



## Effect of tillage practices and residue management on soil quality and crop yield under maize (*Zea mays*)-based cropping system in Mollisol

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### ABSTRACT

A field experiment was conducted during rainy (*kharif*) and winter (*rabi*) seasons of 2007–08 and 2008–09 to evaluate the feasibility and suitability of tillage and residue management practices for soil physico-chemical properties, irrigation water requirement, yield attributes and yield of maize (*Zea mays* L.) in maize–maize crop rotation on Mollisol. Methods comprised the tillage and residue management namely zero tillage with (ZT<sub>+</sub>) or without maize residue (ZT<sub>-</sub>), raised fresh bed (RFB), permanent raised bed with partial maize residue (PRB<sub>+</sub>) and convention tillage (CT). The different tillage and residue management practices could potentially lead to significant difference in soil organic carbon (SOC) content, bulk density and irrigation water requirement. Inclusion of partial crop residue remarkably improved SOC content by 12.60%, bulk density by 6.27% and reduced irrigation water by 18.88% over traditional method. Anthesis silking interval (ASI) was found non-significant among different tillage methods but was smaller in crop residue incorporated tillage methods. Tillage systems had significant influence on grain yields in both the seasons. Maximum grain yield was obtained in RFB, followed by CT and least with ZT<sub>-</sub> in both the seasons. Raised fresh bed being statistically at par with CT resulted in significant increase in mean grain yield by 20.8 and 19.6 % (*kharif*) and 22.5 and 15.3 % (*rabi*), respectively, over the ZT<sub>-</sub>. The maximum saving of irrigation water in *kharif* (12.3%) and *rabi* (10.6 %) was noticed with RFB. Grain yield was significantly and negatively correlated (–0.958\*, –0.955\*) with bulk density during both seasons. Soil properties, irrigation water requirement and grain yield were highly linearly related to different tillage methods in both the seasons.

**Key words:** Maize, Mollisol, Physico-chemical properties, Residue management, Zero tillage

The impact of a zero tillage and crop residues management associated with soil health and quality by improving soil properties, minimizing soil erosion, soil water evaporation and conserving soil moisture is well documented. Hence reduced tillage practices have been widely used in the last decades as an attractive alternative over conventional tillage practices because of their potential to reduce production/operating costs and benefit for the environment and can save considerable time with seedbed preparation compared with conventional tillage practices (Al-Kaisi and Yin 2004). However, yield variability with reduced or zero tillage methods still remains a major concern among maize growers. Delayed early plant growth due to higher mechanical

impedance of soil, poor crop establishment and low plant stands may be the primarily associated causes of low maize grain yields on conservation tillage methods (Fischer *et al.* 2002). A number of studies have reported that maize yields were similar with zero tillage as to that of traditional tillage systems. But most of research has shown a great variability in corn yield response to no-tillage treatments, which often depends on previous crop and soil drainage characteristics. A number of field studies have been conducted to determine the effects of varying tillage practices on the soil surface residue cover, soil water distribution and maize production but more efficient moisture use and improved soil physical properties associated with zero tillage are often cited as reasons for the success of zero tillage systems on well-drained soils (Griffith *et al.* 1986, Drury *et al.* 2003). Raised beds are widely used in agriculture in developed countries and have proven to be an excellent option for wheat and hence have become very popular in irrigated, high-yielding, and wheat-growing areas of Mexico (Sayre and Moreno Ramos 1997). Similarly permanent raised beds may also

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offer benefits for rice–wheat systems in South Asia, in terms of both production and the possibility that furrow-irrigation may be more efficient than flood irrigation. In India many research evidences have indicated promises to maintain the productivity of different cropping systems by modifying the tillage and planting systems (Parihar 2004, Yadav *et al.* 2005). Since the *tarai* soils are dominated with intensive rice-wheat cropping system over last few decades and due to immense indiscriminate use of resources and changing of environmental conditions, this system may not be profitable in future. Hence, maize may be a substitute over this dominant cropping system and may fulfill the future demand of human and animal feed. The impact of various tillage and residue management methods on soil properties, yield attributes and yield of maize as related to seasons, particularly in fine-textured soil of this region has not been studied in detail. Therefore, an attempt was made to find out the effect of different tillage and residue management methods in terms of soil potential and production sustainability of maize crop in Mollisols with maize–maize cropping system.

