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Contents

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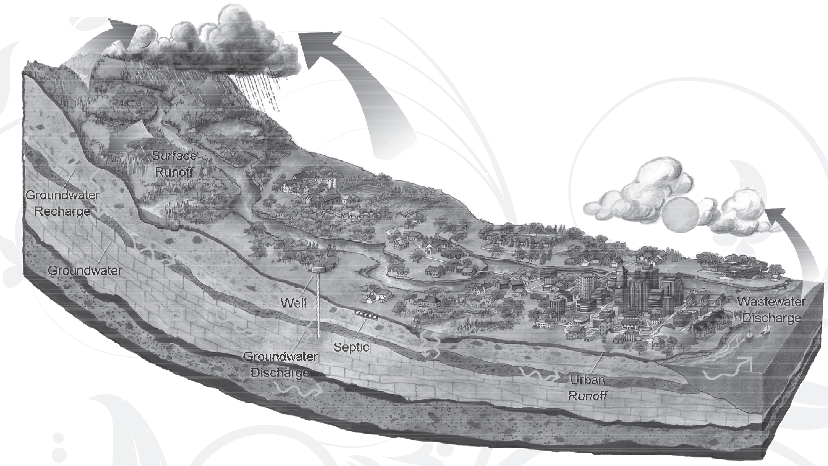

I pledge to conserve Soil,
that sustains me.
I pledge to conserve Water,
that is vital for life.
I care for Plants and Animals and the Wildlife,
which sustain me.
I pledge to work for adaptation to,
and mitigation of Global Warming.
I pledge to remain devoted,
to the management of all Natural Resources,
With harmony between Ecology and Economics.

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Changes in vegetation cover and soil erosion in a forest watershed on removal of weed *Lantana camara* in lower Shivalik region of Himalayas

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ABSTRACT

In a hilly forest watershed located in lower Shivalik region, the invasion of *Lantana camara* weed resulted in a drastic reduction in plant biodiversity and ground cover, thereby increasing the rate of soil erosion. In order to reduce soil erosion and restore biodiversity, Lantana was removed from four micro-watersheds (WS_1, WS_2, WS_3, and WS_5) in year 2005. The changes in soil erosion and vegetation cover area in the ground storey (grasses + small shrubs) and middle storey (shrubs) were monitored in top, middle and lower reaches of four micro watersheds during the period 2005-2010 and were compared with a pure grass watershed (WS_4) located in the same watershed. Due to Lantana removal, the canopy cover of Lantana reduced from 80-90% in 2005 to 5-10% in 2009, resulting in better light penetration and improvement in ground cover vegetation of native grasses like *Eulaliopsis binata*, *Chrysopogon fulvus*, seasonal grasses, and native shrubs like *Adhatoda vasica*, *Murraya koenigii*. There was a reduction in soil loss in all the watersheds in 2010, which was found directly related to the ground cover improvement, mainly in the top reaches of micro-watersheds. It is concluded that the ground vegetation cover plays a major role in soil erosion and its reduction due to of *Lantana camara* invasion has a direct impact on hydrological behavior of the watershed. The removal of this weed can restore ground vegetation thereby reducing soil erosion.

Key words: Forest watershed, *Lantana camara*, Lower Himalayas, Run off, Shivaliks, Soil erosion, Soil loss, Vegetation cover

INTRODUCTION

Lantana (*Lantana camara*) is a major weed in many tropical and sub-tropical regions where it invades natural and agricultural ecosystems and forest watersheds and has been nominated as among 100 of the "World's Worst" invaders (Day *et al.*, 2003). In disturbed native forests, it can become the dominant under-storey species, disrupting succession and decreasing biodiversity due to its allellopathic qualities (Luna *et al.*, 2007; Talukdar and Talukdar, 2016). In a watershed, the dense stands of *Lantana camara* are reported to reduce the ground grass cover thereby lowering its capacity to absorb rain, increasing the run-off and soil erosion (Fensham *et al.*, 1994; Day *et al.*, 2003; Thakur *et al.*, 2013). In an earlier study conducted in degraded forest watershed at Research farm, CSWCRTI (now IISWC), Chandigarh, bioengineering measures resulted in gradual decrease in soil loss from 37 Mg ha^{-1} yr^{-1} to just 1.0 Mg ha^{-1} yr^{-1} during the period 1964 to 1985. However, this reducing trend was reversed after the invasion of *Lantana camara* during the period 1990-2000, along with suppression of native vegetation and a drastic reduction in evenness index and Shannon biodiversity index (Sharma *et al.*, 2009). The available chronological data on vegetation and soil loss from this forest watershed suggests that the reduction in ground cover due to dominance of Lantana has resulted in increase in soil erosion, thereby increasing the threat to forest ecosystem stability and water resource management (Sharma *et al.*, 2009). The present study was conducted to study the impact of Lantana removal on vegetation cover and changes in run off and soil loss in four lantana infested micro-watersheds and compare it with that of grassed watershed.

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MATERIALS AND METHODS

Site description

The study was conducted in five micro-watershed (WS_1, WS_2, WS_3, WS_4 and WS_5) located in Shivalik Himalayan region at ICAR-IISWC Research Farm, Mansa Devi, Panchkula, Haryana (Latitude 30°-45' N and Longitude 70°-45' E, 370m above msl) with characteristics as given in Table 1. The soil was sandy-to-sandy loam in texture with full of boulders, low in nutrients as well as water holding capacity and was classified as class VII e and light textured hyperthermic, Udic Ustocrept (Grewal *et al.*, 1996). The area was highly degraded due to frequent soil erosion and it receives an annual rainfall of more than 1100 mm. The watersheds had slope between 30 to 50% and area ranged from 0.81 ha to 4.75 ha. Bioengineering measures resulted in stabilization of these watersheds with improvement in vegetation cover and reduction in soil erosion. The invasion of ingress and proliferation of *Lantana camara* L. (verbenaceae) during late eighties, resulted in poor penetration of light through heavy lantana canopy causing drastic reduction of ground grass cover and increase in runoff and soil loss (Sharma *et al.*, 2009). The initial vegetation survey in forest watersheds showed that *Acacia catechu* was the most dominant tree in top tier with the highest IVI, while *Lantana camara* and *Murraya koenigii* became the most dominant shrubs in middle tier and the ground cover was very poor with *Adhatoda vasica* and little or no grasses (Table 1). The grassed watershed (WS_4) was taken as control and had a luxurious ground cover of *Eulaliopsis binata*.

Vegetative manipulation

To reduce and maintain vegetation cover for obtaining an optimum runoff and reduction in soil loss, vegetation manipulation was started from 2005-06 onwards with the removal of *Lantana camara* from all the micro-watersheds. Fifty per cent crown of each tree was also removed to allow the light to penetrate to the ground floor to encourage the natural vegetation and to improve the ground cover. The canopy cover in the top and the middle tier was maintained by continuous removal of regenerated canopy every year.

Measurement of run-off and soil loss

Rainfall, run-off and soil loss data were monitored every year in the watershed during the period 2005-10. All the micro-watersheds are being gauged by 0.6m deep 2:1 broad crested triangular weirs. The runoff was measured by automatic water level recorders. The rainfall was recorded by recording type of rain gauge and the run-off was gauged by 0.6 m deep 2:1 broad crested triangular weirs. The soil loss was determined by analyzing the run-off samples collected from time to time. All the watersheds were calibrated for initial two years (2005-06).

Vegetation survey

The vegetation survey was done following quadrant method (Mishra, 1968), with quadrants equally and randomly distributed at the three physiographic positions of top, middle and lower reaches of the hill slope. The ecological succession of shrubs and trees was measured through the importance value index (IVI) obtained through summing up of the relative dominance, relative density and relative frequency according to standard procedures given by Mishra (1968). Since soil erosion is mainly a function of total canopy cover area, the potential threat posed by huge

Table 1. General characteristics of five micro-watersheds

Watershed	Slope %	Area (ha)	Vegetation type	% Cover area of three tier vegetation in year 2005			Important Value Index of dominant vegetation in year 2005				
				Top	Middle	Ground	*Acacia catetchu*	*Lantana camara*	*Adhatoda vasica*	*Murraya koeningii*	*Grasses-E.binata*
WS1	44.9	4.5	natural mixed forest	30.4	53.6	18.8	70.9	71.5	39.2	37.7	0.0
WS2	32.1	2.0	-do	15.4	74.0	12.4	71.7	114.3	30.7	27.7	0.0
WS3	48.9	4.7	-do-	43.9	68.8	28.8	44.3	60.7	64.5	24.1	0.0
WS4	50.4	0.8	Grasses	1.9	13.3	75.5	0	16.0	0	0.0	151.2
WS5	50.6	1.7	natural mixed forest	38.2	29.8	27.5	56.6	56.7	72.0	26.6	0.0

canopy cover of Lantana could be underestimated by IVI alone. Therefore, the total vegetation cover area in top middle and ground tier of the three tier vegetation at different locations was measured by planimeter method (Mishra, 1968). The relative cover area occupied by each plant species in a 10x10 m quadrant and was accordingly plotted on a graph paper. The area on graph paper was computed by planimeter and the percentage of canopy area occupied by different plant species in three tier vegetation was calculated separately.

Soil and microbial analysis

Forest floor was analyzed for litter fall and top soil properties. Composite samples of fresh and decomposed leaf litter were collected from 1 square feet area from different locations in the watersheds and litter fall per hectare was computed based on mean dry weight of the litter. Composite soil samples were collected at 30 cm soil depth and analyzed for different soil parameters i.e., soil organic carbon (Walkley and Black, 1934), and water stable aggregates (Elliot and Gambardella, 1991). Soil respiration was measured by incubating soil in sealed flasks containing a vial of NaOH to at 28°C for 24 hrs, followed by estimating the evolved CO_2-C trapped in NaOH by addition of an excess of 1.5 mol. L^{-1} $BaCl_2$, and titration with standardized HCl (Zibilske, 1994). Spores of Vesicular Arbuscular Mycorrhiza (VAM) were obtained by wet sieving and decanting of the fresh soil samples and the spores were counted in a graduated petri plate under a dissecting microscope (Daniels and Skipper, 1982).

RESULTS AND DISCUSSION

Litter fall and soil properties

Lantana has a high litter fall resulting in improvement in soil organic carbon and high respiration rate due to litter decomposition (Table 2). There is more improvement in soil properties in Lantana infested watershed. The lower and middle reaches had higher litter fall and soil organic carbon as compared to top reaches (Table 2), possibly due to washing away of litter from top reaches. The grassed watershed had more water stable aggregates and higher number of spores of vesicular arbuscular mycorrhiza (VAM) as compared to Lantana infested watershed (Table 2). The dependency of plants on VAM to survive under degraded environment and the improved soil aggregation under VAM colonized roots has been widely reported (Azcon and Barea, 1997; Franzluebbers *et al.*, 2000). High proliferation of grass roots combined with network of VAM hyphae may play an important role in soil stabilization and reducing the soil loss.

Changes in vegetation cover during 2005 to 2009

The dominant plant species found were Khair (*Acacia catechu*), Basuta (*Adhatoda vasica*) and sweet neem (*Murraya koenigii*) in all the watersheds. On comparing plant canopy in upper storey between 2005 and 2009, it was found that the tree canopy has improved in all the forest watersheds and highest tree canopy was observed in WS1 possibly due to ingress and fast growth of *Prosopis* in this

Table 2. Initial soil properties under lantana infested forest watershed and the grassed watershed in the top, middle and lower reaches

Watershed	Location on the slope	Initial properties of forest floor					
		Litter fall (q/ha^{-1})		Soil properties (0-30 cm soil depth)			
		Fresh litter	Decomposed litter	Organic carbon %	VAM spores No./ 10gm soil	Soil respiration (mg CO_2 C/gm soil/24 hr)	Water stable aggregates %
Lantana infested watersheds (WS1,WS2, WS3 &WS5)	Upper reaches	26.9	63.6	1.02	5	1.45	52.3
	Middle reaches	38.4	136.5	1.32	7	1.08	57.1
	Lower reaches	31.8	116.8	1.38	10	0.86	51.7
Grassed watershed (WS5)	Upper reaches	—	—	0.48	19	0.81	67.6
	Middle reaches	—	—	0.60	23	0.90	54.9
	Lower reaches	—	—	0.66	27	1.41	56.8

watershed (Fig.1). In the middle tier, the continuous removal of Lantana during 2006 onwards from all the watersheds, there was a drastic reduction in canopy of lantana from 80-90% to 5-10% in 2009 (Fig.2). As a result, the light could penetrate to reach the ground vegetation which has significantly improved growth of ground cover. As a result, Basuta (*Adhatoda vasica*) and sweet neem (*Murraya koenigii*) which formed ground cover in 2005 have become as the principal species in middle storey in 2009. The area occupied by bhabhar (*Eulaliopsis binata*), dholu (*Chrysopogon fulvus*) and local grasses have also improved in 2009 as compared to 2005 (Fig.3). The local native grasses have formed major ground cover in WS_1, WS_2, WS_3, and WS_5. The top reaches in WS_1 have the poorest ground cover, possible due to high density of tree cover in this watershed. But there is good grass cover in the middle and lower reaches of this watershed.

