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Waterlogging problems at Wonj-Shoa sugar industry: Identifying feasible mitigation or remedial measures

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ABSTRACT

Wonji-Shoa Sugar Estate (WSSE) has been producing sugar for about 60 years and is currently affected by chronic waterlogging problem. Waterlogging is threatening the sustainable production and productivity of the study area significantly. Unless corrective measures for mitigating GW rise are developed and the existing problems are tackled soon, severe crises in the region are inevitable. Therefore, the current study attempted to present the current status of GWTD and then suggest feasible remedial measures. More emphasis were placed on diagnosis and mitigation of shallow groundwater issues. The feasible management measures to be adopted in the future pathways to reduce, if not avoid, the effects of waterlogging for the sustainability of irrigated agriculture are suggested. The effectiveness of the recommended correction measures requires greater coordination and collaboration of each and every department and administrative bodies within the sugar estate, including research and training directorate.

Key words: Drainage, Groundwater, Irrigation, Management measures, Piezometers, Waterlogging

INTRODUCTION

In Ethiopia, irrigation development has been prioritized as an important catalyst to stimulate the national economic growth of the country since it is considered as a cornerstone of food security and poverty reduction (MoWR, 2002; World Bank 2006; Hagos *et al*., 2009). The Ethiopia Government made a remarkable investment for the development of irrigated agriculture in recent time (post-2000), especially in Awash River basin. A concerted effort has been made to develop new irrigation schemes and rehabilitate the existing ones (Awulachew *et al*., 2007; Dinka, 2010).

However, irrigation development has multiple benefits to food security and economic development if and only if there is proper utilization and management of the available water resource. For instance, Wonji-Shoa Sugar Estate (WSSE) is currently affected by critical waterlogging problem. Majority of the sugarcane plantation fields are affected by critical waterlogging problem (Dinka and Dilsebo, 2010; Dinka and Ndambuki, 2014a), which resulted in significant yield reduction and other allied problems. The current study, therefore, presents the status of waterlogging and suggests potential mitigation measures to combat the impacts of waterlogging to the sustainable production and productivity of WSSE.

METHODOLOGY

The Study Area

Wonji-Shoa Sugar Estate (WSSE) is located in Wonji Plain, Upper Awash valley, Ethiopia (Fig.1), at a distance of about 110 kms south east of Addis Ababa. Sugarcane is the most crop grown in the plantation. WSSE is one of the key and early large scale irrigation schemes in the Awash River Basin.

Wonji plain experiences bimodal and erratic rainfall distribution pattern. Temperatures of the area (14.5 - 27.7 °C, av. 21.4 °C) are specifically suitable for sugarcane crop. The soils of WSSE vary from light sandy loam (course textured) to heavy black clayey (fine textured) soils.

Data Collection and Analysis

Networks of piezometers (all PVC types, Fig. 1) were installed manually (2007) in order to monitor GWTD of WSSE. The locations of each piezometer were registered using hand held Geographic Positioning System (GPS). Groundwater depth monitoring was commenced just after piezometer tube re-installation and continued until 2010; with the monitoring frequency of twice per month. In addition, various secondary data such as digital plantation base map, toposheet, production data, and meteorological data were collected from different sources: database of the sugar estate, researchers and friends,

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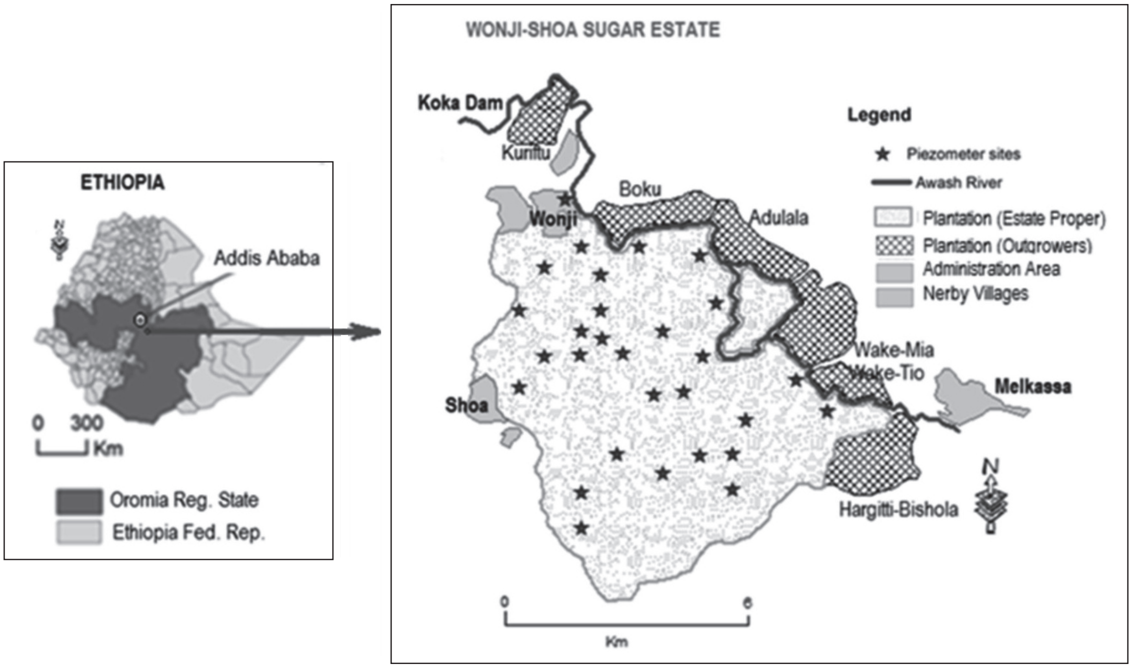


Fig. 1. Left: Wonji-Shoa Sugar Plantation (estate proper and outgrowers) showing GW monitoring sites, storage reservoirs, networks of irrigation and drainage canals, administrative areas, and villages/towns. Right: PVC tube manual installation at WSSE using auger tubes and the PVC after installation.

previous reports and own personal observation. The observed GWTD values were analysed for seasonal and annual values. The hydrographs (water-level vs time) of representative pizometers were plotted in sigma plot (Ver. 12.0). GWTD maps were produced in ArcView 3.3 from the monthly observed GWTD point measurement data.

RESULTS AND DISCUSSION

Status of Groundwater Table Depth

The recent (2007-2010) magnitude and seasonal characteristics of GWTD values for some selected piezometers are presented in Fig. 2. The figure depict that the GWTD of the study area ranged between 0.1m and 2.5 m below the ground. The mean average values are in the range of 0.2 – 2.0; thus, all plantation fields are classified to be shallow (i.e. waterlogged). Majority (> 90%) of the plantation area has average GWTD less than 1.50 m below the ground surface, hence, classified as critically waterlogged since they are above the critical depth (1.5m) recommended for sugarcane crop (Kahlown *et al*., 2005).

Feasible Management (Remedial or Control) Measures

The current study result and other studies (Dinka and Dilsebo, 2010; Dinka and Ndambuki, 2014a; Dinka and Ndambuki, 2014b) revealed that the GWTD of the study area is very shallow and showing fluctuation, mostly rising trend. Such characteristics of GWTD are expected to negatively impact the socio-economics and environment of the region significantly; and thus, a concern for the sustainability of the sugar estate. Dinka and Ndambuki (2014b) identified the main potential causes of groundwater rise in the study area as: (i) excess recharge from direct rainfall and surface runoff coming from the surrounding escarpments; (ii) un-controlled irrigation water management (iii) poor drainage facilities (*natural & artificial*); (iv) flat topography and clay soil property; (v) contribution from Awash River; (vi) flooding problem; (vii) seepage and tail end losses.

Any strategies that reduce water recharge/ abstraction to/from groundwater are highly recommended. Some of the feasible management measures recommended by the authors to control the rise of GWTD in the study area presented in the subsequent sub-sections. Most of the measures illustrated are those that reduce groundwater recharge and/or increase groundwater abstraction.

(i) Rehabilitation of the existing irrigation

These require a complete redesign, optimization and rehabilitation of the existing furrow irrigation systems based on the actual prevailing soil, crop, climatic and GWTD conditions. Appropriate methods of irrigation water management options can be practiced specific to each plantation section. These includes: (i) real time irrigation scheduling, (ii) improving water use efficiency at farm and field levels, (iii) extending irrigation interval (i.e. reducing irrigation intensity), and/or (iv) reducing the amount of water applied. These recommended options can be practiced effectively until the average GWTD is lowered below the recommended threshold level (1.5m). Real time irrigation scheduling requires determining the contributions of shallow GWTD to the crop root zone through capillary action and then comparing it with the water requirement of sugarcane to decide the amount and timing of irrigation.

(ii) Rehabilitation of the existing irrigation system

Drainage plays an essential part in safeguarding the threats of shallow water table to production and productivity of the area. Complete redesign and rehabilitation of the existing drainage system plays a great role to control groundwater table rise. The authors would like to suggest the following available strategies: (a) creation of additional new drainage systems; (b) strengthening the existing drains; (c) construction of intercepting drains along the main irrigation and drainage canals; (d) strengthening the border dykes; and (e) improving natural drainage system.

(iii) Use of alternative irrigation and drainage system

Based on the current GWTD condition and soil type of the area, the authors suggest that the sugar estate introduce use of other efficient irrigation and drainage methods. Horizontal or vertical drains can be effectively utilized. Construction of shallow skimming wells, as demonstrated in the States of Punjab and Haryana (Rao *et al*., 1986), is a technically feasible and economically viable solution to combat waterlogging (Sharma *et al*., 2011). Moreover, combined uses of surface and sub-surface drainage systems are necessary in most of the poorly drained soils. Surface drainages are required to remove excess rainfall (during and after heavy rainfall) and excess irrigation (during and after irrigation water application); while sub-surface drains remove excess water stored in the effective root zone of crops. However, the sugar estate can choose to use the existing ones or new technologies for irrigation and drainage system depending on the cost effectiveness (determined based on cost-benefit analysis) and efficiency.

(iv) Conjunctive use of surface water and groundwater

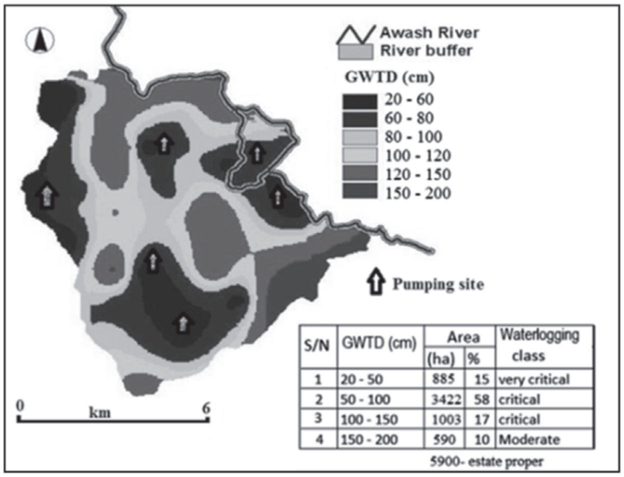
Theoretical and experimental studies (Sharma et al., 2011) have revealed conjunctive (or consumptive) use is one of the most effective strategies for lowering water table. Fortunately, the groundwater quality in the study area is within the recommended safe range for irrigation. Therefore, pumping surplus water in very shallow GWTD areas (as shown by the upward arrow in Fig. 3) and use for irrigation purpose should be highly prioritized by the management of the sugar estate. Pumping out water from north-eastern (E_1) near to storage reservoir along the ex-Awash route, central (L_1) around reservoir, southern (R_3 or L_3), eastern (E_2) and western (R_1) parts of plantation sections and storing in the nearby reservoirs are highly recommended. The introduction of conjunctive use (e.g. lift irrigation) technique for groundwater utilization in the area has dual opportunity in reducing the groundwater level as well as use for irrigation supply, which has a further advantage in saving water and energy and reducing the penalty/risks associated with waterlogging (eg. reduced productivity and others).

(v) Lining of canals

Seepage from canals and night storage reservoirs could be one of the main culprits of rising water table in the study area since almost all available (irrigation and drainage) canals and reservoirs are alluvial type. Thus, an attempt should be made to reduce the seepage of water from the canals and watercourses through lining. This method is found to be a successful strategy for the control of groundwater rise or reclamation of waterlogged fields in other parts of the world like India and Pakistan (Aswa, 1999). Lining some of the irrigation and drainage canals and night storage reservoirs, if not all, is advantageous not only in reducing seepage losses, but also in facilitating the flow of water by decreasing flow resistance, reducing erosion by stabilizing canal beds and banks, reducing sediment deposition by promoting movement, controlling weed growth and accumulation, and reducing maintenance costs. Any of the good performing lining materials such as concrete, masonry, geosynthetic, alluvial soils (bentonite clay, lime, compacted earth) can be used.

(vi) Strengthening groundwater monitoring

In the study area, groundwater monitoring was interrupted in 2010 due to the frequent damage to the installed piezometers by heavy machinery (*during land preparation, cultivation and harvesting operations*) and humans (theft). Continuous monitoring of groundwater through piezometers or observation wells (holes) is extremely important to check the status of groundwater (depth and quality). Thus, installation of continuously monitoring piezometers and observation holes within the plantation and surrounding areas are highly recommended.



S/N	GWTD (cm)	Area (ha)	Area %	Waterlogging class
1	20 - 50	885	15	very critical
2	50 - 100	3422	58	critical
3	100 - 150	1003	17	critical
4	150 - 200	590	10	Moderate

Fig. 2. Delineated GWTD for WSSE (Estate Proper) for the average recorded period (2007-2010) and recommended pumping sites (indicated by upward arrows).

(vii) Introducing new technologies for water management

New technologies like Remote Sensing (RS) and Geospatial Information system (GIS) combined with hydrologic models plays a significant role for efficient water management. Spatial records (data bases) for soil, climate, water and crop data can be stored in computer (GIS) for each field number or section so that the requirement for irrigation can be monitored easily. Some of the applications of RS, GIS and hydrologic models in water management includes: irrigation planning and operation, estimation of optional management practices and irrigation system characteristics, modeling the temporal and spatial variability of groundwater, mapping GW recharge and discharge areas, detecting waterlogging and salinization, and estimation of evapotranspiration. Detailed applications of RS, GIS and hydrologic models in irrigated agriculture can be obtained from different literatures (Schultz, 1997; Moulin *et al*., 1998; Bastiaanssen and Bos, 1999).

Apart from the above, other feasible strategies suggested by the authors to control waterlogging problem in the study area may include: (i) increasing the tariff of water, (vii) use of crop rotation, and (iii) provision of training on water management.

CONCLUSION

The study result clearly revealed that shallow GWTD is threatening the production and productivity of the sugar estate. In the area, there is a possibility for the occurrence of total groundwater inundation in the near future, resulting in deleterious effects on the environment and the socio-economics of the region in particular and Awash Basin in general. Most of the problems caused by shallow GWTD might be mitigated or avoided. Therefore, different feasible management strategies to be adopted in the future pathways to reduce, if not avoided, the effects of waterlogging for the sustainability of the sugar estate are suggested. Above all, the authors would like to underline that the sustainability of irrigation scheme in the area largely depends on the appropriate water management measures, mostly irrigation and drainage system. Managing irrigation and drainage system helps to control the rise of GWTD as well as to maximize the water productivity of sugarcane. Therefore, radical redesign, rehabilitation and optimization of irrigation and drainage systems plays a leading role for the control of GWTD in the sugar estate and hence, should be prioritized by the managers of WSSE.

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Visual soil quality assessment: A review

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ABSTRACT

Many physical, biological, and, to a lesser degree, chemical soil properties show up as visual characteristics; altered markedly by changes in land use and management. Many visual indicators like colour, structure, aggregation, texture, porosity, moisture conditions, earthworm casts are closely related to key quantitative indicators of soil quality. As indigenous people have done before, soil science and soil advisory services utilize the same common field diagnostic criteria within defined frameworks and check their validity over larger scales. Conventional methods for assessing soil quality under different management practices require considerable time and knowledge. Visual techniques of soil examination and evaluation are of immense value for soil management, particularly methods associated with the rapid assessment of soil. They complement newly developed techniques for soil assessment such as remote sensing and soil-landscape modeling, and well established procedures such as laboratory analysis of soil samples.

Key words: Peerlkamp, Profil culture, Soilpak, Soil quality, Soil structure

INTRODUCTION

Soil quality has been defined as 'the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation' (Karlen *et al*., 1997). In discussion of the ambiguity of environmental terms and the need to standardize their meanings, Johnson *et al*. (1997) defined soil quality as 'a measure of the condition of soil relative to the requirements of one or more biological species and/or to any human purpose'. The term 'soil health' is preferred by some (Doran and Parin, 1996; Doran and Jones, 1996) because it portrays soil as a living, dynamic system whose functions are mediated by a diversity of living organisms that require management and conservation. Soil health, biodiversity, and soil resilience are severely limited in extreme environments and are more sensitive to anthropogenic disturbance. The concept of soil quality (Doran and Jones, 1996; Karlen *et al*., 1997) is useful to assess the condition and sustainability of soil and to guide soil research, planning, and conservation policy.

The need to increase agricultural production with less impact on the environment has renewed interest in assessing how land use systems and management influence soil properties (Batey and McKenzie, 2006). Soil and crop management practices can enhance or reduce soil quality, which in turn can be associated with an increase or decrease in soil productivity (Pankhurst *et al*., 2003; Ogle *et al*., 2012). The importance of soil quality lies in achieving sustainable land use and management systems, to balance productivity and environmental protection. Conventional methods for evaluating soil quality needs measuring soil properties, identifying minimum datasets as soil quality indicators and, scoring and weighing these indicators to get soil quality indices. These require varied methodological knowledge, resource infrastructure (equipment and laboratories) and considerable time and money (Guimaraes *et al*., 2011). Therefore a reliable, rapid method to quantify soil quality that is sensitive to the effects of management on soil quality would be useful for both scientists and farmers. Visual techniques for assessing soil quality in the field are useful to diagnose and control erosion, soil compaction and decisions about systems of tillage (Shepherd, 2000; Ball and Douglas, 2003; McKenzie, 2001a; Mueller *et al*., 2009b, 2010).

Visual assessment of soil structure, root growth, organic matter, colour and surface condition offers a holistic means of assessing soil physical condition.

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Soil aggregate stability is widely recognized as a key indicator of soil health (Karlen and Stott, 1994; Arshad *et al*., 1996). Kerebel and Holden (2013) used slope gradient; landscape position, soil roughness, weed abundance, grittiness and hydromorphic characteristics (e.g., soil mottling, red channels) as visual indicators of soil quality. Such assessment also enables evaluation of current soil management by pinpointing specific problems such as compaction, impeded drainage, erosion and restrictions to roots.

The visual methods provide a low cost alternative for semi-quantitative assessment of soil quality (Shepherd, 2000) for use in extension and monitoring (Shepherd, 2000; McKenzie, 2001b) or even modeling (Roger-Estrade*et al*., 2004). Visual assessment methods should be simple, inexpensive, reliable, and highly accurate; produce results fast and be understood by researchers, technical advisors and farmers (Shepherd, 2003).Visual methods for objectively and reproducibly evaluating soil quality based on field assessment and measurements have been developed (Shepherd, 2000, 2009; Ball and Douglas, 2003; Ball *et al*., 2007), tested (Mueller *et al*., 2009a, b) and modified (Guimaraes *et al*., 2011; Murphy *et al*., 2013). These methods range from easily understood and quick tests to more complex multifaceted assessments, but all are designed to help land managers make better decisions as part of their soil management system, and scientists to acquire low-cost, objective, reproducible data on soil structure over large areas with high sampling frequency. The simpler methods such as Shepherd (2000) and Guimaraes *et al*. (2011) do not require particular knowledge and specific equipment yet provide a rapid and meaningful result (Giarola *et al*., 2010).

Visual assessment scores are correlated with measured data of soil parameters (Murphy *et al*., 2013; Lin *et al*., 2005) and crop yield (Mueller *et al*., 2009b; Mueller *et al*., 2013; Giarola *et al*., 2013; Munkholm *et al*., 2013). However, clearly defined rules and scoring methods are necessary to minimize subjective errors. Visual methods based on, or supplemented by illustrations, have clear advantages for the reliable assignment of a rating score based on visual diagnostic criteria.

Visual Soil Quality Indicators

An indicator of soil quality is a measurable surrogate of a soil attribute that determines how well a soil functions (Burger and Kelting, 1999). Many soil quality indicators have been rationalized and proposed, and a few have been tested and validated. Visual and tactile methods for soil quality assessment mainly utilize the soil physical indicators. The fact that, USDA (2006) selects seven physical, three chemical, and two biological indicators, out of ten indicators which represent a minimal dataset to characterize soil quality, shows the importance of soil physical properties as indicators of soil quality. An agricultural soil with ''good physical quality'' is one that is ''strong'' enough to maintain good structure, hold crops upright, and resist erosion and compaction; but also ''weak'' enough to allow unrestricted root growth and proliferation of soil flora and fauna. Soil with good physical quality also has fluid transmission and storage characteristics that permit the correct proportions of water, dissolved nutrients, and air for both maximum crop performance and minimum environmental degradation (Topp *et al*., 1997).

Soil structure and aggregation is main focus in visual soil quality assessment (Murphy *et al*., 2013; Peigne *et al*., 2013; Boizard *et al*., 2013; Giarola *et al*., 2013; Ball *et al*., 2007). Soil structure is known to interact with physical, chemical and biological properties (Da Silva *et al*., 1997; Kay *et al*., 2006; Mueller *et al*., 2009a, b), and these in turn are directly influenced by arable management (Mosaddeghi *et al*., 2009). In addition, many soil functions related to biological diversity, activity, and productivity, which provide soil physical stability and support plant growth, nutrient and carbon cycling, are also related to soil structure and are indicators of soil quality (Kavdir and Smucker, 2005).Soil structure has been described in terms of aggregate size and hardness (Batey, 2000), density and appearance (Peerlkamp, 1959), aggregate shape, ease of breakup (Ball *et al*., 2007; Mueller *et al*., 2010) and presence of roots (Daniells and Larsen, 1991).

Visual evaluation has also moved beyond soil structure to include other soil properties and crop and topographic conditions. Kerebel and Holden (2013) used slope gradient; landscape position, soil roughness, weed abundance, grittiness and hydromorphism (e.g., soil mottling, red channels) as visual indicators of soil quality. The Visual Soil Assessment (VSA) scheme (Shephered, 2000) uses soil indicators such as soil porosity, soil colour, number and colour of mottles, earthworm counts, depth of hardpan, and degree of soil erosion. The number of biogenic pores has also been used as visual indicator (Werner and Thaemert, 1989).

Methods for Visual Assessment of Soil Quality

Several methods have been developed over the past five decades. One of the oldest but most accepted methods is that of Peerlkamp (1967). The traditional French method "Le profil cultural" (Roger-Estrade *et al*., 2004) is more sophisticated method providing detailed information on the total soil profile. Most methods found to be providing similar correlations with measured physical parameters (Mueller *et al*., 2009b).

Types and sizes of aggregates and abundance of biological macro-pores are the most reliable criteria as related to measurement data and crop yields. Differences in soil management could be recognized by visual structure criteria (Mueller *et al*., 2009a,b). Unfavorable visual structure is associated with increased dry bulk density, higher soil strength and lower infiltration rate. Effects of compaction may be detected by visual examination of the soil (Batey and McKenzie, 2006). The New Zealand VSA, (Shepherd, 2000, 2009) as an illustrated multi-criteria method enables reliable assessments of the soil structure status. These are feasible tools for structure monitoring and management recommendations. However, they may explain only part of crop yield variability, as the influence of inherent soil properties and climate on crop yield is dominant, particularly over larger regions. In France, agronomists have studied the effects of cropping systems on soil structure using a field method based on a morphological description of soil structure. In this method, called ''profil cultural'' or soil profile in English, the soil structure of the tilled layer is observed on a vertical face of a pit. Herrick *et al*. (2001) described a stability kit which can be inexpensively and easily assembled with minimal tools. It permits up to 18 samples to be evaluated in less than 10 min and eliminates the need for transportation, minimizing damage to soil structure.

Among all these methods, two main types can be distinguished: (i) methods based on the topsoil examination withVisual Soil Examination and Evaluation(VSEE) (Ball *et al*., 2007), or the VSA drop test (Shepherd, 2000) and (ii) those based on soil profile evaluation like SoilPAK and Profil Cultural Method(Roger-Estrade *et al*., 2004; McKenzie, 2001a,b; Batey and McKenzie, 2006).

VSEE (Visual Soil Examination and Evaluation)

The Peerlkamp method

The Peerlkamp method involves digging a hole that is slightly wider and deeper than the spade. Then a spade-full of soil is removed and laid on the ground and recognizable or pre-determined layers or horizons separated. The key criterion is to assess the total soil block or the separated layers for its potential as a medium for rooting. Beginning with the top layer the soil is gently broken apart into aggregates and placed on the soil surface or a sheet of paper. A score number is assigned according to the scale description given by Peerlkamp (1967). The scale for clay and loam soils is:

1–2 ''Plough layer consists entirely of big clods, smooth dense crack faces, roots only in cracks'',

3–4 ''Plough layer big dense aggregates, smooth crack faces, roots between aggregates'',

5–6 ''Plough layer big porous aggregates, rather smooth crack faces'',

7–8 ''Plough layer mostly porous crumbs partly combined as porous aggregate. Occasional denser clods'',

9–10 ''Plough layer all porous crumbs, very few dense aggregates''.

The latest development of the Peerlkamp method provided by Ball *et al*. (2007) is well illustrated. The main advantages of this method are speed and minor soil disturbance, providing comparative statistical analyses both in large fields and also in small plots of long-term trials. However, the scoring frame has potential for subjective errors. Some methods like that of Peerlkamp (1967) and its revised version by Batey and Ball (2005) and Ball *et al*. (2007) or the structure score of Diez and Weigelt (1997) could be characterized as Peerlkamp type methods as they are based on a single scale of conjoint parameters. In case of disagreement between single parameters from the description or sample photograph, the scoring person has to find a compromise. For example, the method of Peerlkamp, modified by Batey and Ball (2005) combines in the highest (best) class: ''Friable, crumbling aggregates, low size after crumbling, highly porous, roots throughout aggregates''. This makes methods of the Peerlkamp type very fast in handling but sensitive to subjective scorings. If one or more features are not present for this description (e.g. absence of roots, difficulties with break-up caused by drought) the operator can underestimate structural quality. Separate assessments of several parameters as in the methods of Werner and Thaemert (1989), or Munkholm *et al*. (2005) provide more reliable single scorings but this is more time consuming, the total assessment is difficult and a total numerical score, though desirable, may not be part of the test.

Werner method

An alternative to the Peerlkamp type of measurement is a multi-parameter technique such as the Werner method (Werner and Thaemert, 1989). Soil handling prior to scoring is similar to that of the Peerlkamp test but separate scoring of different soil layers of the topsoil and subsoil (down to about 50 cm depth) is recommended. Scorings are separately performed for five different criteria:

a) Aggregate size, given classes are 1 fine (<5 mm), 2 medium (5– 20 mm), 3 large (20–50 mm) 4 very large (>50 mm) 5 structureless.

b) Aggregate type, given classes are 1 rounded, 2 edgeless-rough planes, 3 sharp edged-smooth planes, 4 unseparated, massive.

c) Shape of intra-aggregate voids, given classes are 1- rough cavities, 2- rough fissures, 3- smooth cavities, 4- smooth fissures, 5- unseparated.

d) Width of aggregate interfaces, given classes are 1-open, 2-halfopen, 3-closed, 4-no interfaces.

e) Proportion of biogenic macro pores (>1 mm), given classes are 1- very high, 2- high, 3- medium, 4 -low.

This last criterion is scored not from soil broken-up by hand but by careful vertical removal of soil layers and counting of macro pores at the bottom of each layer. Classes are characterized by a specific table (Werner and Thaemert, 1989) containing numbers for different pore classes. The result of the Werner method is a five digit number of the dominating class of each criterion. A soil of very best structure would have the theoretical optimum number of 11,111. But common numbers have mixed digits (for example 12,224 or 32,222) and are thus not numbers but strings, e.g. nominally scaled data, which are difficult to handle. Development of a method of weighted averaging would remove this difficulty.

Visual Soil Assessment

VSA (Shepherd, 2000, 2009) is scoring method based on the visual assessment of key soil 'state' and plant 'performance' indicators of soil quality. Soil quality is ranked by assessment of the soil indicators alone. Plant indicators, however, require knowledge of immediate crop and paddock history. Because of this, only those who have this information will be able to complete the plant indicator score card satisfactorily. By looking at both soil indicators and plant indicators, VSA links the natural resource (soil) with plant performance and farm enterprise profitability. Because of this, the soil quality assessment is *not* a combination of the 'soil' and 'plant' scores. Rather, the scores should be looked at separately, and compared.

Each indicator is given a visual score (VS) of 0 (poor), 1 (moderate), or 2 (good), based on the soil quality observed when comparing the paddock sample with three photographs in the field guide manual (Shepherd, 2000). The scoring is flexible, so if the sample being assessed does not clearly align with any one of the photographs but sits between two, a score in between can be given, for example 0.5 or 1.5. An explanation of the scoring criteria accompanies each set of photographs. Because some soil factors or indicators are relatively more important for soil quality than others, VSA provides a weighting factor of 1, 2 or 3. For example, soil structure is a more important indicator (a factor of 3) than clod development (a factor of 1). The score you give each indicator is multiplied by the weighting factor to give a VS ranking. The total of the VS rankings gives the overall ranking score for the sample you are assessing. Compare this with the score ranges at the bottom of the page to determine whether your soil has good, moderate, or poor soil quality.

Fig. 1. Two paddocks of black soils with different aggregation, porosity and root densities

Drop Shatter Test

The drop shatter test requires the block of soil (200 mm _ 200 mm _ 50 mm) to be dropped three times from a height of one meter onto a firm surface (a tray or board). The soil is then teased apart into the aggregate using only ''very gentle pressure''. The object is to break the clods by hand along exposed cracks or fissures. If clods are not easily separated the cracks or fissures are not continuous and so are not available to readily transport air or water within the soil. The aggregates or fragments formed by this dropping process are then graded with the larger fragments or aggregates being moved to one end of the tray and the finest to the other end. This procedure produces a graded display or sample of fragment and aggregate sizes (Fig. 2). The Drop Test Friability or DT Friability is calculated as (Murphy *et al*., 2013):

$$\text{DT Friability} = \frac{\text{Length of aggregates of size} < 20\,\text{mm}}{\text{Total length of aggregate display}}$$

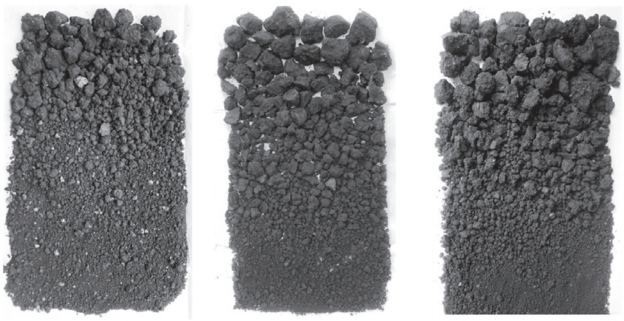

Fig. 2. Example of drop/shatter test for some Vertosol soil on the black soil regions of India. The paddock sampled was under soybean cultivation.

SOILpak scheme

The SOILpak score (McKenzie, 2001a) used visual assessment of the soil structural form to derive an overall score. The 'SOILpak scoring procedure' has been developed within the Australian cotton industry to allow semi-quantitative assessment of soil structural form. It allows compaction severity in Vertisols to be separated into as many as 20 categories on a scale of 0.0 (severely compacted) to 2.0 (excellent structure for root growth). The procedure is based upon visual assessment of soil samples in the field as they are pulled apart by hand. The SOILpak scoring system is well accepted by advisory staff because of its speed and simplicity. However, there have been some problems with operator bias, and an inability to deal with continuity of vertical macro pores, degree of encroachment of under-furrow compaction into the ridges where cotton is planted, and the presence of thin smeared layers. The SOILpaktest is done first on the 0–50 mm layer and then the 50–100 mm layer. The scores are based on the size of primary clods, ease of breakage of the soil into clods, behaviour of fresh roots, shape of clods, amount of compound clods, internal porosity, and internal colour of clods. Each of the factors is given a value between 0 and 2, with 0 being the worst condition and 2 the best. The final score is calculated after applying a weighting to the different factors and a normalizing factor of 36, which gives a final overall score between 0 and 2.

Profil Cultural Method

In France, agronomists have studied the effects of cropping systems on soil structure using a field method based on a morphological description of soil structure. In this method, called ''profil cultural'', the soil structure of the tilled layer is observed on a vertical face of a pit. As the profil cultural method was first devised to evaluate the effect of agricultural operations in ploughed tillage systems, the focus was initially on topsoil. But the profil cultural method also allows us to examine the subsoil (Gautronneau and Manichon, 1987). Peigne *et al*. (2013) presented the profil cultural method in detail, along with the improvements made to quantify the ability of roots to penetrate compacted zones in the transition layer. They proposed two indicators: (i) number of earthworm burrows per m^2 counted on a horizontal surface at the bottom of the transition layer in the soil pit (ii) cracking quantified by taking a 50-mm x 50-mm x 100-mm sample of soil from the transition layer and examining the number of cracks.

Field soil aggregate stability kit

Field soil aggregate stability kit (Herrick *et al*., 2001) is an inexpensive and easy to assemble tool for assessing soil quality based on aggregate stability. It permits up to 18 samples to be evaluated in less than 10 min and eliminates the need for transportation, minimizing damage to soil structure. The kit consists of two 21x10.5x3.5 cm plastic boxes divided into eighteen 3.5x3.5 cm sections, eighteen 2.5-cm diameter sieves with 1.5-mm distance openings and a small spatula used for soil sampling. Soil samples are rated on a scale from one to six based on a combination of ocular observations of slaking during the first 5 minutes following immersion in distilled water, and the per cent remaining on a 1.5-mm sieve after five dipping cycles at the end of the 5-min period. A laboratory comparison yielded a correlation between the stability class and per cent aggregate stability based on oven dry weight remaining after treatment using a mechanical sieve. The methods has been applied in a wide variety of agricultural and natural ecosystems throughout western North America, including northern Mexico, and been found highly sensitive to differences in management and plant community composition (Herrick *et al*., 2001). Although the field kit cannot replace the careful laboratory-based measurements of soil aggregate stability, it can clearly provide valuable information when these more intensive procedures are not possible (Herrick *et al*., 2001).

Correlation of visual scores with soil properties

Visual assessment scores are correlated with measured data of physical soil quality (Murphy *et al*., 2013; Kerebel and Holden, 2013; Giarola *et al*., 2013; Guimaraes, 2013; Lin *et al*., 2005), chemical soil quality (Murphy *et al*., 2013) and crop yield (Mueller *et al*., 2009b; Mueller *et al*., 2013; Giarola *et al*., 2013; Munkholm *et al*., 2013). Murphy *et al.* (2013) compared three tests namely VSA scores, SoilPak scores and DT Friability and correlated with ESP (exchangeable sodium percentage), ESI (electrochemical stability index), MOR (modulus of rupture) and SOC (soil organic carbon). ESP, ESI and MOR were found well correlated with those scores whereas SOC was poorly correlated and non-significant in some cases.Giarola *et al.* (2013) assessed Oxisols of Ponta Grossa in the central-southern part of Parana State, southern Brazil with VESS and VSA scores. The relationship between Sq. index based on VESS and clay content was not significant ($p < 0.26$), whereas the relationship between VS index and clay content was highly significant ($p < 0.0002$). The Sq. obtained by the method of Ball *et al*. (2007) ranged from 3.0 to 4.2, with a mean of 3.68±0.38, while that VS obtained through the method of Shepherd (2009) ranged from 0.5 to 1.5, with a mean of 1.11 0.32. Munkholm *et al*. (2013) reported weaker correlations of VESS scores with the quantitative soil physical properties. Guimaraes *et al.* (2013) reported a positive relationship between VESS score and bulk density with $r^2 = 0.51$ for the clayey soil and 0.62 for the sandy loam soil. A strong significantly positive correlation was shown between VESS score and resistance to penetration only under native forest in both soils, with $R^2 = 0.65$ for the clay soil and 0.72 for the sandy loam soil. Soil air permeability showed a weak negative correlation with VESS. Peerlkamp score and relative bulk density has shown significant linear negative correlations ($P < 0.05$) with large scatter around regression line (Mueller *et al.*, 2009b). Strong and significant correlation were found between VESS scores and tensile strength and visible porosity of five soils with clay content ranging from 13.9 to 78 per cent (Guimaraes *et al*., 2011).

The relationship between VESS score and crop yield was significant only at the 10% level probably because the ranges of scores and yields were narrow, despite the wide range in soil texture along of transect Giarola *et al.* (2013). Munkholm *et al.* (2013) indicated with experimental results a rather good correlation between topsoil structure and crop yield. Corn yields decreased linearly with increasing VESS Sq. values ($R^2 = 0.35^{**}$). The correlation between Peerlkamp score and grain yield of cereals was significant and $P = 0.06$ and thus very close to the common significance level of $P = 0.05$ (Mueller *et al.,* 2009b).

Comparison of different visual assessment methods

In general all the visual soil quality assessment methods are found to be significantly correlated as most of them refer to size and type of aggregates as diagnostic features (Muller *et al*., 2009). Murphy *et al.* (2013) found DT Friability well and significantly correlated with VSA score and SOILPakscores, whereas, the correlation between VSA and SOILPak scores were found weak due to non-similar ranges (0.5 to 1.5 for SOILPak and 10 to 40 for VSA). Although the range between the two indices is similar, the VSA and VESS scores were not significantly related ($p < 0.178$) (Giarola *et al*., 2013). Muller *et al*. (2009) evaluated five methods of visual soil quality assessment, namely, Peerlkamp (Peerlkamp, 1967), Diez and Weigelt (Diez and Weigelt, 1997), VSA (Shephered, 2000), Werner and Thaemert (Werner and Thaemert, 1989), FAO (2006), and Peerlkamp method, modified by Ball (2007). All visual methods under study were significantly correlated.

CONCLUSION

The use of techniques of visual evaluation of soil quality is now well established and proving valuable in explaining differences in crop performance and yield due to soil management and type. These are feasible tools which may provide fast semi-quantitative information on the status of physical soil quality and fertility. The shape and size of aggregates are crucial and quickly recognizable diagnostic features of visual soil quality. Structure scores of most methods gives similar results after standardizing data. The tests are particularly helpful in conveying the importance of soil structure to farmers and in fostering the exchange of soil knowledge. Visual evaluation has also moved beyond soil structure to include other soil properties and crop and topographic conditions. The subjectivity of visual assessment methods has been a concern raised by scientists more familiar with quantitative measurement. However, the visual soil quality scores are reported to be well correlated with soil physical and chemical properties and crop yield.

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Mulch farming techniques for improving resource conservation, carbon sequestration and crop production in rainfed regions - A review

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ABSTRACT

Mulching is a technique which covers soil surface around the plants to create compatible condition for its growth. In this article a review on various types of mulching materials, their impact on water-use efficiency, soil properties, carbon-sequestration, runoff, soil and nutrient losses and crop production, have been systematically presented. The study recommended that organic mulches have significant impact on soil organic carbon build up and carbon sequestration. Plastic mulching is the best option for weed control and increases water use efficiency up to 90%.Straw mulches (@ 2-6 t ha^{-1}) conserve moisture significantly and produce minimum runoff (up to 60%) and sediment losses (up to 75%). Gravel mulches play significant role in temperature control of soil. The knowledge gaps such as cost effective and readily available organic and inorganic mulching materials, their application rate, and runoff, soil and nutrients losses reduction potential in different agro ecological regions needs to be identified. Considering the benefits of mulching technique and change in crop productivity and resource conservation, this can be strongly recommended for widespread adoption of mulching in rainfed regions

Key words: Mulching, Soil moisture, Runoff, Soil loss, C-sequestration, Crop production

INTRODUCTION

Rainfed agriculture is predominant in arid, semi-arid and sub-humid regions of the country. These regions are home to about 81% of rural poor in the country. Hence, rainfed agriculture has a crucial role to play in sustaining the economy and food security of India. At present, about 55% of the net sown area is rainfed contributing 40% of the total food production, supports 40% of human and two-third of livestock population. However, aberrant behaviour of monsoon rainfall, eroded and degraded soils with multiple nutrient and water deficiencies, declining ground water table and poor resource base of the farmers are major constraints for low and unstable yields in rainfed areas. In addition, climate variability including extreme weather events resulting from global climate change poses serious threat to rainfed agriculture. The rainfed regions are characterized with peculiar ecological and socio-economic settings, frequent failure of crops, absence of irrigation facilities, low cropping intensity, low farm income, malnutrition and poor quality of drinking water, small size of farm holdings and high population pressure on land, low level of literacy and poor resource base of the farmers, unemployment for most of the period of the year, farmers are to depend on the favours of the monsoon or on financing institutions which are reluctant to provide assistance as there is more risk in the recovery of the released amount from farming. Rain-water management is the most critical component of rainfed farming. The successful production of rainfed crops largely depends on how efficiently soil moisture is conserved *in-situ* or the surplus runoff is harvested, stored and recycled for supplemental irrigation. With climate change posing a major challenge for rainfed agriculture and the constraints in further expansion of irrigated area in the country, rain-water harvesting and recycling for efficient water-use are inevitable options to sustain rainfed agriculture in future. In rainfed regions, the in-situ moisture conservation measures, such as mulch farming and crop-residue management (Bhushan and Sharma, 2005; Regar *et al.*, 2009; Rockstrom *et al.*, 2009; Chakraborthy *et al.*, 2010; Kumar *et al.*, 2008), Conservation tillage (Nitant and Singh, 1995; Rao *et al.*, 1998; Lal 2008, Patil and Sheelavantar,

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2006; Palaniappan *et al.*, 2009, Rockstrom *et al.*, 2009; Kahlon and Lal, 2013; Surin *et al.*, 2012; Baskaran and Kavimani, 2015), Compartmental bunding, tied ridges and furrows, small micro catchments (Ojasvi *et al.*, 1999; Rockstrom *et al.*, 2009; Jadhav *et al.*, 2012; Kahlon and Lal, 2014) have increased the soil moisture availability and significantly increase the crop yields.

Mulching is a technique which covers soil surface around the plants to create compatible conditions for their growth. Mulching reduces soil moisture loss through evaporation and also controls weed germination and its further growth. It insulates soil, protecting roots from extreme summer and winter temperatures. Mulching improves soil biology, aeration, structure (aggregation of soil particles), and drainage over time and can improve soil fertility as certain mulch types decompose. It exerts decisive effects on earliness, yield and quality of the crop (Bhardwaj, 2013). Mulch farming technique increases the moisture availability in the root zone of the crops and enhances the productivity and production in rainfed regions. Mulch is a layer of material applied to the surface of an area of soil. Mulching the soil surface with a layer of plant residue is an effective method of conserving water and soil because it reduces surface runoff, increases infiltration of water into the soil and retard soil erosion. Mulching is useful in moisture conservation, to improve the fertility and health of the soil, to reduce weed growth, to enhance the visual appeal of the area. Mulch is simply a protective layer of a material that is spread on top of the soil. Mulches can either be organic or inorganic. The organic materials such as hay, leaves, manure, compost, vermin-compost, wood, bark, cocoa hulls, rice straw, peanut hulls, plastics, gravel, and geo-textiles and the inorganic materials mostly plastics can be used as mulch. The mulches increasing soil organic carbon (SOC) status, reducing evaporation losses, insulating soil against extreme heat and cold by moderating soil temperature, reducing soil compaction, and controlling wind and water erosion (Kahlon and Lal, 2014). Both organic and inorganic mulches have numerous benefits. Mulching improves the ecological environment of the soil and it avoids decrease in soil water levels (Chawla, 2006; Khurshid *et al*., 2006; Muhammad *et al*., 2009).