#### MATERIALS AND METHODS

A field experiment was conducted at Crop Research Centre of GBPUA&T, Pantnagar, in *tarai* region of Uttarakhand, with fixed crop rotation of maize–maize during *kharif* and *rabi* seasons of 2007–08 and 2008–09. The experimental site is located at 28°58′–29°01′N latitude and 79°24′–79°31′E longitude at an altitude of 243.84 m above msl and lies in a narrow belt to the south from the foothills of the Shiwalik range of Himalayas. The climate of the area is humid sub-tropical with an annual rainfall of 1 433 mm, of which more than 85% is received during monsoon season from June to September. Occasional rains occur during winter months also. The maximum temperature may go up to the 43°C in May and minimum below 2°C in January. The experimental soil is derived from the calcareous alluvium, rich in organic matter content, and classified as fine silty, mixed hyperthermic *Aquic Hapludoll* (Deshpande *et al.* 1971). The following five treatments replicated thrice in a randomized block design were taken during the experiment.

| Treatment   | Symbol             |
|---|--------------------|
| T <sub>1</sub> conventional tillage without residue incorporation   | CT                 |
| T <sub>2</sub> zero tillage with one-third residue incorporation  | ZT <sub>1/3</sub>  |
| T <sub>3</sub> zero tillage without residue incorporation   | ZT <sub>0</sub>    |
| T <sub>4</sub> fresh raised beds formed without crop residues incorporation                                   | RFB                |
| T <sub>5</sub> zero tillage with continued reuse of existing raised beds with one-third residue incorporation | PRB <sub>1/3</sub> |

Early maturing composite maize variety Surya was sown in both the years to evaluate the soil health and productivity under different tillage management practices. At initial stage of the experiment establishment, one common pre-sowing

irrigation water of 50 mm was applied in all tillage methods for good crop emergence, followed by further ploughing and planking at field capacity (except ZT) for seed bed preparation. One third nitrogen, total phosphorus and potassium @ 120, 60 and 40 kg/ha, respectively, were applied as basal in all the treatments and rest of the nitrogen at two stages, i.e. at knee-high and tasseling stage. Raised beds are then prepared with the help of raised bed planter and sowing of seeds was done by zero till seed-cum-fertilizer drill in ZT method and manually in rest of the methods. The irrigation was applied in the crop according to crop growth stages and before and after each irrigation, soil samples were collected at 15 cm interval up to 90 cm depth and soil moisture contents were measured gravimetrically and then depth of irrigation water was determined. The surface soil samples (0–15 cm) were collected from individual treatment before the sowing of crop in each season, then air dried and processed. The samples were analyzed for soil pH, electrical conductivity in 1:2 soil: water suspension, oxidizable organic carbon (OC) by following the standard methods as suggested by Jackson (1973) and bulk density by core method (Baver 1956). Total number of plant stand and cobs were counted from each plot at the time of harvest and converted into per hectare basis whereas average value of five randomly selected plants from each plot were used to calculate plant height, ASI and dry root biomass. Average per plant dry root biomass taken after harvesting was then multiplied by total plant population and converted to hectare basis. Grain yield of each plot was recorded at 15% moisture content on a dry weight basis and then yield/ha was calculated. Statistical analysis of data was carried out according to the procedure of Snedecor and Cochran (1982) and simple correlation coefficients among relevant soil physico-chemical properties, yield attributing parameters, yield and required irrigation water were performed by applying the standard statistical procedures as suggested by Neter and Wasserman (1974).

#### RESULTS AND DISCUSSION

##### *Effect of tillage practices on soil physico-chemical properties*

The soil SOC and bulk density among different tillage methods ranged from 7.28 to 7.55 g/kg and 1.34 to 1.38 Mg/m<sup>3</sup> and 7.36 to 8.22 g/kg and 1.34 to 1.46 Mg/m<sup>3</sup> in *kharif* and *rabi* seasons, respectively (Table 1). No significant effect of different tillage practices on the soil properties, viz soil reaction and electrical conductivity was noticed in any season over the period of study. Conventional tillage and RFB, in general, resulted higher soil pH and electrical conductivity in both the seasons to those found in other tillage methods. Tillage systems had significant influence the soil bulk density in both the seasons. Zero tillage without residue incorporation (ZT<sub>0</sub>) was found to be increased soil bulk density from 1.5–3.0% and 2.1–9.0% in *kharif* and *rabi* seasons, respectively, over the other methods, followed by treatments receiving