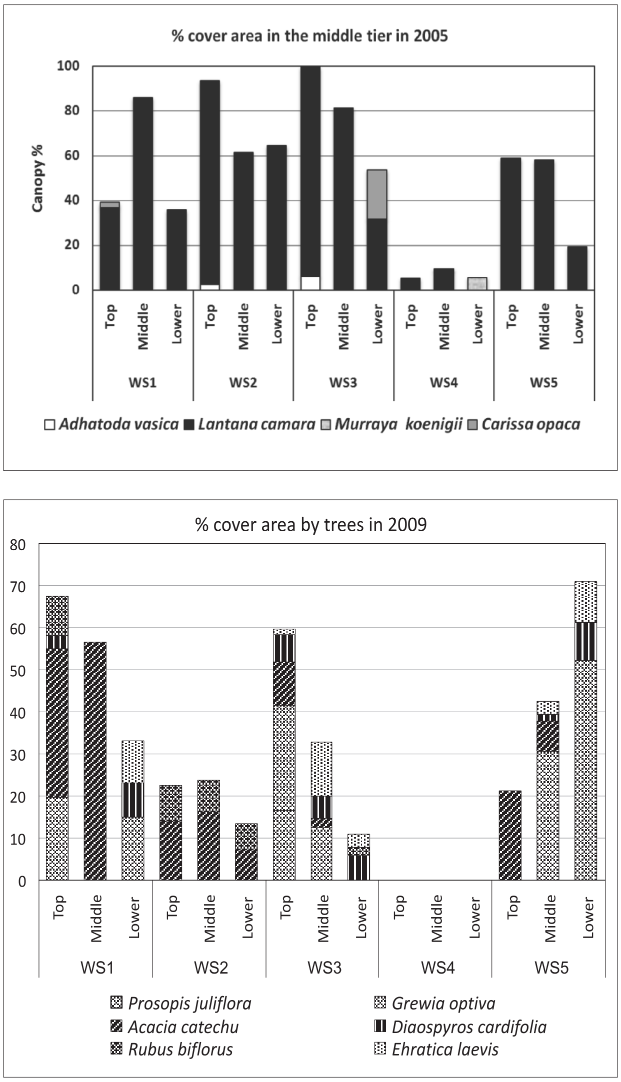

Fig. 1. Vegetation cover area (%) in top tier by trees in year 2005 and after Lantana removal (2009)

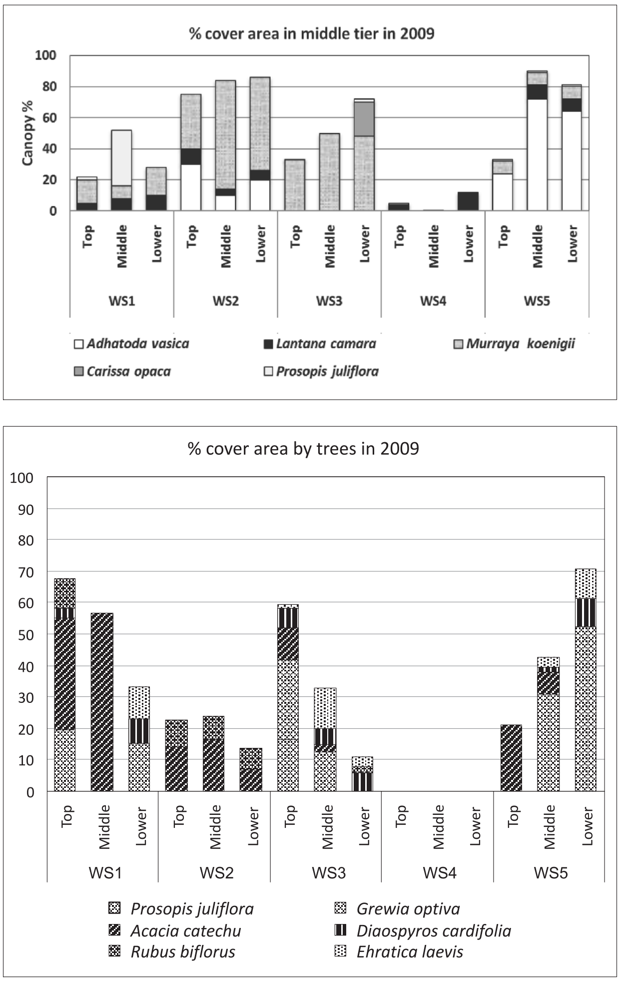

Fig. 2. Vegetation cover area (%) in middle tier in year 2005 and after Lantana removal (2009)

Runoff and soil loss

Runoff from all the watersheds for last four years (Table 3) indicates that water shed WS_2 gave lowest runoff among all the watersheds. On comparing soil loss from all watersheds it was found that in general soil loss has decreased from 2007 to 2010.Vegetation manipulation has shown clear impact on soil loss as there is reduction in soil loss from 2007 to 2010 even after higher rainfall in 2010 (Table 3). Calibration curve and validation curves indicate that runoff have slightly increased from all watersheds during year 2010 in comparison to two years of calibration period from 2005-2006. Total soil loss was also found minimum in WS_2 watershed, which may be due to highest improvement in middle as well ground grass cover in top, middle and lower reaches.

Runoff values were found maximum in WS_1 in 2010 with 74 % improvement in run off as compared to that in 2005-06, while the other watersheds (WS_2, WS_3 and WS_5) showed a reduction from 9.5 to 63%. The reduction in soil

Table 3. Soil loss from watersheds during 2007 and 2010

Watershed	% Runoff			Soil loss(kg ha^{-1})		
	2007 (Initial)	2010	% change	2007 (Initial)	2010	% change
WS1	8.5	14.8	+74.1	357	239.1	-33.0
WS2	2.1	1.9	-9.5	52	1.1	-97.9
WS3	21.7	8.0	-63.1	2137	42.4	-98.0
WS4 (Control)	8.7	8.8	+1.2	442	123	-72.2
WS5	11.5	8.3	-27.8	5521	42.6	-99.2

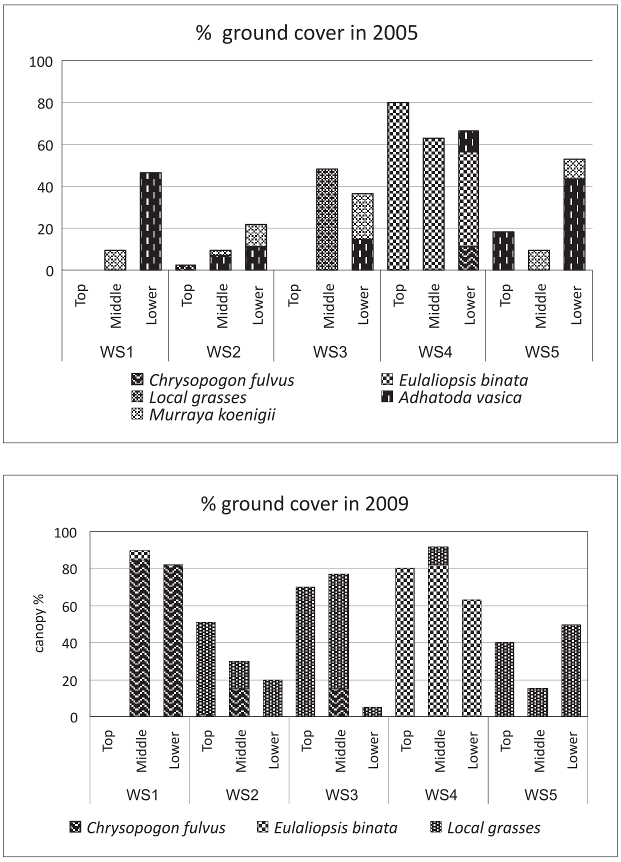

Fig. 3. Cover area (%) in ground cover in 2005 and after Lantana removal (2009)

loss was also minimum in WS_1 (33%), while it was maximum (97-99%) in WS_2, WS_3 and WS_5, reaching the levels of control grass watershed WS_4. The highest run off and soil loss in WS_1 may be attributed to poor ground cover in WS_1 in top reaches of the watershed. This was also reported by Sharma and Arora (2012) that ground cover influence runoff and soil loss.The luxurious ground cover obtained in WS_2, WS_3 and WS_5 in all the reaches may have resulted in reduction of soil loss and run off.

CONCLUSION

It is concluded that the ground cover vegetation plays major role in hydrological behavior of the watershed. The reduction in ground cover due to poor light availability under Lantana canopy may be the major cause of increased soil erosion after Lantana invasion. Since the top reaches are the main sources of run off and soil loss, the maintenance of ground cover in top reaches has a more important role to play. Further in-depth studies are required on interactions between three tier vegetation and the maintenance of optimal vegetation cover for improving water quality from a watershed.

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Salt affected soils in Jammu and Kashmir: Their management for enhancing productivity

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ABSTRACT

Saline soils in valley of Kashmir and *Kandi* belt of Jammu have been reported, having soluble salts in the range of 0.15 to 0.45% with Cl, NO_3, SO_4 and HCO_3 anions. Saline soils have been reported in many soils of Jammu district derived from alluvium parent material in the plains as well as in soils of Parmandal and Uttar bani areas which are their origin to Siwalik group of rocks. Presence of soluble salts greater than 0.2% was found harmful to plants. In the canal command area, located in the Kathua and Jammu districts it was found that an area of 25,670 ha become unproductive due to salinization alkalization as well as waterlogging. The soils are very strongly alkaline having pH range from 8.6 to 10.5 (average pH 9.9), with dominance of exchangeable Na (ESP 25.3) and sodium adsorption ratio (SAR) of 78.41. The highest ESP was recorded in Tarore soil with ustic and aquic moisture regimes associated with hard surface crust, calcic and natric sub-surface horizons. Gypsum requirement (GR) to amend sodic soil was calculated and applied at the rate of 100% GR. This application has increased rice and wheat yields 43.3 and 86.9%, respectively, over control. Improvement in soil properties was noticed, soil pH decreased from 9.7 to 8.8, bulk density decreased from 1.52 to 1.48 Mg m^{-3} and infiltration rate was improved.

Key words: Saline soil, Sodic soil, ESP, Waterlogging, Jammu, Kathua, Infiltration

INTRODUCTION

The soils showing higher content of soluble salts and more percentage of exchangeable sodium (Na^+) are known as salt affected soils. The former group of soils is called the saline soils and those of the latter as sodic or black alkali. When soluble salts content becomes greater than 4 dS / m or millimhos per centimeter and exchangeable Na^+ percentage more than 15 percent of the cation exchange capacity, the fertility status of salt affected soils, renders very low. As a result, the productivity of crops grown in such soils gets considerably reduced. These soils are, therefore, required to be reclaimed prior to sowing crops on them.

Out of 6.73 million hectares (Mha) of salt affected soils in the country, nearly 4.5 Mha are under saline category and the remaining 2.2 Mha are sodic in nature (NRSA and Associates, 1996). Sodic soils are mostly present in the Indo-Gangetic plains of Haryana, Punjab, Uttar Pradesh and to some extent in other states including parts of Jammu and Kashmir. Contrary to this, saline soils are confined to irrigated, semi-arid and arid regions of Rajasthan, Gujarat, Karnataka, Andhra Pradesh and parts of Punjab, Himachal Pradesh and Jammu and Kashmir including *Kandi* belts of these states.

Occurrence of salt affected soils in Jammu and Kashmir

Although exact area under salt affected soils has not been completely delineated in Jammu and Kashmir state so far yet sporadic studies conducted by various researchers and compiled (Gupta *et al.*, 1992; Nazar, 1993; Nazar and Gupta, 1996; Gupta *et al.*, 2011) have confirmed their presence. Saline soils in valley of Kashmir and *Kandi* belt of Jammu have been reported, having soluble salts in the range of 0.15 to 0.45 percent with Cl, NO_3, SO_4 and HCO_3 anions. Salinity have been reported in many soils of Jammu district derived from alluvium parent material in the plains as well as in soils of Parmandal and Utter bani areas which owe their origin to Siwalik group of rocks. Presence of soluble salts greater than 0.2 percent is found harmful to

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plants (Gupta, 1967). Osmotic effects of salts, ionic concentration of soluble ions like Na, K, Mg, Cl, NO_3, SO_4, HCO, reduce the availability of essential plant nutrients due to competitive uptake, and thus, affect the plant growth in saline soils (Gupta and Verma, 1992; Gupta and Raina, 1994). Excess salinity, in fact, delays the seed germination, which as a consequence causes poor growth or stunted growth and eventually reduces the yields of crops.

Sodic or alkali soils are mainly confined to alluvial belts of Jammu region, especially in irrigated areas of Jammu and Kathua districts, where there is improper water management, and increased water induced by the seepage of water from channels of the Ranbir, Ravi and Partap canals. Locally, these soils are known as, "*Kalar ali Mitti*"(Gupta *et al*., 2011). These soils have high pH value, in the range of 8.6 to 10.5 or even more.

Due to occurrence of more percentage of exchangeable Na^+, these soils are highly dispersed and impervious to the flow of air and water. These soils like those of saline are also unproductive and, therefore, required to be reclaimed before sowing the crops.

Extent of Salt Affected Soils

In Jammu district alone, salt affected soils have been found to the tune of about 10,000 ha in Jammu, Ranbir Singh Pura and Bishnah tehsils as per the findings of Nazar (1993). However, such soils have not been shown in the satellite maps probably due to their occurrence in sporadic areas. Salt affected soils are also present in Ladakh sub-division of Jammu and Kashmir state known as 'cold arid zone' of the country like Lahaul Spiti and Kinnaur districts and Pangi tehsil of Chamba district as well as in the soils of Kaza and Rangreek of Lahul and Spiti (Gupta *et al*., 2000) in Himachal Pradesh, where salt affected soils are also present to some extent. About 25,000 ha area has been reported under salt affected soils in Ladakh region.

Salt affected soils in canal command

A study was conducted to ascertain the emergence of salt affected soils in canal command area of Jammu. The catchment area of Ravi-Tawi canal is covered by forests with gentle to steep slopes. The command area where irrigation is targeted through Ravi-Tawi scheme has 0-2% slope and dominantly agricultural lands with rice-wheat and maize-wheat cropping systems apart from vegetable cultivation in some pockets (Kumar *et al*., 2004). Remote sensing data of the command area was used to delineate the existence of salt affected soils (Jalali *et al*., 2004). False colour composite (FCC) prints of path 93 row 48 were prepared from band 3 enlarged to 1:25,000 scale for monoscopic visual interpretation. Information of river, drainage and relevant ground features was incorporated from the Survey of India toposheets while preparing the base map. Delineation of soil salinity and water logging hazards was made using various image models and classifier i.e. normalized difference water index (NDWI), normalized difference vegetation index (NDVI), water vegetation index (WV) unsupervised classifier, respectively on the imagery (Jalali *et al*., 2004, 2005). Amongst various image elements tone was found prominent in the identification and delineation of both alkaline and waterlogged soils. Other image elements, which facilitated identification and delineation, were landuse, shape, and drainage pattern. Salt-affected soils in the Ravi-Tawi command area have been identified, demarked and mapped by using LISS III data and interpreted with the help of ERDAS software using ground truth soil characteristic data. Barren alkaline soils with 1-2 cm thick surface salt-crust appeared in similar tones. Salt affected area was estimated through the image data to cover an area of 25,000 ha (Sharma *et al*., 2012). Information on spatial distribution and extent is very important for managing problematic soils of an area. The salt-affected and/or waterlogged soils covering an area of 25,000 ha are mainly confined to the blocks of Gho, Sajadpur, Samba and Rajpura (Jalali and Arora, 2013).

(A) Reclamation of salt affected soils to increase their crop productivity

As already stated that the salt affected soils have to be reclaimed before sowing various crops. Reclamation of saline soils includes:-

- Leaching of soluble salts: In this method, irrigation is resorted prior to sowing the crops to leach sown the soluble salts.
- Lowering of water table depth: It is done through improving subsurface drainage.
- Selection of suitable salt tolerant growing crops: Salt tolerant crops like barley, oats and rice should the grown.
- Growing of forest tree species: Like salt tolerant crops, certain tree species like *kikar, phulai, khair, sarin, shisham* and *neem* have also been found to be tolerant to saline soil conditions vis-à-vis sodic soil environment. It is, therefore, required to grow such tree species in saline and alkali soils.
- Use of farm yard manure: Use of farm yard

manure alone at the rate of 5 tonnes ha has been found to increase the yield of crops grown in saline and sodic soil conditions. In *Kandi* belt of Jammu use of farm yard manure has shown increase in yield in wheat crop, ranging from 11.2 to 12.2 per cent over control.

(B) Reclamation of sodic soils

In sodic or alkali soil, the exchangeable Na^+ is so great as to make the soil almost impervious to water. But even if water could move down ward freely in sodic soils, the water alone would not leach out the excess exchangeable Na^+. This exchangeable Na^+ must be replaced by another cation for its leaching down ward out of plant roots zone. For this purpose, Ca^{++} is often used to replace Na^+ through gypsum (calcium sulphate) in large quantities. Use of this much quantity of gypsum is beyond the reach of the Indian farmers due to involving of heavy amount. Hence, use of in organic of + organic amendments came to fore.

