

## Effect of tillage and residue management on soil physical properties and crop productivity in maize (*Zea mays*)–Indian mustard (*Brassica juncea*) system

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### ABSTRACT

Field experiments were carried out on a sandy loam (Typic Haplustept) soil in semi-arid climate of New Delhi to evaluate the effect of tillage (conventional and zero) and residue management (incorporation, retention and removal) on soil physical properties *vis-à-vis* plant growth after 3 years of continuous maize (*Zea mays* L.)–Indian mustard [*Brassica juncea* (L.) Czern. & Coss.] sequence. Maize (July–October) and mustard (October–November) were grown with conventional (disc plowing, followed by 2 cultivators) and zero tillage (no plowing) and crop residues were applied at sowing @ 3 tonnes/ha for maize and 2 tonnes/ha for mustard. Residue incorporation significantly ( $P < 0.05$ ) lowered the bulk density of surface (0–0.15 m) soil layer. Zero tillage with residue retention recorded significantly higher soil organic carbon and microbial biomass carbon, and also mean weight diameter and geometric mean diameter of soil aggregates. Though a compact zone ( $>2$  MPa soil resistance) between 0.3 and 0.4 m in the profile was observed in all the plots, residue incorporation reduced the soil resistance to penetration at surface (0–0.15 m). Zero tillage resulted in higher infiltration rates, initial as well as steady state (0.120 and 0.029 m/hr where residue retained; 0.108 and 0.028 m/hr where residue removed). Seedling emergence rates were faster in zero-tilled plots without residue for maize and mustard crops, but the quick emergence could not be effectively transformed in producing more biomass or yield. Increase in leaf area was faster under conventionally-tilled plots with residue incorporation, and the peak leaf area index was also the maximum (3.37 and 5.60 in maize and mustard, respectively). Biomass at maturity differed significantly between conventional and zero tillage, but no difference was observed between residue management practices within same tillage system. Root weight density in maize was significantly higher in conventional tillage with residue incorporation, though at deeper depths, the differences were mostly insignificant. In mustard also, maximum root weight was obtained under conventional tillage with residue incorporation. Although zero tillage optimized water use by 14 and 12% in maize and mustard, respectively as compared to conventional tillage, maximum water-use efficiency was obtained in conventional tillage with residue incorporation, mainly because of maximum yield in maize (2.93 tonnes/ha) and mustard (1.83 tonnes/ha) obtained under the treatment.

**Key words:** Bulk density, Crop growth, Infiltration, Maize, Mustard, Tillage, Water use

The overwhelming effort in increasing agricultural production in India is attributed to several changes facing intensive agriculture like excessive tilling of land, water and fertilizer applications as well as risk in environmental pollution and degradation of soil and water resources

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(Hajabbasi and Hemmat 2000). Of late, it has been established that disturbing the soil too much through tillage operations is not actually required to obtain good crop yields (Prasad *et al.* 2006), and also a major portion of energy (25–30%) in agriculture is utilized for either field preparation or crop establishment (Tomar *et al.* 2006), where conventional tillage is mostly followed. Rising cost of fuel and availability of effective package of practices for conservation tillage are now redefining tillage in India in recent years. However, the impact of conservation tillage on soil physical environment is not always positive and varies from one soil to the other and also between the cropping systems.

Maize (*Zea mays* L.) is the second important summer (*kharif*) crop in India, which is mostly cultivated as rainfed and the average yield is quite low (national average of 1.93 tonnes/ha as against 4.20 tonnes/ha of global average),

indicating a huge scope in bridging the gap. Indian mustard [*Brassica juncea* (L.) Czern. & Coss.], the second most important oilseed crop in India, is also cultivated as rainfed during winter (*rabi*) season using profile-stored soil moisture, which depletes through land preparation making 1 or 2 irrigation necessary for proper germination and seedling establishment. Conservation tillage has been found to be very important in sustaining the rainfed farming. Some useful data showing the effect of various tillage practices in maize and mustard as component crop in different cropping sequences are available, but the same is lacking under maize–mustard cropping system. Hence, a study was conducted to investigate the possible effect of tillage and residue management on soil physical properties, crop growth and yield in maize–mustard system in an Inceptisol in semi-arid climate of north India.