crop residue ( $ZT_{+r}$  and  $PRB_{+r}$ ). But no changes in bulk densities were observed between CT and RFB in both the seasons. Gosselink and Hatton (1984) in marsh soils found that bulk density was entirely determined by mineral matter and independent of organic carbon content. Moreover, bulk density did not show any clear relationship with the soil organic C content. Tillage methods significantly influenced organic C content in *rabi* season while in *kharif* no significant changes have been found. In general, treatments receiving crop residue contained higher soil organic C content than other tillage methods resulted enhancing of soil organic C in  $ZT$  (2.2–2.6, 7.0–11.7%) and permanent raised bed methods (3.3–3.7 and 6.5–11.1%) in *kharif* and *rabi* seasons, respectively, over other methods. The increase in soil organic C content with inclusion of residue was also reported by Sarora and Lal (2003). Zero tillage without residue ( $ZT_{-r}$ ) had significantly higher organic C than CT in *rabi* but in *kharif* it was statistically at par. In contrast, the organic C content in *rabi* season was found relatively higher in all methods to the respective methods of *kharif* season which might be due to the higher temperature which stimulate microbial activity to a greater extent in *kharif* resulting in rapid decomposition of crop residue.

#### Irrigation water requirement

Average required irrigation water of *kharif* and *rabi* seasons of both the years ranged from 172 to 207.3 mm and 448.0 to 552.3 mm received 1576.8.1 mm and 35.6 mm average rain (Figs 1a, 1b), respectively, indicating that intensity of rainfall decreased the irrigation water demand. No significant effect on irrigation water requirement was obtained under various tillage practices. The residue retention

methods resulted less water requirement which is most likely due to low percolation of water caused by more conserve of organic carbon and increased bulk density. The different tillage methods followed the water use trend of  $CT > ZT_{-r} > ZT_{+r} > FRB > PRB_{+r}$  in *kharif* and  $CT > ZT_{-r} > FRB > ZT_{+r} > PRB_{+r}$  in *rabi* season. Although  $ZT_{-r}$  saved 4.5 and 6.8 % water compared to CT but produced 16.4 and 13.3% less grain yield (Tables 1, 2) in *kharif* and *rabi* seasons, respectively, suggested that the *rabi* season had more pronounced benefit over *kharif*. Moreover, inclusion of partial crop residue either in  $ZT$  or RPB helped in achieving equal productivity as of CT with saving irrigation water. However, in general, amount of irrigation water increased grain yields in both seasons.

#### Yields attributes and yield of maize

Total plant stand with each of the five tillage systems did not differ significantly in both seasons. Conventional tillage 71.3 ('000/ha) and RFB 85.5 ('000/ha) did show the superiority of the plant stand in *kharif* and *rabi* season, respectively, over the other methods, whereas  $ZT_{-r}$  produced least plant stand in both seasons (Table 2). In contrast, on comparing the total plant stand of each method in *rabi* season with respective methods in *kharif* season, it was found 4.4–24.3% higher in *rabi* than *kharif* season. This could be attributed to the unfavorable soil conditions enhanced by heavy precipitation (Fig 1a) during initial period of maize growth in *kharif* season. In  $ZT_{-r}$  the number of plants was lowered by 5.5 and 7.0% in *kharif* and *rabi* seasons, respectively, compared with CT. Memon *et al.* (2011) also reported that no-tillage reduced corn emergence by 5.2% compared with conventional tillage. By contrast, plant density

Table 1 Effect of tillage practices on physico-chemical properties and water requirement under different tillage methods over two years (pooled data for two years)

| Treatment                         | pH  | EC (dS/m) | Organic C (g /kg) | Bulk density (Mg /m <sup>3</sup> ) | Irrigation water required (mm) |
|-----------------------------------|-----|-----------|-------------------|------------------------------------|--------------------------------|
| <i>Kharif</i>                     |     |           |                   |                                    |                                |
| Conventional tillage              | 7.2 | 0.34      | 7.30              | 1.34                               | 207.3                          |
| Zero tillage with residue         | 7.2 | 0.31      | 7.47              | 1.36                               | 193.3                          |
| Zero tillage without residue      | 7.1 | 0.32      | 7.31              | 1.38                               | 198.0                          |
| Raised fresh bed                  | 7.2 | 0.33      | 7.28              | 1.34                               | 181.7                          |
| Permanent raised bed with residue | 7.0 | 0.33      | 7.55              | 1.36                               | 172.0                          |
| SEm±                              | 0.1 | 0.01      | 0.02              | 0.01                               | 3.45                           |
| CD (P=0.05)                       | NS  | NS        | NS                | 0.02                               | 11.3                           |
| <i>Rabi</i>                       |     |           |                   |                                    |                                |
| Conventional tillage              | 7.3 | 0.35      | 7.36              | 1.34                               | 552.3                          |
| Zero tillage with residue         | 7.0 | 0.32      | 8.22              | 1.43                               | 475.0                          |
| Zero tillage without residue      | 7.1 | 0.33      | 7.68              | 1.46                               | 515.0                          |
| Raised fresh bed                  | 7.3 | 0.35      | 7.46              | 1.34                               | 493.7                          |
| Permanent raised bed with residue | 7.0 | 0.30      | 8.18              | 1.42                               | 448.0                          |
| SEm±                              | 0.1 | 0.01      | 0.02              | 0.03                               | 11.05                          |
| CD (P=0.05)                       | NS  | NS        | 0.05              | 0.08                               | 36.03                          |