(i) Effect of Inorganic and organic amendments

A study conducted evinced that an application of gypsum in conjunction with dhaincha grown as green manure improved the soil properties with concomitant increase in yield of rice (Table 1). The data showed that the increase n yield was in the range of 8.3 to 25.8 percent and 4.8 to 21.2 in respect of grain and rice straw, respectively as compared to control, irrespective of various treatments. Among the various amendments (treatments) the highest yield of groins (14.7 q / ha) was obtained in *Dhaincha* + gypsum treatment followed by FYM + gypsum treatment (13.3 q / ha) and the least in control (11.7 q / ha). The percent increase over control being 25.8, 14.0 and 12.2, respectively. The yield of straw was also significantly affected by the application of various amendments (Table 1).

In another study in 2003-04, a representative site was selected for field experiment in Tarore village to test the efficiency of gypsum based on gypsum requirements (GR) for the reclamation of sodic soil. On farm experiment at farmers' field was conducted with paddy-wheat sequence was conducted. Gypsum requirement of the sodic soil was determined as 12.38 Mg ha^{-1} that was applied one month prior to transplanting paddy in *kharif* (summer) season. Seedlings of rice variety PC-19 were transplanted in *kharif* 2003 and wheat variety PBW-175 in r*abi* (winter) season 2003-04. Basal application of recommended doses of N, P, K and Zn @ 120:60:25 and 20 kg ha^{-1} in paddy and 120:60:40 kg ha^{-1} in wheat were applied at appropriate times as per crop requirements during the experimental period.

Table 1. Effect of amendments on rice yield in salt affected soils

Treatments	Yield (q / ha)		Percent Increase	
	Grain	Straw	Grain	Straw
Dhaincha	13.2	27.8	13.6	17.4
Dhaincha + Gypsum	14.7	28.7	25.8	21.2
Farm yard Manure (FYM)	13.1	27.2	12.2	15.0
FYM + Gypsum	13.3	28.0	14.0	18.4
Gypsum	12.6	24.8	8.3	4.8
Control	11.7	23.7	8.3	4.8
CD (p=0.05)	0.63	0.58	8.3	4.8

Source: Nazar and Gupta (1996)

The grain yields of paddy and wheat showed significant increase in yield at different doses of gypsum (Table 2). Highest yield of paddy was obtained when gypsum was applied @100% GR, however, it was statistically at par with 150% GR treatment. Yield increase in paddy was 43.0% and in wheat 86.9 % over the yield in control treatment. From the data, it is observed that gypsum @ 100% GR gave similar yield as gypsum @ 150% GR in paddy. Yield data further indicate that there was marked increase in wheat yield after applying gypsum in the paddy.

Table 2. Relative efficiency of various doses of gypsum on crop yields (Mg ha^{-1})

Treatment	Paddy	Wheat
Control (T_0)	2.54	1.45
GR (50%) (T_1)	3.33	2.37
GR (100%) (T_2)	3.64	2.71
GR (150%) (T_3)	3.61	2.38
CD (p=0.05)	0.266	0.302

GR = gypsum requirement

There was decrease in soil pH from 9.70 to 8.91 in paddy plots and during wheat it decreased from 9.61 to 8.84 after harvest (Table 3). This decrease in pH is attributed to the addition of Ca^{2+} from gypsum and increased content of SO_4^{2-} apart from increased biological activity resulting in higher production of CO_2 evolution and carbonic acids. Similarly, ECe significantly decreased after paddy as well as after wheat, indicating ameliorative effect of applied gypsum. High application rate of gypsum increased the soluble Ca^{2+} content which replaced the exchangeable sodium and thus reduced the ESP (Yaduvanshi, 2001).

Bulk density of the surface soil in control was greater than where soil was treated with gypsum.

Table 3. Changes in soil properties after gypsum application in paddy-wheat

Treatment	pH		ESP		SAR (mmoles/l)$^{0.5}$	
	After paddy	After wheat	After paddy	After wheat	After paddy	After wheat
Control	9.70	9.61	48.80	48.48	4.08	4.07
GR (50%)	9.41	9.12	30.55	29.57	2.05	1.91
GR (100%)	9.11	9.00	28.73	28.00	1.91	1.81
GR (150%)	8.91	8.84	26.54	23.63	1.74	1.46

GR = gypsum requirement

The bulk density was reduced from 1.52 to 1.48 Mg m^{-3} with treatment of gypsum in the sodic soils, this may be due to improved soil tilth and reduced compactness with the addition of amendment (Yaduvanshi, 2001). The initial average infiltration rate for gypsum treated soil (2.40 cm hr^{-1}) was much higher than that for the untreated sodic soil (1.80 cm hr^{-1}). The average steady state in filtration rate for a period of 3 hours were 0.07 and 0.04 cm hr^{-1} which is nearly two times more in the treated soil than in untreated soil (Fig. 1). The average value for cumulative infiltration after three hours was 3.58 cm in the treated and 2.69 cm in untreated soil. The increased water transmission in the treated soil is be due to the improvement of soil structure, lower bulk density and availability of larger pores for water transmission (Patel and Suthar, 1993). The infiltration rate was higher initially and remained almost steady after three hours (Fig. 1). This steadiness in infiltration rate is due to decrease in potential gradient with time in the transmission zone caused by the presence of flow restricting layer due to excess amount of exchangeable sodium (Sawhney and Baddesha, 1989).

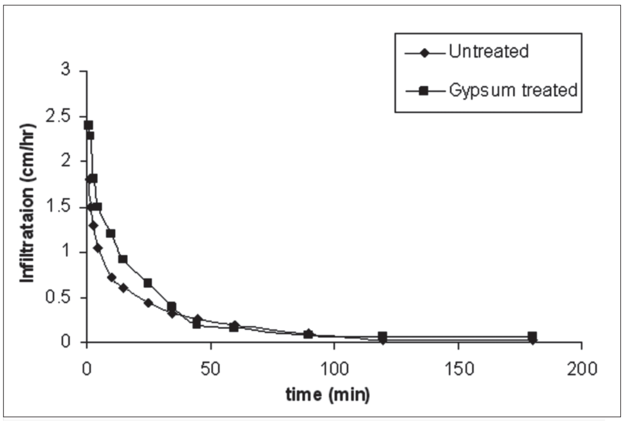

Fig. 1. Effect of gypsum treatment on infiltration rate

(ii) Planting of salt tolerance trees and crops:

Crops differ in their tolerance to soil sodicity (Abrol and Bhumbla, 1979). The relative tolerance of crops and grasses to soil exchangeable sodium per cent (ESP) is given in Table 4.

Crops and Cropping Pattern: Different crops vary widely in their tolerance to soil exchangeable sodium. In general, cereal like rice is more tolerant than legumes as they require less Ca, availability of which is a limiting factor in alkali soils. Crops which can stand withstand excess moisture conditions are generally more tolerant to alkali conditions. Among the cultivated crops, rice is most tolerant to soil sodicity. It can with stand an ESP of 50 without any significant reduction in yield. It is followed by sugar beet while crops like wheat, barley and oats etc. are moderately tolerant.

Table 4. Relative tolerance of crops and grasses to soil sodicity (ESP)

Tolerant (ESP: 35-50)	Moderately tolerant (ESP: 15-35)	Sensitive (ESP: < 15)
Karnal grass (*Leptochloa fusca*)	Rhodes grass (*Chloris gayana*)	Para grass (*Brachiaria mutica*)
Bermuda grass (*Cynodon dactylon*)	Rice (*Oryza sativa*)	Dhaincha (*Sesbania aculeata*)
Sugarbeet (*Beta vulgaris*)	Teosinte (*Euchlaena maxicana*)	Wheat (*Triticum aestivum*)
Barley (*Hordeum vulgare*)	Oat (*Avena sativa*)	Shaftal (*Trifolium resupinatum*)
Lucerne (*Medicago sativa*)	Turnip (*Brassica napus*)	Sunflower (*Helianthus annus*)
Safflower (*Carthamus tinctorius*)	Berseen (*Trifolium alexandrinum*)	Linseed (*Linum usitatissimum*)
Onion (*Allium cepa*)	Gralic (*Allium sativum*)	Pearl millet (*Pennisetum typhoides*)
Gram (*Cicer arietinum*)	Mung (*Phaseolus mungo*)	Chickpea (*Cicer arietinum*)
Lentil (*Lens esculenta*)	Soyabean (*Glycine max*)	Groundnut (*Arachis hypogea*)
Sesamum (*Sesamum oriental*)	Mash (*Phaseolus aureus*)	Pea (*Pisum sativum*)
Cowpea (*Vigna unguiculata*)	Maize (*Zea mays*)	Cotton (*Gossypium hirsutum*)

Source: Abrol and Bhumbla (1979)

Legumes like gram, mash and lentil, chickpea and pea etc. are very sensitive and their yield decreases significantly even when the soil ESP is less than 15. Sesbania is an exception among the leguminous crops as it can grow at ESP up to 50 without any reduction in yield. Due to this it is an excellent crop for green manuring in alkali soils. Some of the natural grasses like Karnal grass and Rhodes grass are very tolerant to soil sodicity, and in fact they grow normally under high alkali soil conditions. Green manuring practice of *Sesbania* sp. continuously for four to five years not only improves the permeability of alkali soils but also helps to reclaim the sodicity of the soils completely.

Salt Tolerant Varieties: A sizable part of the salt-affected area is in possession of small and marginal farmers who are themselves poor. Under such situations, chemical amendments based reclamation technology without government subsidy is not sustainable. Development of salt tolerant varieties of important field crops is an option of great promise for utilization of such areas. Most of these varieties give significant yield without or with little application of chemical amendments. Rice, wheat and mustard are dominant in Jammu and Kathua, salt tolerant varieties of these crops have been developed having potential to yield reasonable economic return both in high pH alkali soils and also in saline soils (Singh and Sharma, 2006). In case of rice, the most promising varieties include CSR10, CSR13, CSR19, CSR23, CSR27, CSR30, CSR43 and CSR36. These varieties can be cultivated in soils with pH and EC range from 9.4 to 9.8 and 6-11 dS m^{-1}. For wheat, KRL19, KRL1-4, KRL210, Raj3077 and WH157 are suitable for soils with pH and EC range from 8.8 to 9.3 and 6-10 dS m^{-1}. Pusa Bold, Varuna, CS52 and CS54 are salt tolerant mustard varieties. These can be better option for farmers for optimizing yields and restoration of salt affected soils.

Microbial approach for bio-remediation

Due to scarce availability of mineral gypsum and good quality waters, both physical and chemical methods for saline / sodic soil reclamation are not cost-effective. The biotic approach ‘plant-microbe interaction’ to overcome salt stress has recently received a considerable attention from many workers throughout the world. Plant-microbe interaction is beneficial association between plants and microorganisms and also a more efficient method used for the reclamation of salt affected soils (Arora *et al.*, 2014a,b). Halophilic bacteria are the most commonly used microbes in this technique. These halophilic rhizosphere bacteria improve the uptake of nutrients by plants and /or produce plant growth promoting compounds and regenerate the quality of soil. These plant growth promoting bacteria can directly or indirectly affect plant growth (Arora *et al.*, 2012; Trivedi and Arora, 2014). Indirect plant growth promotion includes nutrient transformations and prevention of deleterious effects of phytopathogenic organisms by inducing cell wall structural modifications, biochemical and physiological changes leading to the synthesis of proteins and chemicals involved in plant defense mechanisms.

CONCLUSION

Using RS and GIS data as well as ground truthing suggest emergence of salt affected soils in state of Jammu and Kashmir especially in canal command areas. There is more than 25000 ha land affected by salinity / sodicity. These soils need to be reclaimed for optimizing crop production. Application of 100%GR of agriculture grade mineral gypsum enhanced the rice-wheat yield and improved soil physical and chemical properties. However, the other approaches for amelioration of these soils include phytoremediation through cultivation of salt tolerant crops and varieties as well as bioremediation through halophilic plant growth promoting microbes. Accordingly the scientists of SKUAST-Jammu especially of Agronomy and Soil Science and Agricultural Chemistry are required to work in this line for farmers benefit.

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Runoff and soil loss estimation using hydrological models, remote sensing and GIS in *Shivalik* foothills: a review

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ABSTRACT

Shivalik foothills are considered as one of the eight most degraded eco-systems of the country. A large portion of monsoon rainfall goes as runoff in the torrents originating from the *Shivalik* foothills. The average annual soil loss in the *Shivalik* foothills is 16 t ha^{-1} $year^{-1}$ and in some watersheds it is more than 80 t ha^{-1} $year^{-1}$ owing to steep slopes, lack of vegetation and high intensity rainfall storms. Hydrological models, remote sensing and GIS techniques can be applied to quantify runoff and soil loss from the watersheds because manual quantification of runoff and soil loss is difficult, laborious and cumbersome. Different hydrological models are available and have been used individually and in conjunction with remote sensing and GIS to simulate and quantify runoff and soil loss from the watersheds in *Shivalik* foothills. Empirical and semi-empirical models like SCS curve number method, USLE, MUSLE, RUSLE and Morgan–Morgan–Finney model when integrated with remote sensing and GIS have proved to be more efficient in predicting runoff and soil loss both at field as well as at watershed scale. Deterministic models like ROMO2D, DREAM and WEPP models tested in different regions of lower *Shivaliks* also gave satisfactory results although their input data requirement is high. So empirical and semi-empirical models integrated with remote sensing and GIS as well as deterministic models can be successfully used for development of decision support systems for soil and water conservation planning in the region.

Key words: Runoff, Soil loss, Hydrological models, GIS, Shivaliks

INTRODUCTION

Soil erosion by water is the root cause of ecological degradation in *Shivalik* foothills of Northern India. It remains a major threat to the *Shivalik* region of sub Himalayan mountainous environment. The *Shivalik* foothills are a part of the Himalayan mountain chain which continuously runs from Jammu, Kangra Valley, Sirmur district to Dehradun and finally end up at Bhabbar tracts of Garhwal and Kumaon. The *Shivalik*s are facing serious problems like soil erosion, degradation of water catchment areas which is reducing agricultural productivities (Gupta *et al*., 2010). The erosion has led to loss of a large amount of soil causing the soils to become shallow and erodible. The extent of degraded land in this area was 194 km^2 in 1852, 2000 km^2 in 1939, while it increased to 20,000 km^2 in 1981 (Patnaik, 1981). Erratic distribution of rainfall, small landholdings, lack of irrigation facilities, heavy biotic pressure on the natural resources, inadequate vegetative cover, heavy soil erosion, landslides, declining soil fertility and frequent crop failures resulting in scarcity of food, fodder and fuel are the characteristics of this region. A large portion of monsoon rainfall (35-40%) goes as runoff in the torrents originating from the *Shivalik* foothills (Bhardwaj and Rana, 2008; Sharma and Arora, 2015). The average annual erosion rate in the *Shivalik* foothills is 16 t $ha^{-1}year^{-1}$ and in some watersheds it is more than 80 t $ha^{-1}year^{-1}$ (Singh *et al.*, 1992; Bhardwaj and Kaushal, 2009a; Kukal and Singh, 2015). This clearly shows that some form of soil conservation or soil protection policy is needed urgently in this area for which it is essential to quantify runoff and soil loss in the *Shivalik* foothills.

