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Soil health as affected by altered land configuration and conservation tillage in a groundnut (*Arachis hypogaea*) - *toria* (*Brassica campestris* var *toria*) cropping system

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ABSTRACT

A field experiment was conducted during the year 2009-11 at ICAR Research Complex for North Eastern Hill Region (NEHR), Meghalaya to study the influence of land configuration and conservation tillage on soil health in a groundnut-*toria* cropping system. The experiment consisted of seven treatments [i. flat bed farmer's practice (FP) no residue; ii. broad beds and furrows (BBF) with residue incorporation; iii. BBF with residue + hedge leaves (*Tephrosia* sp) incorporation; iv. BBF with residue + hedge leaves (no tillage, NT); v. raised bed (RB) with residue incorporation; vi. RB with residue + hedge leaves incorporation; vii. RB with residue + hedge leaves (NT)] laid out in randomised block design and replicated thrice. The conservation treatments were found to significantly improve biological activity and chemical properties of soil. However, physical properties such as texture and bulk density were not significantly affected by any of the treatments. Infiltration rate and hydraulic conductivity were 108% and 46% higher, respectively, in the treatments under RB with residue + hedge leaves (NT) as compared to FP. Soil microbial biomass carbon was 67% higher under RB with residue + hedge leaves incorporation than FP after the harvest of both the crops in the second year while dehydrogenase activity was 135% higher in RB with residue + hedge leaves (NT) after the harvest of groundnut and RB with residue incorporation after the harvest of *toria* than FP, respectively. System productivity under RBs were significantly higher than that recorded under BBF and FB. Conservation treatments showed better soil health at the end of the cropping cycles and it is concluded that raised beds along with residue management can provide an alternative and sustainable technology contributing to sustainable agriculture in the NEHR of India which can be extrapolated to other similar areas..

Key words : Conservation agriculture, Land configuration, Residue management, Soil health

Conventional tillage has been the most common practice for the agricultural production in India. In the hilly tracts of the North eastern hill region (NEHR) of India, clean cultivation is practiced leading to loss of top soil due to steep topography and heavy rains. This leads to loss of top fertile soils due to erosion which is about 40 tonnes/ha in the region as compared to the national average of 16 tonnes/ha and deteriorates the soil health (Singh *et al.* 1981). Moreover, due to the heavy rains the region produces a very large amount of weed biomass which along with a crop residue production of 8.9 million tonnes and organic manure of 47 million tonnes makes the region sufficient for even going organic (Bujarbaruah 2004). Under such situations, *in-situ* residue management and conservation agriculture might be the right proposition for improvement of soil.

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Organic matter affects crop growth and yields either directly by supplying crop nutrients or indirectly by modifying soil physical properties such as stability of aggregates and porosity that can improve the root environment and stimulate plant growth. The use of crop residues, weed biomass, hedge plants biomass etc. can have a beneficial role as mulching materials and supply plant nutrients on decomposition. The need therefore is towards conservation agriculture which is characterized by minimum soil disturbance, leaving and managing the crop residues on the soil surface and adopting spatial and temporal crop sequencing/crop rotations to derive maximum benefits (Abrol and Sagar 2006). Conservation tillage is defined as any tillage practice that minimizes the loss of soil and water, which often requires the presence of at least 30% of the mulch or crop residue on the soil surface throughout the year. Conservation tillage minimizes soil erosion, conserves water within the root zone and improves soil productivity and is being practiced in about 95 million ha worldwide (Derpsch 2005). Alteration of land configuration is also a very good technique for proper land management and utilizing the residual soil moisture effectively for post-monsoon crop cultivation (Saha and Ghosh 2010).

MATERIALS AND METHODS

A field experiment was carried out in the Water Management field of ICAR Research Complex for NEH region, Umiam, Meghalaya located at a latitude of 25^o 41' N, longitude of 91^{o}54'E and an elevation of 980 m from mean sea level during the year 2009-11.The area falls under the mild tropical hill zone and the climate is per-humid. The daily temperature during a year varies widely between 2.5°C (January) and 32.5°C (August). The region receives an average rainfall of 2439 mm with high degree of temporal and spatial variations. Maximum rainfall was received during the month of June 2010 (586.6 mm) and a mean total amount of 2385 mm was received through the crop growing season. The mean total PAN evaporation recorded during the entire cropping period was about 568.8 mm in which highest evaporation was recorded during the month of May 2010 (85.1 mm) and lowest in December 2009 (49.4 mm). Mean maximum and minimum temperature were 28.5°C in August 2010 and 20.4°C in December 2009. Average relative humidity ranged from 79 – 89% in the morning and 57 - 81% in the evening.