In this article a review on various types mulching materials, their impact on water- use efficiency (WUE), soil properties, C-sequestration, runoff, soil and nutrient losses and crop production is presented. This paper also presents the knowledge gaps and future strategies on mulching in crop fields for sustainable production in rainfed regions of India.

Effect of Mulching on Soil Properties

The various scholars have reported that mulch farming has significant impact on soil properties (Table 1). Residue Mulch increased organic matter content, water retention, infiltration of water and aggregation, and decreased bulk density of the surface soil (Ghuman and Sur, 2001). Porosity increased by wheat straw mulch 35-46% @ 4 Mg/ha and enhanced available water capacity by 18–35% @8 Mg/ha, increased soil moisture retention at low suctions from 29 to 70% (Mulumba and Lal, 2008). Erosive response quickly decreases with time

Table 1. Mulching effect on soil properties

Type of mulch	Effect on soil properties	Source
Straw mulch	Reduced estimated soil evaporation by 114–163mm	Vial *et al.* (2015)
Plastic Mulch	Soil temperature increased by 1.25°C and 0.84°C	Dong *et al.* (2014)
Gravel & Plastic Mulch	Increased cumulative soil thermal time by 150–220°C	Bu *et al.* (2013)
Wheat straw mulch	Erosive response quickly decreases with time after prolonged storms (30 min)	Jordán *et al.* (2010)
Gravel and sand mulch	Increased soil temperature, increases porosity, causes more evaporation	Xie *et al.* (2010)
gravel mulch	Reduced the evaporation from bare soil surface	Yuan *et al.* (2009)
Wheat straw mulch	Increased porosity by 35–46%, available water capacity by 18–35%, soil moisture retention 29 to 70%	Mulumba and Lal (2008)
Straw Mulch	Reduced soil erosion losses and soil temperature up to 1.4–2.4°C, @ 6 t ha^{-1} mulch	Bhatt and Khera (2006)
Gravel Mulch	Interception accounted for 36.4% @pebble size 2.5 cm	Li *et al.* (2005)
Residue Mulch	Increased organic matter content, water retention, infiltration, and decreased bulk density of the soil	Ghuman and Sur (2001)
Crop residueMulch	34-50% reduction in soil water evaporation	Hatfield *et al*. (2001)

Table 2. Effect of mulching on soil moisture content and water use efficiency (WUE)

Type of mulch	Soil moisture content and WUE	Source
Plastic film and straw mulch	Plastic mulch improved WUE from 5.7 to 8.1 and by straw mulch 9.0 kg m^{-3}	Wang *et al.* (2015)
Gravel and Plastic mulch	Gravel mulch improved WUE by 15% and 51% and by plastic film mulched (FM) 23% and 90%	Bu *et al.* (2013)
Plastic mulch	Higher water stability of soil macro-aggregates >2 mm was observed in plastic mulch ridges relative to the furrows after rain season. Plastic mulch implication useful for soil and water conservation in vegetable culture	Zhang *et al.* (2013)
Cultural mulch	WUE was the highest in deep tillage and cultural mulch	Mishra *et al.* (2012)
Straw mulch	Increased WUE by 1.8 kg ha^{-1} mm^{-1} @ 5 t ha^{-1}	Regar *et al.* (2009)
Stone mulch	Maximum rainfall use efficiency (6.22) observed	Rehman *et al.* (2009)
Paddy straw mulch	Soil moisture content @ 1 kg/m^2 increased by 33%	Kumar *et al.* (2008)
Plastic mulch	Increased WUE by 2–61%	Xie *et al.* (2005)
Gravel-sand mulch	Increased WUE by 25.3%, or 3.7 kg m^{-3}	Wang *et al.* (2004)
Gravel mulch	Increased WUE by 1.8 times	Li *et al.* (2000)

after prolonged storms (30 min) by wheat straw mulch (Jordan *et al.*, 2010). Soil thermal time (TT Soil) increased by plastic mulch 150-220°C (Bu *et al.*, 2013). Soil temperature increased by plastic mulch 1.25°C and 0.84°C (Dong *et al.*, 2014). Mulch slows down evaporation and reduces the irrigation requirement. Evaporation reduced by straw mulch 114-163 (Vial *et al.*, 2015).

Plastic mulch improved WUE by 2-61%, gravel and sand mulch by 25.3%, and paddy straw mulch increased soil water content by 33% (Xie *et al.*, 2005; Wang *et al.*, 2004; Kumar *et al.*, 2008). Changes in Water use efficiency (WUE) and soil water content in different crops by using mulching application is shown in table 2. From the table it is observed that the plastic mulch has higher WUE (90%) in comparison to gravel mulch (51%) (Bu *et al.*, 2013).

In comparison to plastic mulch, organic mulches have pronounced effect on soil properties. These much increases the bulk density, water absorption, WUE and after decomposition of much is adding the nutrients and carbon to the soil. In natural resource conservation perspective organic mulches should be promoted in rainfed regions.

Effect of mulching on weed infestation

Aladesanwa and Adigun (2008) observed that maize and sweet potato of 60 cm×50 cm as most promising live mulch in weed suppression. Cirujeda *et al.* (2012) reported that weed control was high (80-100%) for biodegradable plastics, paper mulches and PE and yield was72%-108% of the yield achieved by PE. Application of bio-mulches restricted weed growth with their high weed controlling efficiency in the range of 25to 60% due to better surface cover, restricting the penetration of incoming sun rays (Aggarwal *et al.*, 2003). Gupta *et al.* (2013) observed that dry weight of weeds could be reduced in the range of 50-60% over no mulch treatment. Kitis *et al*. (2011) found common vetch (*Vicia sativa* L.) as living mulch application reduced weed density and cover proportion average of 42.8% and 45.9% respectively compare to control. Biomass and dry weight of weeds were also reduced by living mulch in all years of the experiment. Kolodziejczyk (2015) recommended mechanical treatments coupled with sowing living mulches, particularly *fabaceae*, have high degree of efficiency in limiting the biomass of weeds and low level of adverse effects on the production of potatoes. Kumar and Singh (2013) reported black polythene mulch was quite effective in controlling weeds, improving establishment and growth of nursery plants. Higher weed control efficiency (97.6%) next to weed free treatment was recorded in black polythene mulch. Meena and Singh (2013) reported rice residue mulching management was the best among the given residue management practices and tank-mix sulfo sulfuron 25 g/ha + metsulfuron 4 g/ha was better among the herbicides in terms of weed growth reduction and increased wheat yield. Verdu and Mas (2007) reported black geotextile and almond husk controlled the presence of weeds as well as or better than the applications of glyphosate at least during the first year after their introduction. No significant differences were found between the mean weed cover of black geotextile

(0.88%), almond husk (4.04%) and herbicide plots (2.04%). Ossom *et al.* (2001) also observed significant differences in weed control between mulched and unmulched plots of eggplant. White or clear mulch and green covering had little effect on weeds, whereas brown, black, blue or white on black (double colour) films prevented emerging weeds (Bond and Grundy, 2001). The studies shown that the mulching particularly plastic much has significant impact of weed control. It that mulching is one weed control strategy in mandarin orchards that also provides other benefits in terms of sustainable agriculture, such as soil protection or avoiding herbicide pollution.

Effect of mulching on runoff, soil and nutrient losses

The soil surface covers affect runoff generation and soil loss processes. Splash erosion occurs by the impact of raindrops on the soil surface. As a result of this process, raindrops detach soil particles; destroy soil structure, and finally, increase runoff and erosion. The mulch on soil surface reduces the raindrop splash erosion and increases the infiltration opportunity time of the soil and thereby reduces the runoff, soil and nutrients losses. The organic mulches such as paddy and wheat straw, stubbles, residues etc. will able to reduce the raindrop splash erosion and increase the infiltration (Kukal and Sarkar, 2010; Parlak and Ozaslan-Parlak, 2010). Splash erosion decreased with an increase in cover percentage and decrease in slope. The effect of mulching on runoff, soil and nutrients losses has been reported by various scholars (Table 3). From the table, it has been observed that runoff reduced by stubble mulch by 59%, by rice straw mats 22.1-100%, by forest residue mulch 26 to 15%, by straw mulch by 33%, by Dry maize stover mulch 49% and 30% during long rains and short rains, by plastic mulch reduced runoff by 33%. Soil loss reduced by stubble mulch by 37.2%, no sediment was yielded if rice straw mats cover was 900 gm^{-2}, forest residue mulch reduced sediment losses from 5.41 to 0.74 Mg ha^{-1} (Kurothe *et al*., 2014; Won *et al*., 2012; Prats *et al*., 2012). Straw mulching reduced surface runoff and soil loss in rainfed foothill region of Punjab (Bhatt *et al*., 2003).

The most of the studies conducted and reported on organic mulches. These organic mulches reduces the raindrop splash erosion, increases the infiltration opportunity time, slowdown the runoff velocity, and act as filter and there by significant reduces the runoff, soil and nutrient losses. Plastic mulches, reduce the raindrop splash erosion, but it decreases the infiltration, water absorption by the soil and the mulches may not be effective for reduce the runoff, soil and nutrient losses. In natural

Table 3. Effect of mulching on runoff, soil loss

Type of mulch	Runoff and Soil Loss	Source
Maize stubble mulch	Decreased runoff 15%	Choudhary (2015)
Stubble mulch	Runoff by 59.6% and soil loss by 37.2%	Kurothe *et al.* (2014)
Dry maize stover mulch	Runoff was reduced by 49% and 30% during long rains and short rains in 2011. Sediment yield was reduced by 41% and 7% during long and short rains respectively	Okeyo *et al.* (2014)
Plastic mulch	Wide-plastic-mulch treatment significantly ($P < 0.05$) reduced runoff and soil loss compared to the narrow-plastic-mulch	Zhang *et al.* (2013)
Rice straw mats	Runoff reduction varied between 22.1% and 100%., no sediment was yielded if mat cover was 900 gm^{-2}	Won *et al.* (2012)
Forest residue mulching	Reducing the runoff coefficient from 26 to 15% and sediment losses from 5.41 to 0.74 Mg ha^{-1}	Prats *et al.* (2012)
Residue mulch	Minimize soil loss when 75% of the cane mulch and water loss when 50% of cane mulch maintained in soil	daSilva and deSouza (2012)
Wheat straw mulching	Reduction in runoff generation and soil losses @ 5 Mg ha^{-1} $year^{-1}$ mulching rate.	Jordán *et al.* (2010)
Residue mulch	Runoff and soil loss decreased with the amount of mulch used and increased with slope.	Adekalu *et al.* (2007)
Straw mulch	Runoff reduced by 33% @ 6 t ha^{-1} mulching rate	Bhatt and Khera (2006)
Gravel mulch with Plastic-covered ridges	Plastic-covered ridges with gravel mulch in corn field had average runoff efficiency (runoff/rainfall) of 87%	Li *et al.* (2000)
Plastic mulch	Runoff is reduced by 30% and erosion rates by 50% in the plastic ± crown plot that enhanced infiltration	Wan and El-Swaify (1999)

Fig. 1. Stubble Mulches in Cowpea+ Castor
(Courtesy: Bagdi *et al*., 2005)

Fig. 2. Stubble mulches in cotton crop
(Courtesy: Rao *et al.,* 2015)

resource conservation perspective organic mulches should be promoted in rainfed regions.

Effect of mulching on Crop yields

The mulching has significant impact on crop yields in rainfed regions. Various studies showing positive effects of mulching on crop yield and plant productivity (Table 4). The straw mulch increases yield of pea by 36.2%, taramira by 25%, turmeric by 56.7%, potato by 33% and wheat yield by 56% (Choudhary, 2015; Jun *et al*., 2014; Regar *et al*., 2009; Kumar *et al*., 2008; Kar and Kumar, 2007; Huang *et al*., 2005). Gravel mulch increased the yield of maize

Table 4. Effect of mulching on crop yield

Type of mulch	Crop Yield and growth parameters	Source
Gravel and plastic film mulching	Gravel mulch increased maize yield by 17.1, 70.3 and 16.7% and by Plastic mulch 28.3, 87.6 and 38.2% in year 2010, 2011 and 2012, respectively	Lin *et al*.(2015)
Paddy straw mulch (PSM)	Registered 36.1% higher pod yield of pea	Choudhary (2015)
Polythene mulch	Black colour polythene mulch registered maximum yield of tomato per hectare (60.61 Mt/ha)	Bhujabal *et al.* (2015)
Plastic mulch	Rain-fed spring hybrid millet (*Setaria italica*) grain yield increased by 13.25% (plastic ridge and furrow) and 6.64% (plastic mulched flat soil)	Dong *et al.* (2014)
Straw mulch	Increased forage dry matter yield of alfalfa by 420 kg ha^{-1} (by 6.7%)	Jun *et al*.(2014)
Plastic film mulch	Grain yield of maize (*Zea mays* L.) increased by 0.6 to 1.2 Mg ha^{-1}	Liu *et al*.(2014)
Dry maize stover mulch	Increased maize yield by 75%,	Okeyo *et al.* (2014)
Gravel mulch and Plastic film mulch	Gravel mulch increased maize yield by 17% and 70%. And plastic mulch increased by 28 and 87% in year 2010 and 2011, respectively.	Bu *et al.* (2013)
Polyethylene and straw mulch	Polyethylene mulch and straw mulch resulted in 73.4% and 72.6% more maize grain yield	Bahar and Singh (2013)
Straw mulch	Increased mean seed yield of taramira by 25% @ 5 t ha^{-1}	Regar *et al.* (2009)
Paddy straw mulch	56.7% fresh yield of turmeric were recorded @1 kg/m^2	Kumar *et al*.(2008)
Gliricidia mulch	Rhizome yield of ginger 72.93 q/ha proved significantly superior	Dass *et.al* (2006)
Straw mulch	Increased biomass yield by 37 and 20%, and wheat yield by 52% and 26%, in year 1997 and 1998, respectively.	Huang *et al.* (2005)
Plastic mulch	Wheat yield increased by 4.0–110.3%	Xie *et al.* (2005)
Gravel-Sand mulches	Average yield of watermelon increased by 25.4%, or 11,400 kg ha^{-1}	Wang *et al.* (2004)
Plastic covered ridge + Gravel mulch	Corn grain increased 1.9 times.	Li *et al*.(2000)

by 70.2%, watermelon by 25.4% (Bu *et al*., 2013; Wang *et al*., 2004). Plastic or polythene mulch increased grain yield of rain-fed spring hybrid millet (*Setaria italica*) by 13.25%, grain yield of maize upto 87.5% Wheat yield upto 110.3% (Dong *et al*., 2014; Bu *et al*., 2013; Xie *et al*., 2005). Mulching resulted in higher crop growth and yield of maize in rainfed foothills region (Arora *et al*., 2008).

Effect of mulching on carbon sequestration

The organic mulches have significant impact on soil organic carbon build up and carbon sequestration. Razafimbelo *et al.* (2006) observed carbon sequestration increased in 6-year green trash management (MUL), which amounted to 0.65 Mg C ha^{-1} $year^{-1}$ at 0–10 cm depth and corresponded to 14% of above ground residue carbon returned to the soil. Kahlon *et al.* (2013) reported that use of no-till (NT) along with residue mulch application enhances 1.26 to 1.50% carbon concentrations in the soil. Sudha and George (2011) observed that Surface mulching with crop residues could maintain organic carbon up to 1.37%. Wang *et al.* 2011 reported soil organic carbon and total nitrogen stocks were highest (46.9 Mg ha^{-1} SOC and 2.8 Mg ha^{-1} TN) in the medium gravel mulch sites with 40–50% gravel, and lowest (29.5 Mg ha^{-1} SOC and 1.4 Mg ha^{-1} TN) in no gravel mulch sites. Youkhana and Idol (2009) observed gravel mulch additions significantly increased soil C and N in the top 20 cm by 10.8 and 2.12 Mg ha^{-1}, respectively. Higher organic carbon content of soil was recorded with sunhemp mulch (0.71%) followed by silkworm bed waste (0.68%), paddy straw (0.66%) mulched plots and least organic carbon content (0.48%) in non-mulched plot (Shashidhar *et al*., 2009). Choudhary *et al.* (2015) reported maize stubble mulch improved soil organic carbon (SOC) by 1.9%. These studies shown that, the mulching has significantly increased the soil organic carbon content and carbon build-up.

Knowledge gaps

Some of the knowledge gaps which were identified during this review and need further research are as follows:

- Innovative, cost effective and readily available mulching materials in different agro ecological regions needs to be identified.
- Organic mulching material availability and economics of supply and demand of organic materials is full of uncertainties.
- Lack of long-term studies limits the understanding of mulching materials interaction in a real world scenario where various natural dimensions are active.
- No standard application rate of organic mulching materials for specific soils, crop combination and weather interactions to get maximum positive results is available.
- Limited knowledge is available decomposed plastic mulches and their long term impact on soil properties.
- Limited information on mulches their resource conservation in terms of runoff, soil, nutrient losses and carbon build up in different agro ecological regions of India

CONCLUSION

The experiments on various mulching techniques particularly plastic much has significant impact on weed control. So the mulching can be, one of weed control strategy for sustainable agricultural production and other benefits, such as soil protection or avoiding herbicide pollution in rainfed regions. The organic mulches have significant impact on soil organic carbon build up and carbon sequestration. There is need to promote crop residues stubbles as mulching materials. Considering the benefits of mulching technique and change in crop productivity and resource conservation, this can be strongly recommended for widespread adoption of mulching in rainfed regions. However, there is need to address and fulfil the above mentioned gaps so that the mulch farming techniques are the better options for natural resource conservation and sustainable production in rainfed regions of India.

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A framework for adaptation to climate change effects in salt affected agricultural areas of Indo-Gangetic region

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ABSTRACT

Indo-Gangetic plain (IGP) constitutes about 13% of the total geographical area of the India, and it produces about 50% of the total food grains. Salt infestation in soils is rampant which poses threat to productivity of agricultural lands, and change in climate could play vital role in further aggravating the problem. Many agricultural practices can slow development of salts in soil and may even mitigate greenhouse gas emissions which contribute to climate change. Crop, soil and water management can provide immediate adaptation measure for changing climate effects, and can also meet long-term mitigation goals. Agricultural management can have interactions with soil sodicity-salinity development at several junctures affecting either one or all of these: GHG emissions, soil carbon balance, water use and landscape water balance, water and salt fluxes, and water quality. For salt affected soils, most of these interactions are influenced by change in rainfall and temperature, and extreme conditions in either direction can lead to increase in salinity and sodicity in soil. Therefore, the management conditions need to be analysed more carefully with life cycle assessment and feedbacks from other interacting elements like society and policy developers. A conceptual framework for systematically meeting the goal of climate change mitigation and adaptation for salt affected soils of Indo-Gangetic region based on these interactions is proposed.

Key words: Sodicity, Salinity, Agriculture, Adaptation, Mitigation, Climate change

INTRODUCTION

Indo-Gangetic region is one of the most populated areas of world and provides livelihood security for several hundred millions of people. Population explosion in the region, and in India as a whole, has result in escalated demand for food, and it is estimated that the food grain requirement by 2020 in the region will be almost 50% more than at present (Paroda and Kumar, 2000). The Indo-Gangetic plain (IGP) is environmentally sensitive, socially significant and economically strategic region where landscape, hydrology and soil fertility are threatened by climate warming coupled with anthropogenic pressure. Climate change has various direct and indirect effects on agriculture production, although these effects may be small to moderate at present. Despite of various efforts taken to mitigate the adverse effects of climate change, significant effects are highly likely to occur over the next century (IPCC, 2007).

According to intergovernmental panel on climate change (IPCC), the rise in global mean surface temperature with the same rate as today would be 1.4–5.8 ºC by 2100 (IPCC, 2001). Countries with warmer climates like India will be more prone to the negative effects of climate change on crop production (Cline, 2007). Reports reveal that all-India mean annual temperature has shown significant warming trend of 0.05°C/10 y during the period 1901 to 2003, however, during 1971 to 2003 it has been accelerated to 0.22°C/10 y (Kothawale and Ropakumar, 2005). Increased emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are mainly responsible for this accelerated rate. Modeling for climate scenario shows that India could feel incidences of warm and wet conditions, altered precipitation frequency and intensity resulting due to climate change (Watson *et al.*, 1996). These changes in climate play an important and effective role for soil productivity of the Indo-Gangetic region.

The agricultural area of IGP is shrinking due to the spread of marginal saline areas in Haryana, Punjab and Uttar Pradesh. On the other hand, the

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productivity of land is also declining due to climate anomalies. About 0.75 t ha^{-1} decrease in rice yield with 2ºC increase in air temperature in high yielding rice areas and about 0.06 t ha^{-1} in the low yield coastal regions has been reported by Sinha and Swaminathan (1991). An increase of 1ºC temperature may cause decrease of 8% wheat yield under salt affected areas of Uttar Pradesh (Mishra *et al*., 2011). It may also reduce wheat crop duration by seven days and reduce yield by 0.45 t ha^{-1} (Aggarwal *et al*., 2004). Though the region specific impacts of climate change are uncertain in India, the farmers of marginally productive and rain-fed lands are going to suffer significantly.

There is a need to identify region specific problems associated with agricultural activity due to the effects of environmental changes on crop production. Management options to mitigate climate change and their effects also need to be delineated. However, adaptation efforts are now being taken as paired measures with mitigation strategies to uphold soil productivity under the climate change scenario, particularly in developing countries. It should be of utmost priority to consider and prepare for impacts of climate change on food production to ensure food security for the global population (Schmidhuber and Tubiello, 2007). Collaborative efforts are required to guarantee the practices applied are significant assuming it as a collective responsibility of all sectors at global level.

Here, we analyze various interactions which management of salt affected agricultural soils could have with climatic changes, and their implications for salt affected areas. We put forth a conceptual framework for meeting the goal of climate change mitigation and adaptation for salt affected areas of Indo-Gangetic region based on these interactions.

Interactions of Change in Climate with Agriculture

Agricultural Land Use Impacts Global Warming

The potential of greenhouse gases like CO_2, N_2O, CH_4 to warm up the environment is referred to as its global warming potential. It is a relative measure of how much heat a greenhouse gas traps in the atmosphere. The overall balance between the net exchange of gases from a crop production system constitutes the net global warming potential (GWP) of that production system. The common unit is referred to as carbon dioxide equivalent or CO_2e. Increased concentration of greenhouse gases in atmosphere over last 250 years has been primarily attributed to the combustion of fossil fuels, and land use changes, including deforestation, biomass burning, draining of wetlands, ploughing and use of fertilizers. It now far exceeds pre-industrial values determined from ice cores spanning many thousands of years (IPCC, 2007).

According to IPCC (1996), agricultural facilities contribute approximately 20% of the annual increase in anthropogenic GHG emissions. When accounting for major GHGs from agriculture, carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) possess top places. Human activities are responsible for altered carbon cycle. They influence addition of carbon as well release of carbon from natural sinks like soil. About 75% of total CO_2 emissions have been accredited to burning of fossil fuels and rest to land use changes in the past 20 years (IPCC, 2001). Global concentration of atmospheric CO_2 has increased from 280 ppm during pre-industrial phase to 379 ppm in 2005 that exceeded by far the natural range over the last 650,000 years (180 to 300 ppm) as determined from ice cores (IPCC, 2007).

Agriculture sector is considered as the largest producer of non CO_2 emissions like methane (CH_4) and nitrous oxide (N_2O), contributing about 60% of total emission (WRI, 2012). Globally, 52% of CH_4 and 84% of N_2O emissions are attributed to the agricultural sources such as animal husbandry, manures and agricultural soils (Smith *et al*., 2008). Flooded rice cultivation is attributed to be the third largest source (91%) source of agricultural emissions, and contributing to 11 percent in the form of methane arising from anaerobic decomposition of organic matter. According to USEPA (2006), the emission of methane in highly populated regions like China and South East Asia are expected to increase by 10 and 36%, respectively, by 2020. However, quantification of methane emission from paddy fields is difficult as it is dependent on the land in cultivation, fertilizer use, water management, density of rice plants and other agricultural practices (Aydinalp and Cresser, 2008). Animal husbandry (7%) and the burning of agricultural wastes (2%) contribute less significantly to CH_4 emissions.

Agriculture accounts for about 38% of global emission of N_2O. Nitrous oxide emissions contributed to 40–44% of the GWP from rain-fed sites and contributed 16–33% of GWP in the irrigated system (Mosier *et al*., 2005). Application of nitrogenous fertilizers, cultivation of nitrogen fixing crops, retention of crop residues and cultivation of soils with high organic carbon content are the main sources. Nitrification and denitrification resulting in N_2O production get enhanced when available nitrogen exceeds plant requirements.

Agricultural Management Impacts Soil Carbon Balance

The carbon pool within the soil systems is considered to be the world's largest terrestrial store of carbon (Post *et al.*, 1982), but various anthropogenic activities like land use change and land management practices are affecting soil carbon stocks and carbon fluxes. Estimates suggest that agriculture production contributes up to 12,000 megatons of carbon dioxide equivalent (CO_2e) a year and up to 86% of all food-related anthropogenic greenhouse-gas emissions (Gilbert, 2012). The accumulation of organic carbon in soil is proportional to carbon assimilation in biomass. It increases with increasing precipitation (Post *et al*., 1982) and decreasing temperature (Burke *et al*., 1989). Therefore, net ecosystem productivity is strongly linked with the climatic conditions.

Net ecosystem productivity (NEP) is used to measure the net exchange of carbon between an ecosystem and the atmosphere; however it is more intricate and difficult to assess. The NEP has been reported to decrease with increase in water stress in forests (Granier *et al*., 2007). It can be taken as a good indicator of carbon accumulation rate within a system though it is largely dependent on prevailing management practices and climatic conditions. For an ecosystem net primary productivity (NPP) and carbon storage are potentially affected by the changes in atmospheric CO_2 concentration and climate. A positive correlation has been established between NPP i.e. the total plant growth per unit area per year, and climatic conditions. Under climate change scenario crop yield may get positively affected because of CO_2 fertilization under high concentration of CO_2 or may decrease due to rising air temperatures (Rosenzweig and Hillel, 1998) and water stress (Fig. 1). Agricultural practices like resource conservation has been related to significant changes on soil carbon build up (Mishra *et al*., 2015).

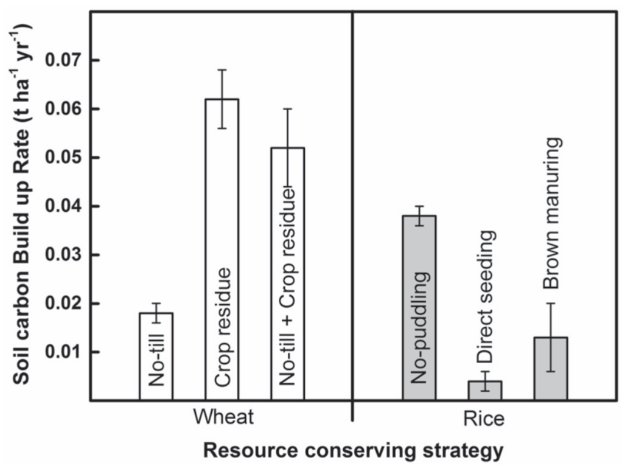

Fig. 1. Soil carbon buildup rates in an Indo-Gangetic region soil under different management practices for wheat and rice crops. (Error bars denote ± 1SE)

Agricultural Management Impacts Water-use and Landscape Water Balance

Projections regarding the change in precipitation patterns, owing to change in climate, indicate that the cropping duration and crop production may be severely affected as over 80% of total agriculture is rainfed (Olesen and Bindi, 2002; Reilly *et al*., 2003). The availability and distribution of soil water responds to climate change due to altered precipitation patterns or drought event. Change in hydrological patterns is expected to increase the uncertainty in water availability leaving some regions more affected than others. Climate change is expected to affect the regional water balances (Eagleson, 1986). Regional water balances comprise division of incoming precipitation into runoff, evapotranspiration, and soil moisture storage. High rainfall intensity decreases downward movement of water whereas low rainfall, conjugated with high temperature, aggravates the problem of soil salinization because of increased rate of evapotranspiration and increased capillary movement of water and salts to the surface of soil.

Evapotranspiration (ET) is primarily a function of water flux through vegetation canopy and is controlled by stomatal conductance and canopy characteristics (Woodward, 1987). Annually, approximately 42.1% of the total rainfall gets converted into evaporation, 48.1% into stream flow and rest lost as seepage (Combalicer *et al*., 2010). Increased ET may cause 20% decrease in runoff relative to precipitation and 58% decrease in soil moisture storage (Marks *et al*., 1993). Climate change has potential effects on evapotranspiration (ET) due to its effects on air temperature, wind speed, cloudiness and atmospheric turbidity affecting the radiations. Increased ET and longer growing seasons would increase the demand for irrigation requirements globally up to 5-20% or more by the 2070s or 2080s (Fisher *et al*., 2006). Climatic factors like temperature, rain, wind and humidity affect the seasonal shift in water balance by influence on evaporation and transpiration. An increase in CO_2 concentration may cause reduction in rate of evapotranspiration due to reduced stomatal aperture and small openings in the leaves, leading to increase canopy resistance (Long *et al*., 2004).

Climate Change Affects Soil Water and Salt Balance

Increased rate of ET and aridity also brings in the problem of salinity especially in the areas where ground water table is shallow. Salts travel along with the capillary water to the overlying soil horizons. The availability of water to plants is influenced by various soil properties viz., porosity, field capacity, plant available water, soil texture etc. (Jarvis 2007; Reynolds *et al*., 2002). Higher salt content in the soil profile and higher salt concentration in the soil solution alters the osmotic potential of water, affecting plant available form. Along with this, high temperatures elevate drier conditions which increase water stress and accentuate demand for water (Fink *et al*., 2004). Salt-affected soils with high pH and presence of certain cations and anions in the soil solution and on exchange sites can have ion specific effects due to change in osmotic potential, and imbalance in plant nutrition (due to deficiency/toxicity of different nutrient). It all may have direct effect on soil biota and plant growth and as a whole on the crop yields (Mengel and Kirkby, 2001).

High temperature and high ET has been found to cause accumulation of salts in the upper soil horizon with decreased rate of downward leaching resulting into soil salinization/alkalization even in places that were not found affected earlier (Dregne, 1976). Studies done in four different climatic regions of world i.e., Mediterranean, semi-arid, mildly arid and arid, reveal a non-linear relationship between soluble salt concentration and rainfall (Pariente, 2001). Salt affected soils result from changes in water balance along with excess salt accumulation at some depth in the soil profile following erosion leaving it exposed to atmosphere (West *et al*., 1994). Plants growing on these soils are susceptible to osmotic stress and specific ion toxicity that overall decreases the quantity (yield) and quality of the crops (Grattan and Grieve, 1999). Salt accumulation negatively affects the soil properties and processes and reduce land potential to be cultivated or for any other use (Kovda and Szabolcs, 1979; Szabolcs, 1990; Varallyay, 1994). High salt content in the soil water along with impaired ratios of elements like Ca and Na make it unavailable to plants. Soil water

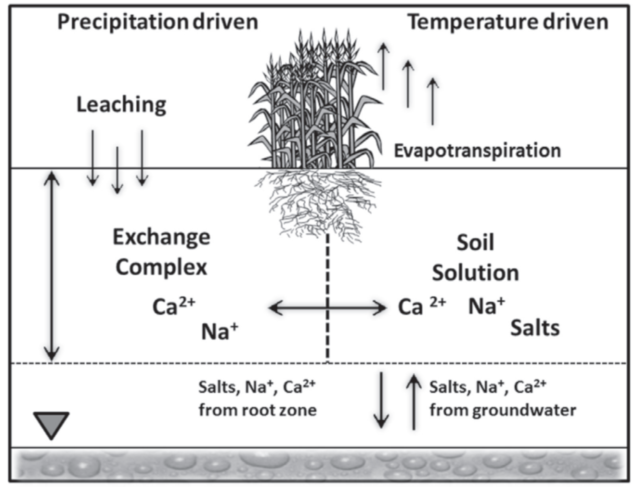

Fig. 2. Illustration of salt development mechanisms in soil and control of climate driven factors for salinity development

phase of salt affected soils shows signs of low nutrient ion activities (Curtin and Naidu, 1998; Grattan and Grieve, 1999).

Climate Change Effects on Salt Affected Soils

Salt affected soils are rich in salts in soil solution as well as exchange complex. They can have several ways of interaction with climate change effects (Fig. 2). Climate change is causing increase in soil salinization/sodicity problem. Dregne *et al*. (1991), reported that in 11 countries, about 29.6 Mha area, out of total 158.7 Mha irrigated area, is affected with high salt content. Increasing salinization of natural resources like soil, land and water is now regarded as serious environmental problem. Changes in hydrology tend to raise the water table and increase the mobilization of salts (Slinger and Tenison, 2005; Charman and Wooldridge, 2007). Further, accumulation of salts creates other problems and inhibits the growth, thus affecting productivity. Also, salt affected soils have poor structure which is a major constraint while using these soils for production.

Marginal Productivity Relates to Higher Susceptibility

Climate plays an important role in maintaining the soil properties. It can have adverse effects on all type of soils yet can have even more deleterious effects on sodic lands. Increased sodicity affects the soil physical properties like dispersion and slaking, and cause dispersion of aggregates and loss of carbon bound within aggregates and physically protected from decomposition (Tisdall and Oades, 1982). Smith *et al*., 2009, estimated that agricultural soil would lose upto 62-164 Tg carbon by 2100 with the changed climate scenario using Century Model.

Sodic soils with high amount of sodium on exchangeable sites affects the plant growth (Gupta and Abrol, 1990), and climate change may aggravate the problem. Altered pattern of rainfall can affect the capacity of soil to maintain the required level of organic carbon and also the soil structure. Sodic soils suffer from ponding on surface due to their lower infiltration rates. High evapotranspiration causes rise in salt concentration in soil solution. The soil moisture available to plant is in very low amount and presence of salts in this water raises the osmotic potential of soil solution. Water becomes physiologically unavailable to plants and may generate water stress and other nutrients deficiencies. Nitrogen is an important element for crop growth especially in sodic soils (Curtin and Naidu, 1998), but the rate of loss of N through volatilization increases in soils with high pH and waterlogged conditions (Gupta and Abrol, 1990; Grattan and Grieve, 1999). Also presence of high level of chloride may also limit the uptake of nitrate (Grattan and Grieve, 1999). All these factors may altogether affect the plant growth, reproduction and senescence by affecting plant's physiological and biochemical functions (Lauchli and Epstein, 1990; Rengasamy *et al*., 2003).

Low Soil Stability Relates to Higher Impacts

Soil structure is a very important factor in crop production, controlling cultivation, plant growth, grain yield and quality (Shepherd, 1992). Increasing sodicity may affect the rate of biomass accumulation and carbon emission and thus can alter the carbon dynamics in the soil. Dispersion of soil aggregates causes loss of soil carbon and generates other conditions like compaction. Formation of soil crust can affect various soil processes like water infiltration, run off, erosion and evaporation. Dispersive clays and soils are much more susceptible to dispersion (Bhardwaj *et al*., 2010). Presence of Na in any clay mineralogical group increases the dispersivity of soil (Bhardwaj *et al*., 2009). High clay content in the soils helps develop cracks when soil is dry. Drier climatic conditions will enhance the problem by increasing the frequency and size of cracks (Climate Change Impacts Review Group, 1991). Owing to rigorous structural degradation, presence of high salt content and consequently developed imbalance in water availability limits the biomass production on sodic soils. Climate change will aggravate the degradation of sodic soils by accelerating salt accumulation in susceptible regions.

Framework for Adaptation to Climate Change

With growing demand for food supply, there is a need to increase the area of arable land. Land resources being limited, reclaiming salt affected lands for agriculture is a highly lucrative alternative. Further, bringing salt affected soils to cultivation require the development and implementation of farming practices which are efficient, inexpensive, and with minimal effects on environment (Qadir and Oster, 2002). The amount of carbon stored in salt affected soils is usually very less than in normal soils (Paustian *et al*., 1998), due to low primary productivity. Sodic soils can be reclaimed using amendments like gypsum, a source of calcium in available form to replace the excess of Na on exchangeable sites that may be leached out then with excess water. These soils can be cropped appropriately, upon reclamation, to enhance productivity, and sequestration of carbon which is considered as an important mitigation strategy against the elevating concentration of CO_2 in the atmosphere. Locking of atmospheric CO_2 into the soil systems also enhance the soil and water quality, and improve the productivity of land. Land management practices that are favorable to plant growth, soil biota and soil structure are believed to enhance the soil organic matter and will increase the soil carbon density. Management practices such as zero tillage, conservation tillage, change in cropping pattern, use of tolerant varieties, and reduced summer fallowing, all complement sequestration of carbon with in the soil system. Reduce/conservation tillage rationalizes the undesirable effects of plowing by causing mechanical disturbances to the soil aggregates (Parr *et al*., 1990). Traditional management practices involve mineralization of soil organic carbon by enhancing the breakdown of soil aggregates. On the other hand conservation agricultural practices decreases this loss by slowing down the breaking of aggregates (West and Post, 2002). The scope of carbon assimilation and sequestration in soil is higher in marginally productive saline and sodic soils which are very low in soil carbon.

Soil carbon sequestration although involves the interaction with other important nutrients/ minerals, several experiments have been conducted by workers to evaluate the improvement in carbon content of salt affected soils cultivated using suitable management practice (Mishra *et al*., 2015; Gupta and Abrol, 1990; Singh, 1989; Garg, 1998; Singh *et al*., 1994, 1997). Several packages of practices have been developed and evaluated.

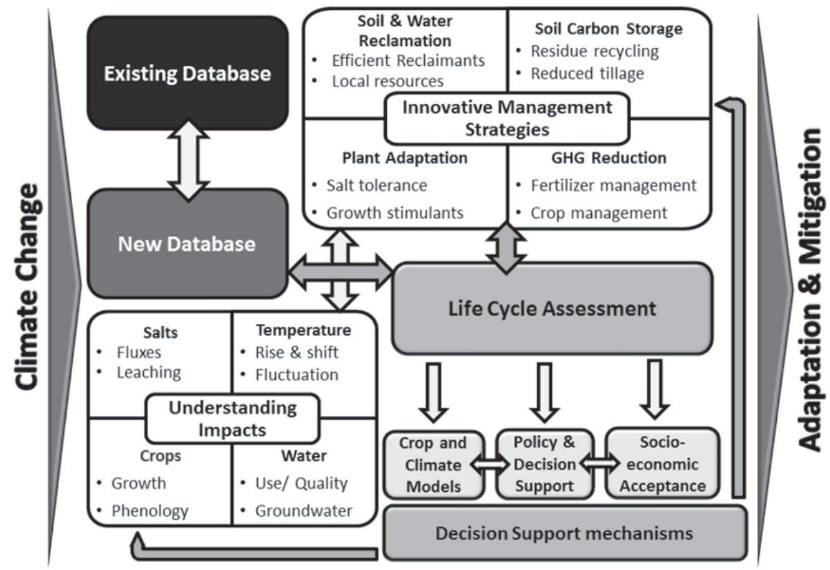

Fig. 3. Framework for adaptation to climate change effects for salt affected soils

Mishra *et al*. (2010) also reported increased in carbon content in sodic soils under different horticulture crops. Use of crops tolerant to high salt levels and those needing minimum tillage will also be beneficial for cultivation on salt affected lands.

Climate change will have more adverse effects on saline and sodic soils than normal soils. At the same time new areas, due to altered rainfall pattern and high temperature, are getting affected by salt accumulation and becoming susceptible to salinity development. Climate change favours development of conditions which enhance salt accumulation in soil profile, their movement to upper horizons and development of osmotic stresses. Agricultural practices like land use change, improper use of fertilizers and cropping patterns with higher emissions of greenhouse gases have also been contributing to climate change phenomena. High temperatures accelerate evapo-transpiration causing upward movement of salt to upper horizons. Salt accumulation in soil solution makes water unavailable to plants, causing decrease in crop yield. This condition is more severe in case of saline and sodic soils that are already affected with high level of salts and have marginal productivity.

Most of recently developed sodic soils are in highly productive regions of world such as Indo-Gangetic plain. Reclamation of these lands and then by putting them under proper management brings great opportunity to increase food supply and livelihood security, especially in developing countries. On the other hand reclamation and management of salt affected areas can increase primary productivity and helps in sequestering carbon in soil to meet the climate change mitigation goals. These soils represent a great potential to sequester carbon with in the soil system, directly by enhancing their primary productivity by improving the soil physico-chemical properties and indirectly by lowering the emission of CO_2 into the atmosphere. Adoption of resource conservation technologies like zero tillage, residue application, permaculture, judicious use of fertilizers, salt tolerant varieties will further enhance the potential of these lands to sequester carbon. Thus, not only salt affected soil but also other waste lands with low productivity can play important role in the current climate change scenario. The two prolonged strategy of enhanced carbon storage in these lands as well as boosting food security makes salt affected areas strategically very important in terms of policy. Development of efficient reclamation as well as management technologies hold the key, though, to the extent of benefits which can be achieved. The immediate challenge is to understand threat and level of impact of climate change in salt affected soils, then to identify alternative management practices, their life cycle assessment, inculcating the generated information into crop, climate and socio-economic models and get the feedback to improve the management (Fig. 3).

Understanding salt development mechanisms in soils, under altered water and temperature regime, is a key to developing sustainable management. Life cycle assessments need to done to reap long term benefits, rather than short term yield based goals. The generated information need to be continuous fed to farmers and policy makers to get feedback on performances under large scale production systems and varied climatic and landscape conditions. Salt development mechanisms are complex and continuously driven by landscape or watershed based management changes. Under impacts at large scale will be crucial to device sustainable strategies to meet the challenge of mitigation and adaptation to climate change. Salt affected marginal lands have a strategic role to play in achieving the goal of enhancing national food security by countering climate change if these principles are followed.

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Contribution of advanced agroforestry research in sustaining soil quality for increased food production and food security

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ABSTRACT

Agroforestry is a land use system that combines agriculture and forestry. From the beginning, the major tenets of agroforestry have been its soil conservation value and sustainability of agricultural production system. The scientific community intervened to harness full benefits of agroforestry land use system and address global issues of land degradation, agricultural sustainability and more recently the climate change and food security. The horizontal (expansion of area) and vertical (innovative research) growth of agroforestry has made significant stride towards wellbeing of the people. The surging interest in agroforestry to search solution for global problem of climate change and food security is based on the scientific revelations that the tree components of agroforestry not only supplement and compliment growth of agro-components by improving soil health but also contribute toward mitigation of climate changes and food security. This review is an attempt to organise research advances of agroforestry in logical order to understand contribution of agroforestry towards complex problems of maintaining soil fertility, meeting goals of climate change and food security. The paper also lists some of the research gaps for future.