There is need to understand the physical process of erosion in relation of topography, land use and management to come up with best management practices. Planned land use and conservation

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measures to optimize the use of land and water resources help in increasing sustainable agricultural production (Arora and Gupta, 2014). However, to achieve this, quantification of runoff and soil loss from the watersheds is must. Since it is very often impractical or impossible to directly measure soil loss on every piece of land, and the reliable estimates of the various hydrological parameters including runoff and soil loss for remote and inaccessible areas are tedious and time consuming by conventional methods. So it is desirable that some suitable methods and techniques are used / evolved for quantifying the hydrological parameters from all parts of the watersheds. Use of mathematical hydrological models to quantify runoff and soil loss for designing and evaluating alternate land use and best management practices in a watershed is one of the most viable options.

Erosion models are used to predict soil erosion. Soil erosion modeling is able to consider many of the complex interactions that influence rates of erosion by simulating erosion processes in the watershed. Various parametric models such as empirical (statistical / metric), conceptual (semi-empirical) and physical process based (deterministic) models are available to compute soil loss. In general, these models are categorized depending on the physical processes simulated by the model, the model algorithms describing these processes and the data dependence of the model. Empirical models are generally the simplest of all three model types. They are statistical in nature and based primarily on the analysis of observations and seek to characterize response from these data (Wheater *et al.*, 1993). The data requirements for such models are usually less as compared to conceptual and physical based models. Conceptual models play an intermediary role between empirical and physics based models. Physical process based models take into account the combination of the individual components that affect erosion, including the complex interactions between various factors and their spatial and temporal variabilities. These models are comparatively over-parameterised.

There have been several hydrological models developed to estimate runoff and soil loss from a watershed. USLE, RUSLE, EPIC, ANSWERS, DREAMS, CORINE, ICONA, MIKE SHE, Erosion-3D, AGNPS, CREAMS, SWAT and WEPP are few among the models. One of the major problems in testing these models is the generation of input data, that too spatially. The conventional methods proved to be too costly and time consuming for generating this input data. With the advent of remote sensing technology, deriving the spatial information on input parameters has become more handy and cost-effective. Besides with the powerful spatial processing capabilities of Geographic Information System (GIS) and its compatibility with remote sensing data, the soil erosion modeling approaches have become more comprehensive and robust (Thakur *et al.*, 2012). Satellite data can be used for studying erosional features, such as gullies, rainfall interception by vegetation and vegetation cover factor. DEM (Digital Elevation Model) one of the vital inputs required for soil erosion modeling can be created by analysis of stereoscopic optical and microwave (SAR) remote sensing data. The integrated use of remote sensing and GIS could help to assess quantitative soil loss at various scales and also to identify areas that are at potential risk of soil erosion (Saha *et al.*, 1992). This paper presents the application of different hydrological models, remote sensing and GIS in estimating runoff and soil loss from the *Shivalik* foothills.

Empirical models like Soil Conservation Services Curve Number (SCS-CN) method, developed by Soil Conservation Services (SCS) of USA in 1969 have been widely used throughout the world for estimation of the direct runoff depth. This method is based on the potential maximum retention of the watershed which is determined by the wetness of the watershed, i.e. the antecedent moisture condition and physical characteristics of the watershed. Mishra (2014) applied the SCS curve number method to estimate the runoff from a watershed in Uttarkashi, Uttarakhand. Analysis of surface runoff by SCS CN model indicated that a considerable portion of precipitation flows off the watershed as runoff resulting in water scarcity and the main reason of agricultural drought in the watershed. The average seasonal runoff was found to be almost 79 per cent of annual runoff. Chanu *et al.* (2015) calculated weighted Curve Number for the entire Dadri Mafi micro-watershed based on site information of the watershed and found to be 82.40 for AMC II. The CN values corresponding to AMC I and AMC III were 66.28 and 91.50 respectively. The runoff for each storm events was estimated using Curve Number method and it was found that among the selected storm events maximum rainfall of 184 mm occurred on July 7, 2012 giving runoff value of 158.44 mm and minimum rainfall of 35 mm occurred on July 13, 2009 with runoff value of 0.61 mm. Runoff volume of the micro-watershed for each storm events were also calculated and maximum runoff was found be 918499.37 m^3. Strong correlation has been observed between rainfall and estimated runoff as well as observed and estimated runoff which indicate applicability of SCS-CN method in predicting runoff for the study area. Raina *et al.* (2009) applied the modified SCS CN method (known as CN-VSA) to estimate and compare the runoff and moisture storage values of treated and untreated watersheds in *Shivalik* foothills. A good agreement of predicted runoff with observed runoff for CN-VSA method when compared with traditional SCS CN method was determined. Jasrotia *et al.* (2002) employed the SCS method to study the rainfall-runoff relationship in the *Shivalik* foothills of Jammu region. Very high coefficient of determination (0.99) was found between rainfall and estimated runoff. The runoff potential map was prepared by assigning individual class weights.

Several empirical equations have been developed for years to quantify the soil loss from the field plots and at the watershed scale. But the computation of soil loss from earlier developed equations was limited only to slope length and slope steepness, which is not justifiable. Apart from slope steepness and slope length, the soil loss is also affected by several other factors, viz. climatic characteristics, soil characteristics, crop management and conservation practices. Taking all these factors into account, Wischmeir and Smith (1965) developed the Universal Soil Loss Equation (USLE) to estimate the soil loss from field-size small area. The USLE is a powerful tool that has been used worldwide from the last three decades for on farm planning and management of the conservation practices, assessing the regional and national impacts of erosion and developing as well as implementing public policy related to the soil conservation. Singh and Khera (2009) used USLE to predict soil loss under different land uses for natural and simulated rainfall conditions in lower *Shivaliks* of Punjab. The nomograph for estimation of K value was modified. USLE does not compute the sediment yield from the watershed directly. Therefore, Williams (1975) modified the rainfall erosivity factor in the USLE to rainfall-runoff factor named it as Modified Universal Soil Loss equation (MUSLE). MUSLE estimates the sediment yield instead of average annual soil loss. Bhatt *et al.* (2012) demonstrated the general ability of erosion models such as USLE and MUSLE to estimate sediment yields from forest micro watershed located in *Shivalik* foothills of Punjab. Values of K, LS, C and P of USLE and MUSLE on the basis of vegetation density, type of soil and slope of watershed were worked out. The estimated values of sediment yield by MUSLE were found very close to observed values than the values estimated by USLE.

Recently GIS techniques have been integrated with these empirical models to compute the spatial and temporal variation in the watershed characteristics and hydrological variables. Jasrotia and Singh (2006) used remote sensing data and GIS techniques to compute runoff and soil erosion in a watershed located in *Shivalik* foothills of Jammu covering an area of approximately 181 km^2. Different thematic layers, for example lithology, land use and land cover map, geomorphology, slope map and soil-texture map were generated from these input data. The SCS curve number method was used to estimate runoff from the watershed. Annual spatial soil loss estimation was computed using the Morgan–Morgan–Finney (MMF) mathematical model in conjunction with remote sensing data and GIS techniques. It was found that a maximum average soil loss of more than 20 t ha^{-1} occurred in 31 km^2 of the catchment area.

Two different erosion prediction models were applied by Jain *et al.* (2001) i.e. Morgan model and USLE model, to estimate the soil loss from a Himalayan watershed located in Doon valley, Uttarakhand covering an area 52 km^2. The input parameters for both the models were generated using remote sensing and GIS techniques. The results of the study indicated that the soil erosion estimated by Morgan model was of the order 2200 t km^{-2} $year^{-1}$ and was well within the limits. On the other hand, USLE model over predicted the soil erosion in the watershed. It was concluded that Morgan model better predicts soil erosion in the watershed as compared to USLE model. Kumar *et al.* (2005) employed GIS environment to predict erosion risk using semi-empirical MMF model. The digital elevation map (DEM) derived from SRTM was used as the base for topographic- related analyses in the model. The soil, land use, and other related input parameters of the model were derived using remote sensing data. The predicted average soil loss for croplands varied from 10.5 to 21.1 t ha^{-1} yr^{-1} whereas in *Shivalik* foothills it ranged from 25.3 to 44.32 t ha^{-1} yr^{-1}. Area under moderate, high and very high soil erosion risk was estimated to be 33.4 %, 26.0 % and 2.92 %, respectively. Jasrotia *et al.* (2002) computed the annual spatial soil loss estimation using MMF model in conjunction with remote sensing and GIS techniques. Higher soil erosion was found to occur in the northern part of the Tons watershed located in Dehradun. The average soil loss for all the four sub-watersheds was calculated, and it was found that the maximum average soil loss of 24 t ha^{-1} occurred in the sub-watershed 1.

The Revised Universal Soil Loss Equation (RUSLE) model is applied worldwide to soil loss prediction. It represents the effect of climate, soil, topography and land use on rill and inter rill soil erosion caused by raindrop impact and surface runoff (Renard *et al.,* 1997). In the recent years, RUSLE has been integrated with remote sensing and GIS to quantify soil loss and prepare soil erosion risk maps for prioritizing, designing and evaluating alternate land use, soil conservation treatments and best management practices in different watersheds. Kumar and Kushwaha (2013) integrated RUSLE-3D with GIS for predicting the soil loss and the spatial patterns of soil erosion risk required for soil conservation planning. High resolution remote sensing data (IKONOS and IRS LISS-IV) were used to prepare land use / land cover and soil maps to derive the vegetation cover and the soil erodibility factor whereas DEM was used to generate spatial topographic factor. Average soil loss was predicted to be lowest in very dense forest and highest in the open forest in the hilly landform. The study predicted that 15% area has moderate to moderately high and 26% area has high to very high risk of soil erosion in the sub-watershed. Similarly, Kushwaha (2015) applied RUSLE model integrated with the GIS framework in a Takarla-Ballowal watershed located in Shivalik foothills of Punjab. Satellite imagery of LISS IV data, Survey of India toposheet (53 A / 8) on 1:50,000 scale, ASTER data for preparing Digital Elevation Model (DEM) and ArcGIS-9.3 software was used in the study. The watershed was divided into nine micro-watersheds (MWS-1 to MWS-9) with area ranging from 88.03 ha to 376.72 ha. The average annual soil loss in the watershed ranged from 63.46 t ha^{-1} yr^{-1} (MWS-1) to 5.73 t ha^{-1} yr^{-1} (MWS-8).

Deterministic models are the complex models, which require lot of data for the operation as they take into account the physics behind the processes which are simulated. A number of deterministic models have been developed and applied (e.g. ROMO2D, DREAM, WEPP etc.) in the Shivalik foothills. Bhardwaj and Kaushal (2009 a,b) developed a two-dimensional physically based distributed numerical model, ROMO2D to simulate runoff from small agricultural watersheds on an event basis. The model writes output for a runoff hydrograph of each storm. The model was applied to a 1.45 ha agricultural watershed located in the *Shivalik* foothills to simulate runoff. The results demonstrated the potential of the model to simulate runoff from small agricultural watersheds for individual storm events with reasonable accuracy. Ramsankarn *et al.* (2011) applied GIS based distributed rainfall-runoff model for simulating surface flows in small to large watersheds during isolated storm events. The watershed was discretized into overland planes and channels using the algorithms proposed by Garbrecht and Martz (1999). The model was tested in a medium-sized semi-forested watershed of Pathri Rao located in the *Shivalik* ranges of the Garhwal Himalayas. The results of performance evaluation indicate that the model has simulated the runoff hydrographs reasonably well within the watershed as well as at the watershed outlet with the same set of calibrated parameters. The model also simulates, realistically, the temporal variation of the spatial distribution of runoff over the watershed.

Distributed Runoff and Erosion Assessment Model (DREAM) was applied in the semi-forested watershed of Pathri Rao, in the Garhwal Himalayas to simulate runoff and sediment yield (Ramsankaran *et al.,* 2012). The model takes account of watershed heterogeneity as reflected by land use, soil type, topography and rainfall, measured in the field or estimated through remote sensing, and generates estimates of runoff and sediment yield in spatial and temporal domains. The validation study conducted to test the performance of the model in simulating soil erosion and sediment yield during different storm events monitored in the study watershed showed that the model outputs were satisfactory. The distributed nature of the model combined with the use of GIS techniques permits the computation and representation of the spatial distribution of sediment yield for simulated storm events.

WEPP model was applied to simulate storm wise runoff and sediment yield from a small forest watershed having an area of 21.3 ha located in *Shivalik* foothills (Yousuf *et al.,* 2015). The sensitivity analysis of the model shows that the model output is sensitive to hydraulic conductivity, rill erodibility, inter-rill erodibility and critical shear of the soil. The model was calibrated and validated using observed data on runoff and sediment yield pertaining to 22 storms. The model simulated runoff and sediment yield with reasonable accuracy as corroborated by low values of RMSE, percent error and high values of correlation coefficient and model efficiency. The results of the study indicate the suitability of the WEPP model for its future application in *Shivalik* foothills. Sharma (2012) used the WEPP model to simulate and quantify runoff from a rangeland watershed having an area of 15.55 ha located in *Shivalik* foothills of Punjab. The watershed area was divided into 33 hillslopes and 14 channel segments. The overall statistical model performance parameters namely percent error of 4.9%, RMSE of 0.56, correlation coefficient of 0.93 and model efficiency of 81% indicated reasonably accurate simulation of runoff at the watershed scale. It was concluded that the WEPP model can be applied to simulate runoff from the watersheds in *Shivalik* foothills. Kumar *et al.* (2005) applied WEPP model to simulate surface runoff and soil loss in a mini watershed (57 ha) of Sitlarao watershed in hilly terrain using the WEPP watershed model v. 2002.7. The surface runoff generated for rain events of low to medium rain intensity by WEPP model matched with observation while its performance was poor for high rain intensity. WEPP model provide explicit spatial and temporal estimate of soil erosion and surface runoff generation of hillslope and in the watershed. Results bring out utility of WEPP model after calibration for soil and water conservation planning at micro / mini watershed level.

CONCLUSION

Hydrological models have a lot of scope in quantifying runoff and soil loss from the watershed in *Shivalik* foothills, especially in those watersheds which are inaccessible. Remote sensing and GIS play an important role in understanding the physiological behaviour of the watersheds. The integration of remote sensing and GIS with the hydrological models has increased the efficiency of the hydrological models, especially in case of empirical models which do not take into the physics of the processes simulated. Deterministic models and empirical models integrated with GIS also give the spatial distribution of runoff and soil loss within the watershed which helps in locating the most erosion prone areas within the watersheds. The integrated outcome of the hydrological models along with remote sensing and GIS can be helpful for the decision makers to evaluate the best management practices and design the necessary soil and water conservation structures to reduce the soil erosion in the *Shivalik* foothills.

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Irrigation water management strategies for wheat under sodic environment

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ABSTRACT

Wheat (*Triticum aestivum*) is a moderately salt-tolerant crop as well as susceptible to excess application of irrigation water. This requires a proper strategy when crop like wheat is grown under sodic environment. As it is evident that, 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. Thus, irrigation strategy for wheat in sodic soils differs from normal soils in terms of irrigation depth and irrigation frequency. An experiment to determine the suitable irrigation strategy along with methods of application namely: Surface (farmer's practice), Sprinkler (double nozzle impact sprinkler), and LEWA (Low Energy Water Application) were initiated in the year 2012 for wheat crop. 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 based on IW/CPE ratios of 1.0, 0.8 and 0.6 through surface, sprinkler and LEWA methods were imposed. The results revealed that Sprinkler and LEWA resulted in highest wheat yield of 2.4 t/ha to 2.5 t/ha, which was 10 to 20 percent higher than the highest wheat yield recorded under surface irrigated plots by using 30 to 40 percent less water. Hence, use of sprinkling devices to irrigate wheat may not only lead to substantial saving of water as well as energy in terms of fuel used for pumping without compromising the crop yield under sodic environment.