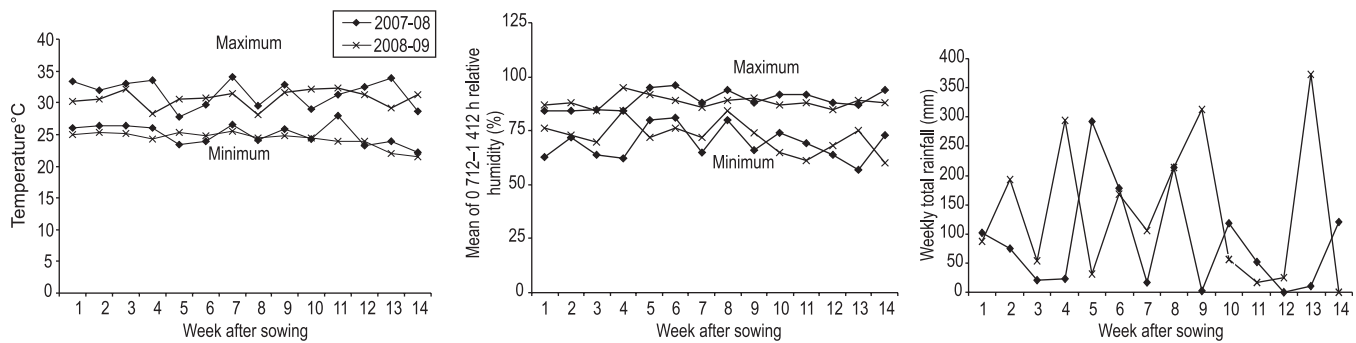


Fig 1a Variation in weather parameters (weekly average) during *kharif* seasons (18 June – 30 September, 2007 and 2008)

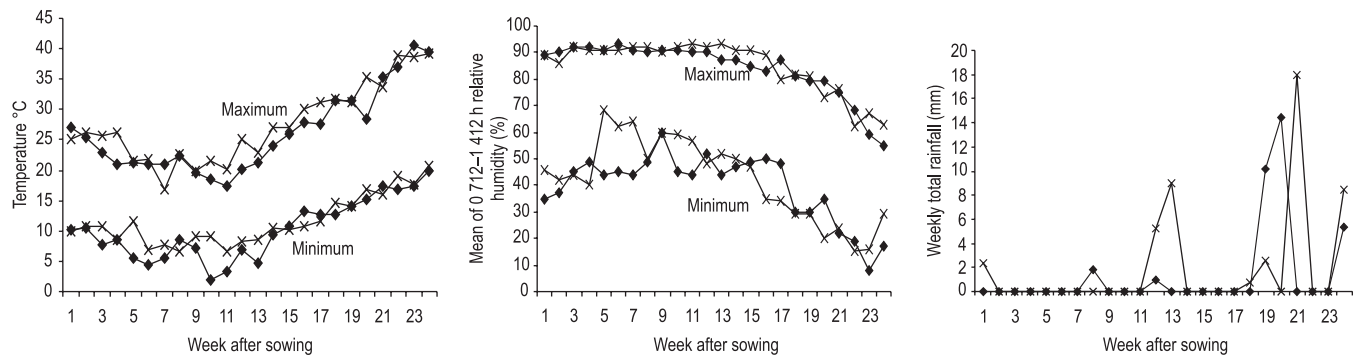


Fig 1b Variation in weather parameters (weekly average) during *rabi* seasons (19 November – 22 April 2007 and 2008)