Key words: Agroforestry land use, Carbon sequestration, Ecosystem services, Nitrogen-fixing trees, Soil quality

INTRODUCTION

Agroforestry is the traditional practice of growing trees on farms for the benefit of the farm family. India has a long history of practice of tree based farming system under diverse agro-ecological conditions. Harappa excavations have indicated that the inhabitants were familiar with species such as date palm, pomegranate, lemon, melon, coconut etc. The agri-horticulture plantation was fostered by emperor Ashoka (274-237 BCE) with mango, jackfruit and grapes. The earliest literary evidences of agroforestry from India can be found in the travelogue of Ibn Battuta (Persian traveller; 1325-1354 CE; Kumar *et al.*, 2012). Although agroforestry as a practice was very ancient, but systematic research in India initiated with All India Coordinated Research Project (AICRP) on Agroforestry by the Indian Council of Agricultural Research (ICAR) in 1983. Later on, ICAR established the National Research Centre for Agroforestry in 1988 with a mandate for Agroforestry research and its development in the country (NRCAF, 2013). At present, the AICRP on Agroforestry has 37 centres in different agro-climates of the country. The intervention of scientific community to harness full benefits of agroforestry land use and address global issues of land degradation and agricultural sustainability has led to horizontal (expansion of area) and vertical (innovative research) growth of Agroforestry. It has made significant stride towards wellbeing of the people. However, for impact-oriented results, the scientific efforts may require further strengthening.

Agroforestry systems in India

India is blessed with different types of agroclimatic conditions, so there are huge variation in agroforestry systems in their structural complexity and species diversity, their productive and protective attributes and their socio-economic dimensions. They range from apparently simple forms of shifting cultivation to complex home-gardens: from systems involving sparse stands of trees on farmlands (e.g. *Prosopis cineraria* in arid regions of Rajasthan) to high-density complex multi-storied homesteads of Kerala: from systems in which trees play a predominantly 'service' role (e.g. shelter belts) to those in which they provide main saleable products (e.g. intercropping with plantation crops) (Dhyani *et al.*, 2005, 2009). In all

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these agroforestry systems, the components of trees, crops and animals are integrated in such a way that it provides long-term conservation, ensure sustainable production and protects the environment (Dhyani *et al*., 2005).

In recent times Indian agriculture is facing diverse challenges and constraints due to growing demographic pressure, increasing needs of food, feed, pulp, fodder and timber, degradation of natural resources and climate change (Pandey, 2007; Dhyani *et al.,* 2013, NRCAF, 2013). It is assumed that diversification of land-use system with agroforestry can address some of these challenges. Therefore, agroforestry has been receiving greater attention by researchers, policy-makers and others for its perceived ability to contribute significantly to economic growth, poverty alleviation and environmental quality. Today, agroforestry is recognized as an important part of the 'evergreen revolution's movement in the country. India launched the National Agroforestry Policy 2014 with focus on improving productivity of small and marginal farmers and providing them sustainable livelihoods; besides helping in natural resource management and improving forest cover (Dhyani, 2014).

Contribution of agroforestry in maintaining soil quality

Agroforestry and soil health

A major tenet of agroforestry is the fact that trees do maintain soil fertility. In addition to soil health, the other tenets of agroforestry include carbon sequestration, ecosystem services, poverty alleviation, risks and vulnerability management due to climate changes, and low carbon or green agriculture.

Strong link between soil quality and agricultural sustainability is well proven and hence, the overriding objective of agroforestry has been to develop integrated land management systems involving trees, crops and/ or animals, which would contribute substantially to decrease deforestation, increase food production, enhance biodiversity, protect environment and improve soil quality. It is always argued that presence of woody perennials in agroforestry system affects several bio-physical and bio- chemical processes that determine the health of soil substrate. The most obvious effects of trees on soil include amelioration of erosion primarily through surface litter cover and under story vegetation; maintenance or increase of organic matter and diversity through continuous degeneration of roots and decomposition of litter; nitrogen fixation; enhancement of physical properties such as soil structure, porosity and moisture retention due to extensive root system and the canopy cover; and absorb and recycle nutrients in the soil that would otherwise be lost through leaching.

In any agroforestry system, competition between woody perennial and annual agro- crop and/ or grass for sharing underground resources particularly the nutrients-NPK and others due to varying nature of growth, nutrient requirement and genetic makeup is quite obvious. The nature and quantum of tree–crop interactions and their effects are not uniform, and depend on many factors like nature of the species grown, age and size of trees, density of components, management practices (spacing, training, pruning, irrigation, fertilization, etc.) and environmental factors (Kaushal and Verma, 2003).

The hypothesis that agroforestry improves soil is based on studies of the efficient transfer of nutrients from litter to trees in natural ecosystems (Vitousek and Sanford, 1986) and on observations of higher crop yields near trees or where tree were previously grown. It is based on assumption that trees in agroforestry systems transfer nutrients to intercropped plants. Palm (1995)examined several issues related to the transfer of nutrients from agroforestry trees to intercropped plants. They concluded that the amount of nutrients provided by pruning are determined by the production rate and nutrient concentrations, both depending on climate, soil type, tree species, plant part, tree density and tree pruning regime. A large number of screening and alley cropping trials in different climate-soil environments indicate that pruning of several tree species contain sufficient nutrients to meet crop demand, with the notable exception of phosphorus. It has been observed that tree biomass containing sufficient nutrients to meet crop demand is not enough; the nutrients must be supplied in synchrony to crop needs (Swift, 1987).Nutrient release patterns from organic materials are, in part, determined by their chemical composition, or quality. Leguminous plants known as nitrogen fixing trees or fertilizer trees release nitrogen immediately, unless they contain high levels of lignin or polyphenols. Non-legumes and litter of both legumes and non-legumes generally immobilize N initially. Field trials with agroforestry species ranging in quality show that as much as 80% of the nutrients are released during the course of annual crop growth but less than 20% is captured by the crop, a low nutrient-use efficiency (Palm, 1995).

Published values for leguminous trees in different agroforestry systems show average annual additions of dry matter biomass of up to 20 t ha^{-1} yr^{-1} (Young, 1997). Leguminous trees in alley cropping systems can contribute as much as 358 kg nitrogen (N) ha^{-1}, 28 kg phosphorus (P) ha^{-1}, 232 kg potassium (K) ha^{-1}, 144 kg calcium (Ca) ha^{-1}, and 60 kg magnesium (Mg) ha^{-1} (Palm, 1995). Fertilizer trees like *Indigofera, Leucaena, Sesbania, Albizia* etc. have been experimented as alley crop or hedge row crop. On an average, pruning of N fixing hedgerow species add 20-80, 3-4 and 8-38 kg ha^{-1} $year^{-1}$ of N, P and K, respectively (Subba Rao and Saha, 2014).

Restoration of degraded land

In India, nearly 120.72 million ha land or 37 per cent of the total geographical area is under one or the other forms of soil degradation (e.g., water erosion: 93 million ha, wind erosion: 11 million ha, salt affected soils: 6.74 million ha, and 16.53 million ha of open forest area; ICAR, 2010). Out of the total degradation, 24.68 million ha area is affected by chemical pollution only. All these areas can be brought under cultivation through agroforestry. In fact; agroforestry played a major role in the recent past in rehabilitation of wasteland such as desert and lands that had been degraded by salinization and ravines, gullies and other forms of water and wind erosion hazards (Dhyani *et al*., 2005).

Agroforestry research has established the potential of many salt tolerant trees and bushes in the biological amelioration and rehabilitation of salt-affected lands (CSSRI, 2010). The restoration of degraded saline and sodic soils through agroforeastry may be attributed to either increases or decreases in soil parameters. In most of the cases, tree cover gradually augments the soil fertility of degraded lands as reflected by higher soil organic C, total N, available P, and exchangeable K, Ca and Mg. The concurrent decrease in soil salinity and sodicity is characterized by reductions in exchangeable Na, pH and electrical conductivity which decrease progressively with tree age. Collectively, these processes contribute to the productivity enhancement of saline and sodic soils by improving nutrient status and detoxifying sodicity (Bhojvaid and Timmer, 1998). Long term tree plantations improve the physical, chemical and biological properties of SAS. Under tree cover, the bulk density of SAS decreases and there is an accompanied increase in soil porosity, water holding capacity, field capacity, permeability and infiltration rate (Mishra *et al*., 2004). Using auger hole technology developed by CSSRI, Karnal, different state forest departments have reclaimed about 60,000 ha of highly deteriorated lands through agroforestry plantations on salt affected village community lands and Govt. lands adjoining roads, railway lines and canals etc. This has significantly improved fuel wood and forage supplies to the landless labourers and small farmers and increased forest cover besides sequestering carbon to moderate the impact of climate change. (Sharma *et al*., 2011). There are numerous examples which support that agroforestry interventions have helped in rehabilitation of more than 3 million ha of salt affected soils.

Evaluation of soil chemical properties of traditional agroforestry system in northeastern region indicated a spectacular increase in soil pH, organic-C, exchangeable Ca, Mg, K, and buildup of avai1able P (Bray's-P) under different agroforestry practices (AFP) within 10-15 years of practice. Accumulation of 2.91% organic-C was observed under areca nut + jackfruit + black pepper + Cinnamom (Tejpata) followed by 1.85% under arecanut + betelvine + miscellaneous trees as against 0.78% only in a degraded land within 10-15 years of this practice. A sharp increase in exchangeable Ca, Mg, K and Na was noticed in all the agroforestry interventions over adjoining degraded lands. The exchangeable Al, potential cause of infertility of these lands disappeared completely within 10-15 years of agroforestry practice. This was attributed to the addition of fresh organic matter which complexed exchangeable Al during decomposition possibly due to formation of Al-humate and accumulation of Ca, Mg, K and Na cations. It eventually increased soil pH by 0.6 to 1.7 units under these AFP. Thus, the potential AFP was found to have built in dynamism for the restoration of soil fertility and sustained yield (Singh *et al.,* 1994). Similar results were obtained when multipurpose trees were evaluated in an extremely P-deficient acid Alfisol in Meghalaya (Dhyani *et al*.,1994).Trees like *Alnus nepalensis*, *Parkia roxburghii*, *Michelia oblonga,Pinus kesiya*, and *Gmelina arboria* with greater surface cover, constant leaf litter fall and extensive root systems increased soil organic carbon by 96.2%, helped with better aggregate stability by 24.0%, improved available soil moisture by 33.2%, and in turn reduced soil erosion by 39.5% (Subba Rao and Saha, 2014).

Research efforts made at National Research Centre for Agroforestry, Jhansi for over two decades has resulted in development of appropriate agroforestry technologies for the rehabilitation of degraded lands of semi-arid Bundelkhand region. By alternate land use systems like silvi-pasture, agri-silviculture and agri-horticulture, the productive and protective benefits from watershed management (WSM) are considerably higher than the investment, benefit: cost ratios ranging from 1.92: 1 to 7.1:1 with 48 to 99 % reduction in runoff and 81 to 98% soil loss besides the check of out migration of population from 26.6% before the implementation of WSM programme to 9.3% during the project period (Samra, 1997; NRCAF, 2012). To combat desertification and wind erosion, massive afforestation work on shelterbelt/ windbreak and sand dune stabilization have been done in Indian arid zone particularly in eleven districts of western Rajasthan. About 2783 rkm (running kilometer) shelterbelts covering an area of about 9271 ha has been planted in Jaisalmer district alone (Mertia *et al*., 2006). These shelterbelts minimize hazardous effects of wind and create favorable micro-environment for farm crops (Prasad *et al*., 2009; Prasad and Mertia, 2009).

Nutrients recycling and intercrop yield

It is scientifically proved that agroforestry promote efficient cycling of nutrients that benefits intercrops. Agroforestry can partially provide the N requirement of crops, however, it depends on a variety of factors including the decomposition rate of organic mulches, biological N fixation and residue management. Trees can provide N inputs in agroforestry systems through biological N_2 fixation (BNF) and deep nutrient capture. The presence of active nodules in roots of leguminous species indicates that BNF can supply considerable N inputs to crops via litter in soils. The non-fixing trees, such as *Cassia* accumulate more N in their leaves than nitrogen fixing legumes, presumably because of their greater root volume and ability to capture nutrients which can be added to the soil as green leaf manuring. *Gliricidia, Leucaena*and *Sesbania* are also known for their N2 fixation and green-manuring potential. Deep nutrient capture by tree roots at depths where crop roots are not present are considered as an additional nutrient input in agroforestry systems because such nutrients are otherwise leached as far as the crop is concerned. They become an input on being transferred to the soil via tree litter decomposition (Yadav *et al*., 2008). Agroforestry, however, cannot supply most of the other nutrients required by crops. Phosphorus is often a critical nutrient in agroforestry. Combinations of organic and inorganic sources of P may result in a more efficient use of nutrients. The deep capture of P is likely to be negligible because of the very low concentrations of available P in the subsoil. Many agroforestry systems do accumulate P in their biomass and return it to the soil via litter decomposition, but such cycling does not constitute an input from outside the system. However, through cycling, some less available inorganic forms of phosphorus in the soil may be converted into more available organic forms. Maharudrappa (1999) reported that incubation of litter of different MPTs enhanced nutrient availability. The release of K to soil was more dependent on the quantity and quality of the litter. *Tectona grandis* recorded significantly higher values than other tree species. The increase in available K may be attributed to the fact that K is not strongly bound in organic structures, unlike that of N and P.

Inclusion of legumes in the agroforestry system makes it N self-sufficient. Introduction of suitable legumes in rangelands, pastures, silvipastures and agroforestry has great significance. The important legumes, which are suitable for introduction in arid and semi-arid silvipastures are *Dolichos lablab, Clitoria ternatea, Atylosia scarabaeoides, Macroptilium atropurpureum* and *Stylosanthes* species, while pigeopea, greengram, blackgram, chickpea, groundnut, soybean, cowpea, pea, lucerne, berseem, etc. can be introduced under cultivated agroforestry (Suresh and Rao, 2000).There are significant differences in estimates of BNF in trees, ranging from high rates up to 472 kg N_2 ha^{-1} $year^{-1}$ in *L. leucocephala*, *Gliricidia sepium*, *C. calothyrsus* to low rates <50 kg N_2 ha^{-1} yr^{-1} in *Acacia melanoxylon* and *A. holoserica* (Giller, 2001). In another beneficial interaction mycorrhizal fungi associated with trees can help in taking up nutrient from deeper soil layers and increasing the availability of less mobile nutrients like phosphorus. Among the non-legumes, Alnus, Myrica and Casuarina are widely recommended in agroforestry system, which fix nitrogen in association with Frankia. The nitrogen fixing potential of *Casuarina equisetifolia* is 50-80 N kg ha^{-1} yr^{-1} and *Alnus nepalensis* is 29-117 N kg ha^{-1} yr^{-1} (Sharma and Kapoor, 2005).

Contribution of agroforestry toward climate change goals

Indian agriculture is highly prone to the risks due to climate change; especially to drought, because 2/3[rd] of the agricultural land in India is rainfed and even the irrigated system is dependent on monsoon (Pathak *et al.,* 2015).The increasing concern for global climate change is that the future rate of climate change will be much faster than in the past and will produce combinations of temperature and precipitation that have no previous analogues. The main cause of global warming is the increase in concentration of greenhouse gases (GHGs) in the atmosphere (Van Noordwijk *et al*., 2011).

To tackle the issue of climate change and put a break on global warming,various mitigation and adaptation strategies have been suggested.The concept of low carbon economy, originated as a response to mitigate greenhouse gases, envisages that the basic activities of a modern society, including production of goods and services, and transportation should have near zero carbon emissions or minimum value to cease or at least slow down the global warming phenomenon. Agroforestry land use can be used as low carbon agricultural technology since itembraces trees into farming systems for producing various marketable food and non-food products besides offering great potential of sequestering atmospheric carbon and an almost zero cost approach for restoration of badly degraded land through nitrogen-fixing trees and shrubs(Prasad *et al*., 2014). In context of climate change, since agroforestry supports both adaptation (ensuring that the land cover can deal with likely climate changes without major loss of function) and mitigation (reducing net emissions by enhancing terrestrial carbon storage), it is referred as 'mitigadaptation' (Van Noordwijk *et al*., 2011). As a mitigadaptation strategy, agroforestry offers additionality over the other option of mitigation. The additionality factor of agroforestry comes from its conservation value and services to the environment (Ram Newaj and Dhyani, 2008).

Carbon sequestration

Agroforestry is often considered a cost-effective strategy for climate change mitigation. Tree-based farming systems store carbon in soils and woody biomass, and they may also reduce greenhouse gas emissions from soils. Compared to plantations of forestry species, carbon sequestration in agroforestry is relatively slow. Majority of the agroforestry systems have the potential to sequester carbon which may vary according to tree species (Prasad *et al.,* 2012) and management practices (Ram Newaj *et al.*, 2001).With adequate management of trees under agroforestry systems, a significant fraction of the atmospheric carbon could be captured and stored in plant biomass and in soils. Carbon storage in plant biomass is feasible in the long rotation agroforestry systems including wind-breaks, shelter belts, woodlots, boundary plantations and others. The average carbon storage by agroforestry practices has been estimated as 9, 21, 50 and 63 Mg C ha^{-1} in semiarid, sub-humid, humid and temperate regions. For smallholder agroforestry systems in the tropics, potential carbon sequestration rate ranges from 1.5 to 3.5 Mg C ha^{-1} yr^{-1}(Montagnini and Nair, 2004).Considerable quantities of carbon (1.1–2.2 Pg) could be removed from the atmosphere in the next 50 years if agroforestry systems were implemented on a global scale (Albrecht and Kandji, 2000).

A preliminary estimate indicated area under agroforestry in India as 25.32 million ha (Dhyani *et al*., 2013), which has now emerged as a promising land use activity and it has the potential to enhance above- and below-ground carbon stocks to mitigate climate change. According to Pandey (2002) carbon sequestration in Indian agro-forests varies from 19.56 Mg C ha^{-1} yr^{-1} in north Indian state of Uttar Pradesh to a carbon pool of 23.46–47.36 Mg Cha^{-1} in tree-bearing arid agro-ecosystems of Rajasthan. CAFRI conducted a survey in 32 districts of 12 states in the country for carbon sequestration potential (CSP) of existing agroforestry systems in the farmer's field. It revealed that agroforestry is practiced in all parts of India and is recognized as having high potential for carbon sequestration. The CSP of existing AFS at district level has been estimated to range from 0.05 to 2.78 Mg C ha^{-1} yr^{-1}. Based on this study, the average CSP of existing AFS at country level was 0.34 Mg C $ha^{-1}yr^{-1}$ or equivalently AFS in India has the potential to mitigate 1.245 Mg CO_2 ha^{-1} yr^{-1}. Thus, the trees in existing agroforestry systems on farmers' fields are estimated to mitigate more than 33% of the total GHG emissions from agriculture sector annually at the country level (Ajit *et al.* in press). The average cost of sequestering carbon through agroforestry systems is lower than other CO_2 mitigation options. It has been estimated that in India in addition to the existing area, 17.85 million ha area is potentially suitable for converting into agroforestry and a 25 to 30 per cent conversion of this land into agroforestry by the year 2030 can sequester up to 47.23 M t C y^{-1} which is substantial (Dhyani, 2012), and is higher than the annual increment of C stock of 38 M t from the forests and tree cover (FSI, 2009).

Ecosystem services

Agroforestry systems are believed to provide a number of ecosystem services. Trees with deep rooting systems in agroforestry can also improve ground water quality by serving as a ''safety net'' whereby excess nutrients that have been leached below the rooting zone of agronomic crops are taken up by tree roots. The other benefits include effectively protecting buildings and roadways from drifting snow, savings in livestock production—by reducing wind chills, protecting crops, providing wildlife habitat, removing atmospheric carbon dioxide and producing oxygen, reducing wind velocity and thereby limiting wind erosion and particulate matter in the air, reducing noise pollution.

Agroforestry is playing the greatest role in maintaining the resource base and increasing overall productivity in the rainfed areas in general and the arid and semi-arid regions in particular (Prasad and Dhyani, 2010). Agroforestry land use increases livelihood security and reduces vulnerability to climate and environmental change. There are ample evidences to show that the overall (biomass) productivity, soil fertility improvement, soil conservation, nutrient cycling, microclimate improvement, and carbon sequestration potential of an agroforestry system is generally greater than that of an annual system (Dhyani *et al*., 2009). Agroforestry has an important role in reducing vulnerability, increasing resilience of farming systems and buffering households against climate related risks. It also provides for ecosystem services - water, soil health and biodiversity. Agroforestry based watershed interventions enhanced provisioning ecosystem services (e.g., crop intensification and yield) and regulating ecosystem services (enhancing base flow, reducing siltation and enhancing groundwater availability), income and livelihood of farmers in Bundelkhand region (Singh *et al*., 2014).

Contribution of agroforestry toward food security goals

In recent time agroforestry has been viewed by research and development communities as a cost-effective means to enhance food security. Agroforestry has been shown to provide a number of benefits to farmers. Regarding adaptation of agricultural production to climate change, agroforestry has potential to moderate climate extremes, in particular high temperatures, as well as intra-annual climatic fluctuations. Tree canopies can create a more adequate microclimate for crops and more resilient ecosystems for better food production. Although microclimatic effects may convey adaptation benefits to farmers, added resilience through enhanced productivity and farming portfolio effects may be a greater contribution to coping with climate change at the farm level. Establishing agroforestry on land that currently has low tree cover has been identified as one of the most promising strategies to raise food production without additional deforestation (Garrity *et al*., 2010).

Agroforestry adoption and management

Scaling up of agroforestry adoption among small holder farmers has always been a key challenge. Agroforestry has not been picked up by small holders despite its excellent carbon sequestering/ production capabilities. Adoption of agroforestry depends on many management goals, drivers and contextual factors. In most cases, assets related to ecosystem services and to food security are the main motivating factors in agroforestry adoption (DeSouza *et al*., 2013). Agroforestry has supportive functions also, for example, soil fertility improvement or water recycling, particularly when management techniques such as mulching or conservation agriculture are applied **(**Bucagu *et al*., 2013**).** Agroforestry is therefore, often considered as a way to intensify farming practices for enhanced food security using socially and cost-effective management techniques. Many agroforestry options achieve this through low external input requirements, high recycling rates and crop-livestock integration (Koohafkan *et al*., 2012**).** They may thus be a viable option for smallholder farmers with limited resources, but where land holdings are small, farmers are often unwilling or unable to spare land for agroforestry establishment (even if this promises higher returns in the long run). Where land holdings are also insecure, farmers are often reluctant to invest in the long-term endeavour of establishing trees that may benefit the next owner of their land rather than themselves.

Another reason for non-adoption of agroforestry in India appears to itslong juvenile phase during which resource poor small and marginal farmers (70% farmers of the India) do not get any return and consequently hesitate in adopting agroforestry land use.For scaling up agroforestry adoption in India. Tewari *et al.* (2013) opined that the best option is to utilize provisions of watershed development projects, which can be used as a tool to promote tree-based farming systems. The Integrated Watershed Management Programme (IWMP) operational in the whole country offers a good launching pad for promotion of agroforestry among small holders and marginal farmers.

The important constraint that discourages agroforestry adoption by small holders is the lack of proven set of management packages for agroforestry systems. The agro part (herbaceous component) of agroforestry is as important as its woody (tree) part; however, in most of the discussions, innovation and improvement are sought and centred on trees ignoring agronomic components. In most cases crop varieties that are developed for high performance under conditions of optimum supply of light, nutrients, and water and freedom from pests and diseases are integrated in agroforestry system where such optimum conditions are lacking. This results in poor yield of crops which, ultimately questions the economic viability of particular agroforestry system. Hence, there is an urgent need to develop crop varieties and cultivars which perform well in below-optimal growth conditions commonly exist in agroforestry. There have been many breeding efforts to develop crop varieties suitable for some special conditions such as drought, water logged, saline and sodic soils and nutrient deficient soils, but breeding or selection of crops varieties that are suitable for sub-optimal light conditions (as exists in agroforestry) has never been attempted. Similarly, there is need to develop set of agronomic package of practices for crop grown as intercrops in agroforestry systems. A recent review on agronomic practices under agroforestry by Ghosh *et al.* (2014) opines that though the basic principles of agronomy remain the same, the agronomic practices are slightly modified owing to presence of perennial component in agroforestry.

Synergies between food security and climate change

Climate change mitigation has not traditionally been a driver of farmers' decisions, and it is unlikely to become a major driver in the future. Clearly, sequestering carbon on farms for the sake of climate change mitigation may not be attractive for a smallholder farmer, especially if mitigation efforts do not lead to short-term increases in income or welfare. Farmers may be very reluctant to sacrifice any part of their often meagre farm incomes to sequester carbon. If such farmers are to contribute to mitigation anyway, carbon-sequestering land use strategies must either be subsidized, to an extent that makes them equivalent to foregone profits from alternative land uses, or they must be profitable in their own right without any compensation. Agroforestry is one the few land use strategies that promises such synergies between food security and climate change mitigation. It is also less likely than other strategies to negatively affect the provision of non-carbon ecosystem services, such as water cycle regulation or biodiversity conservation (Mbow *et al*., 2014).

Future prospects

Agroforestry land use has the real potential to contribute to food security, climate change mitigation and adaptation, while preserving and strengthening the environmental resource base of rural landscapes (Mbow *et al*., 2014). For millions of farmers whose livelihoods are threatened by climate change and land degradation, agroforestry offers a pathway toward more resilient livelihoods. However, not all agroforestry options are viable everywhere, and the current state of knowledge offers very little guidance on what systems work where, for whom and under what circumstances. The following questions that remain unanswered for most places need to be answered by future research and policy planning:

- Which tree-crop-site combinations are characterized by synergistic interactions?
- What extension methods are most effective for promotion of climate-smart agroforestry systems?
- Which agroforestry systems support healthy, ecologically functional landscapes?
- How can ecosystem service delivery through agroforestry systems be optimized?
- How will agroforestry species respond to climate change?
- Are adaptation benefits from agroforestry greater than those of alternative land uses?
- How, if at all, can smallholder farmers benefit from carbon payments or payment for ecosystem services that agroforestry provides?

The above list is by no means exhaustive. In fact, knowledge gaps in agroforestry are greater than the actual body of knowledge on most aspects. It is therefore essential that research efforts on these important cropping systems are intensified, so that future scaling-up of agroforestry can be rooted in robust scientific findings rather than the intuitions of governments and development actors.

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Modelling of soil loss using USLE through Remote Sensing and Geographical Information System in micro-watershed of Kashmir valley, India

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ABSTRACT

The present study was conducted to prediction of soil loss using the Universal Soil Loss Equation (USLE) with the computer capabilities of a Geographical Information System (GIS), using the software package ArcGIS at Khimber micro-watershed of Dal Catchment in Kashmir valley. The USLE estimate the soil loss based on the relationships of factors; rainfall (R), soil erodibility (K), topography (LS), vegetation (C); and erosion control and practice (P). The input data of the factors for each field was derived from available land information and field survey. A digital elevation model (DEM) of study area was created by digitizing contour and grid themes for (K) and (C) factors. The topographic factor incorporates, the length factor (L) and the slope factor (S) of each field, required to compute the LS factor, were derived from field boundary information and DEM. A distribution map indicated the soil loss estimation of each field. The result shows that the average soil loss wasobtained 14.4 t/ha per year. It has also found that combining the USLE with ArcGIS tools is useful for estimating soil loss on a local scale forslope maintaining.

Key words: Watershed management, GIS, Remote sensing, USLE, Soil loss

INTRODUCTION

Land degradation is environmental hazards as it has a direct bearing on decline in productivity on arable and non-arable land. It is estimated that about 80% of the current degradation on agricultural land is caused by soil erosion due to water in the world (Angima *et al.*, 2003). Hydrological disasters coupled with high erosion rates have serious social, economic and environmental implications (Pimental, 2000; Kumar *et al.*, 2012). One of the major negative onsite effects of soil erosion is the loss of fertility status leading to decline in productivity. It is estimated that India suffers an estimated loss of 13.4 million tons of soil in the production of cereals, oil seeds and pulse crop due to water erosion equivalent to Rs. 150.0 billion (Kumar *et al.,* 2013). As per harmonized data base on land degradation, 120.72 million ha area is affected by various forms of land degradation in India with water erosion (68.4%) being a chief contributor (Maji, 2007).This is evident from the fact that almost 175million-ha of land in India, constituting about 53% of its total geographical area, suffers from such deleterious effects. It has been estimated that about 16.4 t/ha of soil is detached annually in our country because of various causes of destruction (Singh, 2000). Jammu and Kashmir is a hilly state and about 4.13 million-ha of land is affected by different forms of soil erosion (ENVIS, 2003; Gupta and Singh, 2010). Soil erosion is one form of soil degradation along with soil compaction, low organic matter, loss of soil structure, and poor internal drainage problem. Erosion hazard is a major land degradation problem in mountainous environment (Pandey *et al.,* 2008). Soil erosion may affect crop production by way of nutrient loss. The human activities, man-made slopes, cuts and embankment are also a main cause of the soil degradation (Billota *et al*., 2012; Khosrowpanah *et al*., 2007). It is difficult to predict the soil loss because of the complexity of the factors involved and the relationship to each other which is wide ranging. The influence factors which are usually related to soil loss are geology, soil type, land surface, temperature, land cover, underground water level, slope aspect, slope inclination and elevation.

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One of the most widely applied empirical models for assessing the erosion is the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978). This model takes into consideration several factors, such as the soil erodibility factor; rainfall intensity; slope length; steepness; cover and management factor and support practice factor. Although USLE has many shortcomings and limitations, it is widely used, especially at regional and national level, because of its relative simplicity and robustness and it represents a standardized approach. USLE has not been designed to operate at field scale, however, it is noted that there is room for improving the accuracy of results by using more detailed digital elevation models, satellite data, with enhanced geometric characteristics, and more detailed soil information (Farooq *et al.,* 2008; Gitas *et al*., 2009; Pali *et al.,* 2014). There is considerable potential for the use of GIS technique as an aid to soil erosion hazard assessment. GIS technique has been recognized as a powerful and effective tool for predicting soil erosion process. A digital elevation model (DEM) is a type of spatial data set, which describes the elevation of the land surface are widely used in applications of GIS (Asres *et al.,* 2010). ArcGIS is one of commercial software product that buildsan integrated collection of GIS and supports a variety of applications (Anon, 2005).Land degradation has become a global issue due to soil erosion by various erosion agents/ processes is highly alarming. The most widely used empirical model for erosion is USLE which is used to estimate annual soil loss. USLE has been used in many locations and applied to innumerable land uses, but this study is a new attempt at predicting soil loss in a micro-watershed using USLE in combination with Arc GIS10. The study will also serve as a model so that same approach may be adopted for other watersheds which may ultimately prove beneficial for conserving and protecting the soil of the watershed. The use of GIS technology in this study opens a new window of application of GIS in watershed management. The present study is aimed to estimation of soil loss in a micro watershed using USLE with the ArcGIS software for delineating micro-watershed, estimation of USLE parameters and estimation of soil loss.

MATERIALS AND METHODS

Study Area

The study conducted at Khimber micro-watershed located in Dal catchment, of Kashmir valley, India. It is located between 74.816°to 74.902° E longitudes and 34.153° to 34.234°N latitudes. The total area covers approximately 42.2km^2. The micro-watershed extends from Tailbal to Shuhama with some area lying in Ganderbal district. The vegetation varies with hilly areas supporting only small shrubs and other low lying areas under orchards and rice cultivation. The micro-watershed has main tributary draining into Dal lake. The map of study area is shown in Fig. 1 depicting different drainage pattern of drainage in the catchment.

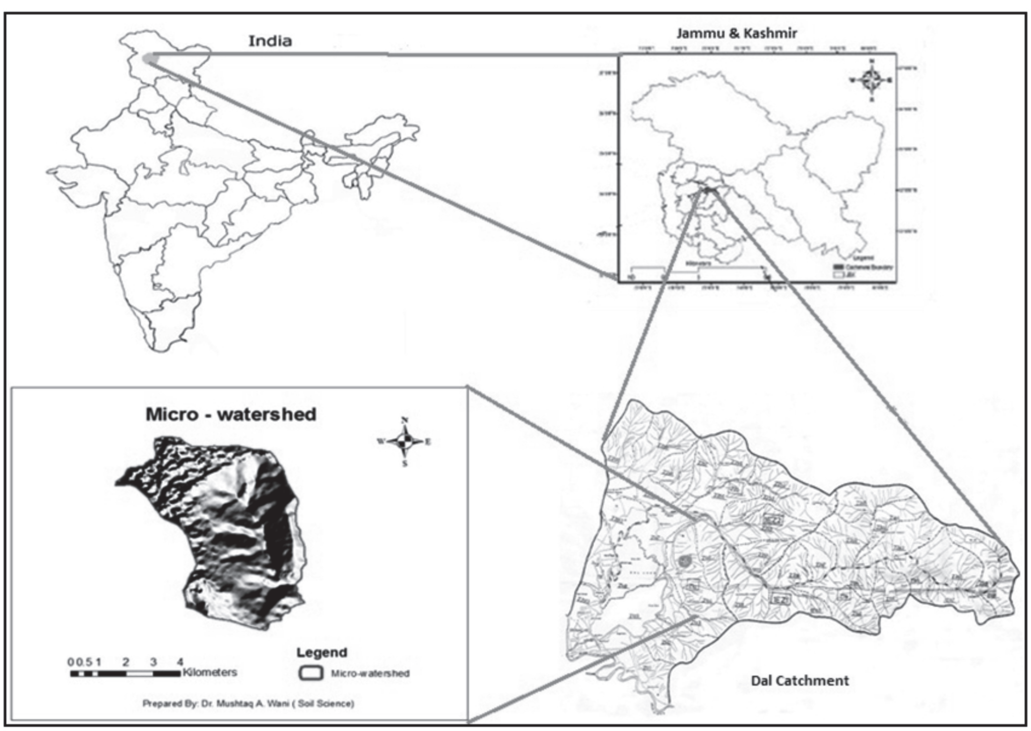

Fig. 1. Study area map

USLE Method

The USLE was developed by Wischmeier and Smith (1978) to estimate the average annual soil loss occurring over an area. The USLE is an empirical equation computes soil erosion as the product of six factors representing rainfall erosivity, soil erodibility, slope length, slope steepness, cover management practices, and support conservation practices. It is based on statistical analysis of erosion measured in the field on scores of test plots under natural and simulated rainfall. The annual soil loss from a site was predicted using the following equation:

$$A = R \times K \times LS \times C \times P \qquad \ldots(1)$$

where, *A*: Computed Soil Loss (t /ha) for a given storm period or time interval; *R*: Rainfall Factor; *K* : Soil Erodibility Value; *L* : Slope Length Factor; *S* : Steepness Factor; *C* : Vegetation Factor; and *P* : Erosion Control and Practice Factor. USLE estimates soil loss from a hill slope caused by raindrop impact and overland flow. The hill slope of micro-watershed of different points is shown in Fig. 2.

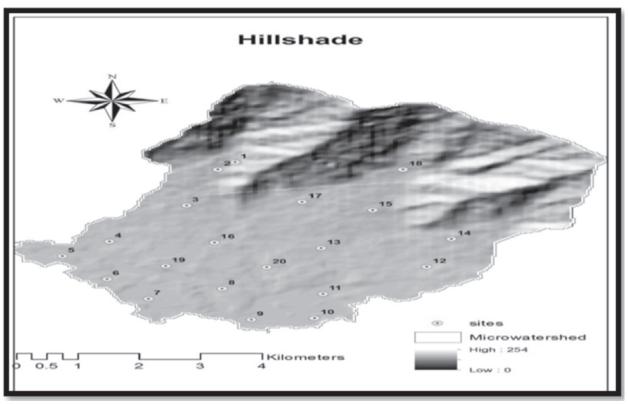

Fig. 2. Hill slope of micro-watershed of different points

The plan of work was divided into following steps: The procedure of watershed delineation is as follows:

a) The elevation contours of the Dal Catchment area was converted into a feature file in ARCMAP 10.1.

b) With the tool Create TIN form features, a TIN file was created using soft line criteria.

c) The TIN file was converted into a Raster DEM with a grid size of 10 x 10 that shows the elevation range in the catchment. This grid resolution was considered convenient to take advantage of the resolution given by the raster land aerial photometry file.

d) The imperfections on the new DEM raster file were filled with the FILL command and converted into a new raster file.

e) This raster image was "masked" with a catchment boundary polygon file encompassing the total area of the catchment.

f) The raster information was limited to the Dal Catchment with all surrounding information being excluded. Subsequently, the slopes were calculated (in degrees) with the 3D analyst slopes. The detail of watershed boundary is given in Fig. 3.

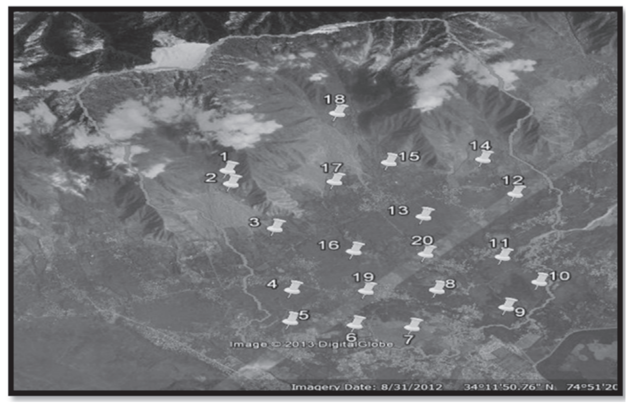

Fig. 3. Google earth-snap depicting the watershed boundary

K-factor

Soil samples from different identified sites were collected. While collecting the soil samples the elevation and location data was also recorded. K-factor was determined by soil analysis. In order to determine the values of K for the different soil of the catchment area, the land capability survey of India soils map were used. The parameters required for this factor are: soil organic matter content; amount of sand % between 0.10 and 2.00 mm; soil structure; and permeability. The information was taken for the layer corresponding to the first 100 mm of soil. The rainfall data was collected from, Division of Agronomy, Sher-e- Kashmir University of Agricultural Sciences and Technology of Kashmir.

Using ArcGIS software for estimating LS-factor

In order to produce the L-factor raster file, raster files were generated for the ë, m, and â factor values by reproducing following equation into the raster Calculator.

$$L = \left(\frac{\lambda}{22.1}\right)^m \qquad \ldots(2)$$

The land use raster file was generated from 1m x 1m aerial photometry raster of the Dal Catchment for crop management(c) factor. The specific land use polygons were digitized in Arc- map 10.1 at a chosen scale of 1:4,000th since all detail could be recognized on the aerial photograph at this scale and the overall view of the surrounding area could still be appreciated. The ERDAS IMAGE® program was used to facilitate the land use digitizing procedure. This program divides the raster cells into categories depending on the light reflection intensity on the land surface. Each different category can be represented by a different color. Based on the conservation practices in place at a particular site the value of P-conservation practice factor is assigned. All the data are integrated and incorporated in ArcGIS and DEM software and risk maps were generated for the study area.

RESULTS AND DISCUSSION

USLE equation is one of the most promising model currently being used with remote sensing and GIS application. The flow direction raster for each grid cell was generated from the DEM raster file. The flow accumulation raster image developed from the DEM raster file. Once the flow direction and flow accumulation have been determined, stream networks can be identified by setting a threshold for the flow accumulation. The map showing flow pattern and accumulation to outlet of watershed is summarized in Fig.4. The different land-use classes in watershed are shownin Fig. 5.

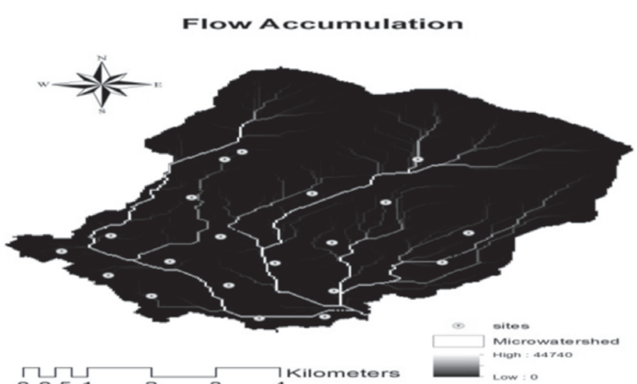

Fig. 4. Flow pattern and accumulation to outlet

The R factor is the climatic factor determining the erosive force of rainfall on the ground. R is the product of event rainfall kinetic energy and the maximum rainfall intensity in 30 minutes (Wischmeier and Smith 1978; Renard and Freidmund, 1994). The rainfall pattern of study area for last 12 year is shown in Fig. 6. The R-factor distribution for Khimber watershed of Dal catchment is determined using different input parameters is shown in Fig. 7.

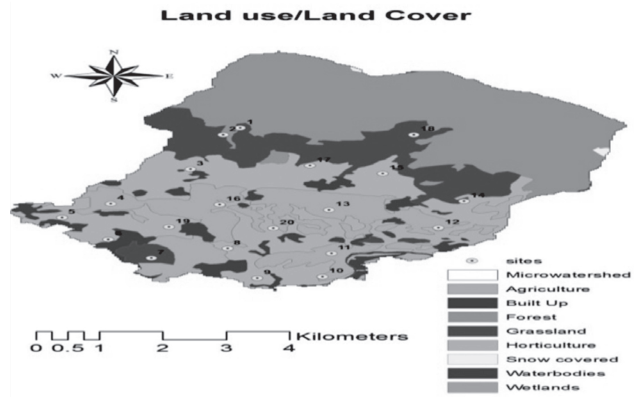

Fig. 5. Land use and land cover of watershed

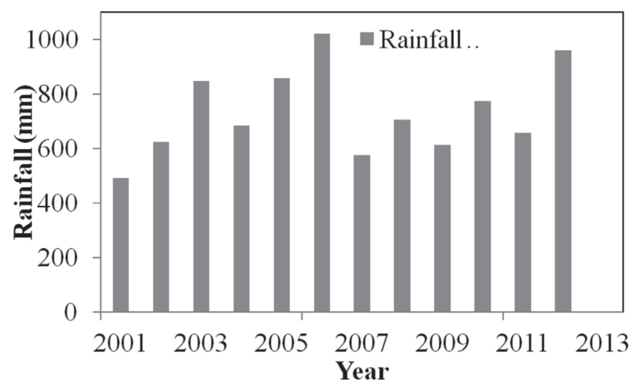

Fig. 6. Rainfall pattern of study area during 2001-20012

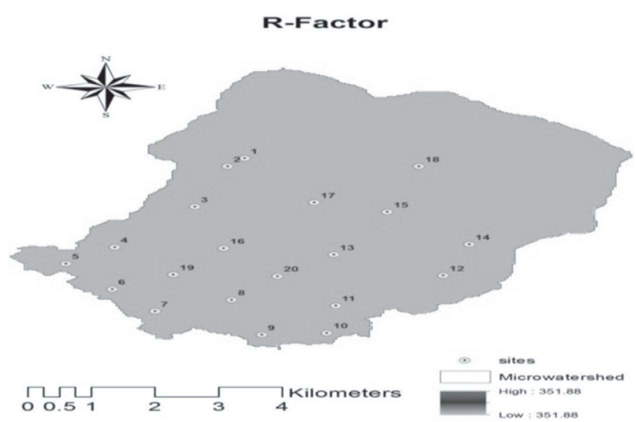

Fig. 7. R-factor distributions for Khimber watershed

K-factor is the measure of tendency of soil eroded; the higher values of K-factor for a particular soil indicate that soil is very susceptible to soil erosion. The K-factor calculation includes soil organic matter content; amount of sand % between 0.10 and 2.0 mm; soil structure and permeability. It can be observed from the K-factor map of hilly areas that have more slope are more susceptible to soil erosion due to the presence of greater amount of sand in the texture. K-factor is a function of soil composition and texture. The susceptibility of land is shown in Fig. 7 and in different colors. K-factor is the measure of tendency of soil eroded; the higher values of K-factor for a particular soil indicate that soil is very susceptible to soil erosion. The K-factor calculation includes soil organic matter content; amount of sand % between 0.10 and 2.0 mm; soil structure and permeability. It can be observed from the K-factor map of hilly areas that have more slope are more susceptible to soil erosion due to the presence of greater amount of sand in the texture. K-factor is a function of soil composition and texture. The susceptibility of land is shown in Fig. 8 and in different colors. The green areas in the map indicate the soil highly susceptible to erosion, whereas the red areas indicate the soils which are fairly resistant to erosion.