Key words: Sodic Soils, Irrigation scheduling, Irrigation Water Productivity

INTRODUCTION

The major characteristics of sodic soils are that they have a relatively low EC, but a high amount of Na^+ occupying exchange sites, often resulting in the soil having a pH at or above 8.5, besides, less available water, poor tilth and seldom a black crust on the surface formed from dispersed organic matter. In Indo-gangetic plains, these soils are generally light to medium textured, sandy loam at the surface, and clay loam in lower depths with $CaCO_3$ concentration at 0.5 to 1.0 m depth. These characteristics of sodic soils posses great threats initially to seedling emergence, thus obstructing the plant growth and further creating unfavorable condition for root penetration. The clay content of soil and associated properties governs the water retention. It is reported that approximately 9.5 Mha of lands facing salt problem in India. Out of this 3 Mha are alkali or sodic soils and most of these are located in Indo-gangetic plains region. Rice in kharif season and wheat in rabi season are the dominant crops in the region. Adoption of faulty irrigation practices are also one of the major reasons for poor crop growth as it is observed that normally irrigation practices recommended for normal soils are being practiced for sodic environment at farmer's field. This further provides stress on wheat crop inspite of challenges faced due to presence of salt in the soil.

Sodic soils have reduced capacity to absorb water due to poor infiltration characteristics, unfavorable soil conditions such as high pH and high levels of exchangeable sodium in subsoil layers in sodic or partially reclaimed sodic soils restricts root penetration of crops to lower soil layers, confining roots to the upper few centimeters

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depending upon the degree of soil improvement (Abrol *et al.*, 1988). This requires to explore appropriate irrigation strategies as the general irrigation practice is to provide irrigation based on crop growth stages (counting number of days from sowing) with application of 6 cm to 8 cm of irrigation depth depending upon the location, soil characteristics etc leading to 3 to 4 irrigation. These strategies, resulting in to inefficient use of water as well as energy (diesel or electricity used for pumping irrigation water) while practicing irrigation in wheat under sodic environment. Hence, a suitable irrigation strategy needs to be devised not only for water and energy saving but in achieving optimum crop production.

In this direction, various studies reports considerable irrigation water savings through improved irrigation strategies (Prihar *et al.*, 1974; 1978a). The guidelines for irrigation scheduling were established for wheat on the coarse textured soils of northwest India. It has been mentioned that application of 40 cm of depth per irrigation in lieu to evapo-transpiration is required which can be applied at different crop growth stages with a total of 4-5 irrigation. Nos. of irrigation may be increased to 6-8 for sandy loam soil and reduced to 3-4 irrigation for clay soil. Prihar *et al*. (1978b) concluded that wheat should be irrigated at around 60 % to 70% depletion of plant available soil water storage to avoid yield loss, with the lower value for the lighter soil. Similar recommendations have been made by Singh and Malik (1983), where they reported 50% for sandy loam soil. Increased relative growth rate, rooting density, productive tiller per meter and grain yield of wheat by increasing the irrigation frequency in wheat grown in sodic soils as reported by Sharma (1994). It was also mentioned that three irrigations given at crown root initiation, tillering and milk stage gave significantly higher grain yield with maximum water use efficiency, where, most of the evapotranspiration demand occurred from the 0–15 cm soil layer. Frequent irrigation maintains better water availability in the active root zone that result in dilution of salts (Oad *et al.*, 2002). Most of the earlier studies focuses mainly on irrigation scheduling i.e. when to irrigate? However, not much emphasis have been given on mode of irrigation water application and depth of water to be applied, whereas, these decisions are also key in enhancing water use efficiencies. Camp (1998) reports pressurized irrigation systems (sprinkler, surface and subsurface drip) have the potential to increase irrigation water use efficiency by providing water to match crop requirements, reducing runoff, avoiding deep drainage losses, and generally keeping the soil drier reducing soil evaporation and increasing the capacity to capture rainfall. There are few reports of the evaluation of these technologies in rice-wheat systems (Singh *et al*., 2014, 2016). They reported saving of 30% of irrigation water by use of sprinkling methods over surface methods in rice and wheat under sodic environment. Initially, pressurized irrigation was advocated mainly for higher value crop or row crops, but considering amount of water consumed through surface irrigation methods for even in cereals or close growing crops various efforts has been undertaken to develop efficient irrigation technology packages focusing their economic viability.

Keeping this in view, a study was undertaken at Shivri farm of CSSRI-RRS, Lucknow to evaluate the performance of sprinkling irrigation systems over surface method of irrigation under sodic environment. The paper presents the output of the investigation focusing water and energy saving while practicing irrigation in wheat crop under sodic environment. These strategies may suit well to sodic soils for improving crop productivity as well as saving water and energy used for pumping by the prime mover. 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 wheat 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 26^0 47’ 45" N to 26^0 48’ 13" N on latitude and 80^0 46’ 7" E to 80^0 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 Shivri 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 saturated paste) 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 Mg m^{-3} and 1.71 Mg m^{-3}.

Field experiment

Field experiments were carried from 2012 to 2014 and results presented comprises of data recorded for rabi crop seasons (2012-13, 2013-14 and 2014-15). Three methods of irrigation were used namely: Surface, Sprinkler (impact type) commercially available in local market and LEWA (Low Energy Water Application device developed by ICAR-RCER, Patna) (Singh *et al*., 2004, 2008, 2010; Rahman and Singh, 2014; Singh *et al*., 2015). 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 the same 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 wheat crop is application of 5 cm to 6 cm irrigation depth for wheat at various crop growth stages. 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 based on IW/CPE ratios of 1.0, 0.8 and 0.6. Overall, there were a total of nine different irrigation strategies evaluated with three different methods of water application. 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 of the 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 sowing of wheat through seed drill was undertaken. The crop management practices were common to all treatments. The salt tolerant variety recommended for sodic environment of wheat was sown during 3rd to 4th week of November. 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 and Analysis

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.

Crop yield

The crop yield of Wheat were recorded by undertaking crop cutting from three locations in each plots and averaged.

Cost of irrigation

Based on the total expenditure incurred on account of the fuel used for operating the irrigation pump, the cost of the irrigation for each irrigation strategy was analyzed.

Water and fuel 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 fuel energy productivity analyzed in terms of Rs. per unit cost of fuel (diesel) used. The energy productivity represents the ratio of cost of produce and cost of total fuel (diesel) used to pump the irrigation water. The cost of produce under this study was considered as Rs. 14 per kg of wheat grain and the cost of diesel considered was Rs. 60 per litre.

RESULTS AND DISCUSSION

Water and pumping energy use pattern

The average number of irrigation practiced, depth of irrigation applied, pumping hours and expenditure on the fuel incurred to pump the irrigation water in wheat crop is presented in Table 1 and 2. It is observed that irrigation event varies with the irrigation intensity thus the average depth of irrigation. Under surface irrigation method the highest number of irrigation recorded in wheat when irrigation was scheduled at IW/CPE ratio of 1.0 and 0.8. Whereas, lowest irrigation event recorded when irrigation was scheduled at IW/CPE ratio of 0.6. Similarly, the trend incase of sprinkler and LEWA methods reflects that the highest number of irrigation event occurred when irrigation was scheduled at IW/CPE ratio of 1.0 and lowest at IW/CPE ratio of 0.6.

This reflects that with increase in irrigation event the average depth of irrigation increases and vice-versa. The corresponding pumping hours and expenditure on practicing irrigation is depicted through Table 2. It is observed that the trends are similar to number of irrigation practiced and depth of irrigation applied. Irrigation schedule of IW/CPE ratio of 1.0 incurred highest expenditure and IW/CPE ratio of 0.6 incurred lowest expenditure, under surface method of irrigation. Similarly, incase of sprinkler and LEWA methods the highest expenditure incurred when irrigation was scheduled at IW/CPE ratio of 1.0, whereas, lowest expenditure incurred when irrigation was scheduled at IW/CPE ratio of 0.6.

This clearly indicates that with increase in frequency of irrigation the irrigation event will increase which further results in application of higher depth of irrigation water and thus incurring higher expenditure to apply irrigation. These trends were further analyzed of their impact on wheat yield under different irrigation regime and presented further.

Table 1. Irrigation practiced under different irrigation methods and schedules in wheat

Irrigation Method	Irrigated Area (m^2)	Irrigation depth per event (cm)	Irrigation Schedule	Average Number of Irrigation (cm)	Average Depth of Irrigation (cm)
Surface	344	6	IW/CPE – 1.0	2	12
			IW/CPE - 0.8	2	12
			IW/CPE - 0.6	1	6
Sprinkler	480	4	IW/CPE – 1.0	3	12
			IW/CPE - 0.8	2	8
			IW/CPE - 0.6	1	4
LEWA	480	4	IW/CPE – 1.0	3	12
			IW/CPE - 0.8	2	8
			IW/CPE - 0.6	1	4

Table 2. Cost to practice irrigation under different irrigation methods and schedules in wheat

Irrigation Method	Irrigated Area (m^2)	Irrigation Schedule	Pumping hours (hrs)	Fuel used for Irrigation (L)	Cost incurred on fuel (INR) @ 60/-
Surface	344	IW/CPE - 1.0	3.0	3.0	180.0
		IW/CPE - 0.8	3.0	3.0	180.0
		IW/CPE - 0.6	1.5	1.5	90.0
Sprinkler	480	IW/CPE - 1.0	6.0	6.0	360.0
		IW/CPE - 0.8	4.0	4.0	240.0
		IW/CPE - 0.6	2.0	2.0	120.0
LEWA	480	IW/CPE - 1.0	4.2	4.2	252.0
		IW/CPE - 0.8	2.8	2.8	168.0
		IW/CPE - 0.6	1.4	1.4	84.0

Effect of Irrigation Regime on Wheat Yield

The effects of varying irrigation regime on wheat yields are depicted through Fig. 1. It is observed that under all the three methods of application the irrigation schedule of IW / CPE ratio of 0.8 resulted in highest wheat grain yield. Under surface irrigated plots, irrigation schedule of IW / CPE ratio of 0.8 and 0.6 resulted in highest yield but, performance of IW / CPE ratio of 0.6 under surface irrigated plots was not consistent, whereas, IW / CPE 0.8 performed best throughout the three years of experimentation. The sprinkler and LEWA irrigated plots recorded an average wheat yield of 2.4 t ha^{-1} and 2.5 t ha^{-1} when irrigation was scheduled at IW / CPE ratio of 0.8. This reflect that application of lighter depth of irrigation incase of wheat through sprinkling methods may result into 10 to 12% of higher yield over surface method under sodic environment.

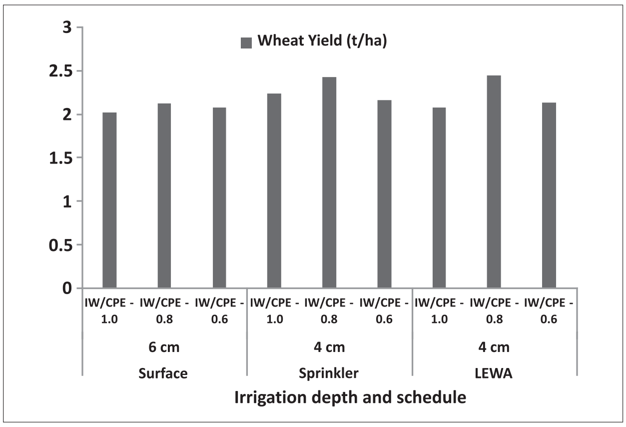

Fig. 1. Effect of varying irrigation regime on yield of wheat

Water and Energy Saving

Considering water and energy saving pattern, it was observed that, under surface irrigated plots, IW / CPE ratio 0.8 uses irrigation water at par to the irrigation schedule of IW / CPE ratio 1.0 but have resulted 5% higher yield, whereas, in comparison to irrigation schedule of IW / CPE 0.6, comparatively higher depth of irrigation water was used. Similarly, under Sprinkler and LEWA irrigated plots, irrigation schedule of IW / CPE 0.8 resulted 10 to 20% higher yield over IW / CPE ratio of 1.0 and 0.6. The water use pattern reflects that IW / CPE ratio 0.8 uses 30% less water in comparison to IW / CPE ratio of 1.0 and comparatively higher water in comparison to IW / CPE ratio of 0.6. This reflects that in view of obtaining higher yield IW / CPE ratio of 0.8 may be the better irrigation stratagey, whereas, considering water and pumping energy saving IW / CPE ratio of 0.6 may be followed by compromising 10 to 20% of wheat yield.

Water and Energy Producitvity and Yield

The water and energy productivity achieved under different irrigation regimes of wheat were analysed and depicted alongwith grain yield in Fig 2. The irrigation water productivity (in monetary returns (INR) per m^3 water used) for different irrigation regimes under surface irrigation was 16.87, 17.71 and 34.72 at IW / CPE ratio of 1.0, 0.8 and 0.6 respectively. The energy productivity (pumping) (monetary returns (INR) per unit cost of fuel used) was 3.87, 4.06 and 7.96 at IW / CPE ratio of 1.0, 0.8 and 0.6 respectively for surface irrigation. This implied that water and energy productivity of surface methods improved when irrigation schedule is switched from IW / CPE ratio of 1.0 to 0.8 and 0.6. Comparing yield trend of these plots it is depicted that IW / CPE ratio of 0.8 resulted in higher yield, whereas, yields under IW / CPE ratio of 1.0 and 0.6 declined marginally. Hence, IW / CPE ratio of 0.8 incase of surface irrigation is suitable option for achieving higher yields or IW / CPE ratio of 0.6 where marginal decline in yield was compensated by saving in terms of cost of water and pumping energy under sodic environment. The irrigation water productivity observed incase of Sprinkler was 18.69, 30.43 and 54.11 Rs. per m^3 at daily, 1-day and 2-day intervals, respectively; and energy productivity was 2.99, 4.87 and 8.66 at daily, IW / CPE ratio of 1.0, 0.8 and 0.6 respectively. Similarly, under LEWA irrigation, water productivity observed was 17.33, 30.66 and 53.50 Rs. per m^3 at IW / CPE ratio of 1.0, 0.8 and 0.6 respectively, and energy productivity was 3.92, 6.93 and 12.08 Rs, per unit cost of fuel (diesel) used at IW / CPE ratio of 1.0, 0.8 and 0.6, respectively. The corresponding yield trends in case of Sprinkler and LEWA, showed higher 10 to 20% yield at IW /

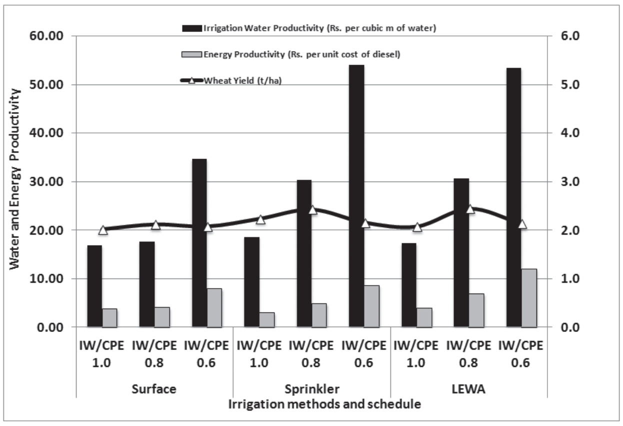

Fig. 2. Water and energy productivity and wheat yield trends

Table 3. Best performing irrigation schedules under wheat crop

Crop	Wheat		
Irrigation Method	Surface	Sprinkler	LEWA
Irrigation area (m^2)	6 cm	4 cm	4 cm
Irrigation schedule	IW / CPE – 0.8	IW / CPE – 0.8	IW / CPE – 0.8
Total depth of irrigation (cm)	12	8	8
Yield (t / ha)	2.1	2.4	2.5
Irrigation Water Productivity (Rs. per cubic meter of water used)	17.71	30.43	30.66
Energy Productivity (Rs. per unit cost of diesel used for pumping)	4.06	4.87	6.93

CPE ratio of 0.8 compared to IW / CPE ratio of 1.0 and 0.6. This suggested that in case of sprinkling (Sprinkler and LEWA) methods, irrigation scheduling at IW / CPE ratio 0.8 will be a better option in terms of higher water and energy productivity.