of corn following alfalfa was found to be significantly higher under no-tillage than CT (Karunatilake *et al.* 2000). The plant height varied significantly ( $P < 0.05$ ) among the different treatments in both the seasons. RFB had produced highest and statistically at par plant stand with other methods except  $ZT_{-r}$ . Moreover, plant heights under all tillage methods were recorded higher in *kharif* over the respective methods in *rabi* season. The maximum cobs number in *kharif* was recorded with RFB (124.9 '000/ha) whereas  $ZT_{+r}$  showed highest cobs number (127.2 '000/ha) in *rabi* season. It is interesting to note that while producing the maximum cobs with  $ZT_{+r}$  in *rabi* season it resulted less grain yield than other methods except  $ZT_{-r}$ . It might be attributed to variation in cob size and length. The abundance of dry root biomass in both seasons was affected by tillage practices significantly and independently with the range of 519.5–938.7 kg/ha and 385.9–997.9 kg/ha in *kharif* and *rabi* seasons, respectively. Fresh raised bed had produced remarkably highest dry root mass, followed by CT in both the seasons which could be due to better physical environment under bed planting in terms of lower soil resistance to root penetration and thereby allow roots to freely explore the soil for water and nutrients availability to roots (Jat *et al.* 2005). Inclusion of partial crop residue slightly increased the amount of dry root mass over the  $ZT_{-r}$  in both seasons suggested that crop biomass could improve soil physical properties leading to improve root growth. Over all, in general, the difference of yield attributes

between respective tillage methods had to be found more in *rabi* than *kharif* season. Among different methods, the differences for ASI were found non-significant, however, ASI was smaller in crop residue incorporated methods compared to other treatments in both the seasons. The smaller ASI could be equated with greater water uptake, moisture conservation and a reduced level of plant water stress (Monneveux *et al.* 2005). However, delayed tasselling and silking in those treatments where soil moisture availability was relatively less suggested that, increase in ASI is an indication of crop susceptibility to moisture deficit at flowering (Bazinger *et al.* 2000). Average grain yields across the two years of the study were significantly different among tillage methods which varied from 3.41–4.12 and 3.65–4.47 tonnes/ha in *kharif* and *rabi* seasons, respectively. Mean maximum and grain yields were noted in RFB while minimum with  $ZT_{-r}$  in both seasons where  $ZT_{-r}$  drastically reduced the yields from 0.22–0.71 and 0.22–0.82 tonnes/ha in *kharif* and *rabi*, respectively, over other methods while with partial residue addition yields increased in both seasons. Grain yields were increased to 19.6 and 15.6% in CT and 20.8 and 22.5 % in RFB than  $ZT_{-r}$  in *kharif* and *rabi*, respectively. In addition to this, RFB being statistically at par with conventional tillage resulted higher grain yields over zero tillage (Chopra and Angiras, 2007). The poor grain yield in  $ZT_{-r}$  may be associated with poor seed germination and plant establishment restricted early root development and variable

Table 2 Effect of tillage practices on yield and yield attribute parameters under different tillage methods over two years (pooled data for two years)

| Treatment                         | Plant stand ('000/ ha) | Plant height (cm) | Cobs no. ('000/ ha) | Dry root mass (kg/ ha) | ASI (days) | Yield (tonnes/ha) |
|-----------------------------------|------------------------|-------------------|---------------------|------------------------|------------|-------------------|
| <i>Kharif</i>                     |                        |                   |                     |                        |            |                   |
| Conventional tillage              | 71.3                   | 210.0             | 115.7               | 609.6                  | 4.7        | 4.08              |
| Zero tillage with residue         | 69.6                   | 210.0             | 102.7               | 524.2                  | 4.6        | 3.64              |
| Zero tillage without residue      | 65.8                   | 195.0             | 95.2                | 519.5                  | 4.7        | 3.41              |
| Raised fresh bed                  | 68.8                   | 212.0             | 124.9               | 938.7                  | 4.7        | 4.12              |
| Permanent raised bed with residue | 68.4                   | 211.7             | 119.8               | 605.6                  | 4.3        | 3.88              |
| SEm±                              | 2.32                   | 3.37              | 10.35               | 68.96                  | 0.17       | 0.76              |
| CD ( $P=0.05$ )                   | NS                     | 11.0              | NS                  | 224.76                 |            |                   |
|                                   | NS                     | 2.48              |                     |                        |            |                   |
| <i>Rabi</i>                       |                        |                   |                     |                        |            |                   |
| Conventional tillage              | 85.3                   | 170.5             | 126.4               | 607.70                 | 4.9        | 4.21              |
| Zero tillage with residue         | 73.9                   | 166.7             | 127.2               | 561.97                 | 4.7        | 3.87              |
| Zero tillage without residue      | 68.7                   | 154.0             | 122.6               | 385.95                 | 4.8        | 3.65              |
| Raised fresh bed                  | 85.5                   | 172.0             | 120.6               | 997.90                 | 4.9        | 4.47              |
| Permanent raised bed with residue | 77.4                   | 169.0             | 124.5               | 602.93                 | 4.8        | 3.93              |
| SEm±                              | 4.19                   | 2.37              | 1.90                | 63.84                  | 0.20       | 1.86              |
| CD ( $P=0.05$ )                   | NS                     | 7.74              | NS                  | 208.08                 | NS         | 6.06              |