The experiment was laid out in a randomized block design and replicated thrice. A groundnut (*Arachis hypogaea* L.) - *toria* (*Brassica campestris*) cropping system was conducted in the experimental site under seven different treatments, viz. Farmer's Practice (FP) (flat bed- no residue- 3 to 4 times ploughing), Length × breadth (LB) = 5 m × 4 m; broad bed and furrow (BBF) with *in situ* residue incorporation, Length × breadth × height (LBH) of broad bed = 4 m × 1.4 m × 0.15 m, LB of furrows = 4 m × 0.4 m; BBF with *in situ* residue + hedge leaves (*Tephrosia candida*) incorporation @ 5 tonnes/ha; BBF with *in situ* residue + hedge leaves retention @ 5 tonnes/ha (No tillage, NT); raised bed (RB) with *in situ* residue incorporation, lbh of raised beds = 5m × 4m × 0.15m; RB with *in situ* residue hedge leaves incorporation @ 5 tonnes/ha and RB with *in situ* residue + hedge leaves retention @ 5 tonnes/ha (NT).

Soil samples were collected initially and after two years of the experimentation and analyzed for important soil properties after the harvest of each crop in the second year only. Three samples were collected from each plot and composited. The collected soil samples were air dried, grinded, passed through 2mm sieve and stored in polythene bags for further analysis. Fresh soil samples at 0-15 cm depth were collected and kept under refrigeration for estimation of soil microbial biomass carbon (SMBC). For the measurement of infiltration rate and hydraulic conductivity *in situ*, two spots were selected at random from each plot and estimated. Hydraulic conductivity was measured by making holes to a depth of 20 cm.

The soil was acidic in nature and classified under *Typic Hapludalf*. The soil was clay loam in texture with a pH of 5.04, 277.48 kg/ha N, 17.14 kg/ha P, 266.38 kg/ha K and organic carbon content of 1.78%. Soil bulk density was estimated by Core Sampler Method (Black, 1965), infiltration rate by Double Ring Infiltrometer (Bouwer 1986), hydraulic conductivity with 2800 K1 Guelph Permeameter, Soil Moisture Equipment Corp., USA, soil organic carbon by Walkley and Black's method (Jackson 1973), available N was estimated by Alkaline Potassium Permanganate Method (Subbiah and Asija 1956), P by Bray and Kurtz No. 1 Method (Jackson 1973), K by Ammonium Acetate Method (Knudsen *et al*. 1982), dehydrogenase activity (DHA) by Triphenyl Formazan reduction method (Casida *et al*. 1964) and SMBC by chloroform fumigation extraction method (Brookes and Joergensen 2006).

The plots were prepared prior to sowing and the leaves and tender twigs of *Tephrosia* (a hedge plant) were cut, chopped and applied to respective plots as per treatment after one ploughing while they were retained in the case of NT plots. Groundnut (ICGS-76) was sown on 7 and 13 of May 2009 and 2010 respectively with a spacing of 40 × 15 cm. In the conservation plots, the weeds and crop residues were retained as per treatment in between the crop rows while they were completely removed from the plots under FP. After harvesting groundnut, the residues along with hedge leaves and twigs were chopped and retained or incorporated as per treatment requirement while they were completely removed in the case of FP. *Toria* (TS 36) was sown on 8 and 12 October 2009 and 2010 respectively with a spacing of 40cm in between the rows. The weed biomass in this case were also retained in between the crop rows in the case of conservation plots and totally removed in the case of farmer's practice. Groundnut received NPK dose of 20:60:40 kg/ha while *toria* received 60:60:40 kg/ha of NPK, respectively. Both the crops were grown with the recommended agronomic practices. The crops were harvested from the plots leaving the outer rows. The samples were sundried to obtain a moisture content of around 14% and then extrapolated to kg/ha basis. Groundnut equivalent yield (GEY) was calculated by multiplying yield of *toria* with its respective price and divided by the market price of groundnut. Data obtained from various studies were statistically analyzed in randomized block design using the technique of Analysis of Variance. The differences between the treatment means were tested as to their statistical significance with appropriate critical difference (CD) value at 5 per cent level of probability (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Soil physical properties

Bulk density

Soil bulk density (data not presented) was not affected significantly by any of the treatments indicating that the application of residues or no tillage for a short period of time do not bring about any significant changes in bulk density of the soil (Stone and Schlegel 2010). Application and incorporation of residues have been reported to decrease soil bulk density after 4-5 years of residue incorporation, however, in present case, the bulk density was not significantly affected by the treatments nor was there any trend relating the biomass input to the bulk density of the surface soil. Dam *et al*. (2005) also reported that the presence of residue did not affect bulk density in any year at any depth in an eleven year experiment carried out on corn under different tillage and residue practices.