### MATERIALS AND METHODS

Field experiments with conventional tillage, conventional tillage plus crop residue incorporated at sowing, zero tillage where crop residues were removed and zero tillage with crop residue retained over surface at sowing, in maize–mustard cropping sequence have been continuing for 3 years (2004–07) at the research farm of the Institute, New Delhi, in a randomized block design with 3 replications. In maize crop, residue of previous mustard crop was applied @ 2 tonnes/ha, while for mustard, maize residue was applied @ 3 tonnes/ha. In conventionally tilled plots, 1 disk plowing, followed by 2 cultivations by cultivator to a depth of 0.15 m was done. No mechanical seed-bed preparation took place in zero tillage system, seeds and fertilizers were placed in the furrow made by seed drill, keeping rest of the area undisturbed. The soil Typic Haplustept, ranged in texture (0–0.15 m) from loamy sand to sandy loam with pH 8.3 and organic C content of 0.6 g/kg soil.

In the third cropping cycle (2006–07) ‘Maharaja Hybrid’ maize was sown on 15 July with 60 cm (row-to-row) and 20 cm (plant-to-plant) spacing. Sixty kg each of N, P<sub>2</sub>O<sub>5</sub>, 40 kg K<sub>2</sub>O /ha was applied as basal and remaining 60 kg N/ha was top-dressed 4 weeks after sowing. Supplementary irrigations were given as per need. The crop was harvested on 13 October, and ‘Pusa Jai Kisan’ mustard was sown on 24 October. The spacing was 35 cm (row-to-row) and 10 cm (plant-to-plant).

Forty kg each of N and P<sub>2</sub>O<sub>5</sub> /ha were applied as basal before sowing and rest 40 kg N/ha was applied as top-dressing (on 30 days after sowing). One pre-sowing light irrigation and 2 irrigation thereafter (on 35 and 100 days after sowing) were applied. The crop was harvested on 13 March 2007.

Mean temperature during maize and mustard growing seasons were 28.6 and 16.9°C, respectively. *Kharif* rainfall was 263.6, 60.8 and 78.5 mm in July, August and September, respectively. Winter rainfall (between November and March) was 112.9 mm mostly occurring in February and March. Mean open-pan evaporation during rainy (*kharif*) and winter (*rabi*) season were 7.6 and 3.1 mm, respectively.

Soil bulk density (0–0.15 and 0.15–0.30 m), aggregation (0–0.15 m), resistance to penetration (0–0.35 m) and organic and microbial biomass carbon were determined at maize and mustard harvest by following standard procedures. Depth-wise (0–0.15, 0.15–0.30, 0.30–0.45 and 0.45–0.60 m) root samples were collected in maize at flowering (65 days after sowing) using root auger, while whole mustard plant was uprooted twice at vegetative (56 days after sowing) and grain filling (96 days after sowing) stages. The cleaned root samples were dried at 60±5°C for 48 hr, weighed and the root weight density (of maize) was expressed as root weight/volume of soil core; for mustard, total root weight/unit area was calculated. Leaf area index during respective growth stages was monitored by canopy analyzer (LICOR-2100) and crop dry matter accumulation was determined from average biomass of 5 plant samples collected at different stages. An area of 1 m<sup>2</sup> from each plot was harvested for determining the grain yield.

### RESULTS AND DISCUSSION

#### Soil parameter

Addition of residue significantly ( $P<0.05$ ) lowered the bulk density in 0–0.15 m soil layer (Table 1). In maize, this effect was similar under both conventional and zero tillage; however, soil with residue incorporation recorded significantly lower bulk density during mustard. There was no significant difference in bulk density at 0.15–0.30 m depth between the treatments, except that conventional tillage + residue incorporation showed a significant decrease in bulk density compared to both zero tillage and zero tillage +

Table 1 Bulk density (Mg/m<sup>3</sup>) of soil under maize–mustard cropping system