stunting as a consequence of increased compactness in the soil surface even under wet conditions. On the other hand, Thiagalingam *et al.* 1991 found a superiority of zero tillage over conventional tillage. Permanent bed with residue retention yielded the same as ZT<sub>r</sub> in both seasons, with the advantage that more varied weeding and fertilizer application practices are possible.

#### *Correlation among soil properties, irrigation water requirement and yield*

The relationship computed among soil properties, irrigation water requirement, yield and yield attributes implied that soil pH and electrical conductivity, in general, did show positive and non-significant relation with most of the yield attributes but bulk density and org. C were found to be correlated negatively under different tillage methods during

both the seasons (Table 3). Grain yield showed negative correlation with bulk density, organic C and irrigation water during both the seasons (Table 4) but bulk density was significantly and negatively correlated ( $-0.958^*$ ,  $-0.955^*$ ). In general, other soil properties and yield attributes were non-significantly and positively correlated (Table 3). Organic C, bulk density, irrigation water requirement and grain yield, in general, are directly related to magnitude of tillage operation. The linear correlations obtained between soil properties, irrigation water requirement and grain yield and different tillage methods, in general, seem to be strong in both the seasons. Organic C content was strongly correlated in *kharif* ( $R^2=0.87$ ) than *rabi* ( $R^2=0.61$ ) due to the addition of crop residue and intensity of tillage operation but bulk density and grain yield, on the other hand, had almost equal strong correlations in both the seasons (Fig 1). Rapid

Table 3 Maize yield and yield parameters correlation with soil physico-chemical properties and required irrigation water over seasons (pooled data for two years)

| Parameter                | <i>kharif</i> |               |         |             |                          | <i>rabi</i> |               |         |             |                          |
|--------------------------|---------------|---------------|---------|-------------|--------------------------|-------------|---------------|---------|-------------|--------------------------|
|                          | Plant stand   | Dry root mass | ASI     | Grain yield | Irrigation water applied | Plant stand | Dry root mass | ASI     | Grain yield | Irrigation water applied |
| pH                       | 0.363         | 0.171         | 0.946*  | 0.159       | 0.593                    | 0.792       | 0.550         | 0.857   | 0.782       | 0.730                    |
| EC                       | 0.466         | 0.365         | 0.035   | 0.752       | 0.057                    | 0.580       | 0.379         | 0.656   | 0.612       | 0.856                    |
| Org. C                   | 0.072         | -0.412        | -0.909* | -0.148      | -0.445                   | -0.562      | -0.347        | -0.880* | 0.566       | -0.839                   |
| Bulk density             | -0.823        | -0.674        | -0.173  | -0.958**    | -0.012                   | -0.985**    | -0.771        | -0.805  | -0.955*     | -0.423                   |
| Irrigation water applied | 0.263         | -0.390        | 0.741   | 0.178       |                          | 0.286       | -0.113        | 0.560   | -0.955*     |                          |