Infiltration rate

No-tillage increased the infiltration rate of water at the harvest of *toria*. Infiltration rate was least in FP (7.65 mm/hr) while the highest (11.2 mm/hr) was recorded in case of RB with residue + hedge leaves (NT) (Table 1). Infiltration rates were highest in mulch treated plots due to the presence of organic matter which was instrumental in improving structural stability and thus increasing infiltration rates. The lower infiltration rate in the FP was attributed to poor aggregate size distribution and stability, thereby causing surface crusting. It could probably be due to rapid structural deterioration caused by slacking and dispersion. The results obtained are in conformity with those of Stone and Schlegel (2010) who found that no tillage plots recorded significantly higher infiltration rates compared to conventional tillage.

Hydraulic conductivity (HC)

Hydraulic conductivity (Table 1) after the harvest of *toria* was found to be highest (1.94×10^{-4} cm/sec) in the case of RB with residue + hedge leaves (NT) which was at par with BBF with residue + hedge leaves (NT) and BBF with residue + hedge leaves incorporation. Minimum was recorded in the FP with a value of 0.93×10^{-4} cm/sec and was at par with BBF with residue incorporation, RB with residue incorporation and RB with residue + hedge leaves incorporation. Higher hydraulic conductivities under NT treatment are an indication of better pore continuity and/or presence of large pores and biochannels in the system. This greater pore continuity as a result of minimal soil disturbance is evident from the results obtained and is in accordance with the findings of Singh *et al*. (1995).

Soil chemical properties

Soil pH and organic carbon (SOC)

The various treatments imposed had negligible effect on the soil pH (Table 1). Soil pH was found to change inconsistently between the three depths. In the present experiment, after the harvest of groundnut, slight increases in soil pH could be seen which may be because of the fact that leguminous crops acquire their greater part of nitrogen requirement from the air as diatomic nitrogen rather than from the soil as NO_3 and their net effect lowers the soil pH (Ali and Venkatesh 2009). However, there was no clear tendency of changes in soil pH by the adoption of conservation practices which are in accordance with the findings of Martin-Reuda *et al*. (2007) in studies carried out on tillage and conservation effects on soil properties.

Incorporation of residues and hedge leaves was found to increase the soil organic carbon slightly under the residue managed treatments at 0-15 cm (Table 1) depth after the harvest of both groundnut and *toria*. The differences were however non-significant. In general, soil organic carbon was found to be higher in the 0-15 cm depth of the soil profile and lowered with increase in depth. The increase in the conservation plots might have resulted from the incorporation of crop residues, weeds and hedge leaves which led to the increase of microbial population that hastened decomposition of crop residues resulting in build up of organic carbon in soil. Benjamin *et al*. (2010) also reported higher SOC in no tillage treatments. An increase in organic C was observed under bed planting system than conventional in well drained than poorly drained soils by Goyal *et al*. (2009).

Available nitrogen (N)

Irrespective of the treatments, soil available nitrogen (Table 1) was higher at the surface layer as compared to the sub-surface after the harvest of both groundnut and *toria*. Application of crop residues and hedge significantly increased the soil available N irrespective of the land configuration (Prasad *et al*. 2010). Soil available N showed a decreasing trend after the harvest of *toria* as compared to the harvest of groundnut crop where it increased as compared to the initial values. The highest soil available N (376 kg/ha and 366 kg/ha) was recorded after the harvest of both the crops in RB with residue + hedge leaves incorporation. The lowest (317 kg/ha and 279 kg/ha) was recorded in FP after the harvest of both groundnut and *toria,* respectively. Soil available N was significantly higher in the plots where residues were retained irrespective of the land configurations after the harvest of both the crops. However, the amount was higher after the harvest of groundnut due to the fixation of atmospheric N_2 by groundnut that left varying amounts of nitrogen in the soil as compared to after the harvest of *toria*. In the treatments where hedge leaves and residues were applied, the mineralization of N from the residues could have led to their higher contents. The lower N in the repeatedly tilled FP could also be due to leaching (Martin-Reuda *et al*. 2007).