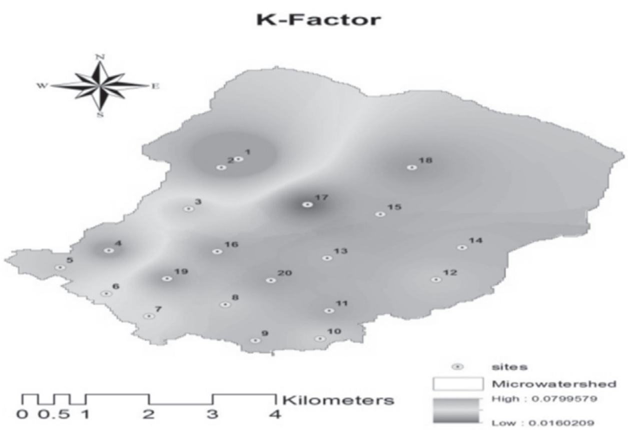

Fig. 8. K-factor range for various soils of the micro-watershed

LS-factor map

The LS factor for different land use was determined for the given area. The LS factor value indicate the erosion affected area. The distribution of LS-factor in the watershed is shown in Fig. 9 in different colors. The crop management practice-factor describes the effect of crop and management on soil loss rates. The hilly areas watershed lack vegetation cover, hence the crop factor value is lesser, whereas in plain areas the crop factor has a high value indicating a contribution of crop cover towards the prevention of soil loss. The P-factor in the USLE equation accounts for the effect on soil loss due to specific support practices and the contour tillage effect. The P-factor depends directly on the agricultural practices used in the study area. Based on the data obtained from the field survey and the satellite image the P-factor map was generated. The distribution value of P- factor and crop management factor are shown in Figs. 10-11 in different colors.

The brown areas in the map represent those areas which are not under any conservation practices for which P value is 1. The green and purple colors indicate that area is under conservation practices such as tillage.

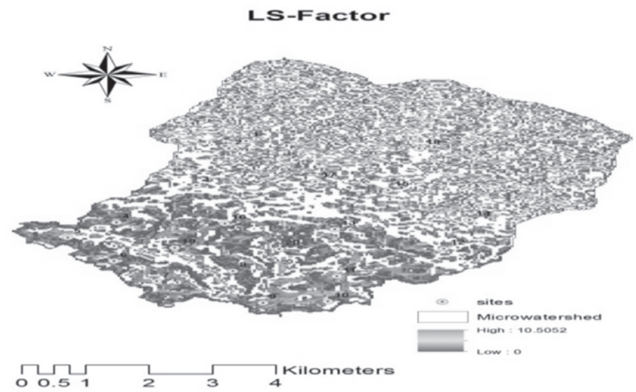

Fig. 9. LS-factor distribution for the Khimber watershed

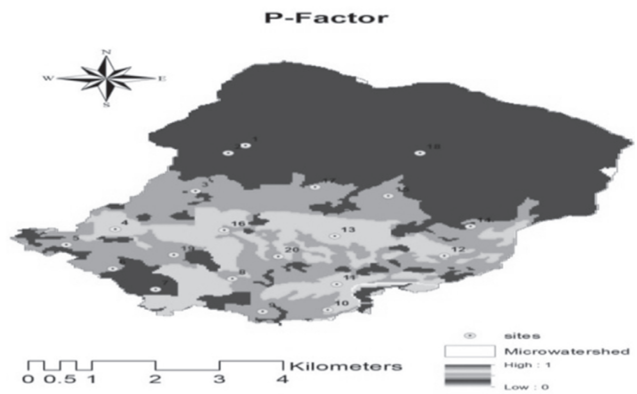

Fig. 10. Distribution of conservation practices (P-factor)

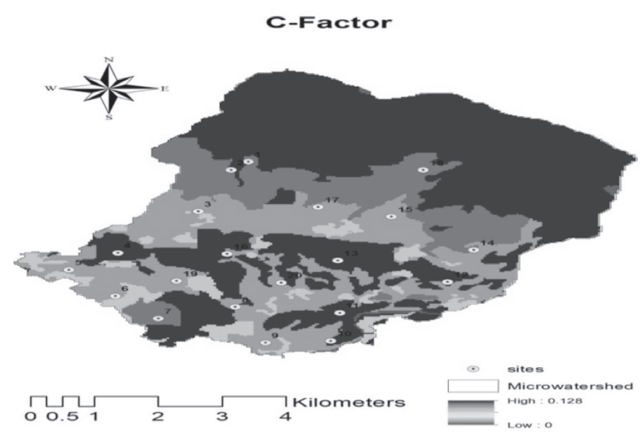

Fig. 11. Crop management factor map for Khimber watershed

Predicted soil loss

Using USLE, the soil loss using remote sensing and GIS technique was determined. Different USLE parameters values were used in USLE. The graphical representation of soil loss in different area of watershed is shown in Fig. 12. The soil loss in different category/ land use is depict in different colors. The estimated soil loss was 14 t/ha/yr, and total annual soil loss of 59077.2 t/yr in the catchment.

CONCLUSIONS

The present study was conducted to asses soil loss quantity using remote sensing and GIS

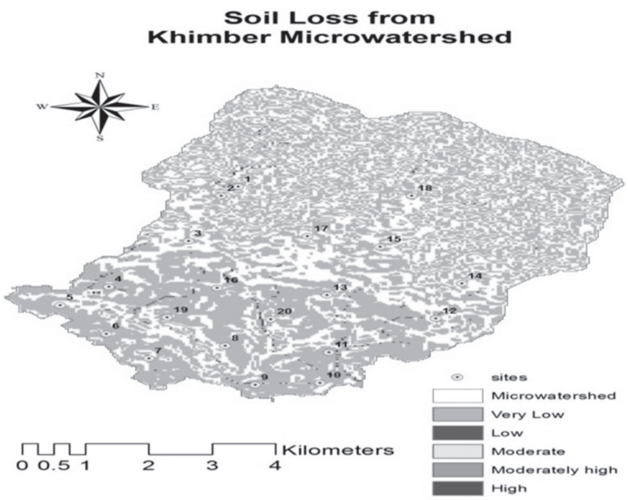

Fig. 12. Soil loss depicting on map using different colors

technique in Khimber micro-watershed of Dal catchment in Kashmir valley. This study presented the prediction of soil loss using USLE with the computer capabilities of a GIS and ArcGIS. The USLE estimate the soil loss based on the relationships factors of, rainfall (R); soil erodibility (K); topography (LS); vegetation (C); and erosion control and practice (P). The mean value of soil loss was estimated14 t/h/yr, and total annual soil loss was 59077.2 t/yr. The areas classified which are represent highly susceptible to soil erosion in the catchment. It is therefore suggested that soil conservation measures based on land slope should be used to minimize the soil loss from the field.

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Augmented groundwater availability by artificial recharge structures in semi-critical area in Chhattisgarh

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ABSTRACT

Artificial Recharge of aquifer systems is gaining importance as one of the strategies of water management in the context of ever growing demands of water resources. It is the process by which groundwater is augmented at a rate exceeding that of natural conditions of replenishment. Artificial recharge to groundwater through scientifically designed structures has been proven as a viable option for augmentation of groundwater resources. The analysis was performed to know the effect of artificial recharge structures on groundwater availability in semi-critical area in Chhatisgarh. The upper Kurudihnala watershed which is a small groundwater basin located in Patan block of Durg district of Chhattisgarh state has been selected for the study. The watershed boundaries, slope, soil texture maps have been generated using Geographic Information System (GIS). Land use/cover map was derived for the study watershed from satellite imageries. Artificial recharge structures in study area were found to be efficient for recharging surrounding area. It was found that artificial recharge structures increased water level by 39 % in both *kharif* and *rabi* seasons.

Key words: Groundwater, Groundwater recharge, Artificial recharge structures, Augmentation of groundwater resources

INTRODUCTION

Groundwater is a precious and the most widely distributed resource of the earth and unlike any other mineral resources, it gets its annual replenishment from the meteoric precipitation. It is the largest available source of fresh water lying beneath the under ground. It has become the major source of water to meet the requirements of domestic, industrial and irrigation sectors in India in the last few decades on account of its ubiquitous occurrences, easy availability and reliability. At present, the groundwater in India contributes more than 58% for drinking water, 52% for agricultural production and 50% for urban and industrial sectors.

Precipitation is the main source of groundwater recharge; the others being seepage from canal system, return flow from the applied irrigation, sub-surface inflow from the adjoining region (Miglani and Agrawal, 2011). Groundwater exploitation, particularly in India, has increased by leaps and bounds over the last 20 years along with the expansion of shallow, most private, wells. The growth of groundwater abstraction structures from 1982 to 2001 clearly depicts the increasing use of groundwater utilization across sectors (Sachan *et al*., 2008).

Healy *et al*. (2002) presented a review of methods that are based on groundwater-level data. The water-table fluctuation method may be the most widely used technique for estimating recharge; it requires knowledge of specific yield and changes in water levels over time. Other methods that use water levels (mostly based on the Darcy equation) are also described. Kumar (2009) presented a detailed technical report on groundwater assessment methodologies and described the significant advantages and limitations of soil water balance method.

Artificial Recharge of aquifer systems is gaining importance as one of the strategies of water management in the context of ever growing demands of water resources. It is the process by which groundwater is augmented at a rate exceeding that of natural conditions of replenishment. Artificial recharge to groundwater through scientifically designed structures has been proven as a viable option for augmentation of groundwater resources.

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The Chhattisgarh state receives adequate rainfall (average annual rainfall is1240 mm). About 87 % area of the state is covered by hard rocks. Groundwater availability is largely influenced in these rocks by the topography and rainfall. Because of varied topography and hydrogeological condition in the state, the groundwater potential is not uniform and it changes from one area to another. Out of 146 blocks in state, 8 have been categorized as semi-critical from groundwater development point of view as the stage of groundwater development is more than 70% but less than or equal to 90 %. Out of these 8 blocks, 6 fall in Durg, 1 in Dhamtari and 1 in Bilaspur District (CGWB, 2004).

MATERIALS AND METHODS

Study Area

The Kurudihnala sub-watershed of Gajara watershed was chosen for detailed study. It is located between 81.29° to 81.34° E longitude and 21.06° to 21.13° N latitude and covers an area of 28.04 km^2. The Kurudihnala sub-watershed is a 3rd order watershed according to Strahler's stream ordering scheme and comprises of 8 villages. Location map of the study area is shown in Fig.1.

The topography of the watershed is almost flat. The slope ranges from 1% to 1.7% and the weighted average slope of the watershed is 1.5%. Predominant soil of the watershed is clay soil. Sandy clay loam, Sandy loam and loam are also found in the watershed.

The elevation of the watershed ranges from 270 m to 310 m above Mean Sea Level (MSL). The watershed receives an average annual rainfall of 1230 mm, out of which the monsoon season (June to October) contributes more than 80% rainfall. The daily mean temperature ranges from a maximum of 36.8° C to a minimum of 7.4° C. The daily mean relative humidity varies from a minimum of 44.2% in the month of April to a maximum of 87.5% in the month of August. Major crops grown in the area are paddy (rice), maize and minor millets in monsoon season.

Hydrological data

The daily rainfall for the Kurudihnala watershed observed for the year 2000-2009 were

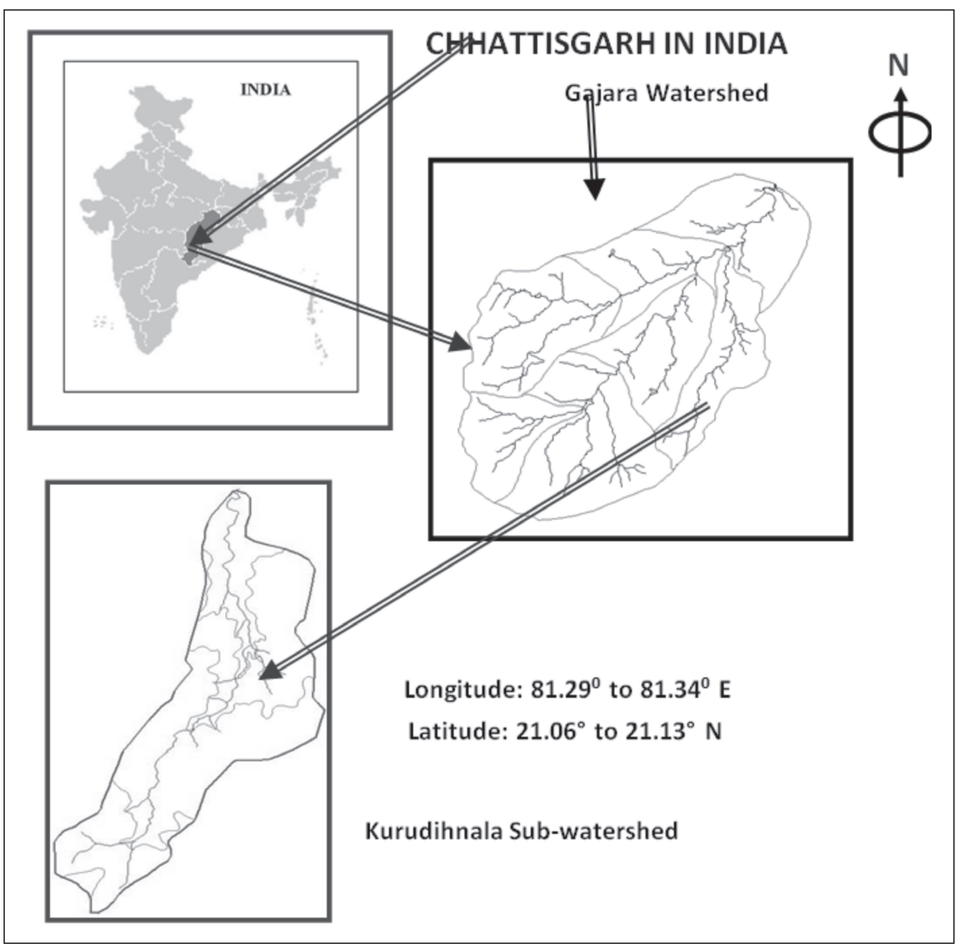

Fig. 1. Location Map of the Study Area

collected from the Data Center, Water Resources Department, Raipur. The average annual monsoon rainfall and average annual non-monsoon rainfall was estimated from available data.

Artificial recharge structures

Detail study of the artificial recharge structures in study area had been carried out by locating the structures and by taking measurement of structures. The three percolation tanks and nine check dams existed in the study area were considered.

Allocation of recharge structures

Location of all recharge structures in watershed were observed by field survey and noted by using the device named Global Positioning System (GPS). Locations of all recharge structures is given in Table 2 and Fig. 6. Recharge structures in study area which includes check dam, percolation tank and loose boulder dam were shown as in Fig. 2, Fig. 3, and Fig. 4.

Fig. 2. Boulder check dam at the upper reaches (Kurudih village)

Measurement of recharge structures

Measurement of the dimensions of all recharge structures had been carried out by measuring tape (Fig. 5). The dimension of all structures is given in Table 1.

RESULTS AND DISCUSSION

Total number of twelve artificial recharge structures are existing in the watershed and all these structures were considered in the present study. Among these three percolation tanks and nine check dams (including one loose boulder dam) are there. Location map of the artificial recharge

Fig. 3. Check dam at the middle reaches of the Kurudihnala

Fig. 4. Percolation tank at the middle reaches of the Kurudihnala (Tarra village)

Fig. 5. Measurement of dimensions of recharge structures in the study area

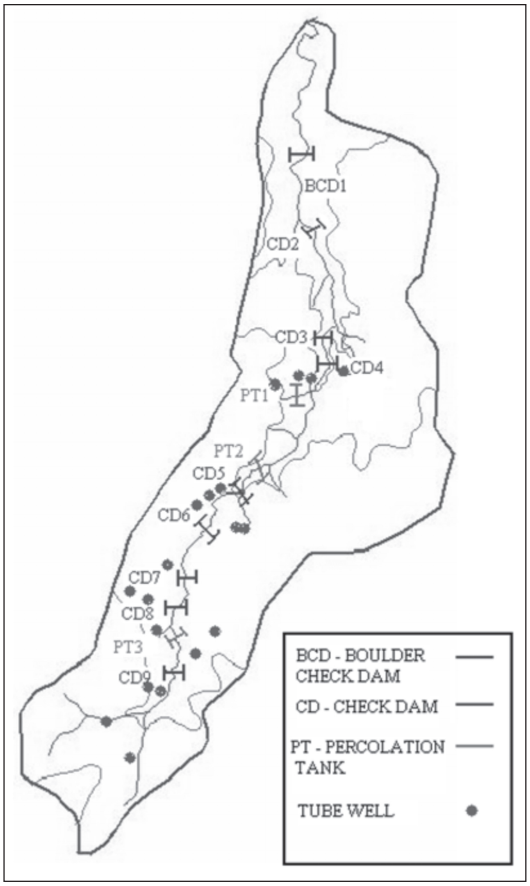

Fig. 6. Location of artificial recharge structures and tube wells surrounding the structures in study Area

structures along with the tube wells existing around the structure are shown in Fig. 6. Locations and dimensions of all the artificial recharge structures in study area are given in Table 1.

Water level trends

Monthly observations of depth to water level for the 2000-2009 were collected and observed for depth to water level during dry period and depth to water level during wet period. The effect of recharging due to artificial recharge structures in the watershed was evaluated by comparing water level trends before construction of recharge structures (2000-2004) and after construction of recharge structures (2005-2009). Fig.7 shows the water level trends of pre-monsoon (dry period) season of the year from 2000 to 2009. It can be visualized that there was gradual increase in water level after 2004 i.e. after construction of recharge structures. Similarly, Fig. 8 shows the water level trends of post-monsoon season of the year 2000-2009 (wet period). It is observed that water level during wet period was gradually decreasing after 2004 (i.e. after construction of recharge structures).

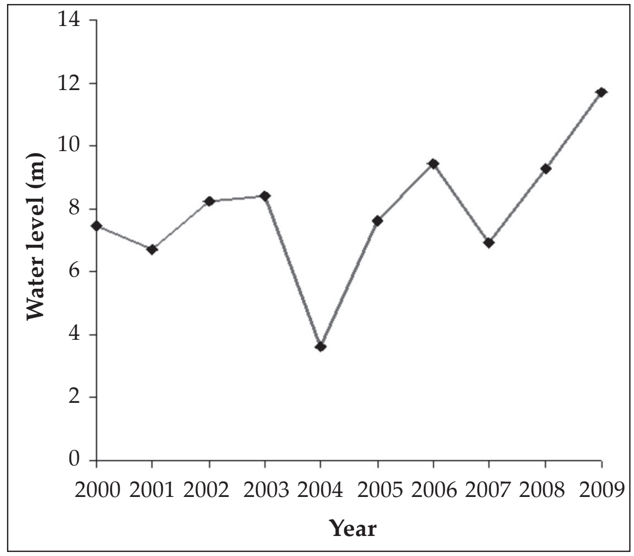

Fig. 7. Water level depth during dry period (pre-monsoon)

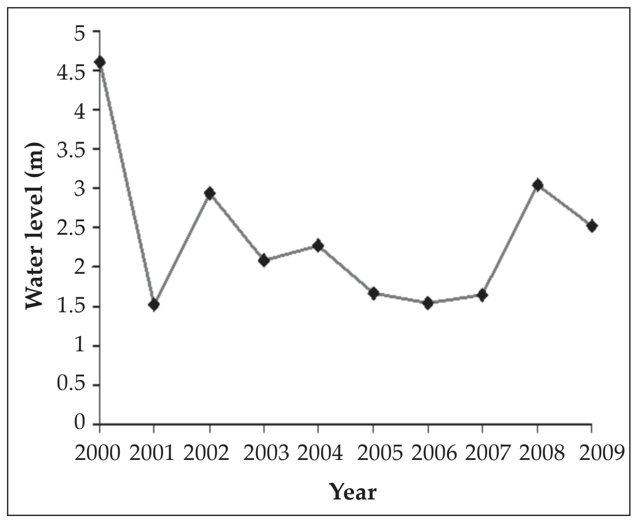

Fig. 8. Water level depth during wet period (post-monsoon)

From collected monthly data average value of depth to water level for each year during dry period was considered for the depth to water level in pre-monsoon season. Hence, from the collected data, average value of the depth to water level during dry period was calculated for each year (Table 1).

Depth to water level during wet period was considered for the depth to water level in post-monsoon season. Hence, from the collected data, average value of the depth to water level during wet period was calculated for each year (Table 2). Rise in water level in monsoon season was calculated by taking difference between depth to water level in dry period and depth to water level in wet period (CGWB, 2007). It showed that rise in water level in monsoon season after construction of recharge structures increases gradually up to 2009.

Table 1. Location and dimensions of artificial recharge structures in the Kurudihnala watershed

S. No.	Recharge structure (code)	Village	Location	Dimensions
1	Loose boulder check dam (BCD1)	Kurudih	Elevation 328 m N-21° 12' 05.0" E-81° 31' 20.7"	Span 7 m Depth 1.94 m Apron 1.99 m
2	Check dam (CD2)	Khamariya	Elevation 276 m N-21° 11' 37.0" E-81° 31' 23.6"	Span 45.60 m Depth 4.55 m Apron 8.55 m
3	Check dam (CD3)	Amlidih	Elevation 280 m N-21° 10' 23.3" E-81° 31' 36.4"	Span 12 m Depth 2.60 m Apron 8.70 m
4	Check dam (CD4)	Amlidih	Elevation 275 m N-21° 10' 17.7" E-81° 31' 39.5"	Span 9 m Depth 0.8 m
5	Percolation tank (PT1)	Amlidih	Elevation 280 m N-21° 09' 42.7" E-81° 31' 25.0"	Length 102.1 m Width 66 m Depth 2.2 m
6	Percolation tank (PT2)	Ameri	Elevation 290 m N-21° 09' 30.9" E-81° 31' 23.9"	Length 74 m Width 104.5 m Depth 2.30 m
7	Check dam (CD5)	Amlidih	Elevation 286 m N-21° 09' 30.8" E-81° 31' 24.0"	Span 24.90 m Depth 3.4 m Apron 5.70 m
8	Check dam (CD6)	Karga	Elevation 289 m N-21° 09′02.8" E-81° 30' 58.5"	Span 9 m Depth 1.9 m Apron 3.70 m
9	Check dam (CD7)	Tarra	Elevation 301 m N-21° 08' 06.8" E-81° 30' 25.1"	Span 9.90 m Depth 1.70 m Apron 2.80 m
10	Check dam (CD8)	Tarra	Elevation 295 m N-21° 07' 42.6" E-81° 30' 23.0"	Span 9.85 m Depth 1.15 m Apron 1.90 m
11	Percolation tank (PT3)	Tarra	Elevation 357 m N-21° 07' 31.5" E-81° 30' 19"	Length 40 m Width 51.6 m Depth 2.4 m
12	Check dam (CD9)	Tarra	Elevation 294 m N-21° 07' 20.01" E-81° 30' 14.9"	Span 11.45 m Depth 1.5 m Apron 4.85 m

Table 2. Depth to water level during dry period wet period and rise in water level in monsoon season

S. No.	Year	Depth to water level during dry period (m)	Depth to water level during wet period (m)	Rise in water level in monsoon season (m)	Per cent increase in water level
1.	2000	7.46	4.60	2.87	—
2.	2001	6.72	1.52	5.21	44 %
3.	2002	8.25	2.93	5.32	2 %
4.	2003	8.38	2.08	6.30	15.5 %
5.	2004	3.63	2.26	1.37	—
6.	2005	7.63	1.67	5.96	77.63 %
7.	2006	9.45	1.54	7.90	24.59 %
8.	2007	6.91	1.65	5.26	—
9.	2008	9.28	3.04	6.25	15.86 %
10	2009	11.69	2.53	9.16	31.79 %

It can be observed from the Table 2 that the water level after 2000 was raised by 44 per cent, after 2001 by 2 per cent and after 2002 by 15.5 per cent (in duration of before construction of recharge structures). Similarly, after 2004 there was 77.63 per cent increase in water level, after 2005 increased by 24.59 per cent and after 2007 increased by 15.86 per cent (in duration of after construction of structures). Hence it can be concluded that water level is increased by 39 per cent after construction of artificial recharge structures. Under semi-arid conditions of western India, Sharda *et al.* (2006) have estimated groundwater recharge as 7.3% and 9.7% of the annual rainfall by water table fluctuation method for two different years while the two years average recharge was estimated as 7.5% using chlorine mass balance method. Recharge in groundwater due to check dams and percolation tanks were also reported by Tripathi *et al.* (2010).

Groundwater use

The recharged groundwater has been utilized every year by the farmers of the nearby area through tube wells during *kharif* as well as *rabi* season. By field survey it was observed that before construction of structures in study area there was lack of availability of water in *rabi* season, but after 2004 i.e. after construction of structures water was available throughout the season for irrigation.

CONCLUSIONS

Artificial recharge structures in study area were found to be efficient for recharging surrounding area. The impact of artificial recharge structures is evident for showing effect on bore wells by increasing water level by 39 per cent in both *kharif* and *rabi* seasons. Farmers are being benefited in terms of increased crop production due to artificial recharge structures.

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Irrigation water and pumping energy use trends in rice (*Oryza sativa* L.) under varying irrigation regimes in partially reclaimed sodic soils

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ABSTRACT

Sodic soils are characterized by a relatively low electrical conductivity (EC), high exchangeable sodium (Na) on exchange sites, soil pH > 8.0, low rate of infiltration, and dispersed soil. From crop irrigation management perspective, the major challenges for sodic soils are their low infiltration characteristics, less available water for plants due to reduced water holding capacity, and low restricted water movement from sub soil to root zone because of poor hydraulic conductivity. This requires frequently replenishing the root zone with optimum volume of water to sustain plant growth. An experiment to determine the suitable irrigation depth and frequency, along with methods of application namely: Surface (farmer's practice), Sprinkler (double nozzle impact sprinkler), and LEWA (Low Energy Water Application) was initiated. Irrigation depth of 6 cm in case of Surface method, and 4 cm in case of Sprinkler and LEWA was applied at each irrigation event. The irrigation events were scheduled at 2-DAD (days after disappearance of water), 3-DAD and 4-DAD in case of surface method, and daily, 1-day and 2-day interval (after initial ponding disappeared) by Sprinkler and LEWA. The results revealed that grain yield varied with varying irrigation regime. Amongst surface irrigated plots the highest grain yield of 4.4 t ha^{-1} was obtained under highest irrigation level of 2-DAD which registered decline by 10% at 3DAD and by 25% at 4 DAD. Yield variation was marginal within Sprinkler and LEWA irrigated plots where highest yield of 4.4 t ha^{-1} at daily and 2-day interval in case of Sprinkler and at 2-day interval in case of LEWA was observed. Sprinkling methods (Sprinkler and LEWA) scheduled at 2-day interval resulted in water saving of 20% to 30% over surface method of irrigation (2-DAD and 3-DAD); whereas, energy use by Sprinkler was higher than Surface method (3-DAD and 4-DAD) as well as LEWA method (all irrigation regimes). This lead to to savings in energy by 20% to 30% using LEWA (at 2-day interval) over surface method of irrigation (2-DAD and 3-DAD), and, by using 5% by Sprinkler (at 2-day interval) over surface method (2-DAD).

Key words: Sodic soils, Irrigation methods, Irrigation scheduling, Water productivity, Energy productivity

INTRODUCTION

Rice crop covers a major area during kharif season (June to October) in Indo Gangetic Plain (IGP). The rice growing area in India during 2011-12 was estimated to be approximately 44 Mha with an average productivity level of 2.3 t ha^{-1}. Most of the states in India produce rice, which is one of the most important staple foods for millions of people in the country. It has been experienced vastly that the current production level of rice is stagnant from last few years. This opens an opportunity to explore options to enhance production in those areas where the productivity is below average.

Over 2.1 million hectares of salt-affected land is located in the country's key bread basket in the North. Uttar Pradesh alone has about 1.37 million hectares of sodic and saline soils, besides, Rajasthan 3.75 lakh hectares, Haryana 2.32 lakh hectares and Punjab 1.5 lakh hectares of land affected by salt accumulation (Sharma *et al*., 2004). The average productivity level of rice is below 1.5 t ha^{-1} under sodic environment due to presence of excess salts in the crop root zone. The sodic soils are characterized by low electrical conductivity of saturation extract (ECe<4 dS m^{-1}), high exchangeable sodium percentage (ESP >15) and high soil pH (> 8.2) (Sharma and Ambekar, 2011). The presence of high exchangeable sodium leads to severe physical deterioration resulting in compaction of surface soil layer, destruction of soil structure, and extremely low permeability and

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hydraulic conductivity. These characteristics of sodic soil influence soil water transmission and water crop-use by affecting infiltration, hydraulic conductivity, soil moisture retention, and profile storage.

Reduced available water in sodic soils has been identified as major concern for crop production (Abrol *et al*., 1988; Bhardwaj *et al*., 2008). Rice is one of the highest water-demanding crops. The typical water requirement of rice is estimated to be 3000 – 5000 L kg^{-1}, leading to an average irrigation water requirement in the range of 900 mm to 2250 mm (150-200 mm for land preparation, 500-1200 mm for meeting evapotranspiration needs, 200-700 mm for seepage & percolation, and 50-100 mm for mid-season drainage) (FAOSTAT, 2004). However, farmers in eastern part of IGP are believed to be using water irrationally by adopting surface flooding, resulting in low irrigation efficiency. In this direction numerous studies have reported considerable irrigation water savings with change from continuous flooding to alternate wetting and drying. Many studies in India have shown that continuous ponding is not necessary to maintain rice yields at reasonable levels (Sandhu *et al*., 1980; Chowdhary, 1997; Hira and Khera, 2000).

Several techniques such as direct seeding, soil water tension based irrigation scheduling and bed planting have been found to be beneficial in terms of water saving in rice. Irrigating bed planted rice at 10 kPa or 20 kPa soil water tension has been reported to result in saving of water by 45-51%, but it also lowered yield by 52-53% compared to transplanted rice (Sharma *et al*., 2002). Fonteh *et al*. (2013) reported saving of 20% to 47% of water by adoption of 3 cm to 5 cm depth of intermittent irrigation in rice compared to continuous flooding. Most of the above strategies might hold well for rice grown under normal soil conditions. In case of sodic environment the irrigation strategies needs to be different because presence of excess exchangeable sodium which leads to low rate of infiltration, poor hydraulic conductivity, decreased soil moisture retention and storage capacity.

It has been realized that low depth of irrigation at frequent intervals may result in favourable soil moisture regime for crop growth. Singh *et al*. (2009) reported 24% of water saving when rice is irrigated two days after disappearance of ponded water compared to continuous submergence. Humphreys *et al*. (1989) reported saving water by 30% to 70% in rice by use of sprinkler. Increase in rice yield by 18% using sprinkler irrigation and reduction in consumption of water by 35% over traditional irrigation system was reported (Kahlown *et al*., 2007). Farmers in Indo-Gangetic region perceive savings in terms of reduced input cost (like pumping energy) better than saving of water. Controlled irrigation alternatives enhance water use efficiency, and reduce run-off and percolation losses (Camp, 1998). These strategies may suit well to sodic soils for improving crop productivity as well as saving water and energy.

In light of above facts, the study was designed to evaluate the performance of three different methods of water application by employing varying schedules of irrigation, with an objective to optimize water and energy use for rice production under sodic environment.

MATERIALS AND METHODS

Study site

The experiments were conducted at Shivri experimental farm of CSSRI-RRS (Central Soil Salinity Research Institute, Regional Research Station), Lucknow, Uttar Pradesh, India which extends 26° 47′ 45" N to 26° 48′ 13" N on latitude and 80° 46′ 7" E to 80° 46′ 32" E on longitude at 120 m above mean sea level. There are three main crop seasons: a) *kharif* (standard week no. 20^{th} to 44^{th}), b) *rabi* (standard week no. 45^{th} to 16^{th}), and c) *zaid* (standard week no. 17^{th} to 19^{th}) are followed in the region. The annual mean precipitation on the basis of data recorded during 2000 to 2012 at experimental farm was 829 mm. Major precipitation events occur during kharif season, with average seasonal precipitation of 786 mm. Mean annual temperature is 24.6 °C, with mean maximum temperature of 39 °C in the month of May and mean minimum temperature of 7.1 °C in the month of January. The soil pHs (1:2 soil: water) for surface layer (15 cm) ranged between 8.0 to 10.7, and ECe (electrical conductivity of saturation water extract (dS m^{-1}) vary between 0.6 to 15.2 (experimental station). The initial analysis of the soil properties of experimental field shows that pH of soil at the depth of 0-15 cm and 15-30 cm was 8.71 and 9.23, respectively. The corresponding EC_2 (soil: water solution) values were 0.33 and 0.48, organic carbon was 0.25 and 0.16 % and ESP was 16.1 and 30.9, respectively. The bulk density of the soil ranged between 1.31 g cc^{-1} and 1.71 g cc^{-1}.

Experimental set-up

Field experiments were carried from 2012 to 2014 and results presented comprises of data recorded for two-kharif crop season (2013-14 and 2014-15). Three methods of irrigation were used namely: Surface, Sprinkler (impact type) and LEWA (Low Energy Water Application device developed by ICAR-RCER, Patna) (Singh *et al*., 2004; Singh *et al*., 2008; Singh *et al*., 2010). The rate of water application for Sprinkler was 2 cm hr^{-1} at an operating pressure range of 1.0 to 1.5 kg cm^{-2} and it was 2.8 cm hr^{-1} for LEWA at an operating pressure range of 0.4 to 0.6 kg cm^{-2}, at nozzle head. In case of surface irrigation, the water supplied to plots via an underground pipeline system which was connected with the water-pumping unit. The water-pumping unit comprised of 5 hp high-speed diesel pump with average discharge of 3.5 L s^{-1}. The fuel consumption rate of diesel pump was 1 L hr^{-1}.

The recommended irrigation practice for rice production in the area is 5 cm to 10 cm of standing water of 1 to 5 days after disappearance of water (DAD). In this light, depth of water applied under surface irrigated plots was fixed at 6 cm and 4 cm for Sprinkler and LEWA. The application of irrigation water was scheduled at 2-DAD, 3-DAD and 4-DAD in case of Surface method of irrigation, and 4 cm in case of Sprinkler and LEWA at daily, one day interval and 2 day interval (when initial ponding disappeared). Overall, there were a total of nine treatments. The reason for selecting lower depths of irrigation water under this study was low infiltration rate of sodic soils, no loss of water while conveying from source to field, percolation losses in case of surface irrigated plots, higher application efficiencies of sprinkling system and evaporative demand area. The surface irrigated plots measured 8.6 m x 40 m (344 m^2) and incase of sprinkler and LEWA the plots sizes measured 12 m x 40 m (480 m^2). An outlet was provided at each treatment at the upstream of surface irrigated plots to apply irrigation water, whereas, a set of two laterals lines were provided in case of sprinkler and LEWA irrigated plots by fixing nozzles on a riser. The riser height was 1 m. The lateral and nozzles were placed at 6 m apart.

Method of direct seeding for sowing the pre germinated rice seed through broadcasting was adopted. The crop management practices were common to all treatments. The salt tolerant rice variety CSR 36 (recommended for sodic environment) was direct sown during third week of June. Recommended fertilizer doses of 150:60:60 N:P:K was applied. Standard agronomic practices (manual weeding etc.) were followed during the crop-growing season.

Measurements

Time of irrigation: Based on the rate of discharge of sprinkling nozzles and the wetted area, the time to operate the irrigation systems was fixed for each treatment and recorded while practicing irrigation during the crop season. Similarly, by considering the outlet discharge and the irrigated area the time to irrigate surface irrigated plots were also fixed and the same was monitored & recorded while practicing irrigation. The time of irrigation for sprinkling nozzles was calculated to be 120 min in case of sprinkler, 85 min in case of LEWA, and 90 min in case of surface irrigation.

Plant observation

The plant observations such as plant height and number of productive tillers were recorded at an interval of 30 days after sowing (DAS) and at harvesting. All observations in each treatment were replicated three times and averaged. Under each replication, two observation stations of one square meter area were marked immediately after sowing. Three plants under each station were tagged for periodical data recording. The yield of rice under each treatment was recorded on the full plot basis.

Water and Energy productivity analysis

The water productivity was analyzed in terms of Rs. (INR) per cubic meter (m^3) of water used. The water productivity was estimated by taking ratio of cost of produce and total depth of irrigation water applied. Similarly, the energy productivity analyzed in terms of Rs. per litre of fuel used. The energy productivity represents the ratio of cost of produce and total fuel in terms of diesel used to pump the irrigation water. The cost of produce under this study was considered as Rs. 10 per Kg of grain and the cost of diesel considered was Rs. 60 per litre.

RESULTS AND DISCUSSION

Water and pumping energy use pattern

The water and pumping energy use pattern during rice growing season is shown in Table 1. The irrigation events with surface irrigation method varied between 10 (for 4-DAD) to 16 (for 2-DAD); and 15 (at 2-day interval) to 33 (at daily interval) using sprinkling methods (Sprinkler and LEWA). Similarly, total depth of irrigation under surface irrigation method varied between 60 cm (for 4-DAD) to 96 cm (for 2-DAD); and with sprinkling methods the variation was between 60 cm (2-day interval) to 132 cm (at daily interval).

Table 1. Irrigation practiced and cost incurred on pumping under different irrigation methods and schedules

Irrigation Method	Irrigation Schedule	Irrigated Area (m^2)	Number of Irrigation	Depth of Irrigation (cm)	Pumping hours (hrs)	Fuel used for Irrigation (L)	Cost incurred on fuel (INR)
Surface	2-DAD	344	16.0	96.0	24.0	24.0	1440.0
	3-DAD		14.0	81.0	20.3	20.3	1215.0
	4-DAD		10.0	60.0	15.0	15.0	900.0
Sprinkler	daily	480	33.0	132.0	66.0	66.0	3960.0
	1-day interval		22.0	88.0	44.0	44.0	2640.0
	2-day interval		15.0	60.0	30.0	30.0	1800.0
LEWA	daily	480	33.0	132.0	46.8	46.8	2805.0
	1-day interval		22.0	88.0	31.2	31.2	1869.6
	2-day interval		15.0	60.0	21.3	21.3	1275.0

Corresponding to the number of irrigations practiced, the pumping hours recorded under surface irrigated plots varied between 15 hrs (4 DAD) to 24 hrs (2 DAD), for sprinkler irrigation it was 30 hrs (2-day interval) to 66 hrs (at daily) and for LEWA the same was 21 hrs (2-day interval) to 46 hrs (at daily interval). This pattern of water-use reflects that, to irrigate one-hectare of rice once, the cost through surface method will be Rs. 2616, for Sprinkler it will be Rs. 2500 and for LEWA it will be Rs. 1771, with similar capacity of pump used as used in our experiments.

Effect of Irrigation and Regime on Plant Growth and Yield

The effect of varying water regime, analyzed to study impacts on plant growth and yield parameters depicted in Table 2. In surface irrigation treatment schedule of 2-DAD resulted in maximum plant height of 106 cm with 383 productive tillers, whereas, under Sprinkler and LEWA irrigation, irrigation schedule of 2-day interval resulted in maximum plant height of 105 cm and 110 cm, respectively with maximum productive tiller count of 382 and 402, respectively.

This resulted in highest grain yield of 4.4 t ha^{-1} when irrigation was scheduled at 2-DAD under surface irrigated plots and at 2-day interval under Sprinkler and LEWA irrigated plots. Considering the water use pattern, it reflected that application of higher depth of irrigation under surface irrigated plots at 2-DAD resulted in higher grain yield as well as biological biomass. A decline in grain yield by 10 % in case of 3-DAD and 20 % in case of 4-DAD with respect to 2-DAD, was registered where applied depth of irrigation was lowered with respect to 2-DAD. Similar trend was not observed in case of sprinkling methods as the highest grain yield of 4.4 t ha^{-1} registered under Sprinkler and LEWA irrigated plots when irrigation was scheduled at 2-day interval. This was marginally higher (by 7 to 9 percent) over irrigation schedules of daily and 1-day interval.

Table 2. Effect of various irrigation regimes on plant growth characteristics and yield of rice

Irrigation Method	Irrigation Schedule	Plant height (cm)				Nos. of Productive Tillers				Yield	
		30 DAS	60 DAS	90 DAS	At harvest-ing	30 DAS	60 DAS	90 DAS	At harvest-ing	Biological (t/ha)	Grain (t/ha)
Surface	2-DAD	31	58	86	106	202	316	344	383	13.1	4.4
	3-DAD	32	58	86	104	197	324	360	367	11.8	3.9
	4-DAD	32	57	82	101	229	318	358	337	11.0	3.5
Sprinkler	Daily	30	53	84	103	232	347	369	311	11.1	4.0
	1-day interval	30	57	82	99	205	311	330	365	10.9	4.2
	2-day interval	29	54	81	105	222	341	363	382	11.9	4.4
LEWA	Daily	33	70	95	109	192	351	381	386	11.3	4.1
	1-day interval	34	64	92	108	188	349	381	382	12.0	4.1
	2-day interval	33	65	92	110	213	371	406	402	12.4	4.4

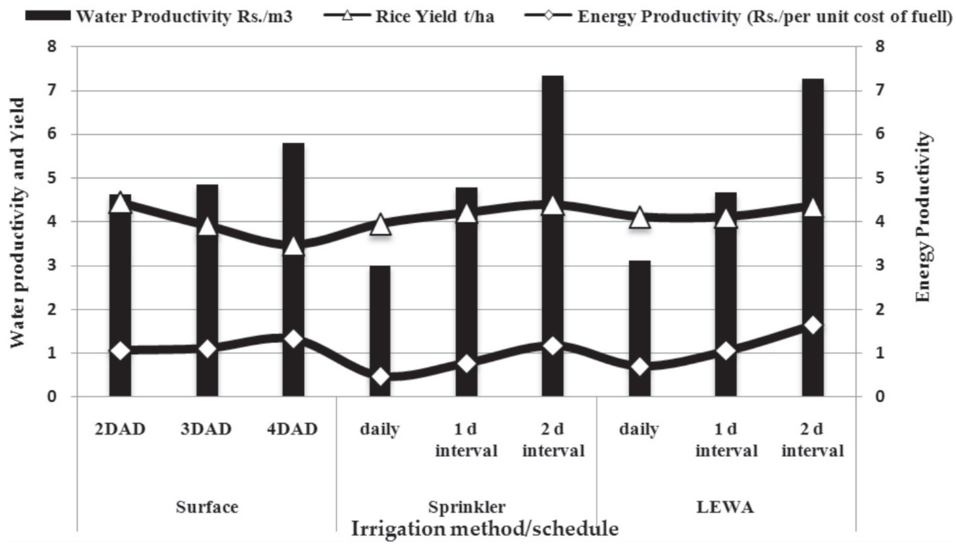

Fig. 1. Water and Energy productivity and Yield trends

Water and Energy Saving

In case of surface irrigation the irrigation schedule of 2-DAD utilsed highest depth of irrigation water (96 cm) requiring 24 litres of diesel (fuel) for the pumping unit during the full rice growing season. Compared to this, irrigation schedule of 3-DAD and 4-DAD resulted in savings of approximately 15% and 37 %, respectively of irrigation water as well as fuel used for pumping. Similarly, water and energy use trends under Sprinkler and LEWA irrigation reflected, that maximum depth of irrigation water (132 cm) was utilised when irrigation was scheduled at daily intervals whereas fuel required to pump irrigation water was 66 litres in case of Sprinkler and 46.8 litres in case of LEWA irrigation. This resulted in saving of approximately 30% and 50% of irrigation water as well as fuel used when irrigation was scheduled at 1-day and 2-day interval, respectively, over daily irrigation schedule .