Crop	Soil depth							
	0–0.15 m				0.15–0.30 m			
	Conventional tillage	Conventional tillage+residue incorporation	Zero tillage	Zero tillage+ residue retention	Conventional tillage	Conventional tillage+residue incorporation	Zero tillage	Zero tillage+ residue retention
Maize	1.50 <sup>bc</sup>	1.45 <sup>a</sup>	1.51 <sup>bc</sup>	1.44 <sup>a</sup>	1.58 <sup>a</sup>	1.56 <sup>a</sup>	1.57 <sup>a</sup>	1.55 <sup>a</sup>
Mustard	1.44 <sup>a</sup>	1.39 <sup>b</sup>	1.52 <sup>c</sup>	1.43 <sup>a</sup>	1.54 <sup>ac</sup>	1.52 <sup>bc</sup>	1.55 <sup>a</sup>	1.55 <sup>a</sup>

Values followed by similar letters are not statistically different

residue retention treatments. Significantly lower bulk density under conventional tillage with residue indicated the effect of residue incorporation in reducing the bulk density which has also been widely reported by Monneveux *et al.* (2006).

The mean weight diameter of soil aggregates was significantly higher in residue incorporated/retained plots under both conventional and zero tillage system (Table 2). Similarly, geometric mean diameter was significantly higher in conventional tillage + residue incorporation, except under mustard, where difference between conventional tillage +

residue incorporation and zero tillage + residue retention was non-significant.

In maize, soil organic carbon and microbial biomass carbon were significantly increased in the zero tillage + residue retention than conventional tillage in the surface (0–0.15 m layer) (Table 3). No appreciable difference was observed between other treatments and least organic C was found under tilled plots. The microbial biomass carbon followed the similar trend.

Soil resistance to penetration in 0–0.35 m depth along

Table 2 Soil aggregation under maize–mustard cropping system

Treatment	Mean weight diameter (mm)		Geometric mean diameter (mm)	
	Maize	Mustard	Maize	Mustard
Conventional tillage	0.51	0.63	0.71	0.53
Conventional tillage + residue incorporation	0.43	0.51	0.65	0.47
Zero tillage	0.48	0.59	0.69	0.54
Zero tillage + residue retention	0.42	0.45	0.63	0.50
CD ( $P=0.05$ )	0.04	0.06	0.03	0.03

Table 3 Effect of tillage and residue management on soil organic carbon (SOC) and microbial biomass carbon (MBC) (0–0.15 m depth)

Treatment	SOC (g/kg of soil)		MBC (mg/g of soil)	
	Maize	Mustard	Maize	Mustard
Conventional tillage	5.8	6.4	220	232
Conventional tillage + residue incorporation	6.3	6.6	225	250
Zero tillage	5.7	6.6	223	248
Zero tillage + residue retention	6.7	6.9	253	270
CD ( $P=0.05$ )	0.8	NS	31	35