Available phosphorus (P)

The effect of altered land configuration and residue management on available P could be clearly seen after the harvest of both groundnut and *toria* as compared to FP on flat bed (Table 1). At the surface soil, BBF with residues + hedge leaves (NT) recorded the highest amount of 31 kg available P/ha at the harvest of groundnut which was at par with RB with residue + hedge leaves incorporation (30.5 kg/ha) while at the harvest of *toria*, RB with residue + hedge leaves incorporation recorded the highest available P of 33.1 kg/ha which was at par with BBF with residue + hedge leaves (NT). Minimum amount (19.3 and 17.8 kg/ha) was recorded in the case of FP at the harvest of both groundnut and *toria,* respectively. Irrespective of the land configurations, higher available P was found in the treatments where residues were retained or incorporated as compared to clean cultivation in FP. The higher amounts of available P was due to the application of residues and hedge leaves which reduces the fixation of water soluble P, increases mineralization of organic P owing to better microbial action and thus enhances the availability of P. Under no tillage system, P was found to be higher as compared to the others after the harvest of *toria* as reported by Martin-Reuda *et al*. (2007) in a tillage and crop rotation effect study on soil. Similar increase in P after residue addition was also reported by Prasad *et al*. (2010).

Available potassium (K)

Significant effect on soil available K (Table 1) was exerted by the influence of applied residues and hedge leaves at the surface layer of the soil profile. Soil available K ranged from 229 to 328 kg/ha at the harvest of groundnut. The highest K was recorded in BBF with residue + hedge leaves incorporation (328 kg/ha) and the lowest under of FP (260 kg/ha). At the harvest of *toria*, BBF with residue + hedge leaves incorporation recorded the highest amount of soil available K (316 kg/ha) which was at par with all other treatments except FP which recorded the lowest K (266 kg/ha). The decomposition of organic matters might have resulted in the increase of soil available K which may be attributed to the direct addition of potassium to the available pool of the soil. Prasad *et al*. (2010) reported an increase in K with the incorporation of crop residues over its initial status. The incorporated and retained residues increased the soil organic carbon level in the soil and in turn released more of nutrients (Mina *et al*. 2008, Martin-Reuda *et al*. 2007). Similarly an increase in available K was also observed under bed planting system than conventional planting system in well than poorly drained soils by Goyal *et al*. (2009).

Soil biological properties

Dehydrogenase activity (DHA)

At the harvest of groundnut, DHA (Table 1) was observed to be highest in RB with residue + hedge leaves (NT) (57.8 µg TPF/g soil/24 hr) which was at par with RB with residue + hedge leaves incorporation (53.3 µg TPF/g soil/24 hr) while the least was recorded in case of FP (24.5 ìg TPF/g soil/24 hr). At the harvest of *toria,* DHA at the surface soil showed a maximum of 48.89 µg TPF/g soil/24hr in RB with residue incorporation which was at par with BBF with residue + hedge leaves (NT) (48.0 µg TPF/g soil/24 hr) followed by BBF with residue incorporation while the minimum was in FP with 20.8 µg TPF/g soil/24 hr. Higher DHA under conservation treatments could be attributed to the reduced tillage and retention as well as incorporation of residues and hedge leaves. This increase in DHA points to the greater microbiological activity as a consequence of the addition of residues. The higher microbial activity leads to better decomposition which ultimately releases essential nutrients in the soil required for both plant and microbial growth. The higher organic matter present increases the carbohydrate content which act as an energy source for microbes (Mina *et al*. 2008). Goyal *et al*. (2009) reported higher DHA in well drained bed planting system as compared to the conventional system.