Water and Energy Producitvity and Yield

The water and energy productivity achieved under different irrigation regimes were analysed and depicted alongwith grain yield in Figure 1. The water productivity (in monetary returns (INR) per m^3 water used) for different irrigation regimes under surface irrigation was 4.6, 4.8 and 5.7 at 2-DAD, 3-DAD and 4-DAD, respectively. The energy productivity (monetary returns (INR) per unit cost of fuel used) was 1.0, 1.1 and 1.3 at 2-DAD, 3-DAD and 4-DAD, respectively for surface irrigation. This implied that water and energy productivity of surface methods improved when irrigation schedule is switched from 2-DAD to 3-DAD and 4-DAD, but this also resulted in yield decline by 10% in irrigation at 3-DAD and 20% in irrigation at 4-DAD. Hence, 2-DAD incase of surface irrigation is suitable option for achieving higher yields or 3-DAD where marginal decline in yield was compensated by saving in terms of cost of water and pumping energy.

The water productivity observed incase of Sprinkler was 2.99, 4.78 and 7.32 Rs. per m^3 at daily, 1-day and 2-day intervals, respectively; and energy productivity was 0.47, 0.76 and 1.17 at daily, 1-day and 2-day interval, respectively. Similarly, under LEWA irrigation, water productivity observed was 3.11, 4.67 and 7.27 Rs. per m^3 at daily, 1-day and 2-day interval, respectively, and energy productivity was 0.7, 1.05 and 1.64 at daily, 1-day and 2-day interval, respectively.The corresponding yield trends in case of Sprinkler and LEWA, showed marginally better or at par yield at 2-day interval compared to daily and 1-day interval scheduling. This suggested that in case of sprinkling (Sprinkler and LEWA) methods, irrigation scheduling at 2-day interval might be a better option in terms of higher water and energy productivity with comparable yields to scheduling at shorter intervals.

CONCLUSION

The field performances of various irrigation methods (Surface, Sprinkler, LEWA) and irrigation schedules for rice production under partially reclaimed sodic soils reflected that, while using surface irrigation , schedule of 2-DAD or 3-DAD may be opted to enable efficient use of water and pumping energy, with only marginal or no loss in grain yield compared to shorter intervals. Whilst opting for sprinkling irrigation methods, such as Sprinkler & LEWA, the irrigation schedule of 2-days interval is appropriate to achieve optimum yield alongwith water and energy saving. The comparison between sprinkling type and Surface irrigation methods reflected that the sprinkling type methods scheduled at 2-days interval is better option in terms of water saving to the tune of 20% to 30%,and energy saving by 5% to 30%, without any yield loss over best performing irrigation regimes under Surface methods.

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Water resource characterization in canal command area for Jhansi minor (left bank canal of Bargi dam) of Rani Avanti Bai Sagar irrigation project- A case study

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ABSTRACT

The present study was conducted on Jhansi minor of left bank canal network of Rani Avanti Bai Sagar irrigation project. This paper presents the characterization of command area based on water resource utilisation assessment with conjunctive use of surface and ground water, distribution of tube wells and lift irrigation pumps with reference to cropping pattern in study area. The results indicated that the middle reach of Jhansi minors is larger than its head and tail. The gravity irrigation was maximum during 2001-02 and then continuously decreased within last 10 years however tube well and pumped irrigated area has continuously increased. Cropping pattern also changed after introduction of different irrigation methods with different sources of irrigation. The wheat and chickpea were major crops grown in the area. The un-irrigated wheat, chickpea and pea were replaced by irrigated wheat, chickpea and pea. The water available from canal and tube well to command area was 1.71 Mm^3 and 0.85 Mm^3 respectively. The total number of tube wells in command area was 46. The use of canal water was higher in its head reach than tail and middle reach during initial years but during recent years conjunctive use of canal and ground water was observed in all the reaches of the command area.

Key words: Canal command area, Conjunctive use, Irrigation sources, Water resource assessment

INTRODUCTION

Water is more valuable than land, because when water is applied to land it increases its productivity at least six fold. As the pressure on freshwater resources in water deficient regions increases the need to conserve and use conventional water resources more efficiently in future. Increases in agricultural production will depend heavily on existing water resources (Oweis *et al*., 2000; Wallace, 2000; Hatfield *et al*., 2001; Kijne *et al*., 2003). A canal distribution system for application of gravity irrigation to large area besides providing direct irrigation benefits assist in the modification of the groundwater regime. Such groundwater externalities may generate positive results by providing additional recharge and improving the water table in water stressed area, but may also have a negative impact creating water logging and increasing soil salinity in previously water congested pockets. Performance assessment is considered to be one of the most critical elements for improving irrigation management (Abernethy and Pearce, 1987). An ideal or reference irrigation is one that can apply the right amount of water over the entire region of interest without losses (Zerihun *et al*., 1997). There are a number of performance evaluation terms used to quantify how close the irrigation system is to an ideal one. Traditional analyses of irrigation performance, especially the concept of irrigation efficiency, can mislead planners and policy makers as water availability at the river basin level becomes the primary constraint to agricultural production (Perry, 1999). Based on a review of the literature concerning indicators of irrigation performance, (Rao, 1993) found that the performance of an irrigation system could be evaluated in three categories, namely, water delivery system, irrigated agriculture system and irrigated agricultural economic system. (Menenti *et al*., 1989) have suggested three performance indices which use remote sensing and other collateral data along with various models. (Bastiaanssen, 1998) has listed the performance indicators derived from remote sensing algorithms supplemented by ground data. Conjunctive use of surface and groundwater is one

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Table 1. Crop, their growing period and number of irrigations for canal command area of Jhansi minor

S. No.	Name of crop	Duration (Days)	No. of irrigation	Sowing date
1	Wheat (Early)	95	5	15th Oct
2	Wheat (Late)	120	5	2nd Jan
3	Chick Pea (Early)	126	2	14th Oct
4	Chick Pea (Late)	126	3	13th Nov
5	Lentil	110	2	16th Oct
6	Green Pea	90	6	10th Oct
7	Pea	120	—	15th Oct
8	Vegetables & Others	130	8-10	28th Sep

of the most effective water management alternatives, to deal with increasing irrigation demand and inadequate surface supplies (Khare *et al*., 2007). Conjunctive use is necessary to achieve maximum returns from cropping activities and to resolve the problems of water logging and water table depletion. Hence proper application of water will not only increase productivity of crops but also increases area under irrigation. There is conspicuous disparity in water use in head reaches and tail ends in canal commands. Therefore an attempt was made in this study for water resource characterization of a Jhansi minor (Left Bank Canal of Bargi Dam) Canal Command Area.

MATERIALS AND METHODS

The study area is command area of Jhansi minor (Left Bank Canal) of Rani Avanti Bai Sagar irrigation project, located in the village Bijora that is about 43 km from the Jabalpur city, India. It is located between North latitude 23°3′40′′ to 23°4′45′′ and East longitude 79°41′35′′ to 79°42′5′′. Average annual rainfall is 1350 mm about 80% of which is received during the monsoon period (July to September). The average annual evaporation recorded during the month of May is about 350.46 mm whereas minimum evaporation of 70 mm is observed during the month of December and average annual temperature is 25.7°C. The soil of the study area is clay-loam and has low phosphorous, medium Nitrogen and medium potassium. Daily records of supply head in main canal were obtained from the Department of Irrigation, Government of Madhya Pradesh. Based on cross sectional area, slope and outlet conditions, the discharge delivered to the command area was estimated. Operation hours of selected minor and the schedule of operation for main canal during the irrigation season were observed to estimate the volume of water delivered to study area. Location of different fields, water courses, field channels, area irrigated and sources of irrigation water were also obtained from the records of the local irrigation authorities. The canal delivery schedule was obtained from Sub-Divisional Office, Department of Water Resource, Government of Madhya Pradesh. The cropping pattern and detailed land use data for 2000-01 to 2010-11 were collected through field visits. Information regarding sowing and harvesting of different crops, growing period, irrigation, cropping pattern and other relevant details were collected from the different sources including revenue records of the village which is presented in Table 1. Field observations were recorded to determine the discharge of minor, canal, tube well, centrifugal pump and number of tube well in Jhansi minor at different reaches.

To determine the ground water irrigated area and lift irrigated area in command area at different reach following method was adopted.

$$V_1 = \frac{(Q \times 3600 \times hrs)}{1000} \quad \ldots(1)$$

$$V_2 = V_1 \times \text{Irrigation interval (in days)} \quad \ldots(2)$$

$$D = \left(\frac{V_2}{10000}\right) \times 100 \quad \ldots(3)$$

$$Area\ irrigated\ (ha) = \frac{D}{ADI} \quad \ldots(4)$$

Q = Discharge from tube well (lps)
hr = hours of tube well pumping per day (hrs)
V_1 = Volume of water in one day (m^3)
V_2 = Volume available in irrigation interval days (m^3)
D = Total depth per hectare (cm/ha)
ADI = average depth of irrigation (cm)

RESULTS AND DISCUSSION

1. Characteristics of canal command area

Characterization of Jhansi minor command area at different reach like head, middle and tail

Table 2. Characteristics for Jhansi minor (LBC) of Rani Avanti Bai Sagar irrigation project

Location	Bottom width (m)	Side Slope (H:V)	Top width (m)	Depth of flow (m)	Velocity of flow (m/s)
Jhansi minor	0.30	1:1.5	1.40	0.40	0.454

Table 3. Characteristics of different reaches of canal command area of Jhansi minor

Name of Minor	Area (ha)			CCA	Length of	Discharge
	Head	Middle	Tail	(ha)	Minor (km)	(m^3)
Jhansi	67	111	41	219	2.15	0.196

area, length of minor and discharge are presented in Table 3.

2. Characteristics of water resources in canal command area of Jhansi minor

Area irrigated through different sources of water is presented in Table 4 for Jhansi minor.

3. Cropping pattern in canal command area of Jhansi minor

Area under major crops in Jhansi minor indicates that area under chickpea was higher as compared to wheat crop in year 2003-04 to 2005-06 and then reduced in year 2008-09 to 2009-10. Water availability to area increased consequently as the un-irrigated chickpea, pea and lentil was gradually replaced by irrigated chickpea, pea and lentil in Table 5. In the year 2004-05 minor was closed for construction work then un-irrigated wheat was cultivated in large area. The major crop in this Jhansi minor is wheat covering 60% of total cropped area.

Table 4. Irrigated area under sources of irrigation in Jhansi minor command area from 2001-2011

Year	Irrigated area (ha)			
	Minor	Pumping from canal	Tube well pumping	Total
2001-02	105.98	8.9	14.4	129.28
2002-03	97.74	8.9	14.4	121.04
2003-04	94.45	12.8	23.6	130.85
2004-05	0	17.8	38.4	56.2
2005-06	55.08	21.7	48.8	125.58
2006-07	64.01	30.88	85.2	180.09
2007-08	73.6	32.95	101	207.55
2008-09	50.11	32.89	129.76	212.76
2009-10	22.03	31.6	158.78	212.41
2010-11	22.55	28	168.45	219

4. Water resource assessment and characterisation

Field observations were carried out for measuring the discharge of minor during irrigation in command area. Table 5 shows average discharge obtained and volume of water supplied from Jhansi minor. There are number of tube wells in command area of minor, which are used to supplement canal irrigation. Number of tube well fitted with different pump sets is shown in Table 6. It was observed that maximum number of 26 tube wells exists in middle reach of Jhansi minor. The irrigated area from Jhansi minor works out to be 219 ha. Fig.1 shows variation of water in different reaches. It was observed that water availability through minor decreases in tail reaches. The deficit of irrigation water is supplemented by tube well water. It is clear from figure that farmers are using groundwater for irrigation of the crops, whenever required in conjunction with canal water. It was observed that tube well water used for irrigation of crop is mainly in *Rabi* season due to non-availability of water in minor at the tail end.

Table 5. Irrigated and un-irrigated area under crops in ha from 2003-2010 in command area of Jhansi minor

Year	Wheat		Chickpea		Pea		Lentil	
	I*	UI**	I*	UI**	I*	UI**	I*	UI**
2003-04	59.40	0.00	104.70	12.80	0.00	5.00	0.00	4.10
2004-05	19.50	33.60	19.10	91.30	3.40	0.00	0.00	8.60
2005-06	56.80	0.00	95.20	13.00	14.60	5.40	0.00	15.30
2008-09	127.40	0.00	69.90	0.00	7.60	0.00	11.70	0.00
2009-10	138.85	0.00	59.90	0.00	14.20	0.00	8.10	0.00

*Crop area under irrigation **Crop area un-irrigated

Table 6. Water availability in different reaches in command of Jhansi minor during year 2010-11

Minor Reaches	Canal water		Tube well water		Total Volume	Area	Water
	Discharge (lps)	Volume(m^3)*	Number of tube wells	Volume (m^3)	(m^3)	(ha)	availability (m^3/ha)
Head	112	870912	11	215136.0	1086048.0	67	16209.67
Middle	71	552096	26	461376.0	1013472.0	111	9130.378
Tail	37	287712	9	170035.2	457747.2	41	11164.57
Total		1710720		846547.2	2557267	219	11677.02

*Operating hours of canal was considered as 24 hours for 90 days

Table 7. Distribution pattern of tube wells and lift irrigation pumps in command area of Jhansi minor

MinorReaches	Jhansi Minor							
	No. of tube well				No. of Centrifugal Pumps			
Year	Head	Middle	Tail	Total	Head	Middle	Tail	Total
2001-02	1	2	0	3	1	1	0	2
2002-03	1	2	0	3	1	1	0	2
2003-04	2	3	0	5	2	1	0	3
2004-05	2	5	1	8	2	2	0	4
2005-06	2	7	1	10	3	2	0	5
2006-07	5	10	3	18	3	3	1	7
2007-08	5	12	5	22	4	3	1	8
2008-09	7	17	6	30	4	3	2	9
2009-10	9	22	8	39	4	4	2	10
2010-11	11	26	9	46	4	4	2	10

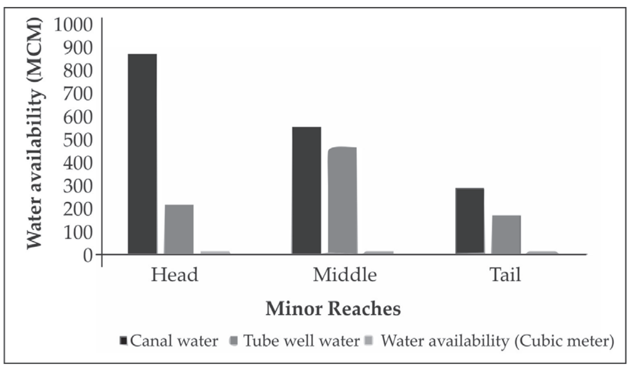

Fig. 1. Variation of canal and tube well water availability at different reaches in command of Jhansi minor

5. Tube well irrigation in canal command area of Jhansi minor

The population of tube wells in different reaches during year 2001-02 to 2010-11 is shown in Table 7.Large number of tube wells in middle reach indicates increased use of ground water for irrigation in command area. There are 46 tube wells in command of Jhansi minor. Numbers of wells are predominantly higher in middle reach as compared to other two reaches.

6. Lift irrigation in canal command area of Jhansi minor

Usage of centrifugal pump in minor at different reaches is shown in Table 7. The use of centrifugal pump is gradually increasing in all three reaches. In tail reach use of pumps started in year 2006-07 and in head and middle reach population of centrifugal pumps was constant.

7. Surface and ground water resource utilization pattern in canal command area of Jhansi minor

The usage of surface water in command area started with introduction of canal in year 1989 and amount of water delivered into area as well as area irrigated by canal were found increasing. The canal water was used mainly through flood irrigation and lift irrigation pumps. The pattern of utilization of ground water and surface water and trends is shown in Fig. 2 under Jhansi command area and also in different years since 2001. The yearly use of surface water decreased till 2007 and increased thereafter but use of ground water continuously increased.

In order to study distribution of water resource utilization, area irrigated in different reach was separated under different source of irrigation. The area irrigated through minor, pumping from minor and that from tube wells in head, middle and tail reach of minor is presented Table 8. The irrigated area through gravity irrigation is continuously decreasing in the head reach and lift and tube well irrigation increased and same condition persist in middle reach and tail reach. The lift and tube well

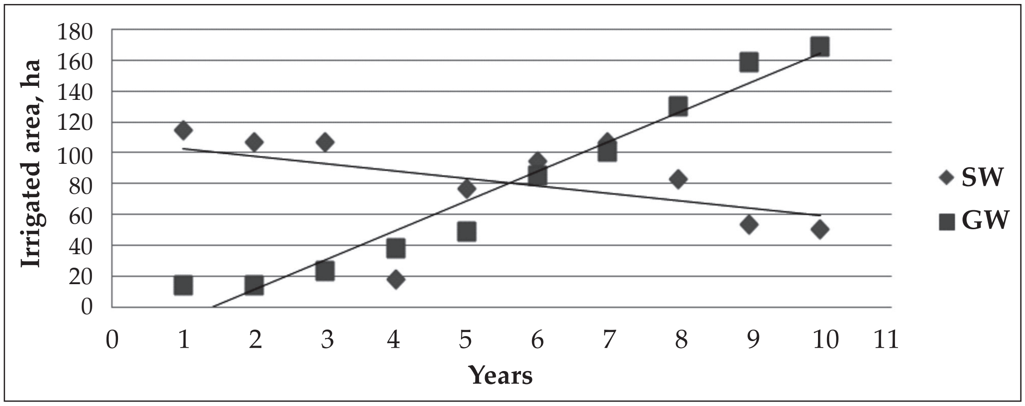

Fig. 2. Variation of surface and ground water utilization pattern in command of Jhansi minor

Table 8. Water resource utilization in reaches under different irrigation methods in command area

Year	Area Irrigated (ha)									Total
	Head			Middle			Tail			
Source of Irrigation	CW*	LI**	TW***	CW*	LI**	TW***	CW*	LI**	TW***	
2001	35.65	3.90	4.00	54.33	5.00	10.40	16.00	0.00	0.00	129.28
2002	34.81	3.90	4.00	56.93	5.00	10.40	6.00	0.00	0.00	121.04
2003	36.79	7.80	8.00	54.66	5.00	15.60	3.00	0.00	0.00	130.85
2004	0.00	7.80	8.00	0.00	10.00	26.00	0.00	0.00	4.40	56.20
2005	21.13	11.70	8.00	33.95	10.00	36.40	0.00	0.00	4.40	125.58
2006	25.33	11.70	20.00	35.68	15.00	52.00	3.00	4.18	13.20	180.09
2007	28.77	15.60	20.00	38.83	13.17	59.00	6.00	4.18	22.00	207.55
2008	24.47	14.53	28.00	25.64	10.00	75.36	0.00	8.36	26.40	212.76
2009	8.81	15.60	36.00	9.22	10.00	91.78	4.00	6.00	31.00	212.41
2010	14.87	13.00	39.13	6.68	10.00	94.32	1.00	5.00	35.00	219.00

*Canal irrigation, **Lift irrigation, ***Tube well irrigation

irrigation started in year 2006 and 2004 respectively and flood irrigation area is very less in tail reach because of low discharge. Tube well irrigated area is high as compared to lift and canal irrigation as shown in Table 8.

8. Conjunctive use of surface and ground water in canal command area of Jhansi minor under different reaches

The conjunctive use of surface water and ground water in command area of Jhansi minor in head, middle and tail reach is presented in Table 9.

Table 9. Water resource utilization in reaches under different irrigation methods with ratio of SW and GW in command area

Year	Area Irrigated (ha)												Total
	Head			$\frac{SW}{GW}$	Middle			$\frac{SW}{GW}$	Tail			$\frac{SW}{GW}$	
Irrigation	SW		GW		SW		GW		SW		GW		
Sources	CW*	LI**	TW***		CW*	LI**	TW***		CW*	LI**	TW***		
2001	35.65	3.90	4.00	9.89	54.33	5.00	10.40	5.70	16.00	0.00	0.00	-	129.28
2002	34.81	3.90	4.00	9.68	56.93	5.00	10.40	5.95	6.00	0.00	0.00	-	121.04
2003	36.79	7.80	8.00	5.57	54.66	5.00	15.60	3.82	3.00	0.00	0.00	-	130.85
2004	0.00	7.80	8.00	0.98	0.00	10.00	26.00	0.38	0.00	0.00	4.40	0.00	56.20
2005	21.13	11.70	8.00	4.10	33.95	10.00	36.40	1.21	0.00	0.00	4.40	0.00	125.58
2006	25.33	11.70	20.00	1.85	35.68	15.00	52.00	0.97	3.00	4.18	13.20	0.54	180.09
2007	28.77	15.60	20.00	2.22	38.83	13.17	59.00	0.88	6.00	4.18	22.00	0.46	207.55
2008	24.47	14.53	28.00	1.39	25.64	10.00	75.36	0.47	0.00	8.36	26.40	0.32	212.76
2009	8.81	15.60	36.00	0.68	9.22	10.00	91.78	0.21	4.00	6.00	31.00	0.32	212.41
2010	14.87	13.00	39.13	0.71	6.68	10.00	94.32	0.18	1.00	5.00	35.00	0.17	219.00

The head reach has higher surface water usage than middle and tail reach. In middle and tail reach population of tube well is higher than as presented earlier. As depicted in Table 9, head reach has higher ratio followed by middle and tail reach.

CONCLUSION

The results obtained from study show that canal irrigation is not only source of irrigation in Jhansi command area but ground water is also being used at tail ends of command in ratio of 0.17 to 9.89 (Surface Water : Ground Water) in different reaches of Jhansi minor during 2001-10. Use of ground water is more in middle reach (36.09%) and tail reach (36.01%) than head reach (27%) due to surplus availability of canal water in minor at head reach. Conjunctive use has got a definite impact on cropping pattern because increased use of ground water at tail and middle reaches has brought more area under irrigation at lower and middle reaches of command area. The results also show that farmers are adopting tube well and lift irrigation as compared to gravity irrigation this may be due to timely availability of water at time of sowing and at other stages of crop. The farmers started adopting crops having high irrigation requirement to obtain maximum benefits from farm. The excess use of canal water at head reaches has started creating problems like water logging and salinity however excessive exploitation of ground water at lower reaches has resulted in decline of water table.

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Impact of irrigation methods and mulching on vegetative growth, yield and quality of strawberry under mid hill conditions

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ABSTRACT

An experimental trial was conducted at Regional Agricultural Research Station, Rajouri during 2012-2013 and 2013-2014 to determine the effects of irrigation methods and mulching material on growth, yield and quality of strawberry cultivar Chandler under mid hill conditions of Jammu province. Treatments comprised of two irrigation schedules (drip and flood irrigation) and three mulches *viz.* black polythene, paddy straw, chirpine needles and unmulched conditions. Results of the investigation revealed that strawberry is very responsive to the different irrigation methods and mulching materials. All the treatments improved the vegetative growth, yield and quality of strawberry, but treatment T_1 (Drip Irrigation + black Polythene) which was closely followed by treatment T_2 (Drip Irrigation + Transparent Polythene), which showed superiority in respect of growth, yield and quality parameters viz., plant height (18.11cm), plant spread (28.50 cm), petiole length (14.88 cm), leaf per plant (13.70), leaf area per plant (98.11 cm^2), crown diameter (6.32 cm), crown weight (0.64 g), fruit yield per plant (332.92 g), fruit weight (32.08 g) fruit length (1.31 cm), fruit diameter (1.26 cm) specific gravity (1.17) and juice content (92.67%), which was closely followed over organic mulches and flood irrigation over unmulched + flood irrigation.

Key words: Drip irrigation, Flood irrigation, Strawberry, Growth, Yield

INTRODUCTION

The modern cultivated strawberry (*Fragaria x ananassa Duch.*) is a hybrid of two largely dioecious octoploid species, *Fragaria cheloensis Duch* and *Fragaria varginiana Duch*. Basically, it is herbaceous perennial and short day plant grows predominantly in the temperate climate. Its fruits are rich source of vitamin and minerals. Strawberry is known for its pleasant aroma. It is amongst the few crops, which gives quick and very high returns per unit area on the capital investment, as the crop is ready for harvesting within six months of planting. Strawberry is a delicious fruit consumed fresh in several ways. It is also used to makes ice cream and Jam due to its excellent taste and aroma, and it is a good source of vitamin C also. Since strawberry is relatively shallow-rooted, it is susceptible to conditions of drought. Planting early in autumn allows the plants to make good vegetative growth before the onset of winter. However, in this case it is necessary to ensure that newly planted runners are irrigated frequently after planting, otherwise the mortality of the plants becomes high. Micro (Drip) irrigation system has proved its superiority over other conventional methods of Irrigation, especially in horticultural crops (fruit crop), owing to precise and direct application of water in the root zone. A considerable savings in water and fertilizer use besides increased growth, development and yield of vegetable crops under drip irrigation have been reported (Bhella, 1998; Malik *et al*., 1994).

The use of black polythene mulch in fruit and vegetable crops has been reported to control the weed incidence, reduce nutrient losses and to improve the hydro-thermal regime of soil (Ashworth and Harrison, 1983; Raina *et al*., 2004). Mulching has strong influence on yield, quality and duration of harvesting, which primarily due to better soil and moisture conservation, changes in soil temperature, improved nutrient availability, and suppression weed in number and weed growth, protection from frost injury and reduction in number of dirty and diseased berries (Sharma and Singh 1999, Sharma *et al.* 2001; Sharma 2002). Strawberry, being a shallow rooted plant requires more frequent but less amount of water during each

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irrigation, which can be accomplished more efficiently through drip system. The consequences of drip irrigation in this crop have not yet been completely established. The present studies were, therefore, under taken to evaluate the effect of drip irrigation alone and in con junction with polythene mulch compared to surface irrigation on water use efficiency, yield and quality of straw berry. The strawberry is the most profitable fruit crop in the shortest possible time as compared to other fruits

MATERIALS AND METHODS

The experiment was conducted at Regional Agricultural Research Station, Rajouri, Sher-e-Kashmir University of Agricultural of Sciences and Technology of Jammu during 2012-2013 and 2013-2014 to determine the effect of irrigation methods and mulching material on vegetative growth, yield and quality of strawberry under mid hill conditions of Jammu province. Experiment was laid out in a randomized block design with nine treatments *viz;* T_1 –Drip Irrigation + Black Polythene, T_2 –Drip Irrigation + Transparent Polythene T_3 –Drip Irrigation + Chirpine Needles, T_4-Drip Irrigation + Paddy Straw, T_5- Drip Irrigation + Unmulched, T_6-Flood Irrigation + Black Polythene, T_7- Flood Irrigation + Transparent Polythene, T_8- Flood Irrigation + Chirpine Needles, T_9- Flood Irrigation + Paddy Straw and T_{10}-Flood Irrigation + Unmulched served as control. All the treatments were replicated thrice. Strawberry runners of almost equal size and vigour were transplanted during evening hours at a spacing of 60 cm x 30 cm in the plot of 2.5 x 2.0 meter size. The biometrical observations were recorded on five randomly selected plants of each treatment. The quality analysis of the fruits at harvesting was done using standard method and procedure as per A.O.A.C (1930) and was subjected to statistical analysis.

RESULTS AND DISCUSSION

It is clear from the data depicted in the Table 1 (a and b) and Table 2 (a and b) that there was significant difference on growth, yield and quality of strawberry among the treatments of different irrigation methods and mulching materials. Among the treatments, treatment T_1 (Drip Irrigation + Black Polythene) were proved effective in terms of growth, yield and quality of strawberry cultivar Chandler under mid hill conditions over the rest

Table 1a. Impact of irrigation methods and mulching material on Vegetative growth of Strawberry cultivated under agro-climatic conditions

Treatments	Plant height (cm)			Plant Spread (cm)			Petiole length (cm)			Number of leaf		
	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled
T_1 Drip Irrigation + Black Polythene	18.11	17.15	17.63	28.50	27.89	28.20	14.88	13.89	14.03	14.03	13.81	13.92
T_2 Drip Irrigation + Transparent Polythene	17.89	16.78	17.34	27.63	26.85	27.24	14.11	13.18	12.83	13.47	12.55	13.01
T_3 Drip Irrigation + Paddy Straw	14.11	13.66	13.89	22.49	22.09	22.29	12.33	11.55	12.44	10.44	10.22	10.33
T_4 Drip Irrigation + Chirpine Needles	15.48	14.15	14.82	22.83	21.67	22.25	13.11	12.55	12.39	11.59	11.29	11.44
T_5 Drip Irrigation + Unmulched	14.79	13.87	14.33	22.37	21.37	21.87	12.55	11.66	12.50	11.26	11.07	11.17
T_6 Flood Irrigation + Black Polythene	15.48	14.37	14.93	25.15	24.15	24.65	13.44	12.44	13.00	12.48	12.33	12.41
T_7 Flood Irrigation + Transparent Polythene	14.37	13.41	13.89	24.77	23.76	24.27	13.33	12.55	12.22	11.99	11.55	11.77
T_8 Flood Irrigation + Paddy Straw	14.23	13.46	13.85	21.44	20.44	20.94	11.92	11.11	12.07	9.70	9.55	9.63
T_9 Flood Irrigation + Chirpine Needles	14.70	14.15	14.43	24.61	23.28	23.95	12.99	12.22	11.22	11.22	10.70	10.96
T_{10} Flood Irrigation + unmulched	13.67	11.77	12.72	19.81	18.81	19.31	10.44	9.44	6.39	8.66	8.37	8.52
S Em ±	1.92	1.63	1.78	2.25	2.56	2.41	2.46	2.33	3.67	1.59	2.05	1.82
CD at 5%	4.02	3.41	3.72	5.55	5.35	5.45	5.15	4.88	2.58	4.69	4.30	4.50

Table 1b. Impact of irrigation methods and mulching material on Vegetative growth of Strawberry cultivated under agro-climatic conditions

Treatments	Leaf area (cm^2)			Crown diameter/ mother plant			Crown weight (gm)			Number of runner/ plant		
	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled
T_1 Drip Irrigation + Black Polythene	98.11	97.56	97.84	6.32	6.33	6.33	0.66	0.65	0.66	2.67	2.89	2.78
T_2 Drip Irrigation + Transparent Polythene	92.81	92.78	92.80	6.05	6.10	6.08	0.64	0.61	0.63	2.26	2.22	2.24
T_3 Drip Irrigation + Paddy Straw	62.67	63.51	63.09	5.98	5.93	5.96	0.60	0.59	0.60	3.15	3.26	3.21
T_4 Drip Irrigation + Chirpine Needles	63.77	63.08	63.43	5.97	6.10	6.04	0.62	0.59	0.61	2.66	2.26	2.46
T_5 Drip Irrigation + Unmulched	74.18	76.06	75.12	5.59	5.53	5.56	0.58	0.55	0.57	4.70	5.00	4.85
T_6 Flood Irrigation + Black Polythene	86.22	87.64	86.93	6.16	6.33	6.25	0.65	0.61	0.63	2.44	2.37	2.41
T_7 Flood Irrigation + Transparent Polythene	84.81	85.99	85.40	6.09	6.17	6.13	062	0.60	31.30	1.92	2.11	2.02
T_8 Flood Irrigation + Paddy Straw	54.44	56.22	55.33	5.73	5.80	5.77	0.59	0.57	0.58	2.77	2.81	2.79
T_9 Flood Irrigation + Chirpine Needles	60.44	62.53	61.49	5.86	5.87	5.87	0.61	0.60	0.61	3.89	4.11	4.00
T_{10} Flood Irrigation + unmulched	50.15	52.52	51.34	5.49	5.40	5.45	0.57	0.55	0.56	4.16	4.11	4.14
S Em ±	3.66	3.99	3.83	0.18	0.71	0.45	0.06	0.06	0.06	1.27	1.14	1.21
CD at 5%	7.66	8.36	8.01	0.38	1.18	0.78	0.13	0.12	0.13	2.65	2.39	2.52

Table 2a. Impact of irrigation methods and mulching material on yield and physical characteristics of strawberry cultivated under intermediate agro-climatic conditions

Treatments	Yield (g) / plant			Fruit weight (g)			Fruit diameter (cm)		
	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled
T_1 Drip Irrigation + Black Polythene	309.55	311.73	310.64	32.08	34.08	33.08	1.30	1.29	1.30
T_2 Drip Irrigation + Transparent Polythene	292.74	304.26	298.50	29.44	30.11	29.78	1.26	1.26	1.26
T_3 Drip Irrigation + Paddy Straw	214.26	212.18	213.22	22.50	23.90	23.20	1.21	1.21	1.21
T_4 Drip Irrigation + Chirpine Needles	246.26	259.28	252.77	24.54	24.75	24.65	1.22	1.22	1.22
T_5 Drip Irrigation + Unmulched	158.15	159.15	158.65	16.33	16.97	16.65	1.19	1.19	1.19
T_6 Flood Irrigation + Black Polythene	284.26	292.22	288.24	28.70	27.88	28.29	1.25	1.24	1.25
T_7 Flood Irrigation +Transparent Polythene	286.07	291.40	288.74	27.59	27.59	27.59	1.23	1.23	1.23
T_8 Flood Irrigation + Paddy Straw	209.44	210.63	210.04	19.70	20.02	19.86	1.20	1.20	1.20
T_9 Flood Irrigation + Chirpine Needles	232.89	231.11	232.00	21.48	21.31	21.40	1.21	1.21	1.21
T_{10} Flood Irrigation +unmulched	155.22	161.03	158.13	15.58	17.35	16.47	1.16	1.18	1.17
S Em ±	5.20	8.19	6.70	2.56	5.05	3.81	0.04	0.03	0.04
CD at 5%	10.89	17.14	14.02	5.35	10.57	7.96	0.09	0.07	0.08

treatment, which was statistically at par with treatment T_2 (Drip Irrigation + Transparent Polythene). According to the pooled data of years 2013-14 and 2014-15 the maximum yield 310.64 g per plant was observed in the treatment T_1 (Drip Irrigation + Black Polythene) along with other yield attributing characters like, plant height i.e., 17.63 cm, plant spread i.e., 28.20 cm, petiole length i.e., 14.39 cm, leaf per plant i.e., 13.92, leaf area per plant i.e., 97.84 cm^2, crown diameter i.e., 6.33 cm, crown weight i.e., 0.66 g, number of runners i.e., 2.78, fruit weight i.e., 33.08 g, fruit length i.e., 1.32 cm, specific

Table 2b. Impact of irrigation methods and mulching material on yield and physical characteristics of strawberry cultivated under intermediate agro-climatic conditions

Treatments	Fruit length (cm)			Specific gravity			Juice (%)		
	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled	2013-14	2014-15	Pooled
T_1 Drip Irrigation + Black Polythene	1.33	1.31	1.32	1.14	1.10	1.12	92.67	93.15	92.91
T_2 Drip Irrigation + Transparent Polythene	1.28	1.29	1.29	1.11	1.07	1.09	90.05	88.05	89.05
T_3 Drip Irrigation + Paddy Straw	1.24	1.25	1.25	1.05	1.02	1.04	88.95	88.81	88.88
T_4 Drip Irrigation + Chirpine Niddles	1.23	1.25	1.24	1.07	1.05	1.06	90.05	88.52	89.29
T_5 Drip Irrigation + Unmulched	1.21	1.23	1.22	1.02	1.02	1.02	83.40	84.26	83.83
T_6 Flood Irrigation + Black Polythene	1.27	1.28	1.28	1.09	1.06	1.08	91.40	90.89	91.15
T_7 Flood Irrigation +Transparent Polythene	1.25	1.27	1.26	1.06	1.04	1.05	86.66	87.37	87.02
T_8 Flood Irrigation + Paddy Straw	1.23	1.24	1.24	1.02	1.01	1.02	84.22	84.89	84.56
T_9 Flood Irrigation + Chirpine Niddles	1.23	1.25	1.24	1.03	1.02	1.03	87.04	86.04	86.54
T_{10} Flood Irrigation +unmulched	1.19	1.22	1.21	1.01	1.00	1.01	80.74	81.98	81.36
S Em ±	0.04	0.03	0.04	0.09	0.05	0.07	2.87	3.79	3.33
CD at 5%	0.08	0.07	0.08	0.19	0.11	0.15	6.01	7.94	6.98

gravity i.e., 1.12 and juice content i.e., 92.91 %, which was observed as statistically at par with the treatment T_2 (Drip Irrigation + Transparent Polythene). These results are in accordance with the findings of Rolbiecki *et al*. (1997) who observed higher Strawberry yield under drip irrigation compared to surface irrigation. Both the mulches were found to be effective in increasing the vegetative growth, yield and quality over unmulch treatment. The higher yields observed under different mulches may be explained in the light of results reported by Raina *et al*. (2004). They observed that the paddy straw and polythene mulches are effective in altering the soil hydrothermal regimes, thus providing a favourable soil environment for enhanced root/shoot growth and the nutrient uptake by straw berry. Higher yield under mulch treatments may be ascribed to its favourable effects on weed control. Drip irrigation with polythene mulch gave significantly highest yield (332.92 g/plant)) as compared to surface irrigation in an unmulched condition (154.50 g/ plant). This increased yield in case of black polythene mulch in strawberry may be due to reduced weed incidence and reduced loss of moisture, reduce nutrient losses and improved hydrothermal regime of soil. Strawberry, being a shallow rooted plant requires more frequent but less amount of water for each irrigation, which can be accomplished more efficiently through drip system. Polythene especially black polythene mulch contributed significantly to control leaf spot disease due to less contact of leaves with soil. Higher yield under mulch treatments may be ascribed to its favourable effects on weed control. Quality fruits were harvested due to infestation free crop. Results show that there was 80 per cent weed control was achieved under black polythene mulch as compare to weedy check plot. Mulching could save precious labourer as it requires frequent weeding @ 15 days interval during the growing season. Considering the additional cost of inputs and the selling price of the quality produce, the polythene mulch with drip irrigation may be recommended to the more progressive farmers for cultivation of strawberry in intermediate agro-climatic zone of Jammu province. The corresponding figures for water savings and increase in yield for straw berry were 51 and 19%, respectively. The results further document that irrigation requirement of Straw berry can be met effectively by operating the drip system having discharge rate of 4 lit h^{-1} biweekly during the growing season. Effects of drip irrigation and polythene mulch on production and fruit quality: Drip irrigation without mulch and with paddy straw mulch significantly increased the runner production. However, with drip plus black polythene mulch it was reduced significantly compared with surface irrigation. Since the black polythene could not provide an anchor for the roots of the new runners, this impeded their production. It is therefore, suggested that after crop harvest, black polythene be removed to provide favourable soil environment for higher runner production.

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Development of unit hydrograph for estimation of hydrologic response from Chaukhutia watershed

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ABSTRACT

Unit hydrograph is a very important practical tool in runoff prediction, which has been used since many years ago and to date it remains useful. Present study was undertaken to develop an average unit hydrograph for estimating the peak rate of runoff and temporal distribution of direct runoff and simulation of flood hydrograph for Chaukhutia watershed of the Ramganga reservoir catchment. The developed unit hydrograph was calibrated for ten storm events and verified for four storm events. The performance and adequacy tests of the unit hydrograph were also carried out by comparing the computed direct runoff hydrograph with the observed runoff hydrographs. The peak runoff rates as well as direct runoff hydrographs computed by unit hydrograph were in close agreement with the observed direct runoff hydrographs. Various statistical measures were used for testing its reliability. A mathematical relationship between observed and computed peak runoff rates with effective rainfall, was also established on storm basis and it was found in very close relationship with each other

Key words: Direct runoff, Effective rainfall, Flood hydrograph, Runoff, Unit hydrograph

Water is an essential natural resource for sustaining life and environment. We are now increasingly becoming aware of the importance of water to our survival and its limited supply because it is essential for existence of all life forms but also a principal element that influences the economic, agricultural and industrial growth of human beings. In agriculture it is the main input for crop production. Crop needs water at all its development stages. Its shortage and excess both are harmful for its growth. Rainfall is the main natural source of water supply for crops and drinking water, 52% for agricultural production and 50% for urban and industrial sectors. therefore its conservation is very important in agricultural sectors for increased and safe production of crops. If rainfall is in excess then the hydrograph resulting from excess rainfall is an important component of hydrologic-engineering design as the peak discharge, volume and time distribution of runoff can be represented by it and the water resource management, design of projects, erosion control structures etc., strategies can be planned and adopted. Since there are various limitations in adopting empirical formulae, unit hydrograph method to obtain runoff and for simulation of designed flood hydrograph of the watershed have been thought. The unit hydrograph method is a well-known hydrologic-engineering technique for estimation of the runoff hydrograph given an excess rainfall hyetograph (a time series of excess rainfall). Unit hydrograph can be defined as a direct runoff hydrograph resulting from a unit pulse of excess rainfall generated uniformly over the watershed at a constant rate for an effective duration. Unit hydrographs are valuable for cost-effective and risk-mitigated hydrologic design of hydraulic structures. The unit hydrograph method is in widespread use by hydrologic engineers and others. A unit hydrograph estimate for an arbitrary watershed allows the computation of a direct runoff hydrograph resulting from either measured or design storms.

The unit hydrograph is a very important tool for estimating runoff amounts for various frequencies. Sherman (1932) first introduced the unit hydrograph theory based on the rainfall and runoff data from the gauged watersheds. A distribution hydrograph for Chaukhutia watershed of Ramganga river was developed to estimate the peak runoff rate and temporal distribution of direct runoff on storm basis by Sinha *et al.* (2006). Mala and Kumar (2008) developed a unit hydrograph for estimation of runoff hydrograph for the Kothuwatari watershed by least square method. Rana (2009) analyzed hydrologic data of Gangas sub-catchment of Ramganga reservoir catchment,

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in Uttarakhand with an area of 506 km^2 to develop unit hydrographs. Sinha *et al.* (2014) simulated design flood hydrographs for a Himalayan watershed (Bino) by deriving distribution hydrograph. Keeping the facts mentioned above in view, the hydrological investigations were carried out in the year 2010 at BRSM College of Agricultural Engineering and Technology & Research Station, Indira Gandhi Krishi Vishwavidyalaya, Mungeli, Chhattisgarh, India, under B. Tech. (Agricultural Engineering) project work to develop unit hydrograph for simulation of design flood hydrographs on storm basis for Chaukhutia watershed.