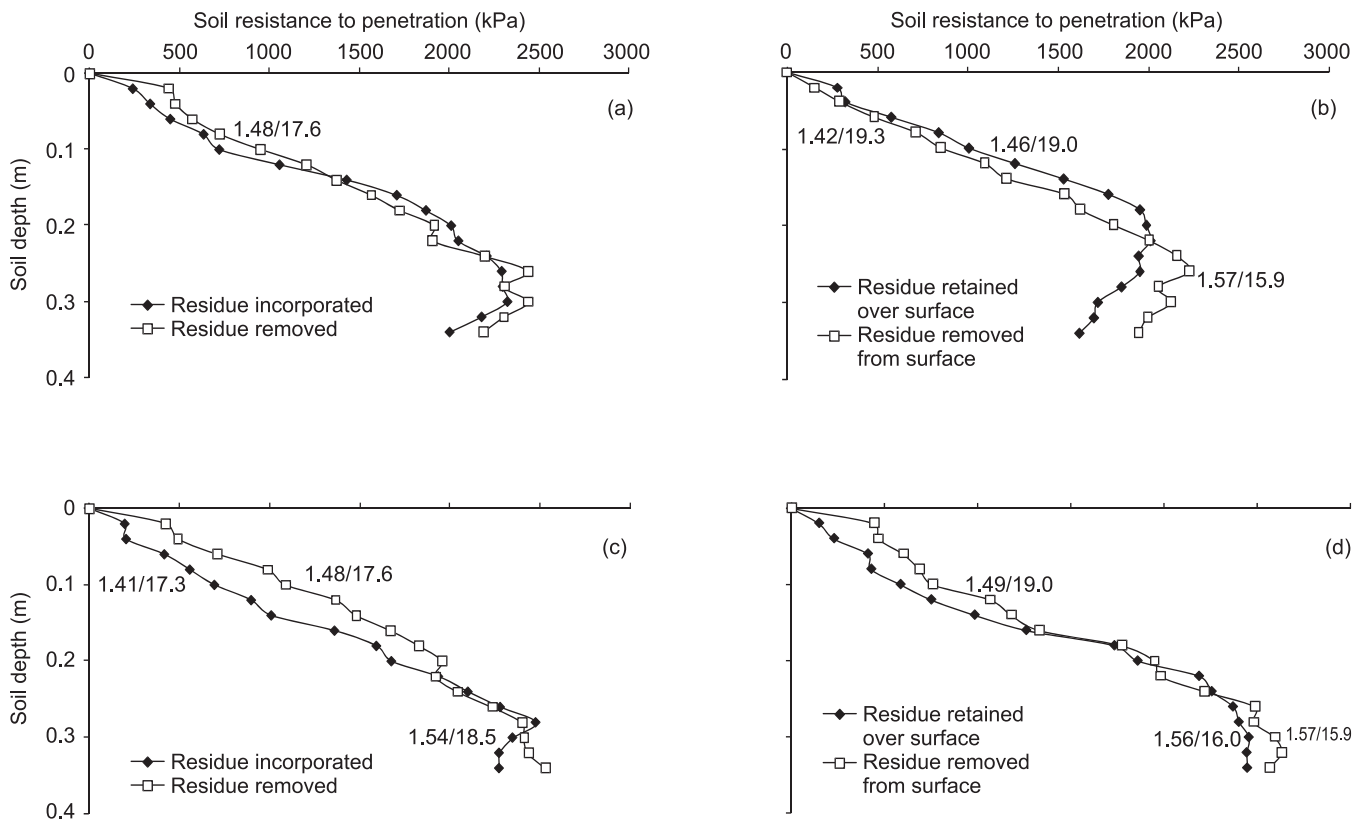


Fig 1 Soil resistance to penetration in maize (a) conventional and (b) zero tillage; and in mustard (c) conventional and (d) zero tillage [values indicate soil bulk density (Mg/m<sup>3</sup>) and moisture content (% v/v) at representative depths]

with its two most influential parameters, bulk density and moisture content at 0–0.15 and 0.15–0.30 m depths (Fig 1) clearly depicts effect of crop residues. Under conventional tillage system, average soil resistance to penetration (0–0.15 m) was less in plots in which residues were incorporated; difference was more prominent in mustard as compared to maize. Similar trend was observed under zero tillage system. In all the treatments, a compact soil zone (>2MPa) beyond 0.25 m was observed. No apparent difference was observed between conventional and zero tillage treatments where residue was removed.

Zero tillage showed considerably higher infiltration, both initial and steady state. Under steady state conditions, cumulative infiltration was highest (0.178 m) in the zero tillage treatment, intermediate (0.169 m) in the zero tillage + residue retention, and the lowest (0.119 m) in both conventional tillage and conventional tillage + residue incorporation treatments (Table 4). Residue-treated plots improved initial water intake, but did not influence steady state infiltration rate (Fig 2). Initial infiltration rate was 0.120 cm/hr in the zero tillage+residue retention treatment, followed by 0.108 m/hr in zero tillage, 0.072 m/hr in conventional tillage+residue incorporation and 0.064 m/hr in conventional tillage treatments. Steady state infiltration rate was 0.028, 0.029, 0.022 and 0.021 m/hr in zero tillage, zero tillage + residue retention, conventional tillage and conventional tillage + residue incorporation treatments, respectively. Green-Ampt and Philip's infiltration models showed better fit to the experimental data and also in characterizing the difference as accrued due to tillage and residue management practices. The sorptivity of soil was found to vary between the treatments; similar is true for parameter 'K' in Philip's model, which is synonymous to the saturated hydraulic conductivity of the surface layer.