Soil Microbial Biomass Carbon (SMBC)

At the harvest of groundnut, RB with residue + hedge leaves incorporation recorded significantly higher SMBC (381 µg/g soil) in comparison to the other treatments. Minimum value was recorded in FP (228 µg/g soil) (Table 1). SMBC ranged from 165 to 276 µg/g dry soil at the

Table 1 Effect of land configuration and residue management on soil biology and water conductivity

Treatment	At harvest of groundnut		At harvest of *toria*		At harvest of *toria*	
	SMBC (µg/g soil)	DHA (µg TPF/g) soil/24hr)	SMBC (µg/g soil)	DHA (µg TPF/g) soil/24hr)	Hydraulic conductivity (10^{-4} cm/sec)	Infiltration rate (mm/hr)
Farmer's practice (flat bed)	228	24.5	165	20.8	0.93	7.65
BBF with residue incorporation	281	42.8	238	41.1	1.28	8.93
BBF with residue + hedge leaves incorporation	360	49.6	265	25.0	1.67	10.2
BBF with residue + hedge leaves (NT)	290	51.1	254	48.0	1.93	10.9
Raised bed with residue incorporation	267	46.1	248	48.9	1.11	9.25
Raised bed with residue + hedge leaves incorporation	381	53.3	276	28.9	1.30	10.8
Raised bed with residue + hedge leaves (NT)	341	57.8	239	31.4	1.94	11.2
SE (m) ±	3.36	1.47	3.33	1.28	0.16	0.89
CD (P = 0.05)	10.4	4.53	10.3	3.95	0.50	1.32

Table 2 Effect of land configuration and residue management on soil organic carbon (%) and soil available N, P and K at 0-15 cm depth (kg/ha)

Treatment	Initial				At harvest of groundnut				At harvest of *toria*			
	SOC	N	P	K	SOC	N	P	K	SOC	N	P	K
Farmer's practice (flat bed)	1.66	282	17.9	251	1.64	317	19.3	260	1.60	279	17.8	266
BBF with residue incorporation	1.74	287	20.3	304	1.82	335	23.6	325	1.81	289	24.9	308
BBF with residue + hedge leaves incorporation	1.73	298	21.9	285	1.79	374	28.4	328	1.76	300	28.8	316
BBF with residue + hedge leaves (NT)	1.72	306	27.7	305	1.71	349	31.0	312	1.72	307	31.8	310
Raised bed with residue incorporation	1.76	293	21.4	308	1.82	348	24.2	310	1.80	302	25.1	315
Raised bed with residue+ hedge leaves incorporation	1.83	345	27.7	296	1.85	376	30.5	304	1.85	366	33.1	313
Raised bed with residue+ hedge leaves (NT)	1.69	294	21.3	286	1.79	356	25.6	312	1.78	295	22.0	316
SEm ±	0.31	3.67	0.64	4.92	0.24	4.15	1.05	3.57	0.23	3.76	0.89	5.01
CD (P = 0.05)	NS	11.3	1.97	15.2	NS	12.8	3.24	11.0	NS	11.6	2.74	15.4

harvest of *toria*. SMBC was found to be higher in the conservation treatments than in the FB. The lowest SMBC of 165 µg/g of soil was noticed under FB while the highest of 276 µg/g soil was recorded under RB with residue + hedge leaves incorporation both of which were significantly superior to other treatments. The positive response of conservation treatments as compared to the FP was probably due to higher levels of C substrates available for microorganism growth, as well as better soil physical conditions and higher water retention due to the altered land configurations and applied residues. Similar results of higher SMBC under conservation treatments have also been reported by Singh *et al*. (2009). Goyal *et al*. (2009) also reported higher SMBC in bed planting system as compared to the conventional system.

Productivity

During the first year (Table 3), groundnut yield was maximum in RB with residue + hedge leaves incorporation (2 398 kg/ha) while *toria* yield was highest in RB with residue incorporation (497 kg/ha). The minimum yields on the other hand was recorded in BBF with residue + hedge leaves (NT) and FP. GEY was highest after the first year in RB with residue + hedge leaves incorporation (2 720 kg/ha). However, during second year, the highest groundnut yields were obtained from RB with residue + hedge leaves (NT) (2 420 kg/ha) and highest *toria* yields were obtained from RB with residue + hedge leaves incorporation (576 kg/ha). GEY in the second year was the maximum in RB with residue incorporation. Addition of crop residues and subsequent decomposition released nutrients that helped in increasing the yield attributing characters of both groundnut and *toria* leading to their higher yields as compared to the flat bed treatments. Feng *et al*. (2010) also reported that no tillage treatments along with wheat stubble improved wheat yield over conventional tillage significantly. Slight increases in the yield of *toria* could be seen in the second year as compared to the first year of cropping which could be due to the conservation treatments. Light showers were also received during the months of November and December in 2010 which might also have improved the productivity of *toria* in the second year.