MATERIALS AND METHODS

The Chaukhutia watershed is a hilly catchment of Ramganga river located at the extreme North-East of Ramganga reservoir catchment in the Chamoli district of Uttar Pradesh between 29°46′15′′ to 30°6′ N latitude and 79°12′15′′ to 79°31′ E longitude as shown in Figure 1. The mean annual maximum and minimum temperatures are 30°C and 18°C respectively. The monthly average daily maximum temperature is highest (39°C) in the month of April whereas it is lowest (22°C) in December. The monthly mean minimum temperature is highest (20°C) in the month of August and lowest (1.9°C) in January. The average annual total precipitation in the area is 1466.76 mm, of which 78 percent is received during the four rainy months (June to September). The rest 22 percent is contributed over remaining eight months, of which January and May contribute the large portion. Drainage in the area is not a severe problem because of a number of tributaries spread over the entire watershed having dendritic stream pattern. Soils are generally coarse textured, stony, shallow, dry and highly erodible. The soil depth varies from 22.5 cm to 135 cm. The soil texture varies from gravely loamy sand to silty loam. The area of the watershed can be grouped under three categories on the basis of land use pattern, viz. forests, cultivated lands and land under grazing, waste and barren lands. The watershed has 27.28 percent area under crop land in which various field and horticultural crops are grown on terraced and unterraced lands. The hydrological data such as topographic features, land use pattern and stage hydrograph rating curves for the study were obtained from the Divisional Forest Office (Soil conservation), Ranikhet(U.P.).

Development of direct runoff hydrographs

The ordinates of the direct runoff hydrographs were computed by subtracting the base flow ordinates from the corresponding ordinates of the total runoff hydrographs using the relation:

$$Q_{Di} = Q_{Ti} - Q_{Bi} \qquad ....(1)$$

where Q_{Di} is the direct runoff in m^{3}s^{-1}, Q_{Ti} is the total runoff in m^{3}s^{-1} and Q_{Bi} is the base flow in m^{3}s^{-1}. The subscript i refers to the time at which runoff values are measured.

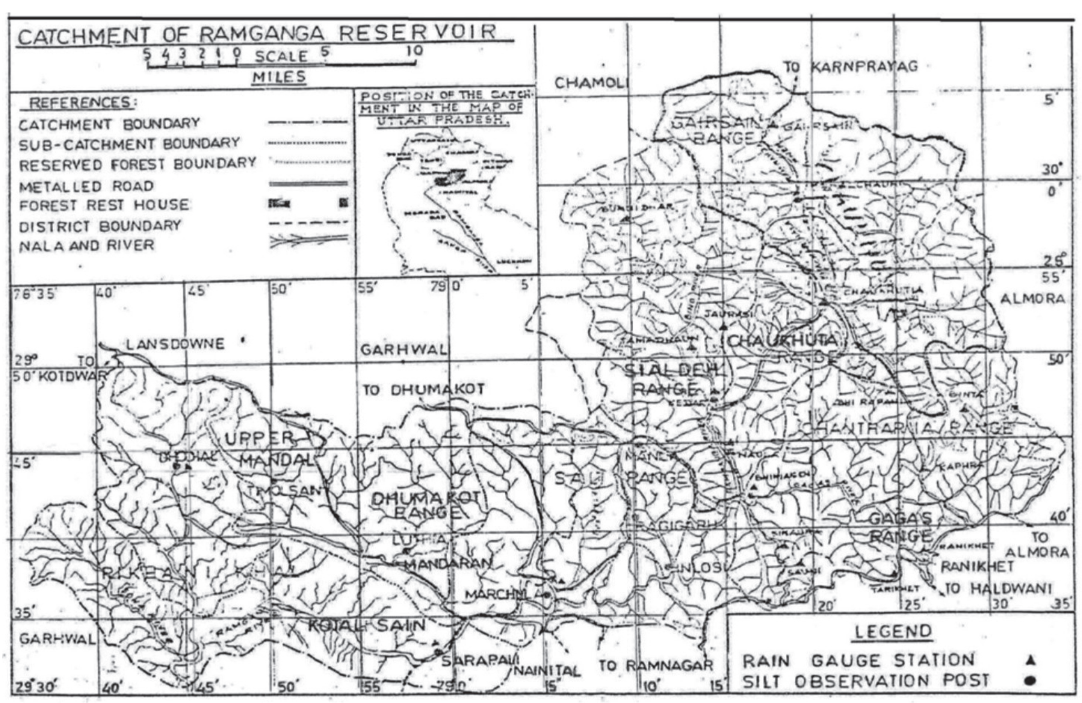

Fig. 1. Location of Chaukhutia watershed in Ramganga reservoir catchment

Development of Unit Hydrograph (UH)

The unit hydrograph ordinates of Chaukhutia watershed for all storm events were determined by dividing the direct runoff ordinates by the effective rainfall. The average unit hydrograph for the watershed was obtained using the following mathematical expression:

$$U_i = \frac{1}{N} \sum_{i=1}^{N} \frac{Qi}{Re} \qquad \ldots(2)$$

where,

U_i = Average unit hydrograph ordinate at i^{th} time

N = Number of storm events

Q_i = Direct runoff hydrograph in cumec (m^3s^{-1}) at i^{th} time

Re= Effective Rainfall in cm

The average unit hydrograph for Chaukhutia watershed is shown in Fig.2.

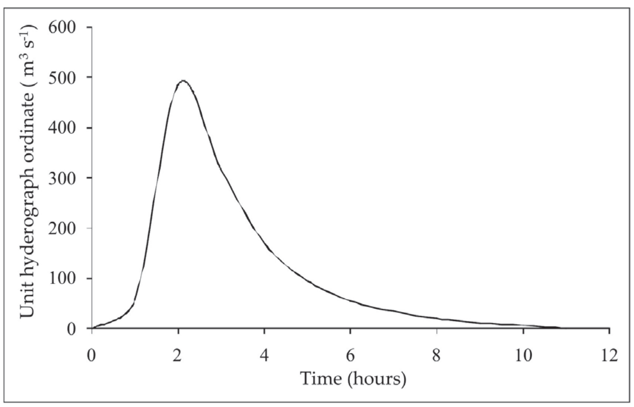

Fig. 2. Unit hydrograph for Chaukhutia watershed

The average unit hydrograph developed for Chaukhutia watershed was utilized for prediction of direct runoff hydrograph for storms events of known effective rainfall. The ordinates of direct runoff hydrograph were estimated by using the relationship:

$$Q_i = \mathrm{U}i \times \mathrm{R_e} \qquad \ldots(3)$$

where,

Q_i = Estimated direct runoff hydrograph ordinate at i^{th} time (m^3s^{-1})

R_e = Effective rainfall of particular storm event (cm)

RESULTS AND DISCUSSION

Performance Evaluation of the Developed Unit Hydrograph

Fourteen storm events were selected to assess the adequacy of the unit hydrograph developed for simulating runoff hydrographs. The data were divided into two sets a calibration set, and a prediction set. The data in the calibration set consisted of ten events which were used for parameter estimation. The data in the prediction set consisted of four events which were used for model verification to test its validity both qualitatively and quantitatively. The qualitative comparison is based on visual observation and peak reproduction, whereas certain statistical parameters were employed for quantitative comparison of the observed and the computed direct runoff hydrographs.

1. Qualitative comparison of computed direct runoff hydrographs with observed direct runoff hydrograph

(a) Comparison of direct runoff hydrographs regenerated by the UH with observed direct runoff hydrographs

The performance of UH was tested by regenerating runoff data which were used to estimate the UH parameters and by comparing regenerated direct hydrographs with the observed direct runoff hydrographs.

The direct runoff hydrographs for the storm events of calibration set were regenerated by convolving one hour unit hydrograph developed in the study with the effective rainfall of the corresponding storm events. It is evident from Fig.3 that the base length, time to peak, rising, crest and recession segments of the regenerated direct runoff hydrographs are in close agreement with those of the observed direct runoff hydrograph for the storm event of September 2, 1983. The slight variations noticed in the regenerated and observed direct runoff hydrographs should not be attributed to defects in the performance of the UH. It may be due to inadequacy of the assumptions of linearity and time-invariance.

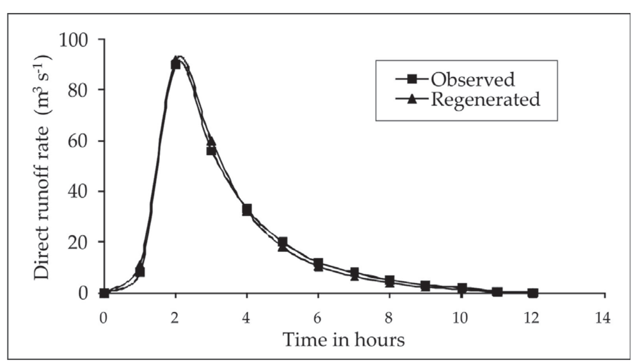

Fig. 3. Comparison of observed and regenerated direct runoff hydrographs for the storm event of September 2, 1983

Table 1. Observed and predicted runoff hydrograph ordinates (m^3s^{-1})

Time(hr)	June 4, 1985		July 24-25, 1985		Aug 10, 1985		Aug 29, 1985	
	Q_{RO} (m^3 s^{-1})	Q_{RP} (m^3 s^{-1})	Q_{RO} (m^3 s^{-1})	Q_{RP} (m^3 s^{-1})	Q_{RO} (m^3 s^{-1})	Q_{RP} (m^3 s^{-1})	Q_{RO} (m^3 s^{-1})	Q_{RP} (m^3 s^{-1})
0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.0	25.00	18.36	15.00	10.31	8.00	7.84	18.00	11.32
2.0	145.00	153.10	90.00	86.03	70.00	65.37	99.00	94.39
3.0	130.00	99.66	50.00	56.00	52.00	42.55	67.00	61.44
4.0	70.00	53.70	30.00	30.17	18.00	22.93	27.00	18.52
5.0	30.00	30.04	22.00	16.87	10.00	12.82	16.00	10.73
6.0	15.00	17.41	16.00	9.78	5.00	7.43	9.00	6.69
7.0	10.00	10.85	11.00	6.10	3.00	4.63	6.00	3.88
8.0	5.00	6.30	8.40	3.54	2.00	2.69	4.00	2.28
9.0	0.00	3.70	4.00	2.08	1.00	1.58	1.00	1.32
10.0	0.00	2.15	0.00	1.21	0.00	0.91	0.00	0.00
11.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$Q_{RO:}$ Observed runoff rate, $Q_{RP:}$ Predicted runoff rate

(b) Comparison of predicted direct runoff hydrographs with observed direct runoff hydrographs

The accuracy of the UH was also tested for runoff data of the storm events not used in development of the UH in a UH evaluated by regeneration of runoff data. A set of four verification events different from those included in the calibration set was chosen for prediction. To check the suitability of the model, predicted direct runoff hydrographs were compared with the observed direct runoff hydrographs. The ordinates of direct runoff hydrographs predicted by the UH for the verification events are given in Table 1. Fig. 4 shows the comparison of predicted direct runoff hydrographs with the observed direct runoff hydrographs for the storm event of August 29, 1985.

The results clearly show that the predictive performance of the model was remarkably good both with respect to distribution of direct runoff and timing. The rising, crest and recession segments of the predicted direct runoff hydrographs were in close agreement with those of the observed direct runoff hydrographs. As mentioned earlier, the variations may be due to the input errors and inadequacy of the assumptions of linearity and time-invariance.

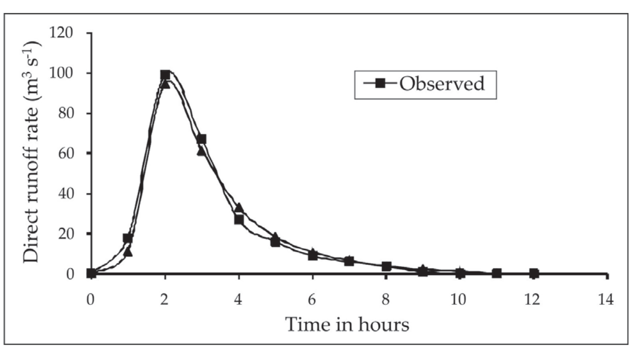

Fig. 4. Comparison of observed and predicted direct runoff hydrographs for the storm event of August 29, 1985

2. Quantitative comparison of computed direct runoff hydrographs with observed direct runoff hydrographs.

In addition to the qualitative comparison of computed direct runoff hydrographs with the observed direct runoff hydrographs, quantitative evaluation of the UH was also done by using certain efficiency criteria as explained below.

(a) Integral square error of the model

The goodness of fit of the computed runoff hydrographs to the observed runoff hydrographs was estimated integral square error as used by Diskin *et al.* (1978). The integral square error is the ratio of the root mean square error to the mean observed runoff ordinates and was computed by the equation:

$$S_E = \left[\frac{\sum_{t=1}^{k} \left[Q_o(t) - Q_c(t) \right]^2}{\sum_{t=1}^{k} Q_o(t)} \right]^{\frac{1}{2}} \qquad \ldots (4)$$

in which S_E is the integral square error of the UH, $Q_c(t)$ is the computed directed runoff ordinates at

Table 2. Computed values of error functions for different storm events

Date of storm event	Values of statistical measures			
	Integral square error (S_E)	Coefficient of efficiency (E)	Relative mean absolute deviation (S_A)	Relative square error (RSE)
August 21-22,1983	0.3876	0.9918	0.0200	0.0056
September 2,1983	0.0262	0.9955	0.0161	0.0029
September 5-6,1983	0.0340	0.9920	0.0197	0.0052
June 8,1984	0.0153	0.9986	0.0068	0.0009
June 25,1984	0.0163	0.9984	0.0078	0.0010
July 15,1984	0.0248	0.9964	0.0132	0.0024
August 18-19,1984	0.0351	0.9932	0.0200	0.0047
August 22-23,1984	0.0323	0.9937	0.0151	0.0043
September 1-2,1984	0.0428	0.9880	0.0169	0.0079
September 17-18,1984	0.0195	0.9977	0.0102	0.0015
June 4,1985	0.1845	0.8398	0.0564	0.1178
July 24-25,1985	0.1047	0.9056	0.0548	0.0569
August 10,1985	0.0732	0.9742	0.0338	0.0188
August 29,1985	0.0491	0.9866	0.0259	0.0093
Average value	0.0497	0.9751	0.0226	0.0171

time t, $Q_o(t)$ is observed direct runoff ordinates at time, t and k is the number of direct runoff hydrograph ordinates. The values of integral square error for all the storm events are given in Table 2. The small values of S_E reveal that overall features of the hydrographs calculated by the model are very similar to those of the observed.

(b) Relative squared error of the model

Wang *et al.* (1992) used relative squared error as a measure of goodness of fit between observed and computed hydrographs to evaluate the quantitative performance of the UH. The relative squared error is the ratio of the sum of squared residuals of the computed and observed runoff hydrograph ordinates to the sum of squared ordinates of observed runoff hydrograph and was estimated by the equation:

$$RSE = \frac{\sum_{t=1}^{k}\left[Q_o(t) - Q_c(t)\right]^2}{\sum_{t=1}^{k}\left[Q_o(t)\right]^2} \quad \text{. . . (5)}$$

in which RSE is the relative squared error. If RSE is equal to zero, the computed runoff hydrograph will coincide with the observed runoff hydrograph because RSE represents overall shape of a hydrograph. The maximum and minimum values of relative squared error are 0.1178 and 0.0009 for the storm events of June 4, 1985 and June 8, 1984 respectively and the average value, of RSE was found to be 0.0171 (Table 2). The low average value of relative squared error indicates that the UH generates closely comparable runoff hydrographs to the naturally observed runoff hydrographs.

(c) Coefficient of efficiency of the model

Nash and Sutcliffe (1970) introduced the term coefficient of efficiency to describe the degree of association between observed and estimated flows. The coefficient of efficiency of the model developed in the study was determined by the following equation:

$$E = 1 - \frac{\sum_{t=1}^{k}\left[Q_o(t) - Q_c(t)\right]^2}{\sum_{t=1}^{k}\left[Q_o(t) - Q_{om}(t)\right]^2} \quad \text{...(6)}$$

where E is the coefficient of efficiency of the model and $Q_{om}(t)$ is the mean of observed runoff ordinates. The coefficient of efficiency measures the regeneration and prediction performance of the UH, and if E = 1.0, all simulated flows are the same as the recorded flows. The average value of coefficient of efficiency was found to be 0.9751. Chew *et al.*, (1993) classified flow estimates as perfectly acceptable simulation resulting in coefficient of efficiency greater than 0.9 (with mean simulated flow always within 10 % of mean recorded flow). The estimation of runoff hydrographs by the UH is under the category of perfectly acceptable simulation because the minimum value of coefficient of efficiency of the UH is 0.83 and the maximum deviation of mean simulated flow from the mean recorded flow is 7.83%.

(d) Relative mean absolute deviation of the model

The goodness of fit of the computed runoff hydrographs to the observed runoff hydrographs was also estimated by computing relative mean absolute deviation as suggested by Diskin *et al.* (1978).

The relative mean absolute deviation is the ratio of the mean of the absolute deviations between observed and the computed direct runoff hydrographs to the observed peak runoff ordinate and was computed by the equation:

$$S_A = \frac{\frac{1}{K}\sum_{t=1}^{k} \left| Q_{op}(t) - Q_{cp}(t) \right|}{Q_{op}(t)} \quad \ldots (7)$$

where S_A is the relative mean absolute deviation of the UH and Q_{op} is the observed peak runoff rate. The average value of relative mean absolute deviation was found to be 0.022652 (Table 2). which indicates accurate estimation of direct runoff hydrographs by the UH.

CONCLUSIONS

Based on the study it can be concluded that the unit hydrograph is good for that the peak runoff rates and runoff hydrographs computed by average unit hydrograph compared satisfactorily with the observed direct runoff hydrograph of Chaukhutia watershed and it is also good for simulating direct runoff hydrographs for a particular watershed and it may have general applicability in the same watershed and support their adaptability to real time forecasting. It will be very useful for designating water harvesting structures, regulating soil and water erosion, watershed development programme, development of water resources for agricultural and other purposes in very efficient and effective manner.

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Variations in soil physical properties, distribution and storage of micronutrients in soil as influenced by high density mango (*Mangifera indica* L.) plantations

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ABSTRACT

The aim of this study was to assess the vertical distribution and storage of micronutrients (Fe, Mn, Cu and Zn) and their relationship with soil properties as influenced by high density mango plantation systems maintained over 20 years under semiarid subtropical condition. The study indicated that planting density had strong impact on the micronutrient distribution and its storage in soil. The micronutrient concentrations under different density systems had higher content in the top layer with a tendency to decrease down the depths. Micronutrients densities were estimated using the values of micronutrient concentrations, bulk densities and depth of soil layer. Micronutrients densities were significantly higher in high density systems as compared to normal density plantation. Maximum distribution of Zn, Cu, Mn and Fe densities was recorded in the category 1.1 to 1.5 kg ha^{-1} (54.2%), 11 to 20 kg ha^{-1} (62.5%), 31 to 40 kg ha^{-1} (66.7%) and 21 to 30 kg ha^{-1}(45.8%) respectively. Significant positive correlation was observed between soil organic carbon (SOC) and micronutrients (r = 0.725** to 0.878**) while inverse relationship was recorded between available Zn, Fe and Cu densities with clay + silt content (r = -0.62* to -0.92**). SOC content had positive correlation with clay content (r = 0.951**) and inverse relation with clay + silt content (r = -0.982**). Clay and clay + silt should be considered as an important soil factor as they might impact the micronutrient stocks and SOC content.

Key words: High density system, Micronutrient distribution, Micronutrients storage, Soil organic carbon

INTRODUCTION

High density orchards establishment is being considered as an alternative orchard plantation system for efficient utilization of land and ensuring optimum productivity. This has resulted from the ever growing economic demands of conventional low density system of planting on long-term orchard profitability and resource conservation with sustainability in quality fruit production (Adak *et al*., 2012). For maintenance of sound soil health and sustaining the productivity of fruit tree based ecosystem, maintaining a satisfactory level of soil micronutrients is an integral component of long-term soil management strategy (Patiram *et al*., 2000; Kumar *et al*., 2011). The role of micronutrients as essential nutrient elements is well established for tree growth and quality fruit production. However, the knowledge of its distribution within the profile is important owing to have understanding of micronutrient dynamics (Gupta *et al*., 2003; Ibrahim and Umar, 2012). Soils under orchard ecosystem are different as compared to intensively cultivated annual agro-ecosystem in respect to micronutrient availability to fruit crops. Singh *et al*. (2006) indicated that the change in land use affects soil properties, which may alter the availability and forms of micronutrients in soil. Changes in tree density can have important ecohydrological implications and due to long term management of orchard soils, soils under a particular land use system may affect physio-chemical properties which may modify DTPA-extractable micronutrients content and their availability to fruit crops. Thus, knowledge of status of available micronutrients and their interrelationship with soil characteristics is helpful in understanding the inherent capacity of orchard soil to supply these nutrients to tree plants.

Orchard management can have substantial impact on the dynamics of soil micronutrients, organic carbon and other physical, chemical and biological indicators (Ayres *et al*., 2009; Dinesh and Chaudhuri, 2013). Tree response to chemical fertilizers undoubtedly depends on soil moisture

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and soil organic carbon status. Bhriguvanshi *et al*. (2012) inferred that distribution of micronutrients in mango orchard soils is a function of soil moisture and organic carbon content. The degree of variability of such nutrient dynamics appeared to be 41-82 per cent under different fertigation regimes. Soil organic carbon and micronutrients distribution are thus interdependent and are significantly influenced micronutrient release pattern, their mobility and interactions with the tree roots. Sometimes tree density and different tree species also impacted the soil organic carbon and its stock variation (Saha *et al*., 2009). It was further noted that the stock of soil organic carbon was impacted by the distance from tree trunk (Howlett *et al*., 2011). It has been reported that tree-based land use system has greater potential for storing more stable carbon in the soil than with the treeless culture (Haile *et al*., 2010). Apart from the soil organic carbon (SOC) content, physical properties like bulk density, porosity, water holding capacity, clay and silt content also play vital role in the soil system. Improvement in soil physical quality viz., water retention, porosity in tree based system was observed by Silva *et al*. (2011). Soils with high clay content are known to have higher field capacities and sometimes the type of clay is considered more critical than the total amount in controlling soil carbon (Powers and Schlesinger, 2002). Clay had a close relation with the floating free light fraction of organic carbon and along with silt content, strongly indicates as a control factor not only for mineral associated organic matter but also for SOC and micronutrient storage (Paul *et al*., 2008). Kasel and Bennett (2007) observed strong correlation of silt and clay in predicting the organic carbon. Thus, there is an urgent need to examine the micronutrient distribution along with stock from view point of different soil properties and density system. Therefore, the present study was intended to evaluate the long-term effects of high density mango plantation on soil physical properties and micronutrient density and its distribution in the orchard soil.

MATERIALS AND METHODS

Study area and field experimentation

The study site was located in the research farm of ICAR-Central Institute for Sub-tropical Horticulture, Rehmankhera, Lucknow, Uttar Pradesh, India at a Latitude of 26° 54′ N and Longitude of 80° 45′ E with an altitude of 127 m above mean sea level, having a typical sub-tropical climate with dry hot summer and cold winters. The monthly average maximum temperatures varied between 37.0 and 17.7 ^{0}C and corresponding values for minimum temperatures were 25.2 and 6.5 ^{0}C respectively during the sampling year (2013). The location received a cumulative rainfall of 1004.1 mm. Majority of this rainfall is contributed by southwest monsoon from July to September and the rest amount is received through the 'Western Disturbances' from December to February. Mean daily pan evaporation ranged from 2.3 to 3.2 mm per day during winter and 5.6 to 9.0 mm per day during summer months. Soil is *Typic Ustocrepts* with Silty loam texture. Six different density plantations of mango cv *Dashehari* at a spacing of 2.5 × 2.5, 2.5 × 5.0, 5.0 × 5.0, 5.0 × 7.5, 7.5 × 7.5 m and 10.0 ×10.0 m with 1600, 800, 400, 267, 177 and 100 plants per hectare respectively were maintained since 1992 till date. The experiment was in a randomized block design with four replications. High density in this case indicated 2.5 m to7.5 m spacing combinations (177 to 1600 plants per ha) than normal density population (10.0 ×10.0 m i.e.100 plants per ha). Each year uniform nutrient and water management crop protection measures were applied in the entire high density plantations.

Observations and measurements

Soil samples were collected randomly from four different sites within each planting density at 0-30, 30-60 and 60-90 cm soil depth during first week of September 2013. A total of 72 soil samples were collected (6 densities × 4 replications × 3 depths), air dried, processed (< 2 mm) and stored in sealed polythene bags for chemical analysis. Available Fe, Mn, Cu and Zn in soil were extracted with 0.005 M diethylene triamine penta acetic acid (DTPA), 0.01 M $CaCl_2$, and 0.1 M triethanolamine (TEA) pH of 7.3 and determined by atomic absorption spectrophotometer.

Soil moisture content was determined by drying sieved fresh soil samples for 24 h at 105 °C and expressing as percentage of the dry soil weight. For estimating soil pH, a suspension of 10 grams of sieved air dried (< 2 mm) soil mixed with 25 ml water was used. Soil organic carbon content was estimated by chromic acid wet digestion method. Undisturbed core soil samples were collected from four sites of each plantation at three depths (0-10, 10-20 and 20-30 cm) from tree basin for estimating bulk density, particle density, water holding capacity and porosity as per the standard methodology (Tan, 2005). Particle size distribution was assessed as per standard international pipette method.

Total porosity (TP) was calculated as

$$TP (\%) = [\{1- (BD/\rho_s)\}*100]$$

where BD is bulk density (g cm^{-3}) and ρ_s is the particle density (g cm^{-3}).

DTPA-extractable soil micronutrient density was calculated by the formula (Jiang *et al*., 2009):

$$SM_p = \sum_{i=1}^{n} (SM_i \times \rho_i \times d_i)/10$$

where SM_p is DTPA-extractable Fe, Mn, Cu or Zn pool (kg ha^{-1}) at a given depth, SM_i is the concentration of test micronutrient g kg^{-1} of layer i, ρ_i is bulk density (g cm^{-3}) of layer i, d_i is the depth of layer (cm) or thickness of layer and n is the number of layers/depths.

The DTPA-extractable micronutrients densities were estimated for the root zone (0-30 cm) soil depth.

Statistical analysis

A descriptive statistical analysis of all soil data involving standard deviations, coefficient of variation, skewness, kurtosis, range, mean value and standard error of mean across different treatments were determined. A two-way analysis of variance (ANOVA) was performed using depths and density parameters. Statistical analysis was performed using SPSS for windows version 12.0. Histograms and correlation matrix were developed using SPSS software package. Required graphs were generated using MS Excel software. Duncan multiple range test (DMRT) was performed for different treatment means and denoted by different letters (a, b, c and d) at 5% level of significance (i.e. at 95% level of probability). Same letter indicated statistical non-significance among the mean values of different parameters while different letters indicated statistical significance. Functional relationship among SOC (%) and clay content (%) as well as clay + silt content (%) was determined. Furthermore, the relationship between clay, clay and silt with micronutrients were also evaluated.

RESULTS AND DISCUSSIONS

Vertical distribution of DTPA-extractable soil micronutrients

Different planting density systems recorded higher content of DTPA extractable Fe, Mn, Zn and Cu in the surface layer and showed tendency to decrease down the soil depths (Table 1a). Descriptive statistical analysis indicated significant difference among the DTPA-extractable micronutrients across different planting densities and soil depths indicating that both planting densities and soil depths are the key factors affecting the distribution of micronutrients in the soil profile. The plantation densities had significant effect on Zn availability throughout soil depths. Pooled data showed higher Zn content at root zone depth (0-30 cm) than deeper soil horizons. Copper concentration in top soil layer (0-30 cm) was significantly higher than that in 60-90 cm soil depth. There was non-significant difference among the plantation densities. A wider range of 0.92 to 4.36 mg kg^{-1} of Cu concentration was recorded in the medium (5.0 × 5.0 m) density plantation, recommended for this region. DTPA- Fe concentration was highest in the higher density plantations with 177-1600 plants per hectare (6.56 to 7.99 mg kg^{-1}) as compared to normal density with 100 plants per hectare (5.19 mg kg^{-1}) at 0-30 cm soil depth. Higher Fe concentration was observed in the root zone soil depth (0-30 cm) which however, decreased to a range of 3.88 to 5.1 mg kg^{-1} at 60-90 cm soil depth (Table 1b). Such variations may be because of higher microbial activities, litter fall, organic matter decomposition and addition of fertilizers in the upper soil layers. Considering the critical limit of Fe concentration (2 mg kg^{-1}), majority of the soil samples had sufficient level of Fe concentration across different planting densities. Similarly, higher Mn concentration (>7.15 to <8.8 mg kg^{-1}) was observed in the root zone (0-30 cm depth) of higher planting density (2.5 × 2.5 m to 7.5 × 7.5 m) as compared to 6.71 mg kg^{-1} in 10.0 ×10.0 m. Considering the critical limit of 4.0 mg kg^{-1} all plantations had sufficient Mn in the soil irrespective of planting density.

Micronutrients are considered to be essential for fruit tree growth and quality fruit production as they are involved in various enzymatic as well as metabolic activities within the plant ecosystem. Micronutrients availability to the fruit tree depends on several physical, chemical and biological factors of soil; of course, the total quantity of availability is a rare indicative of soil solution as the labile pool is either directly or indirectly influenced by the soil pH, clay content, organic matter, water content adsorptive surface and other related soil properties (Singh *et al*., 1988; Rangel, 2007).

The vertical distribution of DTPA-extractable micronutrients under different planting density systems consistently decreased from the surface to

Table 1a. Vertical distribution of micronutrients* and its descriptive statistical analysis under different high density mango plantation systems

Depth (cm)	Tree spacing / Density (m)	Micronutrient concentration	Sd	CV (%)	Skewness	Kurtosis	Range
		Zn (mg kg^{-1})					
0-30	2.5×2.5	0.39 ± 0.0008[a]	0.07	18.5	0.29	1.6	0.28 - 0.52
	2.5×5.0	0.36 ± 0.0010[ab]	0.04	14.4	-0.10	-0.5	0.22 - 0.34
	5.0×5.0	0.32 ± 0.0013[b]	0.04	16.8	-0.37	-1.1	0.16 - 0.26
	5.0×7.5	0.34 ± 0.0008[ab]	0.09	23.8	0.27	-0.8	0.24 -0.48
	7.5×7.5	0.29 ± 0.0012[bc]	0.05	21.2	-0.50	0.1	0.16 - 0.32
	10.0×10	0.25 ± 0.0009[c]	0.04	23.1	-0.50	0.8	0.10 -0.22
30-60	2.5×2.5	0.28 ± 0.0002[a]	0.10	30.3	-0.08	-2.1	0.20 - 0.44
	2.5×5.0	0.25 ± 0.0004 [ab]	0.05	24.0	0.30	-0.8	0.15 - 0.30
	5.0×5.0	0.22 ± 0.0004 [b]	0.05	29.8	0.78	0.5	0.10 - 0.24
	5.0×7.5	0.24 ± 0.0003 [ab]	0.07	21.7	-0.08	-1.6	0.24 -0.44
	7.5×7.5	0.23 ± 0.0005 [b]	0.05	18.7	0.84	-0.5	0.20 - 0.32
	10.0×10	0.21 ± 0.0008 [b]	0.05	28.0	0.05	-2.1	0.13 - 0.26
60-90	2.5×2.5	0.21 ± 0.0002 [a]	0.09	30.9	0.42	-0.4	0.18 - 0.44
	2.5×5.0	0.17 ± 0.0002 [ab]	0.06	26.9	0.87	-0.8	0.16 - 0.32
	5.0×5.0	0.16 ± 0.0003 [b]	0.03	21.3	-0.58	0.1	0.10 - 0.20
	5.0×7.5	0.19 ± 0.0004 [ab]	0.08	31.5	-0.03	-1.2	0.14 -0.36
	7.5×7.5	0.16 ± 0.0002 [b]	0.08	35.8	-0.18	-2.4	0.12 -0.30
	10.0×10	0.15 ± 0.0003 [b]	0.05	30.6	0.16	-1.6	0.10 -0.22
		Cu (mg kg^{-1})					
0-30	2.5×2.5	4.36 ± 0.04 [a]	0.50	11.5	0.64	-1.2	3.82 - 5.16
	2.5×5.0	4.08 ± 0.04 [a]	1.11	38.7	0.23	-1.0	1.48 - 4.50
	5.0×5.0	3.17 ± 0.12 [b]	1.16	64.3	0.85	-1.1	0.76 – 3.64
	5.0×7.5	2.43 ± 0.06 [bc]	0.51	12.4	0.74	1.5	3.38 - 5.00
	7.5×7.5	2.37 ± 0.10 [c]	0.55	23.1	0.42	-1.7	1.58 - 3.00
	10.0×10	1.75 ± 0.03 [c]	0.32	17.0	-0.31	-1.2	1.42 -2.26
30-60	2.5×2.5	2.86 ± 0.17 [a]	0.90	28.4	-0.03	-1.7	1.98 - 4.36
	2.5×5.0	2.23 ± 0.04 [ab]	0.75	45.7	2.01	4.5	0.96 - 3.24
	5.0×5.0	1.64 ± 0.08 [b]	0.33	26.8	0.89	-1.1	0.92 - 1.74
	5.0×7.5	1.78 ± 0.01 [b]	0.63	25.9	1.38	1.9	1.74 - 3.64
	7.5×7.5	1.58 ± 0.02 [b]	0.32	18.0	-0.39	-0.5	1.28 - 2.22
	10.0×10	1.45 ± 0.04 [b]	0.28	25.0	-0.61	0.2	0.64 -1.46
60-90	2.5×2.5	1.80 ± 0.19 [a]	0.83	35.1	1.55	3.0	1.52 - 4.04
	2.5×5.0	1.88 ± 0.01 [a]	0.34	21.6	-0.11	0.2	1.03 - 2.08
	5.0×5.0	1.24 ± 0.02 [b]	0.29	30.4	0.04	-1.5	0.58 - 1.36
	5.0×7.5	1.11 ± 0.01 [b]	0.46	26.4	0.14	-1.0	1.16 -2.44
	7.5×7.5	0.95 ± 0.01 [b]	0.55	38.2	0.60	-1.0	0.84 - 2.30
	10.0×10	0.91 ± 0.003[b]	0.15	17.0	0.54	1.5	0.68 - 1.18

* Mean ± standard error of mean
Different letters in the same depth indicate significantly different values at $P < 0.05$ with Duncan's multiple range test comparison

the subsurface layer. This is generally explained by the fact that leaf litter cycling and anthropogenic disturbances and leaching might be the factors affecting the vertical distribution and top soil accumulation of micronutrients (Sharma and Chaudhary, 2007). In the root zone, distribution of micronutrients was mainly controlled by different soil factors however yet root distribution and maximum rooting depth may play an important role in shaping the contents (Jobbáge and Jackson, 2001). Furthermore, there is every possibility that under high density condition, tree may take up

Table 1b. Vertical distribution of micronutrient * and its descriptive statistical analysis under different high density mango plantation systems

Depth (cm)	Tree spacing / Density (m)	Micronutrient concentration	Sd	CV (%)	Skewness	Kurtosis	Range
			Fe (mg kg^{-1})				
0-30	2.5×2.5	7.99 ± 0.05[a]	0.61	7.6	-0.37	1.3	6.94 - 8.90
	2.5×5.0	6.56 ± 0.50[ab]	0.93	14.6	0.03	0.5	4.92 -7.84
	5.0×5.0	6.67 ± 0.59[ab]	0.81	15.8	0.08	-1.5	3.98 -6.08
	5.0×7.5	6.72 ± 0.22[ab]	1.87	28.4	0.41	-1.2	4.18 -9.40
	7.5×7.5	7.13 ± 0.80[ab]	1.55	30.0	0.86	-1.0	3.82 -7.72
	10.0×10	5.19 ± 0.20[b]	1.02	26.3	1.54	2.0	2.98 -5.88
30-60	2.5×2.5	6.36 ± 0.12[a]	2.03	30.4	1.23	-0.4	5.26 -10.08
	2.5×5.0	5.17 ± 0.34[ab]	1.55	28.6	0.46	0.2	3.28 -8.02
	5.0×5.0	5.43 ± 0.34[ab]	1.50	31.0	0.92	2.3	2.76 -7.68
	5.0×7.5	6.15 ± 0.09[ab]	1.24	18.4	0.74	-0.4	5.34 -8.80
	7.5×7.5	5.70 ± 0.28[ab]	0.81	13.1	0.01	0.4	4.90 -7.42
	10.0×10	4.74 ± 0.12[b]	1.31	22.8	1.32	1.5	4.52 -8.24
60-90	2.5×2.5	5.10 ± 0.09 [ab]	2.36	33.1	1.90	4.0	5.22 -12.08
	2.5×5.0	3.88 ± 0.15 [b]	1.41	24.7	0.25	-2.0	4.28 -7.68
	5.0×5.0	4.85 ± 0.32 [ab]	0.72	14.7	-0.81	0.6	3.58 -5.76
	5.0×7.5	5.74 ± 0.24[a]	1.20	23.1	2.09	4.6	4.36 -7.74
	7.5×7.5	4.85 ± 0.07 [ab]	0.92	19.3	0.78	-1.0	3.82 -6.20
	10.0×10	4.14 ± 0.05 [b]	0.57	13.8	0.24	0.6	3.28 - 5.08
			Mn (mg kg^{-1})				
0-30	2.5×2.5	7.95 ± 1.24[ab]	2.94	37.0	2.20	5.2	5.84 - 14.34
	2.5×5.0	8.01± 0.77[ab]	2.24	31.2	1.10	-0.1	5.30 - 11.10
	5.0×5.0	7.15 ± 0.29[b]	2.31	41.9	0.86	-0.4	2.92 - 9.38
	5.0×7.5	7.98 ± 0.46[ab]	2.31	28.9	1.04	0.9	5.68 - 12.28
	7.5×7.5	8.80 ± 1.52[a]	1.68	25.5	0.39	-0.5	4.42 - 9.28
	10.0×10	6.71 ± 0.71[c]	1.05	21.8	0.87	-0.7	3.76 - 6.50
30-60	2.5×2.5	7.18 ± 0.72[a]	1.42	19.9	-0.35	-1.6	5.06 - 8.84
	2.5×5.0	6.59 ± 0.40[b]	1.11	17.6	-0.67	1.8	4.28 - 7.90
	5.0×5.0	6.28 ± 0.18[b]	0.67	14.9	0.46	-1.3	3.72 - 5.46
	5.0×7.5	6.42 ± 0.31[b]	1.79	22.5	1.18	0.9	6.18 - 11.28
	7.5×7.5	6.64 ± 0.45[b]	1.47	22.9	0.46	0.2	4.34 - 8.84
	10.0×10	6.00 ± 0.15[b]	1.47	30.3	1.21	2.4	3.04 - 7.72
60-90	2.5×2.5	5.51 ± 0.76[a]	3.26	37.0	1.54	3.0	5.62 - 15.38
	2.5×5.0	4.79 ± 0.16[b]	1.77	26.7	0.99	-0.2	5.08 - 9.76
	5.0×5.0	4.50 ± 0.06[ab]	1.23	23.1	0.72	0.7	3.88 - 7.48
	5.0×7.5	4.86 ± 0.31[b]	2.22	33.1	0.40	-1.6	4.36 - 9.90
	7.5×7.5	5.30 ± 0.21[a]	1.02	17.0	0.19	-2.4	4.88 - 7.28
	10.0×10	4.54 ± 0.16[ab]	1.07	23.5	-0.25	-1.1	2.98 - 5.94

* Mean ± standard error of mean
Different letters in the same line indicate significantly different values at $P < 0.05$ with Duncan's multiple range test comparison

more micronutrients from deeper layer and then redistribute them in the soil profile (Russell *et al.*, 2007; Ramos *et al.*, 2011).

Dynamics of soil physical parameters

Descriptive statistical analysis of some soil properties under different plantation system (Table 2) indicated that the soil pH was near neutral (average being 7.2) ranging between 6.9 and 7.6. The bulk density (BD) under different density system varied between 1.36 and 1.61 g cm^{-3} while average particle density (PD) was recorded as 2.53 g cm^{-3}. Higher BD was recorded in the higher density system than plantation with normal density of 100 plants ha^{-1} (Fig. 1). In contrast, lower porosity

Table 2. Descriptive statistical analysis of soil physical properties under high density mango plantation systems

	Mean ±SEm	Sd	Range		CV	Skewness	Kurtosis
			Max	Min	(%)		
pH	7.18 ± 0.002	0.19	7.59	6.90	2.61	0.51	-0.13
BD (g cm^{-3})	1.48±0.0001	0.08	1.61	1.36	5.25	-0.37	-1.13
PD (g cm^{-3})	2.53 ± 0.001	0.16	2.82	2.29	6.31	0.05	-1.16
Sand (%)	30.64 ±1.96	5.93	41.50	22.58	19.36	0.44	-0.97
Silt (%)	61.69 ± 2.46	6.66	72.64	51.86	10.80	-0.06	-1.38
Clay (%)	7.68 ± 0.24	2.09	10.64	4.30	27.17	-0.27	-1.02
WHC (%)	21.17 ± 0.13	1.52	23.72	19.32	7.18	0.34	-1.29
Porosity (%)	59.07 ± 1.80	5.69	68.43	48.27	9.63	-0.14	-0.75
SOC (%)	0.41 ± 0.001	0.12	0.60	0.25	30.51	0.31	-1.39
Soil moisture (%)	20.44 ± 0.33	4.9	29.93	4.17	23.96	-0.77	1.13

SEm stands for standard error of mean

was depicted at dense tree system. Soil organic carbon (SOC) content varied from 0.25 to 0.60% across different treatments with a pooled mean of 0.41%. A range of 19.32 to 23.72% water holding capacity and an average porosity of 59% was observed under different plantation densities. Higher water holding capacity was revealed at the surface soil layer as compared to deeper soil horizons across different planting density systems (Fig. 1). Soil moisture content showed wider variation in the range of 4.17 to 29.93%.