CONCLUSION

Based on impact of water application pattern on yield of wheat the best performing irrigation schedules under different modes are categorized on the basis of highest yield under each rrigation method and depicted through Table 3. The water and fuel used are averaged for three years representing irrigated area, whereas, yield were converted on hectare basis. It is observed that total water use incase of wheat through sprinkling methods (Sprinkler and LEWA) is less without compromising the yield. This resulted in saving of water in the range of 30 to 40% by sprinkling methods over surface methods of irrigation. In turn, the irrigation water productivity of sprinkling methods just doubled than the surface method of irrigation. The fuel used to pump the irrigation has direct impact on energy productivity and reflects that applying water through LEWA have resulted in highest energy productivity followed by sprinkler and surface method. The energy productivity of surface and sprinkler methods is nearly at par; this is, due to higher operating pressure requirement of sprinkler nozzles used during the experimentation. It is suggested to use sprinkler nozzles requiring low operating pressure to achieve higher energy productivity. Overall, it is observed that there is substantial saving of water while practicing irrigation through sprinkling methods over surface method of irrigation.

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Geospatial technology in soil resource inventory and land capability assessment for sustainable development – Wayanad district, Kerala

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ABSTRACT

Geospatial technology has opened new vistas for natural resources mapping and their management. It has been widely used for soil resources inventory and generation of spatial and temporal information for sustainable landuse plan at a specific scale. The present study was undertaken to identify the different physiographic situations, landforms and soil resources to assess the chemical and physical inherent soil properties, topography, slope, climate and land use as an external land feature. IRS-ID (LISS-III) satellite data was used to delineate different physiographic units using image interpretation keys on 1:50,000 scale alongwith exhaustive ground truthing. The soils were classified on the basis of Soil survey and laboratory data. The generated spatial and non-spatial data was integrated in the Geographic Information System (GIS) environment and various thematic layers were derived to prepare land capability map of the district. The main physiographic units identified in the study area were undifferentiated hill slopes, pediments, pediplains and narrow river valleys. The soils found in the area were moderately deep to deep, fine loamy to fine textured on hill side slopes occupying 71.6% area, deep to very deep, fine loamy to fine textured on pediments covering 7.8% area and very deep, fine to coarse loamy soils, mostly aquic in nature in narrow river valleys with 19.3% area of district and classified as Entisols, Inceptisols and Mollisols. It was found that soils of the valley fall in land capability class- II, pediments in class- III and hills in the range of IV to VIII.

Key words: Geospatial, GIS, IRS-ID, LISS-III, Pediment, Land capability

INTRODUCTION

Soil is a life supporting system upon which civilization have been dependent and intensification of agriculture on land used for farming system in last few decades, a sequence of change has immerged in traditional resource use due to population pressure and increasing demand for food, fodder, fuel etc. in the every region. Thus management of natural resources, specially become essential for variety of purposes *viz.* command area development, soil conservation in catchment areas, sustainable agriculture, watershed management, reclamation of degraded lands etc. Soil resource inventory provides an insight into the potentialities and limitation of soil for its effective exploitation and interpretation for multifarious land uses. Understanding the soil distribution patterns in relation to landscape attributes is seen as a step to improve the accuracy of soil mapping in remote locations. However, this variation is not random because the properties of soil vary from place to place. Natural soil bodies are the result of climate and living organisms acting on parent material, with topography or local relief exerting a modifying influence with time required for soil-forming processes to act (Soil Survey Division Staff, 1993).

Topography is often used in soil distribution studies for prediction of soil type as because it has a overwhelming influences on most of the soil forming factors (Jenny, 1980; Pennock *et al*., 1987; Moore *et al*., 1993; McKenzie *et al*., 2000; Ballabio, 2000). Soil physic-chemical properties are one of the important information categories for appropriate land management and environmental modeling (Florinsky *et al*., 2002; Herbst *et al*., 2006; Ziadat, 2007; Dhale *et al*., 2015).

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The soil can be characterized by its structure, color, consistence, texture, and abundance of roots, cracks, and carbonates. These characteristics allow scientists to interpret how the soil ecosystem functions and make recommendations for soil use that have a minimal impact on the ecosystem. It can help them to determine the types of vegetation and land use best suited to a location (Globe, 2005). Characterization of soils is fundamental to all soil studies, as it is an important tool for soil classification, which is done based on soil properties. Soil characterization also helps to document soil properties at research sites, which is essential for the successful transfer of research results to other locations (Buol *et al*., 2003). Natural soil phenomenon and conservation processes play crucial role in designing sustainable land use plan (Joseph *et al*., 2016).

Remote Sensing has emerged as an important tool in soil resource inventory and generation of information on spatial and temporal basis which helps in evolving the optimum landuse plan for sustainable development at specific scale. The satellite data is interpreted as a function of soil properties and soil units delineated with respect to image characteristics and correlated with landform-topography information from Survey of India Toposheets and geology information from district resource map geological survey of India. The dynamic inter-relationship between physiography and soils is utilized for deriving soil information from satellite data (Kudrat *et al.,* 1992). In interpretation of satellite image for soil mapping proper identification of land type, drainage pattern, and drainage condition, vegetation, land use, slope and relief is very essential (Dwivedi, 2001).

Wayanad district stands on the southern tip of the Deccan plateau and Chembra Peak [2,100 metres (6,890 ft)], Banasura Peak [2,073 metres (6,801 ft)], Brahmagiri [1,608 metres (5,276 ft)] are some of the important mountains in the district. The entire area of district is drained by Kabini River and its three tributaries *viz*., the Panamaram, Mananthavady, and Kalindy rivers. Agriculturally the district is characterized by the cultivation of perennial plantation crops and spices. The major plantation crops include coffee, tea, pepper, cardamom and rubber. A recent increase in the area under coconut cultivation is noticed in the lower elevations along with paddy.

In the present study an attempt has been made to generate digital soil map exhibiting distribution of different soils types based on their inherent morphological properties, correlated with laboratory analysis and were classified based on Comprehensive System of Soil Classification (Soil Taxonomy, 2010). It also provides information to the land capability and appropriate soil and land management system which is essential to determine best land use for sustained crop production in district.

MATERIALS AND METHODS

Description of the Study area

Wayanad district forms part of the Western Ghats occupying an area of 2,13,939 hectares geographically located between 11^0 27' to 15^0 58' North latitude and 75^0 47' to 70^0 27' East longitude and it is bounded on the south by Malappuram, west by Kozhikode and Kannur district of Kerala State, north by Coorg district of Karnataka, east by Nilgiris and Mysore districts of Tamil Nadu and Karnataka State respectively. Wayanad district falls in the Agro-climatic Zone-XII (West Coast Plains & Ghat Region) with large area covered under forest. It has a large amount of dry and moist deciduous forest. Wayanad is home to endangered species. The climate of the district is almost cool throughout the year except for April and May which reaches the peak summer; a maximum to 31^0 is rarely reached, with the temperature remaining around 29^0 and hot breezes in summer. In the monsoon season it rains heavily almost with annual average rain of 3200 mm. The winters are cold in some areas of northern part of the district with January as the coldest month. The location map is shown in Fig. 1.

Soil Resource Characterization and Sampling

Digital data of IRS-1D -LISS III (Spatial resolution of 23.5 m) was used to extract the different types of soils association information on the base map derived from Survey of India toposheet on 1:50K, from which soil map was prepared by incorporating morphological characteristics and laboratory analysis data of soil profile. The methodology followed for extraction of information from satellite data is essentially of standard monoscopic visual interpretation based on tone, texture, shape and size. The topographic features (i.e. surface elevation, slope, aspect, relief); major physiographic units and land use (i.e. forest, agriculture, plantation, waste land, and scrub) were extracted from Survey of India Toposheets of 1:50K scale. The origin of soil deposits were extracted from geological map of the district of Geological Survey of India. The data extracted from both the

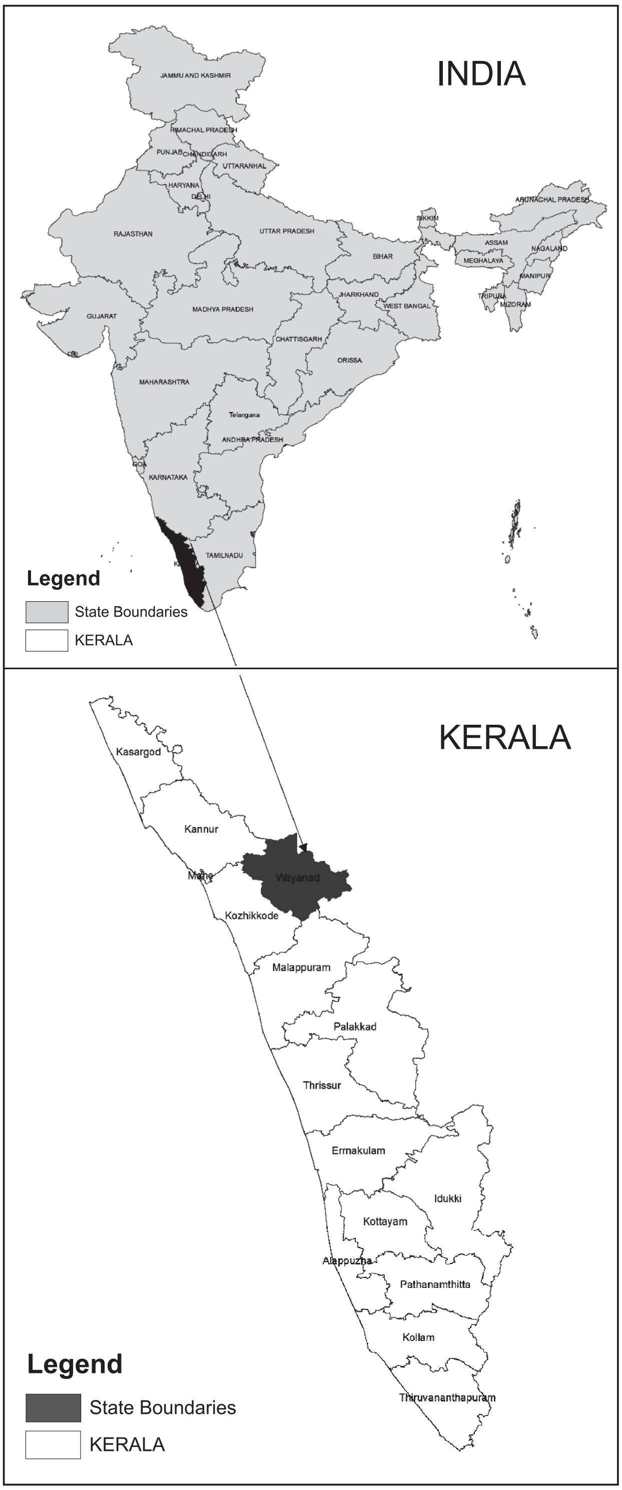

Fig. 1. Location Map of Wayanad District, Kerala

sheets were converted into defined soil units by using satellite imagery and were verified by ground truthing through field observations and soil sample collection. Based on variations of these factors, sample strips have been selected for detailed morphological study of the soils.

Soil profiles were studied based on variations in physiographic unit, parent material type, land use land cover and slope map. Each map represents the factors which influence soil formation. Representative soil profiles were selected to represent delineated soil mapping units; the morphological description of these profiles was carried out according to the guidelines of Soil Survey Manual developed by Soil and Land Use Survey of India AISLUS, 1970. Soil site information was also recorded. Horizon wise soils samples were collected for laboratory analysis physical and chemical properties.

Laboratory Analysis

All Laboratory analyses were done following the procedures in Soil laboratory manual prepared by AISLUS (2000). The soil samples were air-dried and ground to pass a 2-mm sieve and before analysis. Soil texture was determined by Bouyoucos hydrometer method. The pH and electrical conductivity of the soils were measured in water (1:2.5 soil:water ratio). Organic carbon content of the soil was determined following the wet combustion method of Walkley and Black (1934). Exchangeable cations and the cation exchange capacity (CEC) of the soil were determined following the 1 N ammonium acetate (pH 7) method. The exchangeable K and Na in the extract were measured by flame photometer. Calcium and magnesium were measured using EDTA titration method. The available potassium was determined by Morgan's extraction solution and potassium in the extract was measured by flame photometer. Water holding capacity was carried out by Keen R Box Method; Moisture equivalent at 1/3 and 15 bar was carried out by pressure plate apparatus.

Taxonomic Soil Classification and Soil Map Generation

A taxonomic soil classification is directly based on soil characteristics where as capability classification is an interpretive classification based on effects of combination of climate and permanent soil characteristics on risks of soil damage, limitations in use, productive capacity and soil management requirements. The Comprehensive System of Soil Classification (Soil Taxonomy, 2010) was followed to classify the different soils of the district to correlate the physiographic and taxonomic units. Soils of the district were classified under orders Entisols, Inceptisols and Mollisols. All theses maps were transferred to GIS environment, overlaid and used as base map for field survey to incorporate the results with field observations. The soil boundary was delineated based on the boundary inferred by combination of different layers representing soil forming factors that were used in as base map. The polygons representing similar physiographic unit, parent material, slope and vegetation cover was put under same soil type which is confirmed by image characteristics and field survey. Different kind of soil can be expected if there is any change of these factors. The soil map was used for land evaluation. The spatial data were analysed for interpreting capability class of soils based on their characteristics and limitations to evaluate their present and future potentialities. The land capability map was generated for planners to be used as a vital input to prepare a strategic planning for effective and efficient decision making.

RESULTS AND DISCUSSION

Physiography and Soils

According to the climatic data the soil temperature regime of the district is 'Isohyperthermic' and soil moisture regime is 'Udic' in general and "Aquic" in lower valleys.

Based on the Satellite Imagery, Survey of India Toposheets and field checks the physiography of the district was identified. The obtained results revealed that the major physiographic unites in the district area comprises of undifferentiated hills slopes dominating most of the district area (71 percent) followed by pediments, undulating pediplain and valleys.

The major portion of the study area is under forest and plantations of tea, coffee, rubber with coconut in patches and paddy in the lower valleys and pediplains. The soils associations developed on the hills and pediments to undulating pediplains are deep to very deep and that in valleys are very deep soils. The digital soil map with soil mapping units is presented in the Fig. 2.