In all the conservation treatments, mean GEY was found to be higher as compared to the FP except BBF with residue + hedge leaves (NT). Mean GEY was highest under RB with

Table 3 Effect of land configuration and residue management on yield of groundnut, *toria* and groundnut equivalent yield (GEY)

Treatment	2009-10			2010-11			Mean GEY (kg/ha)
	Pods (kg/ha)	Seed (kg/ha)	GEY (kg/ha)	Pods (kg/ha)	Seed (kg/ha)	GEY (kg/ha)	
Farmer's practice (flat bed)	2 380	188	2 510	1 848	185	2 789	2 530
BBF with residue incorporation	2 384	297	2 590	1 819	296	3 072	2 649
BBF with residue + hedge leaves incorporation	2 328	330	2 557	1 852	429	3 333	2 727
BBF with residue + hedge leaves (NT)	1 878	237	2 043	1 374	311	2 509	2 103
Raised bed with residue incorporation	2 196	497	2 541	1 795	546	3 562	2 747
Raised bed with residue + hedge leaves incorporation	2 398	465	2 720	1 749	576	3 505	2 815
Raised bed with residue + hedge leaves (NT)	2 218	329	2 447	1 863	494	3 505	2 717
SEm ±	15.9	5.85	15.3	11.2	4.47	13.3	10.6
CD (P = 0.05)	49.2	18.0	47.2	34.6	13.8	40.8	32.8

residue + hedge leaves incorporation. Treatments under RB were found to have higher GEY compared to those under BBF and FP. In a study carried out by Venkateswarlu and Malaviya (2004) on the performance of groundnut under different land configurations, it was observed that BBF had the highest yields over FP and ridges and furrows. Productivity of the cropping system in terms of mean GEY showed that treatments under RB had higher values as compared to FP and BBF. The application of residues which increased soil fertility and higher soil moisture coupled with favourable temperatures might be the reason for higher GEY in the case of RB. Also, the area available for cultivation is higher in RB as compared to BBF where a considerable amount of area is lost in furrows and hence more plant population. Similar results of higher production efficiency and pearl millet equivalent yields under altered land configurations as compared to FP were also reported by Parihar *et al*. (2009).

The results of this study indicated that NT and residue management helps in improving soil health and maintaining a living soil and improving crop performance. Water movement such as infiltration rate and hydraulic conductivity were higher in the NT plots and the availability of nutrients was also higher in the residue managed plots. Raised beds with residue + hedge leaves (NT) recorded highest system productivity. In spite of the good performance of BBFs, the high labour involved in the land preparation does not make it a very good choice. NT on raised bed is further recommended as a sustainable practice.

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REFERENCES

Abrol I P and Sagar S. 2006. Sustaining Indian agriculture – conservation agriculture the way forward. *Current Science* **91**(8): 1 020–25.

Ali M and Venkatesh M S. 2009. Pulses in improving soil health. *Indian Farming* February 2009: 18–22.

Benjamin J G, Halvorson A D, David C N and Mikha M M. 2010. Crop management effects on crop residue production and changes in soil organic carbon in the central Great Plains. *Agronomy Journal* **102**(3): 990–7.

Black C A. 1965. Methods of analysis. *Chemical and Microbial Properties*, Part II, p 1569. No. 9. American Society of Agronomy Incorporation, Madison, WI, USA.

Bouwer H. 1986. Intake rate: cylinder infiltrometer. (*In*) *Methods of Soil Analysis, Physical and Mineralogical Methods.* 2nd edn, pp 825–844. Klute A. (Ed). Agronomy monograph no. 9, ASA & SSSA, Madison.

Brookes P C and Joergensen R G. 2006. Microbial biomass measurements by fumigation-extraction. (*In*) *Microbiological Methods for Assessing Soil Quality*, pp 77–83. Bloem J, Hopkins D W and Benedetti A (Eds). CABI Publishing, Oxfordshire, UK.

Bujarbaruah K M. 2004. Organic farming: opportunities and challenges in North-eastern region of India. (*In*) Souvenir, International conference on organic food, 14-17 February 2004, ICAR Research Complex for NEH region, Umiam, Meghalaya, pp. 7–13.

Casida L E Jr, Klein D A and Sautoro T. 1964. Soil dehydrogenase activity. *Soil Science* **98**: 371–6.