Better aggregation in soil with residue incorporation might be attributed to increase in soil organic carbon as well as microbial biomass carbon (Sasal *et al.* 2006) in conventional and zero tillage with residue than corresponding tillage practices without residue (Table 3) or as a result of increased biotic activity, especially earthworm (Birkas *et al.* 2004). Association of improved aggregation and increase in organic

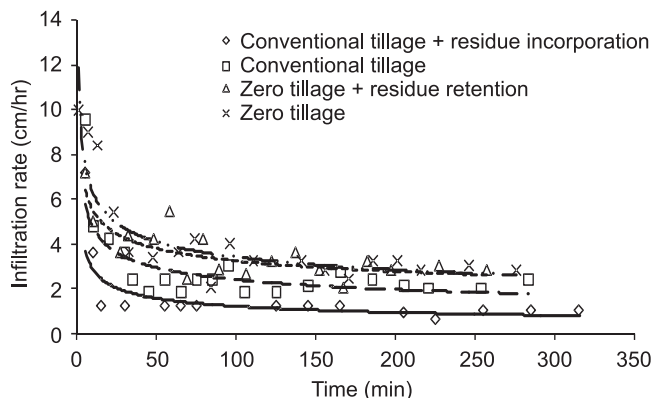


Fig 2 Infiltration rate of soils under different tillage and residue management systems

and microbial biomass carbon was reported elsewhere (Sasal *et al.* 2006, Ozpinar and Cay 2006). Protection of the surface layer by crop residue mulch against the action of falling rain-drops might be the other factor. Our results indicated that where crop residue was incorporated or retained over the surface, the aggregation of the surface soil improved. Zero tillage with residue recorded significantly greater mean weight diameter and geometric mean diameter owing to significantly higher soil organic carbon and microbial biomass carbon. More soil organic carbon and microbial biomass carbon in the zero tillage (with residue retention) was arguably caused by less oxidation of organic matter (crop residue) due to less disturbance of soil by tillage. This might have possibly influenced the infiltration characteristics of the soil where initial water uptake was improved but not the final (steady) infiltration rate. In the absence of so called long-term effects, the macro-channels produced after decay of roots or due to earthworm activities under zero tillage (where the soil is left less disturbed unlike the conventional tillage) are likely to have extended to surface, producing continuity in pores and water movement. The steady state infiltration rate is mostly controlled by the soil profile and less by soil surface; rate of infiltration is higher under zero tillage.

Relatively more compaction below plow layer in the zero tillage (without residue) might be attributed to the continuity

Table 4 Characteristics of soil infiltration parameters as influenced by tillage and residue management practices (I=cumulative infiltration;  $i_0$ =initial;  $i_s$ =final infiltration rates)

Treatment	Green and Ampt $i = i_c + b/I$			Philip $i = (1/2)St^{-1/2} + K$			I (m) for 300 min	$i_0$ (m/hr)	$i_s$ (m/hr)
	$i_c$ (m/hr)	b	$R^2$	S m/hr <sup>1/2</sup>	K m/hr	$R^2$			
<i>With residue</i>									
Conventional tillage	0.017	3.75	0.89	0.29	0.009	0.94	0.119	0.072	0.021
Zero tillage	0.019	8.77	0.85	0.51	0.011	0.83	0.169	0.120	0.029
<i>Without residue</i>									
Conventional tillage	0.017	2.47	0.83	0.21	0.012	0.81	0.119	0.064	0.022
Zero tillage	0.026	9.45	0.73	0.51	0.011	0.87	0.178	0.108	0.028

of macro-pores (due to decay of roots and thereby forming continuous channels) and subsequent movement of soil particles through these pores and their settlement at lower depths, giving a consolidated soil body in deeper depth compared to surface layers.