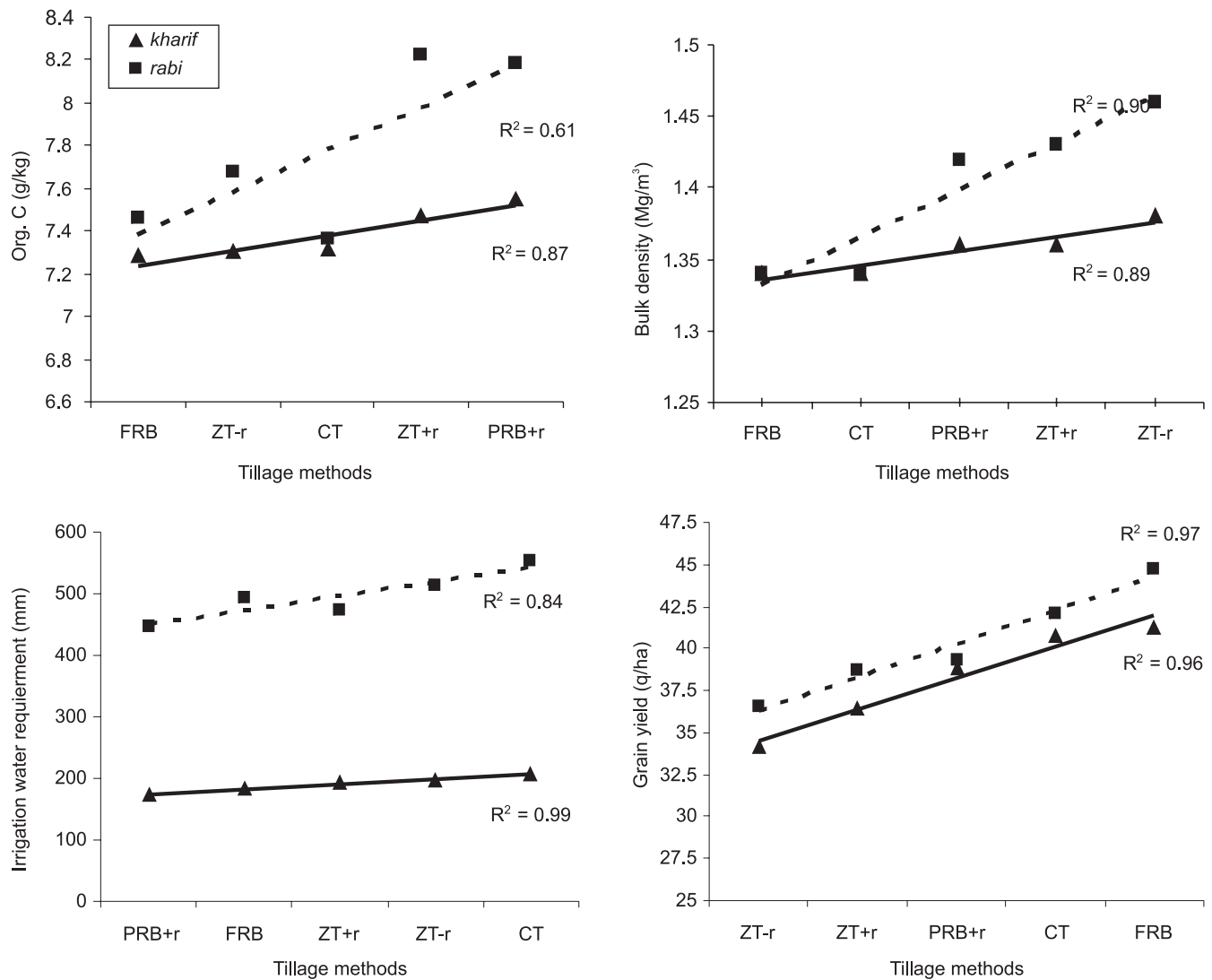


Fig 2 Linear correlation between soil properties, irrigation water requirement and grain yield and different tillage methods over two years

decomposition of crop residues owing to high temperature and moisture availability in *kharif* could be attributed to strong relation of organic carbon with tillage practices than that of *rabi* season. Irrigation water requirement during *kharif* season was more closely correlated ( $R^2 = 0.99$ ) suggesting a strong relationship with tillage methods.

On the basis of study it may be concluded that zero tillage practice in fine-textured *tarai* soil was noticed poorest method of tillage than other tillage methods and inclusion of partial residue on the field is critical for zero tillage practices. Hence, ZT<sub>r</sub> may be unsuitable for heavier textured soils due to restricted root development, plant stand, plant height and grain yield in *kharif* and *rabi* seasons. However, it may take some more time before the benefits are evident. After that, zero tillage with residue retention may be resulted in higher and more stable yields than other tillage and residues management practices. Conventional tillage resulted in intermediate yields. Permanent raised beds combined with

rotation and residue retention yielded almost same as the zero tillage with residue retention, with the advantage that more varied weeding and fertilizer application practices are possible. Overall, raised fresh beds had been observed superior in terms of yield deciding factors and yield over other.