Derpsch R. 2005. The extent of conservation Agriculture adoption worldwide: Implications and impact. *Proceedings of the Third International Congress of Conservation Agriculture*, 3-7 October, Nairobi, Kenya, pp 15.

Dam R F, Mehdi B B, Burgess M S E, Madramootoo C A, Mehuys G R and Callum I R. 2005. Soil bulk density and crop yield under eleven consecutive years of corn with different tillage and residue practices in a sandy loam soil in central Canada. *Soil & Tillage Research* **84**, 41–53.

Feng F X, Huang G B, Chai Q and Yu A Z. 2010. Tillage and straw management impacts on soil properties, root growth and grain yield of winter wheat in northwestern China. *Crop Science* **50**: 1 465–73.

García C, Hernández T and Costa F. 1997. Potential use of dehydrogenase activity as an index of microbial activity in degraded soils. *Communications in Soil Science and Plant Analysis* **28**: 123–34.

Gomez K A and Gomez A A. 1984. *Statistical Procedures for Agricultural Research*, 2nd edition. International Rice Research Institute, John Wiley and Sons, New York, USA.

Goyal S, Walia M and Kumar V. 2009. Effect of bed and conventional planting system on organic and microbial bio-mass carbon, enzyme activities and carbon and nitrogen mineralization. *Indian Journal of Agricultural Research* **43**(4): 251–6.

Jackson M L. 1973. *Soil Chemical Analysis.* Prentice Hall of India Pvt Ltd, New Delhi.

Knudsen D, Peterson G A and Pratt P F. 1982. Lithium, sodium and potassium. (*In*) *Method of Soil Analysis, Chemical and Microbiological Properties*, pp 228–38. Page A L, Miller R H, Keeney D R (Eds). ASA &SSSA, Madison.

Martin-Reuda I, Munoz-Guerra L M, Yunta F, Esteban E, Tenerio J L and Lucena J J. 2007. Tillage and crop rotation effects on barley yield and soil nutrients on a *Calciortidic Haploxeralf*. *Soil & Tillage research* **92**: 1–9.

Mina B L, Saha S, Kumar N, Srivastava A K and Gupta H S. 2008. Changes in soil nutrient content and enzymatic activity under conventional and zero-tillage practices in an Indian sandy clay loam soil. *Nutrient Cycling in Agroecosystems* **82**: 273–81.

Parihar C M, Rana, K S and Parihar M D. 2009. Crop productivity, quality and nutrient uptake of pearl millet (*Pennisetum glaucum*) - Indian mustard (*Brassica juncea*) cropping system as influenced by land configuration and direct and residual effect of nutrient management. *Indian Journal of Agricultural Sciences* **79**(11): 927–30.

Prasad R K, Kumar V, Prasad B and Singh A P. 2010. Long term effect of crop residues and zinc fertilizer on crop yield, nutrient uptake and fertility build up under rice- wheat cropping system in calciorthents. *Journal of the Indian Society of Soil Science* **58**(2): 205–11.

Saha R and Ghosh P K. 2010. Effect of land configuration on water economy, crop yield and profitability under rice based cropping systems in north east India. *Indian Journal of Agricultural*

Sciences **80**(1): 16–20.

Singh B, Chanasyk D S and Mc Gill W B. 1995. Soil hydraulic properties of an Orthic Black Chernozem under long-term tillage and residue management. *Canadian Journal of Soil Science* **76**: 63–71.

Singh G, Babu R and Chandra S, 1981. *Soil Loss Predictions in India*. Bulletin No 12/D9, CS&WCRTI, Dehra Dun, India; 70.

Singh G, Marwaha T S and Kumar D. 2009. Effect of resource conserving techniques on soil microbiological activities parameters under long term maize (*Zea mays*) – wheat (*Triticum aestivum)* crop rotation. *Indian Journal of Agricultural Sciences* **79**(2): 94–100.

Stone L R and Schlegel A J. 2010. Tillage and crop rotation effect on soil physical properties in the west-central plains. *Agronomy Journal* **102**(2): 483–91.

Subbiah B V and Asija G L. 1956. A rapid procedure for the determination of available nitrogen in soils. *Current Science* **25**: 259–60.

Venkateswarlu B, Malaviya D D. 2004. Performance of groundnut as influenced by land configurations and fertilizer management under rainfed conditions of south Saurashtra. *The Andhra Agriculture Journal* **5**: 292–95.