*Seedling emergence, leaf area index and biomass accumulation in plants*

Seedling emergence was faster in zero-tilled plots without residue for both maize and mustard crops (on 5 days after sowing) and significant differences were observed between the treatments. However, the quick emergence could not be effectively transformed in producing more biomass or yield. Resistance to penetration significantly influenced time for 50% germination in mustard, but no such correlation was obtained in maize.

For all the treatments, leaf area index (LAI) increased in almost similar way and reached its peak values at around 1168°C-d growing degree days (GDD) in maize (Fig 3). The rate of increase in leaf area was more under conventionally-tilled plots with residue incorporation in the soil. The peak LAI under this treatment was significantly higher (3.27) compared with the other treatments. In mustard, LAI was maximum in conventional tillage+residue incorporation (5.6) followed by conventional tillage (5.3), difference being insignificant. However, the peak LAI significantly differed

between zero tillage + residue retention (4.31) and zero tillage (3.16) and also, between conventional and zero tillage systems. Irrespective of treatments, peak LAI in mustard was observed at 1100°C-d GDD, after which senescence of leaves started, coinciding with the pod initiation.

The aboveground biomass for maize was attained at 1681°C-d GDD (coinciding with 88 days after sowing) in all treatments, except in zero tillage + residue retention, where the same was recorded 14 days earlier (1395°C-d GDD) (Fig 4). Maximum biomass differed significantly between conventional and zero tillage, but no difference was observed between residue management practices within same tillage operations (conventional and zero tillage). Though the initial rate of dry matter accumulation was higher in conventional tillage + residue incorporation, finally conventional tillage + residue incorporation and conventional tillage treatments recorded 1 033 and 971 g/m<sup>2</sup> biomass, respectively. Growth of mustard under zero tillage was less compared to conventional tillage, though the peak biomass attained almost at the same time (1 550°C-d GDD). The final biomass was significantly higher in conventional tillage + residue incorporation plots (1 025 g/m<sup>2</sup>), as against 743 g/m<sup>2</sup> in zero tillage plots, differences between other treatments were non-significant. Similar to maize crop, though conventionally-tilled plots without residue could not produce enough biomass initially, the rate of accumulation picked up at a later stage

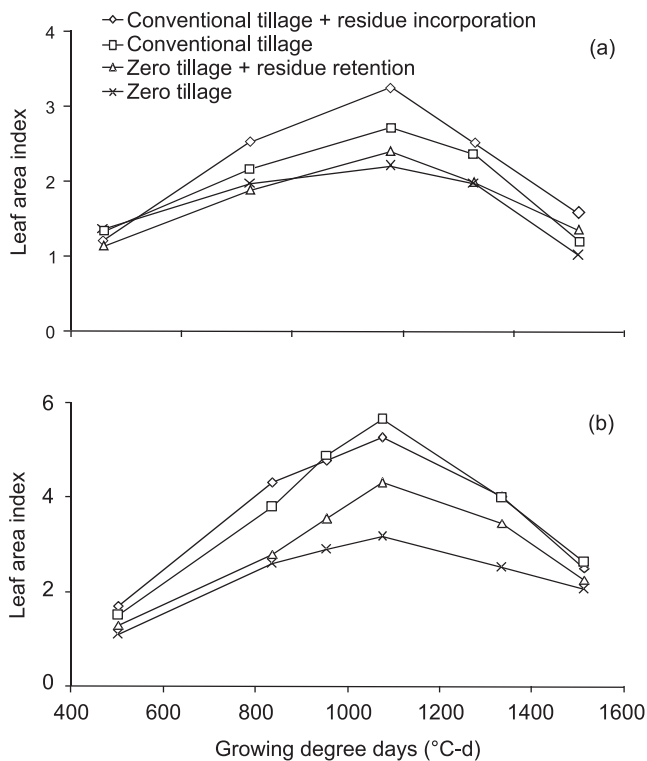


Fig 3 Leaf area index in (a) maize and (b) mustard under tillage and residue management practices (values are means of 3 observations)