Micronutrients density under different tree spacing

The highest and lowest Zn density of 1.75 and 1.05 kg ha^{-1} was recorded among various plantation densities of mango (Table 3). The micronutrient density in soil was *at par* among different high density planting systems however, the Zn density in high density planting systems significantly differed from that under normal density system. Higher range of Zn density (1.19 to 2.25 kg ha^{-1}) was observed in the high density plots while 10.0 ×10.0 m spacing revealed a lower range of

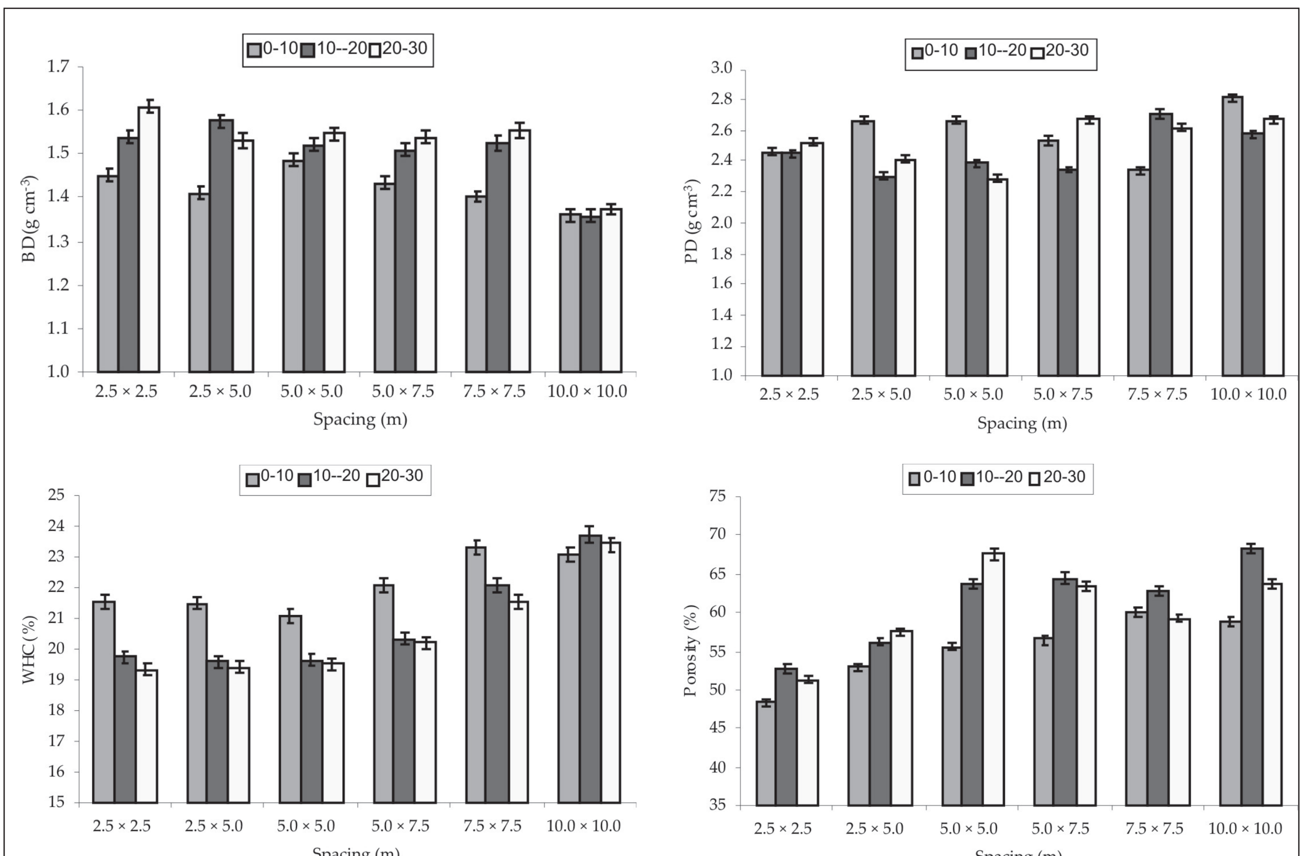

Fig. 1. Soil physical properties under high and normal density plantation system

Table 3. Micronutrient density (kg ha^{-1}) in soil (0-30 cm) in different mango plantation densities

Spacing (m)	Mean ± SEm	CV (%)	Sd	Skewness	Kurtosis	Range
			Zn (kg ha^{-1})			
2.5 × 2.5	1.75 ± 0.04[a]	21.86	0.38	0.72	1.15	1.34 - 2.25
2.5 × 5.0	1.70 ± 0.03[a]	21.14	0.36	1.90	3.70	1.46 - 2.23
5.0 × 5.0	1.48 ± 0.01[a]	15.08	0.22	0.10	1.49	1.21 - 1.76
5.0 × 7.5	1.56 ± 0.01[a]	14.52	0.23	1.46	2.21	1.37 - 1.88
7.5 × 7.5	1.32 ± 0.01[ab]	11.25	0.15	0.00	-5.99	1.19 - 1.45
10 × 10	1.05 ±0.01[b]	20.68	0.22	0.27	0.88	0.80 - 1.32
			Cu (kg ha^{-1})			
2.5 × 2.5	19.75 ± 0.51[a]	7.2	1.42	1.73	3.08	18.7 – 21.83
2.5 × 5.0	18.53 ± 0.70[a]	9.02	1.67	-1.64	2.75	16.10 - 19.81
5.0 × 5.0	13.73 ± 2.92[b]	24.89	3.42	-1.01	-0.43	9.15 - 16.49
5.0 × 7.5	11.15 ± 0.89[bc]	16.90	1.88	0.47	-1.88	9.24 - 13.47
7.5 × 7.5	11.55 ± 5.40[bc]	14.25	4.65	1.66	2.62	8.40 - 18.30
10 × 10	7.16 ± 0.06[c]	6.93	0.50	0.00	-0.91	6.58 - 7.74
			Mn (kg ha^{-1})			
2.5 × 2.5	35.44 ±17.32[ab]	23.48	8.32	1.75	3.04	29.81 - 47.65
2.5 × 5.0	35.85 ± 1.69[ab]	7.25	2.60	1.53	2.87	33.60 - 39.60
5.0 × 5.0	33.07 ± 7.73[ab]	16.82	5.56	-0.41	-2.90	26.39 - 38.44
5.0 × 7.5	36.53 ± 10.66[ab]	17.87	6.53	0.34	-3.52	30.33 - 44.18
7.5 × 7.5	38.75 ± 7.69[a]	14.31	5.55	1.70	2.83	34.97 - 46.84
10 × 10	28.05 ± 6.98[b]	18.84	5.28	-0.57	1.66	21.11 - 33.97
			Fe (kg ha^{-1})			
2.5 × 2.5	36.07 ± 2.67[a]	9.06	3.27	1.48	2.78	33.17 - 40.76
2.5 × 5.0	29.13 ± 1.73[a]	9.04	2.63	1.17	0.99	26.78 - 32.77
5.0 × 5.0	30.13 ± 7.23[a]	17.85	5.38	-0.78	-1.66	23.20 - 34.42
5.0 × 7.5	31.41 ± 4.62[a]	24.35	7.65	0.72	0.32	23.50 - 41.45
7.5 × 7.5	31.28 ± 5.67[a]	15.23	4.76	1.34	1.42	27.36 - 37.97
10 × 10	21.39 ± 2.79[b]	15.61	3.34	-0.03	-5.73	18.15 - 24.42

micronutrient density ranging between 0.80 and 1.32 kg ha^{-1}. Interestingly, out of wider range of Zn density, 1.1 to 1.5 kg ha^{-1} category recorded maximum percentage distribution (54.2%) followed by 29.2% in the range of 1.51 to 2.0 kg ha^{-1} (Fig. 2). Out of total sample size, the lowest percentage distribution of Zn density was observed both in case of lower category of < 1.0 kg ha^{-1} as well as higher category of > 2.0 to <3.0 kg ha^{-1} (8.3 % in both the cases). There was no significant difference in Cu density between the plantation density of 2.5 × 2.5 and 2.5 × 5.0 m but in rest of treatments of planting densities it varied significantly as compared to the normal density of 10.0×10.0 m. Of course Cu density in majority of the samples was in the range of 11 to 20 kg ha^{-1} and only 4.2% was recorded in the upper range of 21 to 30 kg ha^{-1}.

Wide range of variability existed among the values of Fe density. Out of total sample size, maximum distribution of Fe density (45.8 %) was observed in the category 21 to 30 kg ha^{-1} (Fig. 2) followed by 37.5% in the range of 31 to 40 kg ha^{-1}. The lowest value of 8.3 % was recorded in both <20 kg ha^{-1} as well as >41 to <50 kg ha^{-1}. Similarly, the highest distribution of Mn density (66.7%) was found in the category of 31 to 40 kg ha^{-1} and lowest (20.8%) in category of 20-30 kg ha^{-1}. Higher Mn density in the category of >41 to <50 kg ha^{-1} recorded the lowest percentage distribution (12.5%) of soil samples.

Micronutrients availability and its spatio-temporal variations were governed by the soil moisture level (Bhriguvanshi *et al*., 2013) and are highly dependent on the wetting zone around the tree basin. It was inferred from millions of hectares of arable lands in the world suffering from micronutrient deficiency because of low micronutrient availability brought about by the increased demands of growing crops/tree plantations (Alloway, 2008). Even micronutrient

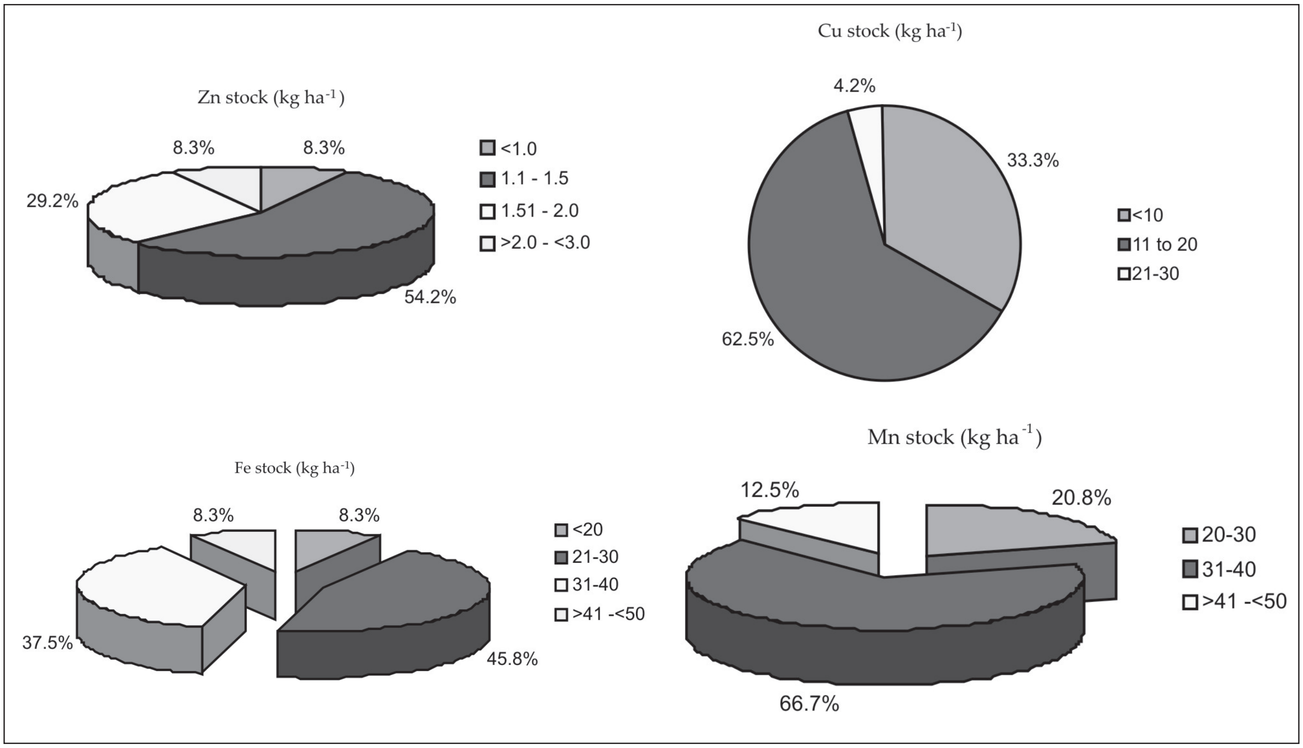

Fig. 2. Distribution of different micronutrient density under high density plantation system

cycling is quite different in different terrestrial system thereby vertical/profile distribution differs and land use changes had strong affect on their distribution particularly its labile fraction (Venkatesh *et al*., 2003; Han *et al*., 2007). Jiang *et al*. (2006) reported that land use effects, soil depth and their interaction on micronutrients were significantly different, even micronutrient stocks in woodland land use system was significantly greater than annual crop cultivation system. Trees planted under agro-forestry/silvi-pastoral/forest/ commercial orchard plantation tend to contribute more micronutrients storage in the root zone niche as they are deep rooted (Schulp *et al*., 2008). Dinesh *et al.* (2010) observed higher availability of Zn, Mn, Cu and Fe in the tree rhizosphere and such enhancement is apparently attributed to increase mobilization of micronutrients due to complexities with organic acids in root exudates.

Correlations among soil properties

Important soil factors like SOC, clay and silt content of high density soil profile system were correlated and it was observed that SOC content showed significant positive correlation with the clay content (r = 0.951**) while it was inversely related with the clay + silt content (r = -0.982**) (Fig. 3). Thus, clay and silt content played a critical role in dynamics of SOC content (Charan *et al*., 2013). DTPA-extractable micronutrients were positively and significantly correlated with each other (Table 4a). All the micronutrients were strongly correlated with SOC content (r = 0.725** to 0.878**). It was further inferred that Zn, Cu, Fe and Mn stocks were positively correlated with clay content (Fig. 4). Micronutrient density particularly of Zn, Fe and Cu showed significant negative correlation with clay + silt content (Fig. 5). Bulk density had significant correlation with Mn and Fe density at 1% level of significance while water holding capacity showed negative correlation with Zn and Cu density. Porosity, however, showed statistically significant positive relationship with Cu and Fe density (Table 4b).

Organic matter is considered as the storage tank of micronutrients in soil and its capacity is determined by the type, quantity, quality as well as maturity of soil organic matter. Soil organic layer and clay content had significant impact on the dynamics of organic carbon stocks (Grüneberg *et al*., 2013). Not only the leaf litter fall, root litter and decomposition rate determines the amount of C stored in the orchard soil but also the potentials of orchard soils to stabilize the organic carbon is a matter of concern (Jha and Mohapatra, 2010). Considering the wide range of soil types across different management and plantation ecosystem, soil organic matter is often correlated with the clay content, silt fraction and /or mineral oxides (John *et al*., 2005). Mechanisms such as legand exchange,

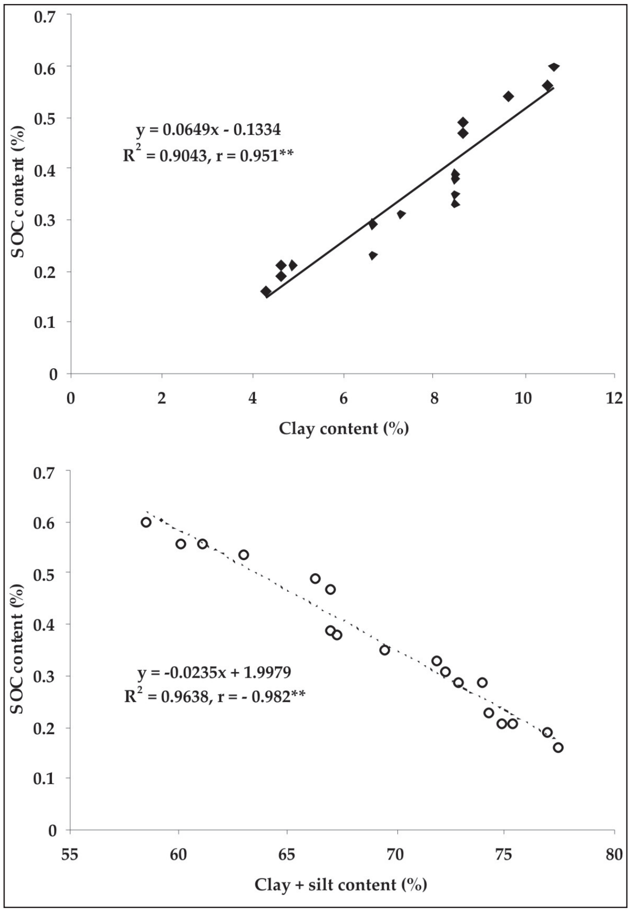

Fig. 3. Functional relationship of SOC content with clay and clay + silt under high density plantation system

hydrophobic interaction, cationic bridges etc. determine the soils surface activity and interaction with SOC content. It was observed that the light fractions of organic carbon as well as carbon in the form of mineral associated organic matter were significantly correlated to clay content (Grüneberg *et al.*, 2013).

Micronutrients were positively and significantly correlated with the SOC content. In fact, the amount of SOC stored in the orchard plantation system is determined by the net balance between the rate of organic C input as leaf and root biomass and its mineralization. Sometimes rejuvenation/deforestation of trees decreased the amount of organic carbon stored in soils. Orchard ground floor management systems combining with plant density also contributes to the quantity of organic carbon and thereby the micronutrient dynamics (Gómez *et al.*, 2009). Higher amount of organic matter may contribute a lot to the increasing micronutrient availability in the root zone. Organic matter, manure or plant/leaf tissues or residues application affect the immediate and potential labile pool of micronutrients. Actually, cationic

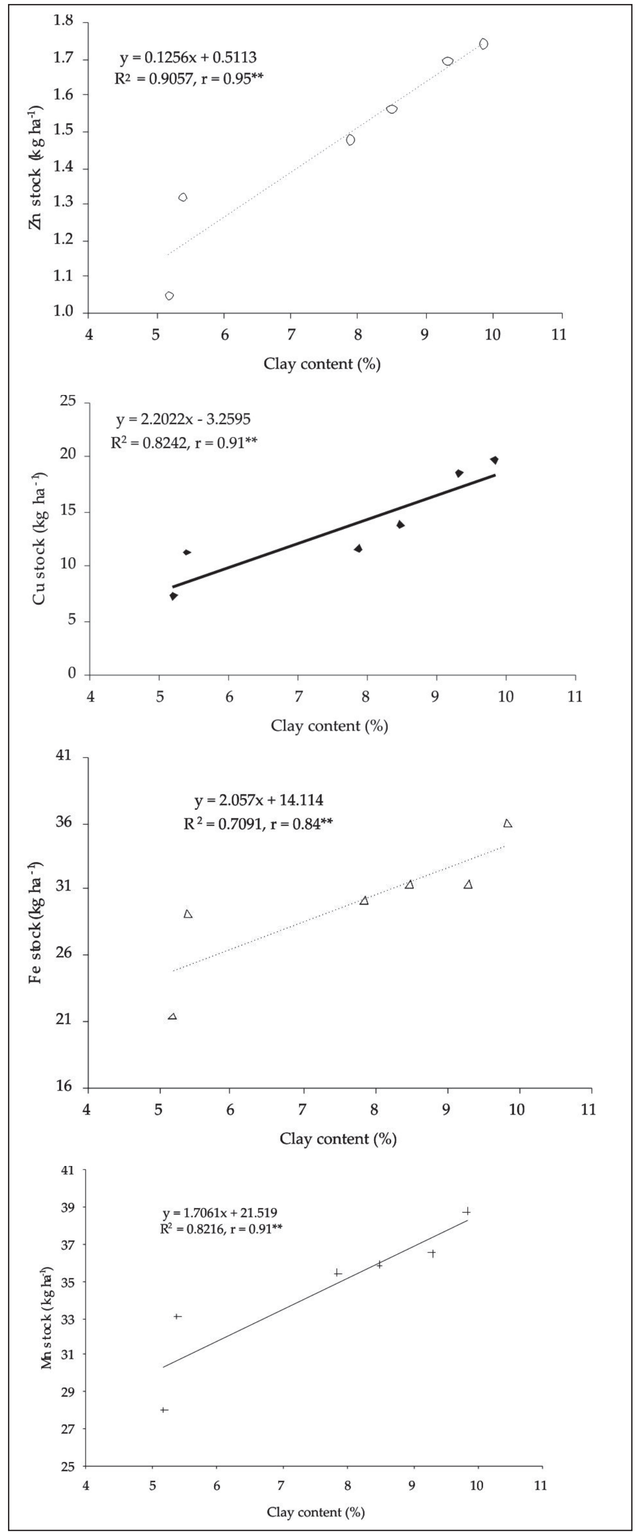

Fig. 4. Positive correlation of micronutrient density with clay content

micronutrients reacts with the organic acids released from organic matter decomposition or soluble organic chelates synthesized by tree roots to form soluble organometallic complexes and enhance the micronutrients availability (Jobbáge and Jackson, 2004). Because of the lower microbial activity and organic carbon content in the deeper

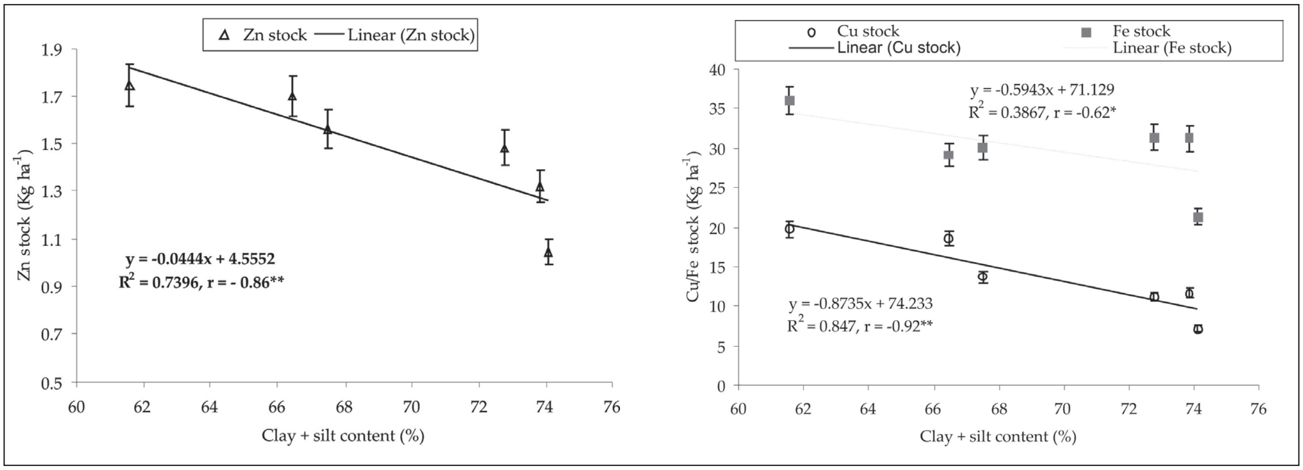

Fig. 5. Inverse relationship of micronutrient density with clay + silt content

Table 4a. Pearson's correlation matrix of SOC (%) with micronutrients content (mg kg^{-1})

	SOC (%)	Zn	Cu	Mn	Fe
SOC (%)	1				
Zn	.878**	1			
Cu	.725**	.921**	1		
Mn	.856**	.903**	.758**	1	
Fe	.732**	.889**	.769**	.849**	1

**Correlation is significant at the 0.01 level (2-tailed)
*Correlation is significant at the 0.05 level (2-tailed)

term orchard ground cover management systems as a result of compactness, higher tree root activities and other related soil consolidation processes (Merwin *et al*., 1994; Walsh *et al*., 1996; Querejeta *et al*., 2000). The present results highlighted that the micronutrients densities were closely related to the clay and clay + silt content. Further, they may be influenced not only by SOC content but its different density fractions too as reported by researchers. High organic carbon in clay rich soils might be as a result of stabilization of soil organic matter (SOM) due to interaction with mineral surface in the mineral organic matter fraction. Von Lützow *et al*. (2006) reported that SOC in fine silt and clay fraction is older or has a longer turnover time as compared to other SOM fraction. Even, free floating light fraction of organic carbon is strongly correlated with clay content. Thus, clay content and clay + silt dynamics had an impact on SOC and thereby micronutrient dynamics and stocks. Our result confirmed that Zn, Cu, Fe stocks were negatively correlated with clay + silt content while Zn, Cu, Fe and Mn stocks were positively correlated with clay content.

Table 4b. Pearson's correlation matrix of soil physical properties with micronutrient density (kg ha^{-1})

	BD	PD	WHC	Porosity	Zn	Cu	Mn	Fe
BD	1							
PD	NS	1						
WHC	NS	.939**	1					
Porosity	-.940**	-.914*	-.941**	1				
Zn	NS	NS	-.825*	NS	1			
Cu	NS	-.814*	-.956**	.926**	.944**	1		
Mn	.869*	NS	NS	NS	NS	NS	1	
Fe	.868*	NS	NS	.828*	NS	NS	NS	1

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

soil horizon, micronutrient availability was restricted. Soil pH had negative correlation which indicates that as soil pH increased, the ionic form of these micronutrients have transformed to insoluble hydroxides and thereby the labile fraction decreased in soil (Sims and Jr Patrick, 1978).

In this study wide variation in physical properties was recorded and mostly higher density plantations had high BD and low porosity. Variations in physical properties in orchard ecosystem are a function of soil management system. Earlier results showed significant variations in BD, porosity, water retention etc. under long-

CONCLUSIONS

The results of the present study revealed that there was a variation in soil physical properties, micronutrient status and its distribution under long-term orchard management (maintained over 20 years) of different planting densities. Higher BD and lower porosity was recorded in the higher planting density than with normal density of 100 plants ha^{-1}. Higher water holding capacity was revealed at the surface soil layer as compared to deeper soil horizons across different planting density systems. Different planting densities influenced the DTPA-extractable Fe, Mn, Zn and Cu across soil depths indicating that both planting densities and soil depths are the key factors affecting the distribution of micronutrients in the soil profile. Higher content of these micronutrients were recorded in the surface soil (0-30 cm) and it decreased down the soil depths. The Fe, Mn, Zn and Cu densities in soil (0-30 cm) were *at par* among different high density planting systems but significantly differed from that under normal density system. SOC content showed significant positive correlation with the clay content (r = 0.951**) and inversely related with the clay + silt content (r = -0.982**). All the micronutrients concentration in soil was strongly correlated with SOC content while Zn, Fe and Cu density showed significant negative correlation with clay + silt content. Thus high density plantation showed wide variations in soil physical properties and greater micronutrient stock as compared to the normal density plantation in subtropical region.

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Physico-chemical properties and erosional behaviour of soil of Shahpur-Basdev watershed of district Hardoi treated under various conservation measures and land uses

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ABSTRACT

The present experiment was conducted under National Agricultural Innovation Project during the year 2008-2011 in district Hardoi, Uttar Pradesh. Maize fallowed by wheat crop was grown on contour across the slope during *kharif* and *rabi* season respectively. Strip-cropping is practiced consisting of long and narrow strip of erosion resisting crops grown across the slope. However cowpea was grown as cover crops in *kharif* season and gram in *rabi* in the projected area. Maize and wheat were grown with mungbean and chickpea as intercropping crops in field having slope less than 2%. The value of bulk density was found lower in the area where conservation measures applied in comparison to control (without conservation measures). The moisture equivalent, water holding capacity and water stable aggregates were observed to have slightly higher values in all soil conservation measures adopted in comparison to control plots. The slightly lower values of CEC in control in comparison to all cropping system might be due to higher clay content, more organic carbon in cropping system. Organic carbon, total nitrogen, available phosphorus and potash contents were recorded higher under all treatments over control. Dispersion ratio, erosion ratio and erosion index were found lower in all soil conservation measures adopted plots in comparison to control. Correlation coefficients (r) between sand, silt + clay and organic carbon and erosion ratio, sand contents showed significant positive with erosion ratio (r=0.8976**) and significant negative with erosion index (r=-0.8973**) and dispersion ratio (r=-0.8930**).

Key words: Soil conservation measures, Soil properties, Dispersion ratio, Erosion ratio, Erosion index, Organic carbon

INTRODUCTION

Soil and water are two most valuable endowment of nature for the growth and sustenance of life, because soil is an important dynamic body to all living being as it provides the foothold and anchorage to plant and serve as a reservoir for the majority of the essential and beneficial nutrients, organic matter, moisture, air and micro-nutrients, needs for satisfactory growth and production. So its judicious use is the primary duty of every individual for the survival of present and future generation. Water is also considered to be sino-quo-non for the living beings as it forms a larger component of the living matter and act as a natural carrier in the uptake process for the nutrients. Soil erosion is the function of erosivity of rainfall and erodibility of the soil. As the world population keeps growing, balanced ecosystem is on decreasing trends and nutrient losses all over the world have become increasingly negative. In almost all countries of the world, food production is currently affected by depleting large quantities of nutrients from soil reserves and this is likely to continue.

Mechanical measures act as the first line defence to arrest runoff and reduce soil erosion. In agriculture watersheds contour bunding, land leveling, graded bunding and bench terracing on steep slopes were found quite effective. However, farm ponds are useful in runoff harvesting and other uses. They are very effective in storing surplus runoff for life saving irrigation to crops during the dry spells in the monsoon season and also for growing second crop in *rabi* season. Contour bunding can be adopted on almost all the soil of the country receiving an annual rainfall up to 600 mm and having adequate infiltration rate. Contour bunding in agricultural watersheds of many regions were found affective to reduce surface runoff and soil erosion considerably (Gupta and Singh, 2007).

For effective soil conservation, the agronomic measures have to be integrated with mechanical

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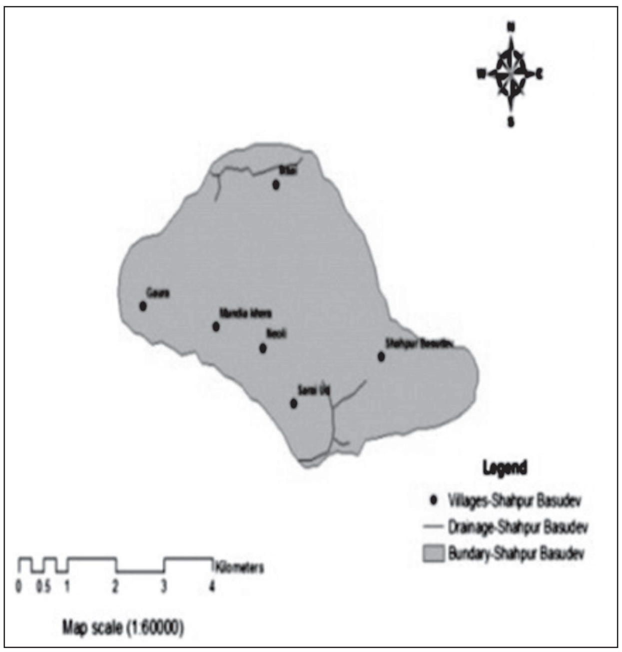
measures and not in isolation. Agronomic measures help to reduce the impact of rain drops through inter option and thus reduce splash erosion. These practices also help to increase infiltration rates and thereby reduce runoff and overland flow. Reduction in runoff along with nutrients could be achieved through appropriate land management practices and associated agronomic practices. (Pali *et al.*, 2014)

MATERIALS AND METHODS

The study was conducted under National Agricultural Innovation Project during the year 2008-2011 in Shahpur-Basdev watershed in district Hardoi, Uttar Pradesh. Hardoi district comprises of two parts bisected by the Hardoi branch of Sharda canal, the principal rivers being Ganga and Gomti, and their tributaries. The area, production and productivity of the major field crops of the district are paddy, wheat, maize, mustard and groundnut, with potato and onion being the principal vegetable crops. Productivity of all the crops in the district is below the state average.



Shahpur-Basdev, District Hardoi

Crop	Area (ha)	Production (MT)	Productivity (q/ha)
Paddy	142184	279392	19.65
Maize	32000	54048	16.89
Groundnut	7247	6892	9.51
Wheat	326194	719258	20.05
Mustard	11891	6893	5.8
Potato	10874	209357	192.53

The selected watershed is situated in Madhoganj block of district Hardoi having geographical area of 2125.7 ha and lies between 26°53′ to 27°46′North latitude and 79°41′ to 80°46′ East longitude. Climate of the Hardoi district is semi-arid and rainfall pattern of district is highly erratic with mean annual rainfall of about 800 mm. Maize fallowed by wheat crop was grown on contour across the slope during *kharif* and *rabi* seasons, respectively. Strip-cropping is grown in which long and narrow strip of erosion resisting crop the strip are laid across the slope. Cowpea is grown as cover crops in *kharif* and chickpea in *rabi* in the projected area. Maize (*Zea mays*) and wheat(*Triticum aestivum*) have been grown with mungbean (*Vigna radiata*) and chickpea (*Cicer aritenum*) as intercropping in field up to a slope of less than 2%. Tree shrub species like subabool (*Leucaena leucocephala*) is grown with napier grass (*Pennisetum purpureum*) both as a fodder crops. Mungbean in kharif and chickpea in rabi season are grown with Guava in selected area. Vegetative barriers of subabool also grown in projected area. Precision land leveling done by *laser* leveler machine. In bunded area, maize and wheat cropping system is adopted. In gully plugging area, maize-wheat cropping system was taken. Sixty two soil samples, thirty each from disturbed and undisturbed state and one sample from control plot were collected from each treatment and control plot. Composite soil samples were collected from three places randomly for each treatment with the help of spiral augar/ tube auger for surface soil separately. Karl Pearson formula was used for correlation coefficient to calculate degree of relationship between two variables.

RESULTS AND DISCUSSION

Physical properties

The data (Table 1) exhibit that there is wide variability in physical properties of different treatments. The mechanical components *i.e.* sand, on an average, varied from 50.40% (Silvipastoral system) to 57.90% (Control). The percentage of sand was found in the order of control > gully plugging > bunding > precision land leveling > strip cropping > inter cropping > contour cropping >vegetative barrier >agri-horticulture >silvipastoral. The increasing percentage of silt and clay was found in order of silvi pastoral >agri-horti> cover cropping > vegetative barrier > strip cropping > contour cropping > precision land leveling >bunding > gully plugging > control. Similar trend was also reported by Gupta and Singh, (2007). Easily dispersible silt

Table 1. Physical properties of soil under different treatment of soil conservation measures and land use

Treatments	Physical properties							
	Sand (%)	Silt (%)	Clay (%)	Easily dispersible silt+clay (%)	Bulk density (Mg m^{-3})	Moisture equivalent (%)	Water holding capacity (%)	Water stable aggregate > 0.25 mm
Control	57.90	27.26	14.83	33.56	1.40	14.36	24.10	14.92
Contour cropping	52.26	29.80	17.50	31.23	1.35	18.91	27.58	17.00
Strip cropping	52.50	29.30	18.00	30.33	1.34	19.43	28.96	17.36
Cover cropping	51.80	29.10	18.80	28.25	1.33	20.63	31.98	18.05
Inter cropping	52.30	30.53	17.00	32.21	1.37	17.97	27.11	16.57
Silvi-pastoral	50.40	29.90	19.50	26.30	1.31	20.88	36.38	19.30
Agri-horticulture	51.60	30.10	18.20	29.76	1.35	19.67	31.73	18.10
Vegetative barrier	52.30	28.90	18.20	29.71	1.34	19.49	30.36	17.99
Precision land leveling	54.30	29.70	16.10	31.80	1.36	17.13	26.43	16.66
Bunding	54.16	29.50	15.83	32.26	1.37	16.91	26.18	16.15
Gully plugging	56.80	27.40	15.50	33.30	1.39	15.42	25.36	14.98

+ clay values were also observed with wide variation showing minimum value in silvipastoral (26.30%) found lowest under control (33.56%). Easily dispersible silt + clay percentage was recorded in the order of control > gully plugging > bunding > precision land leveling > strip cropping > inter cropping > contour cropping, vegetative barrier >agri-horti>silvipastoral was also observed by Das *et al.* (2007). The data on bulk density were found lower in area where all soil and water conservation measures adopted in comparison to control. The values were in the order of control > gully plugging > bunding > precision land leveling > strip cropping > inter cropping > contour cropping > vegetative barrier >agri-horti>silvipastoral. The moisture equivalent, water holding capacity and water stable aggregate were observed to have slightly higher values in all soil and water conservation measures adopted in comparison to control plots. It is also confirmed by Sharma and Bhatia (2003) These results might be attributed to lesser soil erosion and washout, clay and organic carbon contents in practices adopted for soil and water conservation in comparison to control. These two factors are mainly responsible because they act as cementing agents and bind the soil particles together. These properties were found in order of silvipastoral>agri-horti> cover cropping > vegetative barrier > strip cropping > contour cropping > precision land leveling >bunding > gully plugging > control. These results are agreeable with the findings of Sharma and Bhatia (2003), Singh and Khera (2009) and Gupta *et al.* (2010).

Physico-chemical properties

The data on range and average values of physico-chemical properties have been depicted in Table 2. These data obviously show lower values of pH and physico-chemical properties in soil and water conservation practices in comparison to control. The pH and EC values have been observed normal in almost all the erosion control practices. These results were also in conformity of Kumar *et al.* (2005). The slightly lower values of CEC in control in comparison to all cropping system might be due to higher clay content more organic carbon in cropping system. It was also confirmed by Agrawal *et al.* (2002) and Mehta *et al.* (2005). Likewise, physical properties, considerably improved physico-chemical characteristics (pH, EC and CEC) in soil and water conservation treatments were observed in comparison to control. These results are closely related with the findings of Chandra and Bhan (2000) and Pal *et al.* (2014).

Chemical properties/Nutrient status

The average values of chemical properties of soil under different practices of soil conservation, cropping system and control (Table 2) showed that organic carbon, total Nitrogen, available Phosphorus and available Potash contents were observed higher under all treatments in comparison to control. This may be attributed due to the lesser washout of nutrient and addition of organic matter in all treated plots. Similar result was also observed by Das *et al*. (2007). These chemical properties recorded were in order of silvi pastoral >agri-horti> cover cropping > vegetative barrier > strip cropping > contour cropping > precision land leveling >bunding > gully plugging > control. Organic carbon, total nitrogen, available phosphorus and potash contents were observed higher in all soil conservation practices adopted in comparison to

Table 2. Physico-chemical properties and nutrient status of soil under different treatment in relation to erodibility index

Treatments	Physico- chemical properties and nutrient status						
	pH	EC (dSm^{-1})	CEC [cmol(+)kg^{1} soil]	Organic carbon (%)	Total N (%)	Available K (kg ha^{-1})	Available P (kg ha^{-1})
Control	8.4	0.22	9.87	0.19	0.019	162.5	15.1
Contour cropping	8.2	0.20	10.89	0.22	0.025	170.5	18.2
Strip cropping	8.1	0.19	11.39	0.23	0.026	172.6	19.1
Cover cropping	8.0	0.18	12.86	0.29	0.029	165.2	24.4
Inter cropping	8.3	0.21	10.63	0.21	0.023	169.3	18.0
Silvipastoral	7.8	0.16	17.37	0.44	0.042	190.2	27.6
Agri-horticulture	7.9	0.17	16.01	0.36	0.037	184.3	25.8
Vegetative barrier	8.0	0.18	12.86	0.26	0.027	173.1	20.73
Precision land leveling	8.2	0.20	10.46	0.20	0.021	164.5	16.16
Bunding	8.1	0.19	10.84	0.21	0.022	167.0	17.2
Gully plugging	8.2	0.21	10.14	0.19	0.020	164.2	15.3

control. Similar observations were also observed by Hadda and Singh (2005) and Pal *et al.* (2014).

Erodibility characteristics

The data on average values of erodibility characteristics under all treatments and control have been depicted in Tables 3. It is obvious that erodibility characteristics *i.e.* dispersion ratio, erosion ratio and erosion index were found lower in all soil conservation treated plots in comparison to control. The lower values of erosion indices in these treated plots might be due to higher fine particle (clay) and organic content which acted as cementing material for binding the mechanical particles together ultimately resulting in the lower erosion erodibility. The erodibility indices recorded were in the order of silvipastoral>agri-horti> cover cropping > vegetative barrier > strip cropping > contour cropping > precision land leveling >bunding > gully plugging > control. The erodibility characteristics *i.e.* dispersion ratio, erosion ratio and erosion index were recorded considerably higher in control plot in comparison to soil and water conservation practices. Similar trend on erodibility were observed by Dabral *et al.* (2001), Ram Babu *et al.* (2004), Mehta *et al.* (2005), Singh *et al.* (2006) and Pali *et al.* (2014).

Table 3. Erodibility characteristics of different categories of soil under different conservation measures and cropping systems

Treatments	Erodibility characteristics		
	Dispersion ratio	Erosion ratio	Erosion index
Control	79.70	80.18	64.76
Contour cropping	66.10	71.31	51.91
Strip cropping	64.04	69.27	51.61
Cover cropping	58.81	64.62	51.07
Inter cropping	67.84	72.09	54.86
Silvi-pastoral	53.21	57.96	49.71
Agri-horticulture	61.94	66.48	53.54
Vegetative barrier	62.34	67.09	53.61
Precision land leveling	69.57	73.72	56.74
Bunding	70.61	75.58	58.36
Gully plugging	77.68	76.72	63.28

Correlation characteristics

Correlation coefficients (r) between erosion indices i.e. Erosion ratio with physicochemical properties were calculated (cf table 4).It is apparent that erosion ratio was significantly and positive correlated with Sand (r= 0.8976**), Suspension % (r=0.769**), Hydraulic Conductivity (r=0.885**) , erosion index (r=0.9498**) also similar to Chaudhary *et al.* (1999) and Kumar *et al.* (2005), while negatively correlated with Silt (r= -0.517**), Clay (r=-0.922**), Silt + clay % (r= -0.9642**), Bulk density (r= -0.669**), Water Holding Capacity (r= -0.805**), Moisture Equivalent (r=-0.497**), Water holding capacity %(r= -0.697**), Water stable aggregates (> 0.25 mm) (r= -0.833**) and Organic carbon(r= -0.9514**). Similar correlation also have been observed by Mehta *et al.* (2005).

CONCLUSION

Based on these empirical equations soils of the project area are being as erosive in nature and follow the order of erodibility : *silvipastoral>agri-*

Table 4. Correlation between erosion ratio with physio-chemical properties of soil.

Correlation between		Correlation	Regression equation
Soil properties (X)	Erosion ratio(Y)	coefficient(r)	
Sand	"	0.8976**	Ye= 30.0877+0.3299
Silt	"	-0.517**	Ye = 153.617-3.239 X
Clay	"	-0.922**	Ye = 88.592-1.832 X
Silt + clay %	"	-0.9642**	Ye= 29.049+0.4391
Suspension %	"	0.769**	Ye = -30.107+2.406 X
Bulk density	"	-0.669**	Ye = -153.157+139.514 X
Hydraulic Conductivity	"	0.885**	Ye = -32.508 +34.814 X
Water Holding Capacity	"	-0.805**	Ye = 109.915-1.871 X
Moisture Equivalent	"	-0.497**	Ye = 83.829-2.344 X
Water stable aggregates (> 0.25 mm)	"	-0.833**	Ye = 86.721-1.1197 X
Organic carbon %	"	-0.9514**	Ye= 34.616+0.2813

horti> cover cropping > vegetative barrier > strip cropping > contour cropping > precision land leveling > bunding > gully plugging > control that warrant prompt attention for effective implementation of various intensive soil conservation measures in the watershed for conservation of natural resources and sustainable production.

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Short Communication

Multiple input single output (MISO) linear model for sediment yield prediction from upper Ganga basin

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ABSTRACT

High rate of sediment outflow from catchments and high level of sedimentation in rivers and other water bodies is a serious cause of concern globally as it leads to physical disruption of the hydraulic characteristics of rivers and various water bodies. The sediment deposition in water bodies like lakes, reservoirs and ponds not only results in reduction of storage capacity but also adversely hampers irrigation potential, water supply to domestic and industrial use, hydroelectric power generation and drought mitigation programs. The present study was conducted to develop multiple input single output (MISO) model to predict sediment outflow from upper Ganga basin. In the development of this model the present day sediment yield has been correlated with previous days sediment yield, present and previous days runoff. Using the techniques of stepwise regression only significant variables were retained and the remaining variables were excluded at 5% level of significance. The model was developed considering data of 1980-2010. The applicability of the developed model was verified for future prediction using the data set of 2010-2011 which was not considered in the development of the model. It was found that the correlation coefficient values were 0.93 and 0.97 respectively, during training and cross validation period. The model performance was evaluated by performance evaluation indices such as MAPE, RMSE, NRMSE, ISE, CE, IOA and VE. The values of these performance indices were obtained as 50.51% and 4.22%; 1.09 and 1.97 tons/sec; 1.03 and 0.55; 0.03 and 0.09; 87.2% and 93.8%; 96.5% and 98.3%; and -0.02% and -7.65% respectively during training and cross validation.

