Kharub, A.S., Chhokar, R.S., 2005. Wheat Productivity at different sowing time in various agro-climatic zones of India. South Asian Association for Regional Cooperation (SAARC). J. Agric. 3, 191–201.

Unger, P.W., Cassel, D.K., 1991. Tillage implement disturbance effects on soil properties related to soil and water conservation: a literature review. Soil Till. Res. 19, 363–382.

Vidrine, P.R., 1989. Johnsongrass (*Sorghum halepense*) control in soybeans (*Glycine max*) with postemergence herbicides. Weed Technol. 3, 455–458.

Vidrine, P.R., Reynolds, D.B., Blouin, D.C., 1995. Grass control in soybean (*Glycine max*) with graminicides applied alone and in mixtures. Weed Technol. 9, 68–72.

Wicks, G.A., Crutchfield, D.A., Burnside, O.C., 1994. Influence of wheat (*Triticum aestivum*) straw mulch and metolachlor on corn (*Zea mays*) growth and yield. Weed Sci. 42, 141–147.

Yadav, R.L., 1998. Factor productivity trends in a rice-wheat cropping system under long-term use of chemical fertilizers. Exp. Agric. 34, 1–18.

Yenish, J.P., Doll, J.D., Buhler, D.D., 1992. Effects of tillage on vertical distribution and viability of weed seed in soil. Weed Sci. 40, 429–433.

Yenish, J.P., Fry, T.A., Durgan, B.R., Wyse, D.L., 1996. Tillage effects on seed distribution and common milkweed (*Asclepias syriaca*) establishment. Weed Sci. 44, 815–820.

Zhang, J., Hamill, A.S., Weaver, S.E., 1995. Antagonism and synergism between herbicides: trends from previous studies. Weed Technol. 9, 86–90.