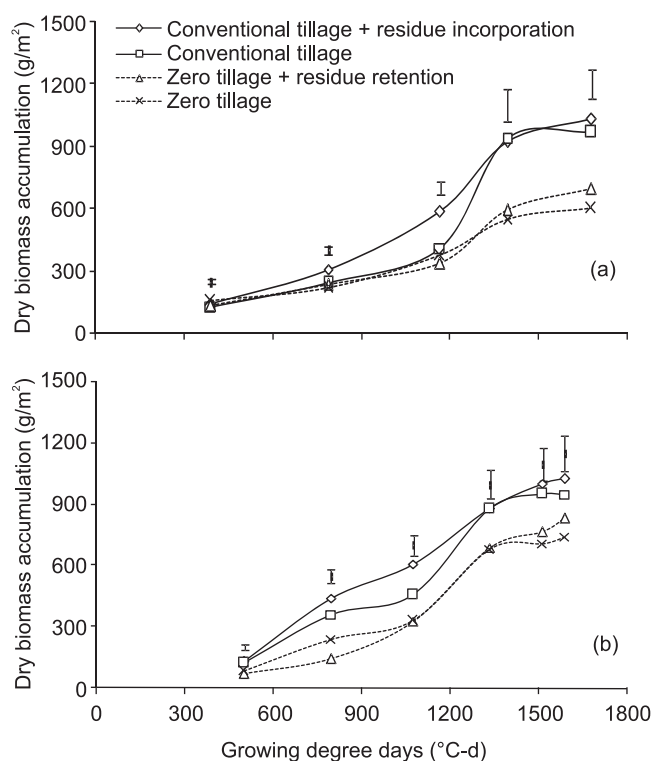


Fig 4 Dry biomass accumulation in (a) maize and (b) mustard under tillage and residue management practices (values are means of 3 plants; vertical bars indicate standard errors of mean)

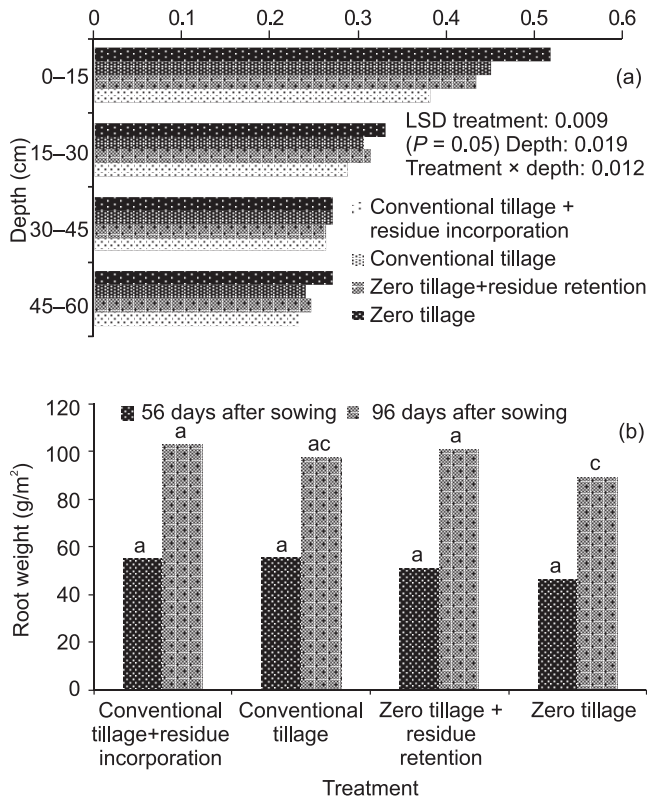


Fig 5 (a) Root weight density in maize and (b) root weight/ unit area in mustard under different tillage and residue management practices (columns within same date followed by different letters are significantly different at  $P < 0.05$ )

to produce biomass at par with residue incorporation practice. No apparent difference in biomass partitioning among different plant parts was observed in either maize or mustard crops.