Key words: Multiple input single output, Stepwise regression, Sediment yield

Soil erosion is a global environmental crisis in the world today that threatens natural environment besides agriculture. Accelerated soil erosion has adverse economic and environmental impacts. It creates on-site and off-site effects on productivity due to decline in land/soil quality. The current rate of agricultural land degradation world-wide by soil erosion and other factors is leading to an irreparable loss in productivity on about 6 million hectare of fertile land a year (Scholes *et al.*, 1994). Asia has the highest soil erosion rate of 74 tons/acre/yr (El-Swaify, 1996) and Asian rivers contribute about 80% per cent of the total sediments delivered to the world oceans and amongst these Himalayan rivers are the major contributors (Rai and Sharma, 1998). Soil resource is important to sustain the productivity in hilly terrain. Livelihood of the people in the Himalayan region is mainly dependent on farming system and especially on subsistence agriculture. Sustainable use of mountains depends upon conservation and potential use of soil and water resources (Ives and Messerli, 1989).

The basic problem in utilizing water resources in the Ganga basin is that in relation to the relatively large annual flow in the basin, the storage capacity of existing and foreseeable reservoirs in India is not large enough to permit conservation of flows during high flow season. The live storage capacity of all reservoirs in the Ganga basin is less than one-sixth of the annual flow, which does not permit a significant degree of flow regulation. Lean season flows in the basin without an adequate storage backup are not sufficient to meet the requirements for various demands while monsoon flows are so high that the Ganga and its tributaries remain in spate almost every year. In the present study, runoff sediment yield model has been developed using previous data set to predict sediment yield from the study area using present and previous runoff and previous sediment yield. The estimation of sediment yield will help to design and plan effective

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soil and water conservation programs in the catchment area.

The Ganga River basin, largest of the basins of India with an area of 8,61,452 km^2 in India, draining into the 11 states of the country, Uttarakhand, Uttar Pradesh, Haryana, Himachal Pradesh, Delhi, Bihar, Jharkhand, Rajasthan, Madhya Pradesh, Chhattisgarh and West Bengal. The Ganga basin lies between east longitudes 73°2′ to 89°5′ and north latitudes 21°6′ to 31°21′ having maximum length and width of approx. 1,543 km and 1024 km. The average water resource potential of the basin has been assessed as 5,25,020 Million Cubic Meters (MCM). The Ganga river basin, with an area of 8,61,452 km^2 passes through varying agro-climatic conditions where the climate transition varies from alpine, temperate, sub-tropical and tropical. The upper Ganga river basin with an area of approximately 2,48,000 Km^2 has been considered for this study from its origin to Kanpur region.

Hydrological models are simplified, conceptual representations of a part of the hydrologic cycle. These are primarily used for hydrologic prediction and for understanding hydrologic processes. In development of model the runoff and sediment yield data for 30 years were used. The input parameters were selected on the basis of lag selection which was determined by using discharge data for autocorrelation function (ACF), partial autocorrelation function (PACF) and discharge-sediment data for cross-correlation function (CCF). On the basis of this study a lag of five days was found to be appropriate in the study area. Therefore, 11 variables were included as input parameters to the model were S_{t-1} , S_{t-2}, S_{t-3}, S_{t-4}, S_{t-5}, Q_t, Q_{t-1}, Q_{t-2}, Q_{t-3}, Q_{t-4} and Q_{t-5}. The general mathematical expression can be written in the following form,

$$S(t) = f(S_{t-1}, S_{t-2}, S_{t-3}, S_{t-4}, S_{t-5}, Q_t, Q_{t-1}, Q_{t-2}, Q_{t-3}, Q_{t-4}, Q_{t-5}) \quad ...(1)$$

where,

S is the sediment yield, Q is the discharge and t, t-1,…t-5 denote present and time lags in days.

The linear model was developed considering the data for the period of 1980-2010 for the sediment load prediction in upper Ganga basin. The discharge and sediment load data during years 1980-2010 were used for the testing and for the period of 2010-2011 were used for model validation.

A number of statistical criteria have been suggested by researchers to evaluate the performance of runoff-sediment models. To assess the accuracy of runoff-sediment models, more than one criterion should be used. The model performance were evaluated using following statistical parameters such as mean absolute percentage error (MAPE), root mean square error (RMSE), normalized root mean square error (NRMSE), correlation coefficient (R), integral square error (ISE), index of agreement (IOA), coefficient of efficiency (CE) and volumetric error (VE). The details of each criterion are described as:

1. Root mean square error (RMSE)

The root mean square error (RMSE) also called the root mean square deviation (RMSD), is often used to assess the prediction accuracy of a model. The root mean square error between observed and predicted values is determined by the following relationship.

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}\left(Q_i - \hat{Q}_i\right)^2}{n}} \quad \ldots(2)$$

2. Integral Square Error (ISE)

The integral square error, another measure of goodness of fit between the observed and predicted runoff is in fact proportion to the ratio of the root mean square error to the sum of observed runoff flow ordinate. The integral square error (ISE) is calculated by the following relationship as proposed by (Diskin *et al.* 1978).

$$\text{ISE} = \frac{\sqrt{\left[\sum_{i=1}^{n}\left(Q_i - \hat{Q}_i\right)^2\right]}}{\sum_{i=1}^{n} Q_i} \times 100 \quad \ldots(3)$$

3. Index of agreement (IOA)

The Index of Agreement (d) developed by Willmott (1981) as a dimensionless standardized measure of the degree of model prediction error and varies between 0 and 1. A value of 1 indicates a perfect match, and 0 indicates no agreement at all (Willmott, 1981). It was not designed to be a measure of correlation but of the degree to which a model's predictions are error free. The index of agreement can detect additive and proportional differences in the observed and simulated means and variances; however, it is overly sensitive to extreme values due to the squared differences (Legates and McCabe, 1999).

Legates and McCabe (1999) highlighted a number of deficiencies with relative measure such as CE and R^2. They note that R^2 is particularly sensitive to outliers and insensitive to additive and proportional differences between modeled and observed data. Index of Agreement (d) is determined by using the following relationship.

$$d = 1 - \frac{\sum_{i=1}^{n}\left(Q_i - \hat{Q}_i\right)^2}{\sum_{i=1}^{n}\left(\left|\hat{Q}_i - \bar{Q}\right| + \left|Q_i - \bar{Q}\right|\right)^2} \quad \ldots(4)$$

4. Coefficient of efficiency (CE)

The Coefficient of Efficiency (CE) developed by Nash and Sutcliffe (1970) is an improvement over R^2 statistic which is used very commonly in hydrology. It gives the proportions of variance of the observation accounted for by the model. It is expressed mathematically as,

$$CE = 1 - \frac{\sum_{i=1}^{n}\left(Q_i - \hat{Q}_i\right)^2}{\sum_{i=1}^{n}\left(Q_i - \bar{Q}_i\right)^2} \quad \ldots(5)$$

where, Q_i is the observed value of daily runoff, $\hat{Q}_i$ is the corresponding predicted value of daily runoff.

5. Volumetric error (VE)

This index is also known as absolute prediction error (Kachroo *et al.* 1992) and it is used to compare the performance of the model, when the same data is used for their development. It is estimated as follows.

$$VE = \left[\frac{\sum_{i=1}^{n}(Q_i - \hat{Q}_i)}{\sum_{i=1}^{n}(Q_i)}\right] \times 100\% \quad \ldots(6)$$

Model development and performance evaluation indices

The stepwise regression was performed and the least significant variables were eliminated from the model. This was done to make the model structure more compact and workable. Considering sediment (S) is in tons per day and discharge (Q) is in m^3/s, the final model for sediment yield prediction was found to be of the following form.

$$S_t = -263998.783 + 0.497 * S_{t-1} - 0.042 * S_{t-4} + 2254.395 * Q_t - 1238.358 * Q_{t-1} - 239.701 * Q_{t-2} + 202.976 * Q_{t-3} \quad \ldots(7)$$

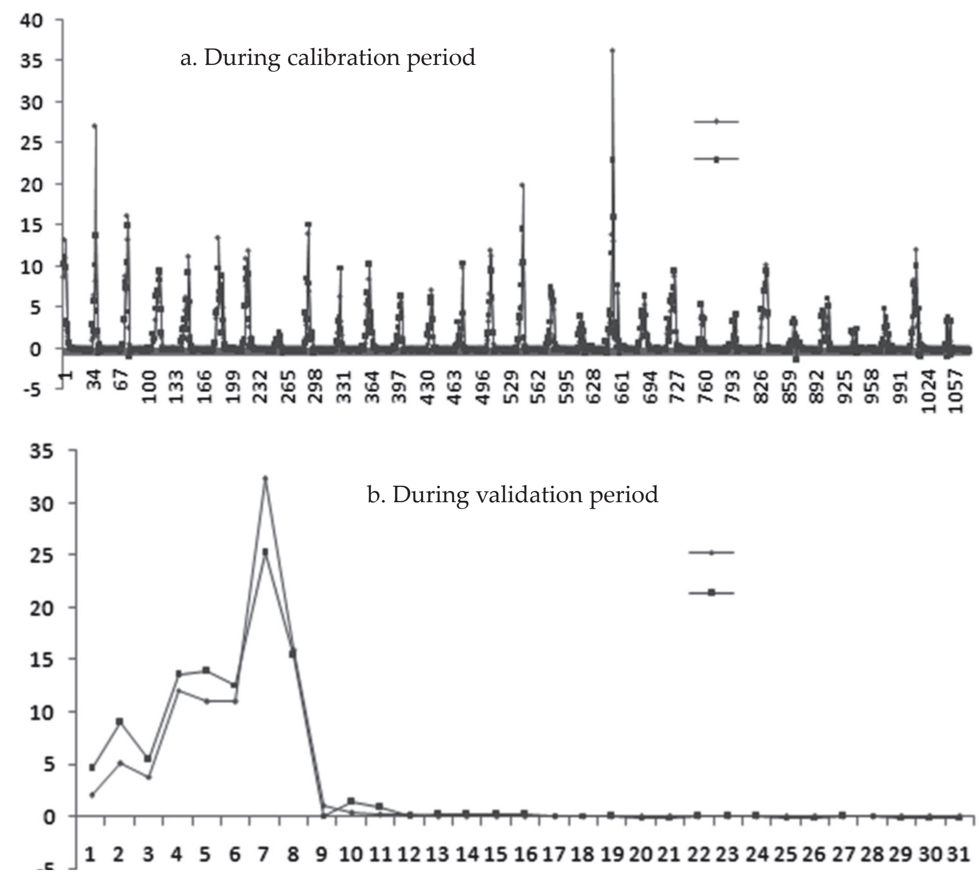

Fig. 1. Observed and predicted sediment yield for developed model

Table 1. Values of performance indices for developed model

	Training Period (1980-2010)	Validation Period (2010-2011)
MAPE	50.51%	4.22%
R	0.93	0.97
RMSE	1.09 tons/sec	1.97 tons/sec
NRMSE	1.03	0.55
IOA	0.97	0.98
ISE	0.03	0.09
CE	0.87	0.94
VE	-0.02%	7.65%

The statistical performance evaluation indices tabulated in Table 1, indicate that the value of R for linear model during the training period was 0.93 whereas in cross validation period was 0.97. Kachroo (1986) reported that a model can be considered satisfactory if R value exceeds 90 per cent and considered fairly good for R in the range of 80 per cent to 90 percent. This indicates that model performance is very good in predicting the sediment yield during training and cross validation.

The values of other indices such as RMSE for the model were 1.09 and 1.97 tons/sec, respectively, during training and cross validation which indicate a good performance of the model.

It was also observed that the other performance indices such as MAPE, NRMSE, IOA, ISE, CE and VE were 50.51%, 1.03, 0.97, 0.03, 0.87 and -0.02% during training period whereas, for cross validation period were 4.22%, 0.55, 0.98, 0.09, 0.94 and 7.65% are all in acceptable range. A visual comparison of observed and model predicted sediment yield from Fig.1 (a & b) also indicates that during the calibration and validation period the model performance is quite satisfactory.

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Short Communication

Soil phosphorus availability with irrigation and nitrogen in pearl millet-mustard cropping system

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ABSTRACT

A field study was conducted during 2005-06, 2006-07 and 2007-08 to evaluate out the effect of continuous use of N fertilizer and irrigation on soil available P at different soil depth under pearl millet-mustard based cropping system in a semi-arid environment. Available soil P increased with increasing levels of nitrogen in all soil depths. It was highest in surface layers (0-15 cm) and decreased with increasing depths. The availability of soil P was slightly higher in irrigated plots than in unirrigated with all N levels. Available soil P was highest 23.0 kg ha^{-1} under irrigated condition with 120 kg N kg ha^{-1} at harvest stage. In case of mustard varieties, soil P in general increased in surface layer as the dates of sowing advanced and decreased with the depth. At the harvest time of mustard, the available soil P increased marginally with increase in irrigation and N levels at all soil depths except at 15-30 cm for N level. However, the maximum increase in available soil P of 1.48 and 1.04 kg ha^{-1} was observed at surface than other depths owing to irrigation and N levels, respectively.

Key words: Soil available Phosphorus, Irrigation, Nitrogen, Pearl millet-mustard

In India 78 % area is under rainfed cultivation. The Indo-Gangetic plane is characterized by highly variable rainfall, soils exhibiting low water holding capacity and poor nutrients status. Pearl millet and mustard are two important crops of the arid and semi-arid region in the country. Despite the potential for higher yield under rainfed conditions and low soil fertility, variety and nutrient management practices are of considerable interest to face the situation of limited yield variations in the region (Parihar *et al*., 2013). Pearlmillet (*Pannisetum glaucum* (L.) R. Br.) is one of the major cereal crops grown in the arid and semi-arid regions of the world. It is the fourth food grain crop in production after rice, wheat and jowar and fifth in total cereal production. Out of the world area of 20 mha under pearl millet, 10.3 mha is in India. Pearlmillet is mostly grown as rain-fed crop without application of fertilizer and wide spatial and temporal variations in rain are the main causes for low production in this region. Under adverse situation the nutrient management strategies in relation to available soil water will be a key feature for attaining higher crop production.

For the oilseed production, India is the third largest country in the world. India, of courses, tops as far as acreage and total production of rapeseed and mustard are concerned in the world but their productivity is comparatively much lower than the major countries producing these crops. Rapeseed and mustard occupy the second place in terms of average production after groundnut and contribute about 25 per cent to the oilseed production amongst important annual oilseed crops grown in the country. Out of the total oil production in the world, about 71 per cent are of plant origin and of this, oilseed *Brassica* account for nearly 14 per cent, only next to soybean and palm oil. During the past 30 years, the country has been facing the problem of shortage of oils coupled with continuous increasing in their prices. However, to fulfill the demand of oilseeds for growing population, during the last five years mounting expenditure on import of edible oils at the expense of precious foreign exchange is being exercised.

Mustard is a major crop grown in *rabi* season with on conserved soil moisture or under limited irrigation conditions. In case of mustard, crop management is relatively better but still has low average productivity of 895 kg/ha as against the world average of 1286 kg/ha during 1991-92 (FAO,

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1993; Economic Survey, 1993-94). Improved varieties can yield better with the use of high fertilizer inputs, irrigation and suitable dates for sowing with other agronomic management practices (Banerjee *at al*., 2011).

Phosphorus (P) is second most essential for plant growth as it stimulates the growth of plant. Organically bound P solubilizes through mineralization process by specific microbes viz. *Pantoea agglomerans* strain P5 or *Pseudomonas putida* strain P13 which are highly influenced by soil moisture and temperature. The absolute quantity of phosphorus ions present in the soil and available for utilization by plant at any one time is very small. The amount that is dissolved and accessible in the soil solution is in equilibrium with solid phase phosphorus. Crops need more phosphorus to grow well; therefore this phosphorus 'pool' must be replenished many times during the growing season. The ability of a soil to maintain adequate levels in the solution phase is the key to the plant available phosphorus. The fixed P pool of phosphate will contain inorganic phosphate compounds that are very insoluble and organic compounds that are resistant to mineralization by microorganisms in the soil. Phosphate in this pool may remain in soils for years without being made available to plants and may have very little impact on the fertility of a soil. The inorganic phosphate compounds in this fixed P pool are more crystalline in their structure and less soluble than those compounds considered being in the active P pool (Busman *et al*., 2002). Some slow conversion between the fixed P pool and the active P pool does occur in soils. These reactions are dependent on soil properties like pH, moisture content, temperature, and the minerals already present in the soil.

Adding to the active P pool through fertilization will also increase the amount of fixed P. Depleting the active pool through crop uptake may cause some of the fixed P to slowly become active P. The conversion of available P to fixed P is partially the reason for the low efficiency of P fertilizers. It is well established that most of the P fertilizer applied to the soil will not be utilized by the crop in the first season. Continuous application of more P than the crops utilize increases the fertility of the soil, but much of the added P becomes fixed and unavailable.

Soils differ in their phosphate holding capacity. Fine-textured soils can generally hold more whereas coarse-textured soils can generally hold much less. Moreover, the subsoil of many soils often has an even greater capacity to hold phosphate than does the corresponding surface soil. However, an important aspect of the ability of a soil to hold phosphate is that a soil cannot hold increasing amounts of phosphate in the solid phase without increasing soil solution phosphate. Increased amounts of phosphate in solution will potentially cause more loss of phosphate through surface runoff or leaching through the soil column. Loading soils with very high level of phosphate will generally not hurt crops but may result in increased phosphate movement to nearby bodies of water. To determine the need for supplemental P under irrigated condition, soil test is often used to estimate the P requirement for pearl millet and mustard.

Field experiments were carried out at the research farm area of the Indian Agricultural Research Institute (IARI); New Delhi. The soils of IARI belong to the major soil group of Indo-Gengetic alluvium. The soil belongs to Mehrauli series classified as sandy loam mixed hyperthermic Typic Ustochrept. It is well drained, deep and yellowish in colour. The soil samples were taken before the sowing and at harvest of the crops from 0-15, 15-30, 30-45 and 45-60 cm depths to determine the physico-chemical properties of the soil. The bulk density has been obtained only once at the beginning of the crop. The soil was low in organic matter and nitrogen, medium in phosphorus and rich in potassium (Table 1). Particle size analysis was carried out by Hydrometerm method (Bouyoucos, 1962), bulk density by core method (Black, 1965), saturated hydraulic conductivity by

Table 1. Physical and chemical properties of soil at the experimental site

Soil depth (cm)	Particle size distribution (%)			Soil texture	Bulk density (Mg m^{-3})	pH	EC (dS m^{-1})	OC (%)	Available nutrients (kg ha^{-1})		
	Sand	Silt	Clay						N	P	K
0-15	76.8	12.0	11.8	Sandy loam	1.46	8.2	0.30	0.42	233	19.5	256
15-30	74.8	11.0	14.7	Sandy loam	1.48	8.1	0.26	0.40	172	15.5	190
30-45	76.4	10.0	12.8	Sandy loam	1.54	8.1	0.26	0.36	144	14.5	165
45-60	77.4	10.8	11.8	Sandy loam	1.53	8.0	0.25	0.30	125	13.5	150

constant water head method (Klute, 1965), pH, EC and CEC (Jackson, 1973), organic carbon (Walkley and Black, 1934), available nitrogen by alkaline permanganate method (Subbiah and Asija, 1956), available phosphorus (Olsen, 1954) and available potassium (Hanway and Heidel, 1952).

The experiment was conducted in a split plot design (SPD) replicated four times. The lay out consisted of total 32 plots each having size 7 × 4 m. The pearl millet (var.HHB-67) crop was grown as test crop during the *kharif* season of 2005-06 and 2006-07 in combination with two moisture levels viz., rainfed (I_0) and irrigation (I_1) and five N levels viz., 0 (N_0), 20 (N_1), 40 (N_2), 80 (N_3) and 120 (N_4) kg N/ha.

The preparatory tillage operation were carried out with the help of tractor drown mould board plough, and then the ploughed field was disked crosswise two times and finally leveled. After making lay out, half dose of N, and full doses of P and K was uniformly applied in the plots and mixed well. Nitrogen @ 0, 20, 40, 80 and 120 kg/ha as per the treatments, 40 kg P_2O ha^{-1} and 25 kg K_2O ha^{-1} were supplied through urea, single super phosphate and muriate of potash, respectively. After making lay out, 45 cm marker was used to draw lines. In each plot rows were formed at 45 cm apart with the help of hand driven plough. The seeds were sown in these rows at the depth of about 5 cm with hand drill. Remaining half dose of N was dressed at vegetative stage (28 DAS). In case of oilseeds, two species viz. *Brassica juncea* cv. Pusa Bold and cv. Pusa Jaikisan (Bio 902) having medium maturity were grown in rabi season. Two experiments were carried out in this crop.

Experiment 1

These two cultivars were sown at 10 days intervals on four different dates in both the seasons as follows.

Crop season	Dates of sowing			
	D_1	D_2	D_3	D_4
2005-2006	21.10.2005	31.10.2005	10.11.2005	20.11.2005
2006-2007	21.10.2006	31.10.2006	11.11.2006	20.11.2006

At the time of final field preparation, recommended dose of fertilizers 120 kg N/ha, 60 kg P_2O_5, 40 kg K_2O and 20 kg sulphur were applied. Half dose of N was applied as basal at the time of last ploughing and remaining half N was applied through top dressing at the time of pod formation (45 DAS).

Experiment 2

In the third season (2007-08) crop was grown with the three irrigation levels *viz*., pre sowing irrigation (I_0), irrigation at 40 DAS (I_1) and irrigation at 70 DAS (I_2) along with three N levels as 0, 40 and 80 kg/ha. Half dose of N was applied as basal at the time of last ploughing and remaining half N was applied through top dressing at the time of pod formation.

Data pertaining to available soil P buildup in different soil layers under variable irrigation and nitrogen levels during 2005-2006 and 2006-2007 are presented in Tables 3 and 5 for pearl millet and mustard, respectively.

In case of pearl millet, the soil available P values increased considerably at harvest stage in different soil depths in both the seasons over the initial levels owing to variations in soil moisture and N levels (Table 2). However, on comparing with unirrigated condition, irrigated plots non-significantly increased the soil P 0.07 kg /ha during 2005-06 and 0.26 kg/ha during 2006-07 only in 0-15 and 45-60 cm, respectively. The increase in soil P at harvest time over the initial levels in the different depths ranged from 0.09-0.71 and 0.06-0.54 kg/ha during 2005-2006 and 2006-07, respectively. However, maximum increase was recorded at surface (0-15 cm).

The soil P in respective of N levels was lower with increase in soil depths during both seasons however it increased with increasing levels of nitrogen at all soil depths. In treatment interactions, the values of soil P were slightly more in irrigated plot than in unirrigated in all N levels (Rathore *et al*., 2006). The soil P was recorded highest 23 kg/ha at harvest stage in I_1N_4 plot while least 13.00 kg/ha in I_0N_0 during 2005-2006 (Table 2).

In case of mustard varieties grown with different sowing dates available soil P data is depicted in Table 3. The data revealed that the soil P in general increased in all plots at harvest over initial levels due to variation in sowing dates and cultivars. The available soil P increased from 0-1.14 and 0-1.73 kg/ha due to soil depths and 0.21-0.82 and 0 - 1.04 kg/ha due to varieties during 2005-2006 and 2006-07, respectively, however soil depth influenced soil P more than varieties. The values were recorded more in surface layers and decreased with the depth. The interactions of mustard varieties and date of sowing did not show any significant changes in soil exchangeable phosphorus. However, in some plots, soil P was

Table 2. Soil P (kg ha^{-1}) as influenced by irrigation and nitrogen in pearl millet

Treatments	Soil depth (cm)															
	2005-2006								2006-2007							
	At initial				At harvest				At initial				At harvest			
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60
Irrigation																
Rainfed (I_0)	20.00	15.86	14.57	13.57	20.71	16.01	14.66	13.75	21.34	16.16	14.80	13.84	21.70	16.58	14.94	13.90
Irrigated(I_1)	20.29	15.88	14.42	13.48	20.77	16.01	14.54	13.69	21.16	16.16	14.57	13.77	21.70	16.47	14.77	14.16
C.D. at 5%	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	0.21	N.S.	N.S.	N.S.	N.S.	N.S.
N levels (kg ha^{-1})																
0	19.30	15.28	14.15	13.43	19.80	15.42	14.32	13.45	20.13	15.60	14.40	13.50	20.63	15.75	14.45	13.38
20	19.75	15.60	14.35	13.47	20.45	15.70	14.17	13.52	20.85	15.94	14.15	13.65	21.10	16.19	14.50	13.75
40	19.92	15.75	14.46	13.52	20.68	15.89	14.65	13.60	21.08	16.00	14.68	14.00	21.55	16.50	15.13	14.10
80	20.27	16.20	14.39	13.55	21.01	16.38	14.85	13.65	21.88	16.48	15.20	13.88	22.48	16.90	14.90	14.32
120	21.48	16.52	15.11	13.66	21.77	16.68	15.00	14.39	22.33	16.80	15.01	14.00	22.90	17.27	15.30	14.60
C.D. at 5%	N.S.	N.S.	N.S.	N.S.	0.80	0.87	N.S.	N.S.	1.25	N.S.	N.S.	N.S.	0.91	0.89	N.S.	0.74
Interaction (IxN)																
I_0N_0	19.20	15.25	14.30	13.50	19.60	15.50	14.40	13.60	20.00	15.80	14.50	13.50	20.50	16.00	14.60	13.00
I_0N_1	19.70	15.60	14.40	13.55	20.50	15.70	14.00	13.65	21.00	15.90	14.30	13.70	21.30	16.38	14.50	13.50
I_0N_2	19.85	15.75	14.42	13.60	20.70	16.00	14.70	13.70	21.30	16.00	14.35	14.00	21.70	16.50	15.00	14.20
I_0N_3	20.00	16.20	14.17	13.60	21.02	16.25	15.00	13.80	22.00	16.35	15.60	14.00	22.50	16.80	15.00	14.30
I_0N_4	21.25	16.50	15.52	13.63	21.75	16.60	15.20	14.00	22.40	16.75	15.25	14.00	22.80	17.20	15.60	14.50
I_1N_0	19.40	15.30	14.00	13.35	20.00	15.35	14.25	13.30	20.25	15.40	14.30	13.50	20.75	15.50	14.30	13.75
I_1N_1	19.80	15.60	14.30	13.40	20.40	15.70	14.35	13.40	20.70	15.98	14.00	13.60	20.90	16.00	14.50	14.00
I_1N_2	20.00	15.75	14.50	13.45	20.65	15.77	14.60	13.50	20.85	16.00	15.00	14.00	21.40	16.50	15.25	14.00
I_1N_3	20.55	16.20	14.60	13.50	21.00	16.50	14.70	13.50	21.75	16.60	14.80	13.75	22.45	17.00	14.80	14.35
I_1N_4	21.70	16.55	14.70	13.70	21.80	16.75	14.80	14.77	22.25	16.85	14.77	14.00	23.00	17.35	15.00	14.70
C.D. at 5%	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

Table 3. Soil P (kg ha^{-1}) as influenced by sowing dates and genotypes in mustard

Treatments	Soil depth (cm)															
	2005-2006								2006-2007							
	At initial				At harvest				At initial				At harvest			
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60
D_1	20.94	16.50	14.70	13.32	21.56	16.80	14.80	13.59	23.30	15.90	15.63	13.50	22.34	17.25	15.50	13.50
D_2	20.40	15.75	14.57	13.00	20.85	16.89	14.38	13.60	21.92	16.25	15.20	13.13	22.40	17.98	14.75	13.73
D_3	18.94	15.88	14.25	13.45	20.00	16.30	14.25	13.35	22.20	16.44	14.40	14.02	22.35	16.92	14.95	14.10
D_4	22.24	17.27	15.20	13.70	22.40	16.20	14.32	13.40	22.70	16.01	14.85	13.92	22.76	17.63	15.75	13.63
C.D. at 5%	1.43	0.59	N.S.	N.S.	0.72	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	0.62	N.S.	N.S.	N.S.	N.S.
Genotypes																
P. Bold (V_1)	20.24	15.76	14.23	13.23	20.56	16.37	14.51	13.67	22.96	15.98	14.94	13.55	21.89	17.02	15.17	13.56
BIO-902 (V_2)	21.02	16.94	15.14	13.51	21.84	16.73	14.36	13.30	22.10	16.33	15.10	13.74	23.03	17.86	15.10	13.92
C.D. at 5%	0.60	0.64	0.51	N.S.	0.70	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	0.39	0.53	N.S.	N.S.
Interaction (DxV)																
D_1V_1	20.00	16.00	14.40	13.40	20.50	16.25	15.00	13.77	22.60	16.00	15.50	13.80	21.80	16.50	14.80	13.00
D_1V_2	21.89	17.00	15.00	13.25	22.63	17.35	14.60	13.40	24.00	15.58	15.75	13.20	22.88	18.00	15.40	14.00
D_2V_1	19.80	15.50	13.90	13.00	20.20	16.78	14.25	13.65	22.83	16.00	14.75	13.25	22.00	17.25	14.50	13.75
D_2V_2	21.00	16.00	15.25	13.00	21.50	17.00	14.50	13.55	21.00	16.50	15.65	13.00	22.80	18.70	15.00	13.70
D_3V_1	19.67	15.25	14.00	12.90	20.00	16.60	14.50	13.70	23.00	16.13	14.48	13.65	22.00	17.00	15.60	14.00
D_3V_2	18.20	16.50	14.50	14.00	20.00	16.00	14.00	13.00	21.40	16.75	14.00	14.40	22.70	16.85	14.30	14.20
D_4V_1	21.47	16.30	14.60	13.60	21.55	15.85	14.30	13.55	23.40	15.78	14.70	13.50	21.75	17.35	15.80	13.50
D_4V_2	23.00	18.25	15.80	13.80	23.25	16.55	14.35	13.25	22.00	16.25	15.00	14.35	23.76	17.90	15.70	13.56
C.D. at 5%	1.20	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

Table 4. Soil P (kg ha^{-1}) as influenced by irrigation and nitrogen levels in mustard

Treatments	2007-2008							
	Soil depth (cm)							
	At initial				At harvest			
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60
Irrigation levels								
I_1	22.18	17.28	15.13	14.21	22.57	17.24	14.77	13.40
I_2	22.53	17.78	15.47	14.75	23.28	17.53	14.68	13.43
I_3	23.13	17.67	15.79	15.24	24.05	17.57	15.32	14.13
C.D. at 5%	N.S.	N.S.	N.S.	0.32	N.S.	N.S.	N.S.	N.S.
N levels (Kg ha^{-1})								
0	22.37	16.97	15.12	14.43	22.69	17.13	15.00	13.40
40	22.63	17.75	15.58	14.84	23.47	17.33	14.92	13.53
80	22.85	18.02	15.69	14.93	23.73	17.83	14.85	14.03
C.D. at 5%	N.S.	0.68	N.S.	N.S.	N.S.	0.60	N.S.	N.S.
Interaction (IxN)								
I_1N_0	22.0	17.00	15.00	14.02	22.60	17.20	14.80	13.00
I_1N_1	22.20	17.20	15.10	14.30	22.60	17.20	14.50	13.50
I_1N_2	22.30	17.60	15.20	14.30	22.50	17.32	15.00	13.70
I_2N_0	22.10	17.10	15.10	14.25	22.25	17.30	15.00	13.00
I_2N_1	22.50	18.00	15.60	15.00	23.60	17.30	14.75	13.30
I_2N_2	23.00	18.20	15.70	15.00	24.00	18.00	14.30	14.00
I_3N_0	23.00	16.70	15.20	15.00	23.23	16.90	15.20	14.20
I_3N_1	23.20	18.00	16.00	15.23	24.22	17.50	15.50	13.80

changed not due to sowing dates and genotypic influence but may be due to moisture, fertilizers and other physico-chemical and microbiological changes in the soil occurring in soils frequently. The total crop period in field may also do cause changes in soil fertility status (Parihar *et al*., 2010).

When mustard was grown with irrigation and nitrogen during 2007-08 (Table 4), the available soil P increased from 0.39-0.92 and 0.32-0.88 kg/ha at harvest stage due to irrigation and N levels, respectively, only on surface layer (0-15 cm) however in other depths it decreased. Soil P was also found to be increased from 0.33-1.03 and 0.63-1.04 kg/ha at harvest due to increased in level of irrigation from pre irrigation (I_0) to irrigation at 40 DAS (I_3) and N level from 0-80 kg/ha, respectively. However, soils P significantly built up in 15-30 cm in both initial and harvest stages (Trivedi, 2014). The interaction effects among irrigation and N levels for available soil P were found non significant the available soil P build up with increasing in irrigation and nitrogen levels.

In general, the effect of treatments was observed non significant in all soil depths in all the plots. Sometimes, it may be the effect of the crop individually and sometimes due to crop rotation. The available soil P under all system was increased from initial content of the soil. It may be due to the regular application of phosphatic fertilizer to each crop caused increase in available P content of soil (Mahala *et al*., 2006). It might have also solubilized the native P in the soil through release of various organic acids by the crop plants. The carbon dioxide released during the decomposition of organic matter formed carbonic acid, solubilizing certain primary minerals. Subsequently availability of P in soil also increased (Ramniwaj and Yadav, 1994; Biswas *et al*., 1975; Santhy *et al*., 1998). The increase in available P in soil owing to increase in nitrogen doses was also confirmed by several workers (Singh *et al*., 2014; Mandal *et al*., 1984; Pawar and Jadhav, 1996).

In most soils, the P content of surface layer is greater than that of subsurface due the adsorption of added phosphorus and greater biological activities and accumulation of organic matter in surface layers (Hedley *et al*., 1982; Stewart and Sharpley, 1987). Bhardwaj and Omanwar (1994) reported that surface layers are richer in available nutrients as compared to sub-surface layer. Balance of available P at the end of the experiment revealed that it was positive under all the crop sequences. It may be due constant increase in available phosphorus content of soil after each phase of cropping. This may be also attributed to lower uptake of phosphorus as compared to amount of P applied (Deka and Singh, 1984, Rao and Sharma, 1978) revealed that phosphatic fertilizers have been reported the buildup of substantial reserves of phosphorus. Similarly, Ramniwaj and Yadav (1994) reported that the P content of all cultivated soil was significantly higher over uncultivated soils.

As phosphorus exists in soils in organic and inorganic forms and soil microbes play chief role to release organic form of P. The activity of these microbes is highly influenced by soil moisture and temperature (Stewart and Sharpley, 1987; Reddy *et al.,* 1988). The process is most rapid in warm well-drained soils. Inorganic P is negatively charged in most soils. The solubility of the various inorganic P compounds and the availability of P is directly affected by crops and plant growth. This is influenced by the soil pH with optimum availability at pH values between 6 and 7. When pH is less than 6, available P is increasingly tied up in aluminum phosphates. As soils become even more acidic (< 5 pH), P is fixed as iron phosphate. Crop generally need more P than normally dissolved in the soil solution for optimum growth, therefore, this P pool must be replenished many times during the growing season. The soil's ability to maintain adequate levels of available P status in the soil solution phase is key to the plant. If the soil P level is not adequate for optimum crop growth, supplemental fertilization may be necessary to ensure adequate amounts of available P. McLaughlin *et al*. (1988) reported that fertilizer P has generally been considered as the major source of plant available P in soils. With the application of P, available P content increases as a function of certain physical and chemical soil properties (Sharpley *et al.,* 1984, 1989).

CONCLUSION

In pearl millet, soil moisture and N enhanced the available soil P considerably at harvest stage. Soil P values of 20.00 and 20.29 kg ha^{-1} in rainfed and irrigated plots respectively in 0-15 cm layer. It was also increased in all soil layers with increasing levels of nitrogen. It was highest in surface layers. The values of soil P was slightly more in irrigated plots than in rain-fed. The soil P was highest in I_1N_4 plot at harvest stage. In case of mustard varieties soil P increased as the dates of sowing advanced in surface layers. Mustard verities increased available soil P with advancement of soil depths. There is also gradual increase in soil P with irrigation water from 22.57 to 24.05 kg ha^{-1} at harvest stage but it was non significant. However, soil P already more at 15-30 cm depth and also at harvest stage in the soil. Soil P increased with increasing N levels from 22.77 to 22.85 kg ha^{-1} at initial stage and 22.69 to 23.73 kg ha^{-1} at harvest.

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OBITUARY

Prof. J.S. Bali (1923-2016)

Professor Jaswant Singh Bali is a man of vision who always looks ahead and his words are action. Prof. Bali was born on 18th December, 1923 in a farming family of village Gharota (near Pathankot) in Punjab. His primary education was completed in the place under a Banyan tree and was a bright student. He obtained Bachelor of Science degree from Lahore, Bachelor of Science (Agricultural Engineering) from Allahabad (winning Gold Medal), and post-graduate courses in the Soil Conservation Service of USA. He did his M.Tech degree from Kharagpur.

He worked extensively for reclaimed gullied waste lands in Damodar Valley Corporation in the 1950s at Bihar. Held distinct positions as chief of all the institutions and establishments of soil and water conservation of Government of India. He was Head of Soil Conservation Research & Training Centre Dehradun, Professor at Indian Institute of Technology, Kharagpur, Head of Soil & Water Conservation Division of Ministry of Agriculture, and United Nations Consultant in Bulgaria, West Indies, Rome and Malaysia.

He introduced the concept of watershed management in the national programmes of conservation and management of natural resources, and created the expanded version of the All India Soil and Land Use Survey. He conceived the idea and successfully led the campaign to create the Central Department of Land Resources. Emphasizing ecology and economics, he highlighted the problem of profit lessness of Indian farming, and introduced (in his pioneering book) the far reaching concept of Bioindustrial Watershed Management, which combined processing industries and sound marketing with resource protection and bio-production, in order to eradicate rural poverty.

He received several awards and medals during his life. He gave to the nation of ''concept and strategy of Bio-Industrial Watershed Management'' to wipe out to the poverty and transform rural India into prosperity.

Prof. M.S. Swanimathan, Father of Green Revolution in India and an internationally renowned scientist has remarked about Prof. J.S. Bali's initiative of bio-industrial watershed management : "I hope soon every watershed in our country will become a bio-industrial watershed, in order to ensure work and income security to rural families".'

He authored three technical books and over 150 papers to his credit. According to Prof. Swaminathan "Prof. J. S. Bali is a creative thinker and writer. Because of his love of nature and commitment to the conservation and sustainable use of natural resources, Prof. Bali has also become a poet."

He also published three poetry books in English. The recent publication "Lyrics of Life" is really voice of Bali for love of nature and compassion for Men, Animals and Plants and Awareness to the Inter-dependent dynamics systems of planet earth. These poems are really inspiring and cover a spectrum of tasks before our country for the welfare of the society.

Prof. Bali conferred with the highest awards of the Soil Conservation Society of India, Indian Society of Agricultural Engineers and the World Association of Soil and Water Conservation (in their World Conference held in China).

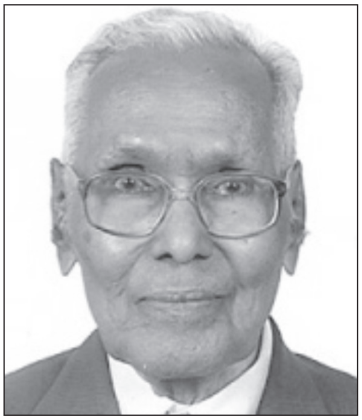
He was founder of Soil Conservation Society of India and instrumental throughout his life to place every brick to make the SCSI a solid body. He was very active even at the age of 90+ and worked for profession of the Soil and Water Conservation. He guided us on every issue, promoted younger generation to take responsibilities and we are proud and privilege to be associated with such a legend.

I pray almighty that his soul rest in peace and we believe that true tribute to him shall be to follow the path he showed for the service to mother land by conserving and managing natural resources to strengthen economy of the poor farming community.

Soil Conservation Society of India remembers Prof. Bali as "Bhism Pitamah" of SCSI and we plan to institute one **JS Bali Memorial Lecture** annually to be organized by SCSI HQ or State Chapters.

Suraj Bhan
President

Prof. C.R. Shanmugam (1922–2016)



His studies and training include Civil Engineering degree from Guindy Engineering College (1941-45), Drilling engineer from Central Ground Water Organisation, Roorkee (1949-50), Soil conservation Sciences in Central Soil Conservation Research and Training Institute, Dehradun (1955-56) and Land development Training in Praire Farming Rehabilitation Administration in Canada (1960) and Master of Sciences in Agricultural Engineering (1961-62) from the University of Saskatchewan, Canada. Beyond his studies, he travelled around the world and spoken in many international conferences on subjects related to Land and Water Development. Graduated in 1945 from Guindy Engineering College, he started his career with Public works Department (PWD). He was an Instructor to the then College of Agriculture in Coimbatore and worked for five and half years (1945-61).

He worked in the government department s for 27 years in various capacities. Initially, he started with the PWD as Sub Engineer and rose through the ranks to become Executive Engineer. He was also one of the founding staff of the Agriculture Engineering Department, and became Superintending Engineer before he took to academics. He worked in Tamil Nadu Agricultural University (TNAU) as one of the founding faculty members of College of Agricultural Engineering (CAE) of TNAU in 1973. He retired as the Dean in 1980. His training in Mechanical Engineering, Civil Engineering, Water Sciences, and Drilling Technologies made him a perfect fit for the early years of the College. His contribution in building the academic discipline of agricultural engineering is notable. Many of his students went on to become Institution builders around the world.

Besides his academic work , Prof.CRS is known for his contribution to soil conservation and agricultural engineering in the then Madras State Agriculture Department. His contribution to the discipline of Agricultural Engineering is phenomenal in many areas. For example, the farmers who took up the Bench Terraces in and around Nilgiri Hills (especially Ooty and around) owe a lot to his efforts. Much before any other hill areas in this country, Ooty has become a place known for conserving soil in steep slopes while producing vegetables through intensive and year round cultivation. He worked in many places of the undivided Madras Presidency and later the Madras State. In many ways, the foundation of the Agricultural Engineering Department (AED) in Tamil Nadu was laid strong through many of his efforts. It is always interesting to hear about his travels to many places within the present day Andhra Pradesh and Tamil Nadu. The manual he has co authored on soil and conservation works remain the sole authority till date for the Department. Prof.CRS is always remembered for his at most discipline, honesty, sincerity, and perfection in work. He always kept these qualities close to heart and never compromised it.

He has authored and coauthored the following books and technical manuals viz., Soil erosion, its prevention and Control(Revised edition), Technical handbook on soil conservation, Farm mechanics and post harvest technology, ISAE Directory, Technical Monograph "Farm Machinery and Energy Research in India (ICAR- CIAE)", Handbook on Irrigation water measurement, "Water Security": Integrated Micro Watershed Development in Tamil Nadu: Report to Tamil Nadu State Planning Commission, Chennai, Technology of Tanks-The Traditional Water Bodies of Rural India.

After his retirement from the CAE (TNAU) in 1980, he ventured into a new area in water, i e Tank Rehabilitation. The success of the academic pilot projects in Centre for Water Resources (CWR) of the Anna University have materialized into a very large statewide program called Modernization of Tank Irrigation (MOTI) funded by the European Commission. This is one of the commendable programs ever developed by an academic Institution in the history of the whole country, to become a major implementable program by a PWD. All the talk of Tank Rehabilitation and Water Harvesting in this country in many ways owe a great debt to Prof.CRS's pioneering efforts. After 1993, he worked with DHAN Foundation in developing their Tank Program. His expertise in training and grooming young professionals helped this Non Government Organisation to materialize into a large organization involved in Tank Development in the country. Prof.CRS always remained a professional and ahead of many others to promote the cause of tank irrigation in this country. One can always consult him for anything about soil and water, Tank Rehabilitation and government procedures.

The Agricultural Engineering Fraternity gratefully remembers the great contributions of Prof. CRS, one of the pioneer Agricultural Engineers. May this great soul Rest Peace and tranquility.

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