The undifferentiated hill slopes under various land use are soil associations of least or partially developed, moist, gravelly fine loamy to loamy skeletal soils belongs to Entisol (Typic Udorthent) supporting forest vegetation on higher sloping landforms and freely drained, deep to very deep having moderate available moisture. These soils are associated with deep to very deep, fine loamy to fine and gravelly fine textured soils of Inceptisol (Typic/Oxic Dystrudepts, Typic/dystric

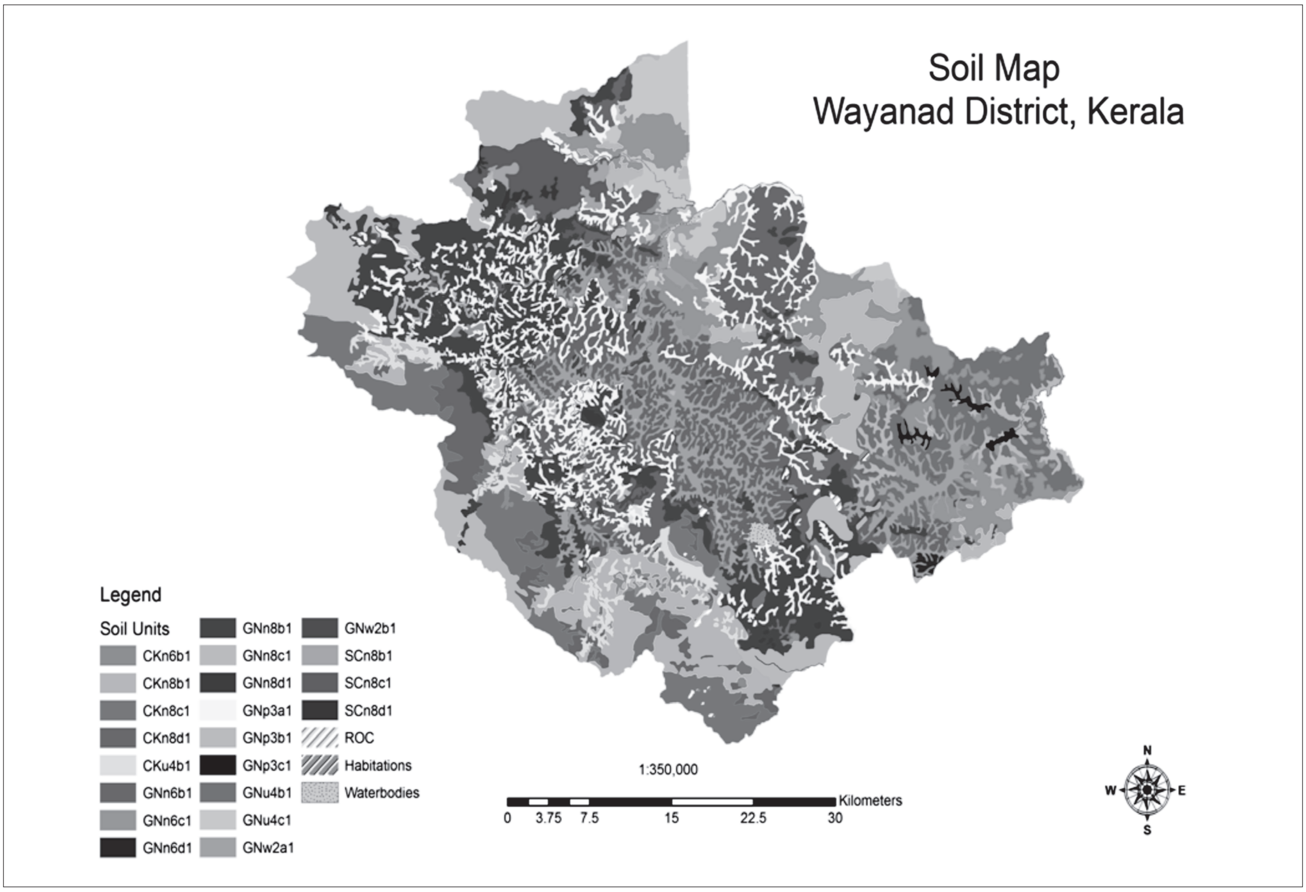

Fig. 2. Soil Map of Wayanad District, Kerala

Eutrudepts).

Third soil associated are soils having mollic epipedon or surface horizon dark colour, high organic carbon cannot by definition be hard or very hard when dry, deep, fine textures Typic Hapludolls subgroups are moist Mollisols. These are rich in organic matter, nitrogen and humus. The soils are dark reddish brown in colour formed by weathering under forest cover with fine loamy to fine texture. The pH of soil ranges from 5.5 to 5.9.

These three soil association has been reported in tea, coffee, rubber plantation area. These soils are dark reddish brown to brown coloured, with pH ranging 4.40 to 6.25 and are high in organic matter covering an area of 78799 ha (37.00%) of the district.

Similarly soils of deep to very deep, fine loamy to fine textured soils of Inceptisol (Oxic/Humic Dystrudepts, Dystric Eutrudepts and Oxic Humudepts) are reported under forest land use covering an area of 59525 ha (27.95%). Similarly deep to very deep, fine textured, soils of subgroup Typic/Oxic Humudepts, Dystric Eutrudepts, observed in openscrub/grasslend type occupying and area of 6096 ha (3.3%).

The soil types identified in the undifferentiated hill slopes area were place in order of their dominance in occurrence as Inceptisols, Mollisols, and Entisols order respectively. The soils classified under Inceptisols show inception of soil development with moderate moisture holding capacity and are generally light coloured and medium textured. Soils classified under Entisols order shows presence of mineral horizon with no soil development. These Soils are excessively drained strongly acidic in nature, low fertility, other constraints are stoniness and moderate to severe erosion.

The soils on pediments are developed on gentle to moderately slope, fine loamy surface and fine to clay skeletal subsurface textured soils of Oxyaquic Eutrudepts, Ruptic Ultic Dystrudepts and Oxic Dystrudepts, spread out in 16561 ha (7.8%) area of the district.

The brown hydromorphic soil is mainly seen in the narrow valleys of the hilly terrain. It is very deep brownish in colour exhibits redox-concentration with sandy loam to clay texture formed over gentle sloping. It is formed by transportation and sedimentation of material from hill slopes. The pH of soil ranging 4.9 to 6.8 and are moderate in their organic matter content (Fig 3). Soils are classified as Aeric Epiaquept and Dystric Eutrudepts in Agriculture and plantation land use having an area 24, 214 ha (11.37%) and soils of Dystric Eutrudepts on forest land use covering an area of 647 ha (0.3%).

Alluvial soils are found along the banks of Kabani, Chaliyar and its tributaries. Riverine alluvium is very deep with sandy loam to clay loam texture on broad valley. The sub group Aquic Dystrudepts, Oxyaquic Eutrudepts and Typic Psammaquents are found in cultivated and soil sub group Aeric Epiaquepts and Aeric Epiaquents found in Plantation area respectively occupying 16,930 ha (7.95%)area. The soils are coarse textured and stratified but the strata are contrasting enough

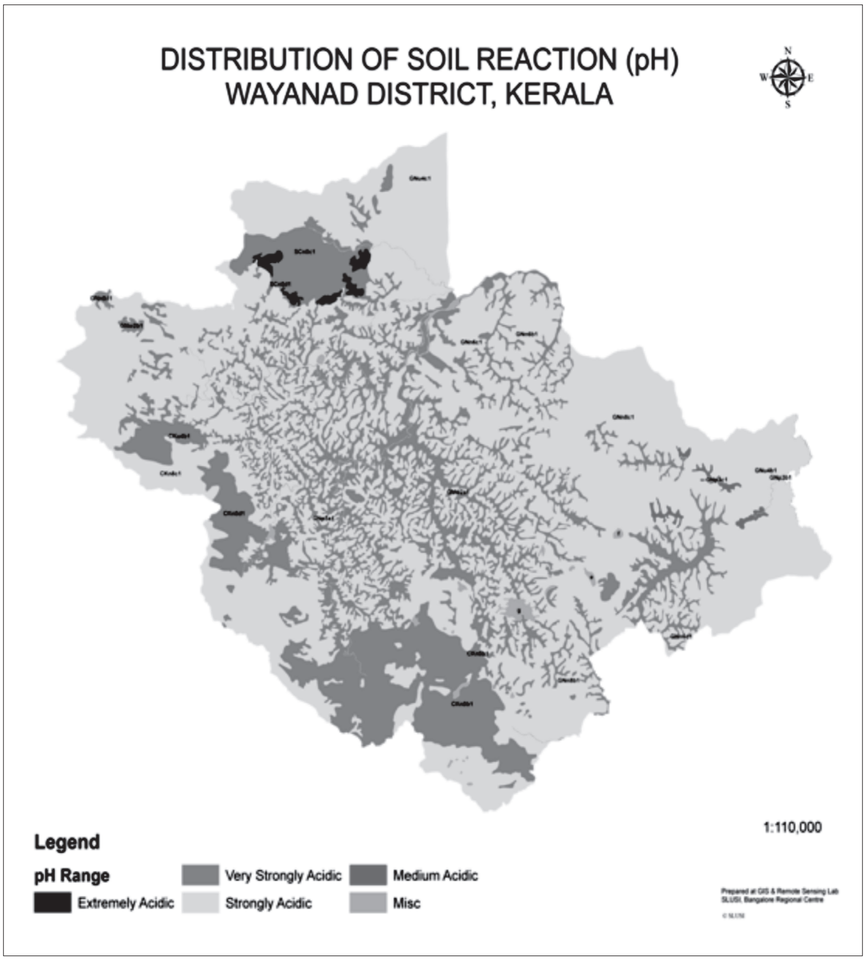

Fig. 3. Soil Reaction Map of Wayanad District

to cause water perching or to have marked impact on permeability. Draining these soils can create moisture stress because there is no buffering effect on moisture content.

Land capability assessment: The spatial analyses technique was adapted to evaluate the agricultural land capability in the study area. The different landforms were identified which was used as a base to delineate soil boundaries to identify different soil types and soil map layer was produced using ArcGIS. The attributed data of land slope, soil organic matter, pH, textural class, soil depth, acidity, CEC, Soil erosion and drainage condition were linked with the units of the digitised soil map in GIS. The incorporated attributes were used to generate thematic layers of spatial distribution of the above mentioned characteristics and properties. The produced layer includes information on capability class and spatial distribution for the soil characteristics. The data obtained indicated that the main limiting factors in the district were slope, terrain, soil texture, drainage, erosion and CEC.

The land capability classification for the soils of the district has been interpreted for agriculture purpose and is depicted in the Table 1. Soils developed on valleys and lower plains have been classified as Class II which requires careful soil

Table 1. Land capability class of Wayanad District

S. No.	Land Capability Class	Soil Units	Associated problem	Recommendations	Area (ha)	Area (%)
1.	Class II	Valleys and Lower Plains - under Agriculture & Plantation	Stratified soil profile. Prone to Water-logging / Flooding. Neutral to acidic reaction (pH). Low base saturation. Shallow ground water.	Suitable for cultivation of Paddy, Coconut, Coffee, Tapioca, Pepper, Tea, Cocoa. Adoption of mechanized cultivation. Cultivation of pulses in summer fallows livelihood support through livestock and fisheries. Popularization of organic farming and certification. Soil test based comprehensive nutrient management. Lime application in soil.	41143	19.3
2.	Class III	Pediments - Plantations	Gentle to moderate slope. Acidic in nature. Low base saturation	Rejuvenation of existing homesteads. Multilayered and mixed farming systems.Popularization of organic farming and certification.Lime application in soil.	16561	7.8
3.	Class IV	Hills (steep slopes) - Plantations	Acidic in nature. Low base saturation.	Renovation &strengthening of water harvesting and storage structures.Cultivation of cool season vegetables.Lime application in soil	36391	17.1
4.	Class VI	Hills (steep slopes) - Open Scrub	Deforestation. Prone to erosion. Acidic nature of soils.	Soil & water conservation through contour/staggered trenching works. Construction of terrace support wall. Pasture development.	271	0.1
5.	Class VII	Hills (very steep slopes) - Plantations	Weak soil development Acidic nature of soils. Prone to erosion	Cultivation of medicinal plants. Formation of bench terraces with vegetative barrier. Contour/staggered trenching works and formation of bench terraces.	42602	20.0
6.	Class VIII	Hills (very steep slopes) - Open scrub /grass	Deforestation. Prone to erosion. Acidic nature of soils.	Treatments of land slip areas with vegetative barrier. Afforestation of denuded forest land. Pasture development.	6715	3.2
7.	Forest (F)	Hills(steep to very steep slopes), Pediments & Valleys under Forest	Deforestation. Prone to erosion. Acidic nature of soils.	Afforestation of denuded forest land. Contour/staggered trenching works and formation of bench terraces. Fire line scrapping, to set up fire protection tower.	66848	31.4
8.	Misc.	ROC,Habitation, Water bodies etc.	-	-	2408	1.1
				Total	212939	100.0

management to prevent deterioration as these soils are under plantation and paddy and had limitations of slope, moderate susceptibility to wind or water erosion, drainage overflow and wetness.

Soil developed on pediments under plantations are classified as Class III with major limitation of moderately steep slopes, high susceptibility to water erosion, frequent over flow and low to moderate water holding capacity. Soils under this class require proper drainage that improves the structure and tilth of the soils. Soils developed on hills with steep slopes under plantations mainly of rubber have been classified as Class IV having very severe limitations that restrict the choice of plants and requires very careful management. The major limitations for this class are steep slopes, erosion. The generated digital land capability map is presented in Fig. 4.

CONCLUSION

Soil Taxonomy was guided by morphogenetic principles but, wherever possible, the parameters that define taxa or classes are important to soil uses. Thus, useful interpretations can be inferred from soil taxa names. Most of the management information is presented at the level of soil series or its phases. Because the system is morphogenetic, surface soil characteristics, which are so critical to crop performance, receive least attention. In this study attempt has been made to develop sustainable land use plan based on soil and land properties along with taxonomic class of soil series It has also confirmed that the physiographic position, Land use and elevation play an important role in the variation in soil properties such as organic carbon, depth, texture, structure irrespective of landscape or parent material, which is a key factor for sustainable land use planning in such least accessible mountainous area.