#### REFERENCES

- Al-Kaisi M M and Yin X. 2004. Stepwise time response of corn yield and economic return to no tillage. *Soil and Tillage Research* **78**: 91–101.
- Baver L D. 1956. *Soil Physics*. 3<sup>rd</sup> edn. Jhon Wiley and Sons, New York.
- Bazinger M E, meades G O, Beck D and Bellon M. 2000. *Breeding for Drought and Nitrogen Stress Tolerance Maize: From Theory to Practice*, 68 pp, Mexico, D F CIMMYT
- Chopra P and Angiras N N. 2007. Influence of tillage and weed control methods on growth, productivity and quality of maize (*Zea mays* L.). *Journal of Crop and Weed* **3** (2): 10–4.
- Deshpande S B, Feherenbacher J B and Ray B W. 1971. Mollisols

- of *tarai* region of Uttar Pradesh, Northern India, 2. Genesis and Classification. *Geoderma* **6**:195-201.
- Drury C F, Tan C S, Renolds W P, Welacky T W, Weaver S E, Hamill A S and Vyn T J. 2003. Impacts of zone tillage and red clover on corn performance and soil physical quality. *Soil Science Society of America Journal* **67**: 867-77.
- Fischer R A, Santiveri F and Vidal I R. 2002. Rotation, tillage and crop residue management for wheat and maize in the sub-humid tropical highlands: II. Maize and system performance. *Fields Crop Research* **79** (2-3): 123-37.
- Gosselink J G and Hatton R. 1984. Relationship of organic carbon and mineral content to bulk density in Louisiana marsh soils. *Soil Science* **137**(3): 177- 80.
- Griffith D R, Kladviko E J, Mannering J V, West T D and Parsons S D. 1988. Long-term tillage and rotation effects on corn growth and yield in high and low organic matter poorly drained soils. *Agronomy Journal* **80**: 559-605.
- Jackson M.L. 1973. *Soil Chemical Analysis*. Prentice Hall of India Pvt. Ltd, New Delhi.
- Jat M L, Srivastava A, Sharma S K, Gupta R K, Zaidi P H, Rai H K and Srinivasan G. 2005. Evaluation of Maize-wheat cropping system under double-no-till practice in Indo-Gangetic Plains of India. *Japan Association for International Collaboration of agriculture and Forestry*. **28**(1): 25-42.
- Karunatilake U, Van Es H M and Schindelbeck R R. 2000. Soil and maize response to plow and no-tillage after alfalfa-to-maize conversion on a clay loam soil in New York. *Soil and Tillage Research* **55**: 31-42.
- Memon S Q, Zakria M, Mari G R, Nawaz M H and Khan Z. 2011. Effect of tillage methods and fertilizer levels on maize production. *Pakistan Journal of Agricultural Sciences* **48** (2) : 117-20.
- Monneveux P, Quillerou E, Sanchez C and Lopez C J. 2005. Effect of zero tillage and residues conservation on continuous maize cropping in a subtropical environment (Mexico). *Plant and Soil* **279** (1-2) 95-105.
- Neter J and Wasserman W. 1974. *Applied Linear Statistical Models*. Richard D. Irwin. Inc., Homewood, Illinois.
- Parihar S S. 2004. Effect of crop establishment method, tillage, irrigation and nitrogen on production potential of rice (*Oryza sativa*)—wheat (*Triticum aestivum*) cropping system. *Indian Journal of Agronomy* **49**(1): 1-5.
- Sayre K D and Moreno Ramos O H. 1997. Application of raised bed planting system to wheat. *Wheat Program Special Report No. 31*. CIMMYT, Mexico, D.F.
- Sarora G S and Lal R. 2003. Soil restorative effects of mulching on aggregation and carbon sequestration in a Miamian soil in Central Ohio. *Land Degradation Development* **14**: 481-93.
- Snedecor G W and Cochran W G. 1982. *Statistical Method*, 7<sup>th</sup> edn. Iowa State Univ. Press, Iowa, USA.
- Thiagalagam K, Gould N and Watson P. 1991. Effect of tillage on rainfed maize and soybean yield and the nitrogen fertilizer requirements for maize. *Soil and Tillage Research* **19**: 47-54.
- Yadav V P S, Raman R S, Kumar R, Kumar R and Bhela S L. 2005. Zero-till technology – A boon for paddy wheat growers. *Lead papers and abstracts of National Seminar on Green to Evergreen: Challenges to Extension Education*, pp 93-5, held during 15-17 December 2005 organized by ISEE at Division of Agriculture Extension, IARI, New Delhi.