#### Root biomass

Root weight density in maize was significantly higher in conventional tillage+residue incorporation ( $0.52 \text{ mg/cm}^3$ ), followed by conventional tillage and zero tillage+residue retention ( $0.45$  and  $0.43 \text{ g/cm}^3$ , respectively) and zero tillage ( $0.38 \text{ g/cm}^3$ ) as given in Fig 5. However, at deeper depths, the differences among the treatments were mostly insignificant. In mustard, maximum root biomass was obtained under conventional tillage with residue at both 56 and 96 days after sowing; differences were statistically insignificant ( $P < 0.05$ ) as compared to zero tillage.

#### Yield and water-use

At the study site, during first cropping cycle, both maize and mustard yielded equally well; however, in second cycle, zero tillage resulted in significantly lower yield of maize by 1.0 tonnes/ha and mustard 0.2–0.3 tonnes/ha (IARI 2005–06). Residue application had no effect in the first cycle, but

Table 5 Grain yield and water use of maize and mustard crops

Treatment	Yield (tonnes/ha)		Water-use (mm)	
	Maize	Mustard	Maize	Mustard
Conventional tillage	2.93 <sup>a</sup>	1.83 <sup>a</sup>	287 <sup>c</sup>	189 <sup>b</sup>
Conventional tillage + residue incorporation	2.57 <sup>b</sup>	1.62 <sup>b</sup>	321 <sup>b</sup>	195 <sup>b</sup>
Zero tillage	2.08 <sup>c</sup>	1.59 <sup>c</sup>	254 <sup>a</sup>	165 <sup>a</sup>
Zero tillage + residue retention	1.43 <sup>d</sup>	1.32 <sup>d</sup>	266 <sup>a</sup>	171 <sup>a</sup>

Values followed by similar letters do not differ significantly from each other

showed beneficial effect in the second cycle. In the third cycle in maize, the highest yield was obtained in plots under conventional tillage with residue incorporation (2.93 tonnes/ha), followed by conventional tillage without residue (2.57 tonnes/ha). Yield under zero tillage was 2.08 and 1.43 tonnes/ha with and without residue retention, respectively. Seed yield of mustard followed similar order: 1.83, 1.62, 1.59 and 1.32 tonnes/ha in conventional tillage + residue incorporation, conventional tillage, zero tillage + residue retention and zero tillage treatments, respectively. Though zero tillage optimized water-use by both maize and mustard, as compared to conventional tillage (Table 5), maximum water-use efficiency was obtained in conventional tillage + residue incorporation, mainly because of higher yield and significantly lower water-use than conventional tillage treatment. Zero tillage with residue significantly reduced water-use and maximized water-use efficiency at par with conventional tillage + residue incorporation treatment.

Residue left over the surface in zero tillage hindered the emergence, while residue incorporation under conventional tillage favoured the same. Similar results were reported by Chen *et al.* (2004) and Dam *et al.* (2005). However, faster emergence failed to result in better biomass and yield of crops, which is evidenced by more LAI, biomass and yield of maize and mustard under conventional tillage with residue. In our study, peak LAI was positively and significantly correlated with corresponding yield of maize ( $r=0.77$ ) and mustard ( $r=0.64$ ). Increase in yield under conventional system with residue was associated with better root growth and increased water use by the crop. Similarly, decrease in yield under zero tillage might be attributed to increased soil strength (as evidenced by bulk density and soil penetration resistance values) and consequent retardation in root growth and reduction in water utilization from deeper layers. In another study, biomass and grain yield of maize were reduced under zero tillage in wet season but not affected during the dry season (Monneveux *et al.* 2006). High seasonal water use and water-use efficiency (because of maximum utilization of increased water uptake for producing higher yield) in conventional system than zero tillage could also be explained

by increased root dimensions and soil mulch on the surface in tilled plots.

Soil physical parameters mostly showed significant improvement under conventional tillage with residue incorporation which facilitated better root development in maize and mustard and resulted in more leaf area, biomass and subsequently higher yields of the crops. Residue incorporation under conventional tillage also reduced soil compaction significantly. Yield reduction under zero tillage was more pronounced in maize than mustard due to perennial weed problem and tilling the land once in 2–3 years is recommended under maize–mustard cropping system under similar set of conditions as in the present study.

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