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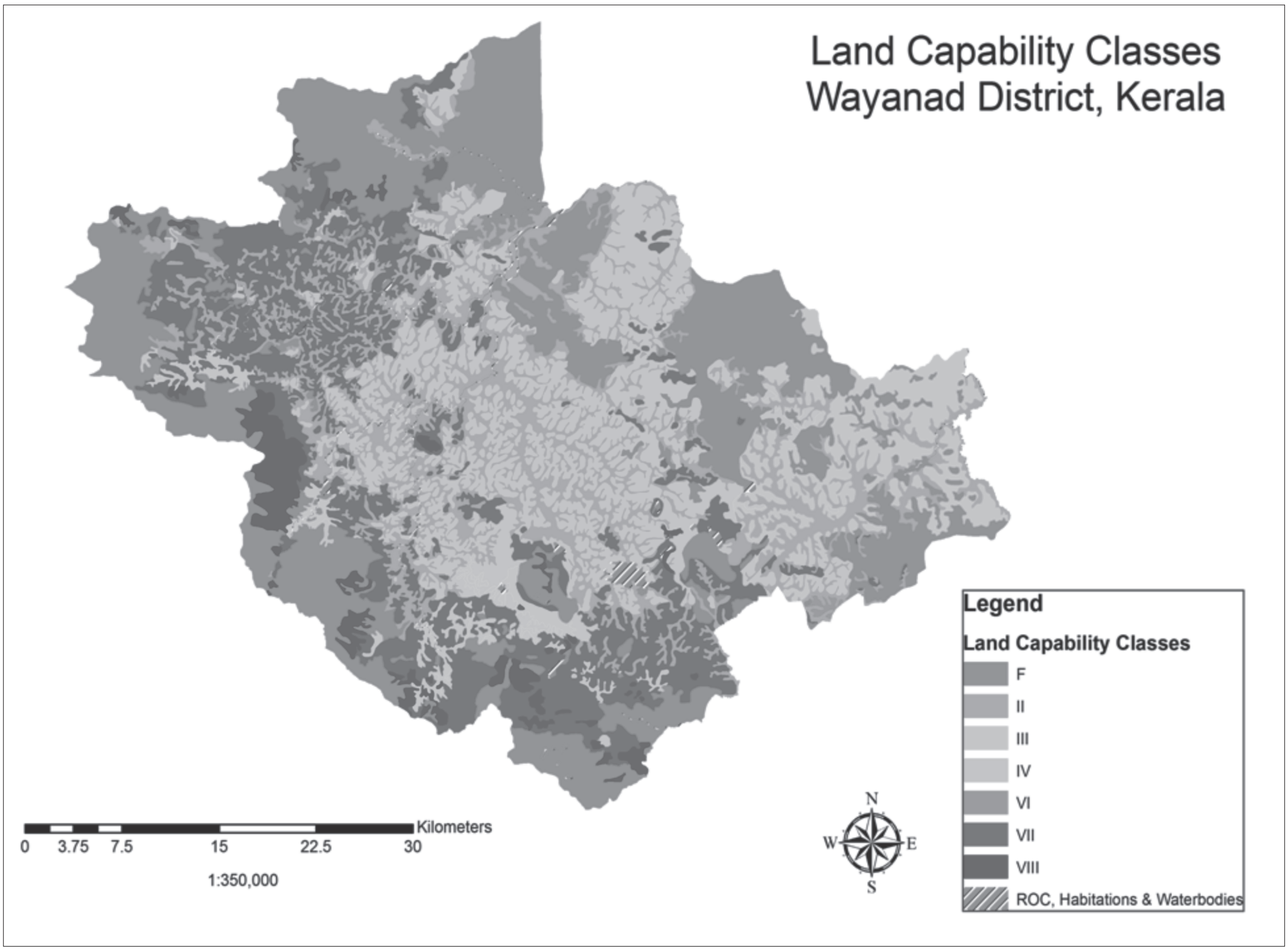

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Impact of *Albizia procera* benth. based agroforestry system on soil quality in Bundelkhand region of Central India

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ABSTRACT

Agroforestry plays an important role in influencing soil quality indicators but their quantitative assessment in *A. procera* based agroforestry system were not existing in Bundelkhand region of Central India. Hence, study was undertaken at Central Agroforestry Research Institute, Jhansi to develop an additive unified Soil Quality Index (SQI) based on functional scores of soil quality indicators comprising of soil physical, chemical and biological properties, and determine how indicators respond to different management practices. Study was conducted in a well established 10 years old *Albizia procera* Benth. based agroforestry experiment consisting of five treatments viz. control (Pure crop), Pure tree (without inter cropping), zero pruning+ inter cropping, 50% pruning+ inter cropping and 70% pruning + inter cropping. Findings revealed that maximum value of SQI was observed for practice of zero pruning (0.54) closely followed by 50% pruning (0.53) and 70% pruning (0.52). Pure crop had the minimum SQI (0.37). Agroforestry plots *viz*. pure tree, zero pruning, 50% pruning and 70% pruning had improved soil health to the tune of 19.7, 31.3, 31.0 and 30.0 per cent, respectively, over pure crop. It has been observed that biological activities and water holding capacity of soil appears to be the most limiting indicators.

Key words: Indicator, Soil health, Soil quality index, Tree pruning, Semi-arid region

INTRODUCTION

Assessment of soil quality or health in agroforestry acquires more relevance due to expansion of area under agroforests in tropics and sub tropics, and their enhanced contribution toward sustainability of agricultural production. In India, as per one estimate, about 25.72 million ha area has been covered under various types of agroforestry plantations. The task force on Greening India (Anonymous, 2001) has identified a potential of 10 million ha in irrigated lands and 18 million ha in rainfed areas that could be developed through agroforestry on a watershed basis. The main driving force and objective of covering such large area under agroforests is to keep the soil resource productive on sustainable basis.

Soil degradation has become a major global issue in recent years. It has been estimated that the degraded area increased from 10% of the world's arable land in early 1970s (Biswas and Biswas, 1974) to 40% in early 1990 (Oldeman, 1994). In India, nearly 188 Mha land area suffers from one or other kind of land degradation. Various forms of soil / land degradation reduce soil's capacity to perform. Reduction in the functional capacity of soil results in decline of productivity. The declining trends in food grain productivity threaten agricultural sustainability. The concept of agricultural sustainability expressed during last two decades of twentieth century is being magnified in twenty first century because of limited arable land resources, rapid increase in population, conversion of agricultural land to other uses and persistence of hunger and malnutrition in several regions of the world (Lal, 1998). Therefore, the question of agricultural sustainability became extremely relevant and led to considerable interest in productivity trends of long-term experiments (Lal and Stewart, 1995). It is also emphasized that maintaining the quality of natural resource base would ensure sustainability of agricultural production.

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Assessment of soil quality depends on indicators that relate to various soil functions. Depending on approaches *viz*. descriptive or qualitative and quantitative soil quality assessment, the indicators can be observational features of soil or plants growing on it, and measure of physical, chemical and biological soil attributes. The quantitative approach offers greater precision but requires more resources for doing assessment. Before selecting soil quality indicators for assessment programme, the basic fact regarding soil to be given due consideration is that soil quality embraces two general elements *viz*. i) inherent properties of soil or inherent capacity and ii) dynamic nature of soil. The inherent capacity of soil is the result of factors of soil formation- climate, topography, vegetation, parent material and time. Attributes of inherent soil quality such as mineralogy and particle size distribution are almost static and show little change over time. The dynamic nature of soil encompasses those soil attributes that can change over relatively short time in response to human management. These soil attributes are referred as indicators of soil health. Hence, assessment of soil quality refers to assessment of dynamic soil attributes (Doran and Parkin, 1994). The selected indicators of soil quality should have greatest sensitivity to changes in soil function (Andrews *et al*., 2004). It is emphasized that soil quality indicators should correlate well with ecosystem processes; integrate soil processes, accessible to many users and sensitive to management and climate (Daran and Parkin, 1996; Sharma *et al*., 2010). Further, the group of indicators selected to measure soil functions must be sufficiently diverse to represent the chemical, biological and physical properties and processes of complex system.

The overriding objective of agroforestry land use, since its inception with establishment of World Agroforestry Centre in 1977, 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 and protect environment (Nair, 1993). It is 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 (Gupta and Arora, 2015); maintenance or increase of organic matter and diversity through continuous degeneration of roots and decomposition of litter (Solanki and Arora, 2015); 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 (Sanchez, 1987). Although soil conservation for restoring quality and health of degraded soil has been advocated as primary goal of agroforestry (Young, 1989), the empirical estimates of accrued benefits are lacking due to temporal and spatial complexity of agroforestry systems and soil resource dynamics.

Use of soil quality index (SQI) value based on summarized soil properties to assess soil quality of agricultural and forest ecosystems is well established, however, the systematic information on use of a unified value of SQI to assess impact of various agroforestry systems on soil quality is lacking. Thus, development and application of a soil quality index for evaluation of changes in soil quality caused due to agroforestry practices is needed. Further it is hypothesized that various agroforestry systems being advocated are productive, remunerative and environment friendly; and to prove this hypothesis, it is essential to assess impact of various agroforestry management practices on soil quality. Therefore, the present study was conducted to assess changes in soil quality indicators and soil quality index due to pruning management practices in *Albizia procera* based agroforestry system in semi arid region of Bundelkhand, Central India.

MATERIALS AND METHODS

Site description: The study was carried out at the farm of ICAR-Central Agroforestry Research Institute (CAFRI), Jhansi during 2010. The soil of the experimental farm is inter-mixed black and red soil, which represent *parawa* group of soil of Bundelkhand region covered under the order of Alfisol. The CAFRI farm is situated at 25º 27' North latitude and 78° 35' East longitude, 271 meters above mean sea level in the semi-arid tract of central plateau of India. Annual rainfall ranges from 700-1150 mm with a mean value of 958 mm of which, about 80% is received during southwest monsoon. The potential evapo-transpiration is quite high in the range of 1400-1700 mm with moisture index value of - 40 to -50. The pattern of the rainfall is highly erratic and more than 90 per cent of the total rainfall occurs within 10 weeks between July to mid September accompanied by intermittent long dry spells. The entire rainfall is received in less than 50 rainy days. Winter showers are rare and uncertain. The frequent drought occurs in entire regions. Usually, monsoon commences by the last week of June but sometimes delayed to the first week of July. The active monsoon often withdraws up to the mid of September or the end of August. Mean annual temperature of the Jhansi is generally high with high degree of variation between maximum (39.8^{0}C in June) and minimum (5.8^{0}C in January) temperatures. Sometimes maximum temperature in the summer months of May and June touches 48^{0}C, which is the peak of summer season.

Experimental design and management: The present study was conducted in a well established 10 years old *A. procera* based agroforestry trial consisting of five treatments viz. control (Pure crop), Pure tree (without inter cropping), zero pruning + inter cropping, 50% pruning + inter cropping and 70% pruning + inter cropping during 2010. The trial was laid out in completely randomized block design (CRBD) with three replications. Trees planted at 8x4 m spacing were intercropped with wheat in winter season. The pruned biomass from 50% and 70% pruning treatment was added in soil as green manure in the month of October, at least one month before sowing of wheat as intercrop. Levels of pruning were based on a percentage of green crown length and pruning was done by cutting lower branches from stem or parent branch. Branches were taken out for using as fuel and green twigs/foliage was incorporated in the soil as green manure. Green biomass in the tune of 1.99 t/ha and 2.27 t/ha was added in 50% and 70% pruning treatments, respectively. Wheat *(Triticum aestivum* L. emend.) variety HD 2189 was grown as an inter crop. Standard package of practices of wheat cultivation were followed.

Soil sampling and analyses for soil health indicators: Rrepresentative soil samples were drawn (0-30cm depth) from all treatment plots before sowing of wheat. The soil samples were air dried and sieved to pass through a 2 mm-sieve. For the determination of bulk density, soil cores were collected. Soil samples collected were separately analyzed for physical, chemical and biological properties as listed below. Bulk density (BD) was determined from the soil cores using the procedure given by Veihmeyer and Hendrickson (1948), and porosity was derived from BD using the following formula: porosity (P) = [1- (BD/PD)]*100, where PD is the particle density determined using a Keen Raczkowald (KR) box (Baruah and Barthakur, 1999). KR box is a circular brass box having an internal diameter of 5 cm and a height of 1.6 cm with perforated bottom having numerous holes of 0.75 mm diameter spaced at 4 mm apart. Maximum water holding capacity (WHC) was determined by equilibrating the soil with water through capillary action in a KR box (Baruah and Barthakur, 1999). Soil pH and EC were determined at 1:2.5 soil–water ratio using a glass electrode and conductivity bridge, respectively. Cation exchange capacity (CEC) was measured by the sodium saturation method (Jackson, 1973). Soil organic carbon (SOC) was determined by dichromate oxidation (Walkley and Black, 1934) and available N by the alkaline potassium permanganate distillation method (Subbiah and Asija, 1956). Available phosphorus (P) in soil was determined by extracting samples with 0.5 M $NaHCO_3$, and determining P colorimetrically using molybdate (Olsen *et al.*, 1954). Available potassium was determined using 1N ammonium acetate extraction followed by emission spectrometry (Jackson, 1973). Microbial biomass carbon was measured by the fumigation extraction method (Jenkinson and Ladd, 1981). Soil dehydrogenase was determined using the method of Klein *et al.* (1971).

Soil quality index (SQI) calculation

Analysis of variance (ANOVA) was performed to determine the effects of pruning treatments in Agroforestry systems on soil quality parameters. For calculating soil quality index (SQI) 12 soil quality indicators *viz*., bulk density, water holding capacity (WHC), porosity, pH, EC, SOC, CEC, available N, P and K; microbial biomass and dehydrogenase activity were as used as parameters. The minimum and maximum threshold values for each indicator are based on the range of values measured from agroforestry systems and on critical values in the literature. After setting thresholds, the soil parameter values recorded under *Albizia procera* based agroforestry system were transformed in to unit less scores (between 0 and 1) and three types of scoring functions *viz*. "More is better", "Less is better" and "Optimum" were generated following Karlen and Stott (1994). Such scoring curves were also used by Masto *et al*. (2007).

Linear scoring function:

LSF (Y) = (x-s)/ (t-s).........(1)

Y = 1-[(x-s)/ (t-s)]............ (2)

Where, Y is the linear score, x is the soil parameter value, s and t are the lower and upper threshold values. Equation 1 is used for "More is better" scoring function, Equation 2 for "Less is better" and combination of both for "Optimum" scoring function (Fig. 1). If the calculated score is > 1.0, it was considered as 1.0. The individual scores were added up to obtain unified soil quality Index (SQI) as below:

$$SQI = \sum_{i=1}^{n} Si / n$$

Where, S denotes linear scores of observed soil quality indicator, n is the number of total indicator included in the index.

RESULTS AND DISCUSSION

Effect of pruning management on soil quality indicators

The data relating to mean values of all physical, chemical and biological parameters of soil under different pruning management regimes of *A. procera* based agroforestry system have been presented in Table 1. As revealed from data, pruning of trees significantly affected all studied soil health indicators except water holding capacity, EC and available K. Maximum bulk density was observed in pure tree plot while minimum in 50 % pruning. In comparison to pure crop plot bulk density was reduced in all agroforestry plots *viz*. zero, 50 % and 70 % pruning plots. Maximum porosity was found in 50 % pruning plot while minimum in pure crop. In general, there was increase in porosity in agroforestry plots subjected to pruning management in comparison to pure crop and pure tree plot. As compared to pure crop, soil pH was reduced in agroforestry plots. Maximum soil organic carbon was found in zero pruning plot while minimum in pure crop. There was significant increased in SOC in all agroforestry plots as compared to pure crop. Maximum CEC was found in 70 % pruning plots while minimum in pure crop plot. Pruning management in agroforesty plot significantly increased the CEC. In comparison to pure crop plot, available N increased in agroforestry plot with maximum in 50 % pruning. However, maximum value of available P was observed in zero pruning plot with minimum in pure crop. Maximum microbial biomass was observed in 70% pruning while minimum in pure crop plot. It increased in agroforestry plot with increasing levels of pruning from zero to 70%. Maximum dehydrogenase activity was found in pure tree plot and minimum in pure crop. In general, all agroforestry plots had more dehydrogenase activity than that in pure crop.

The practice of agroforestry for 10 years and tree pruning management brought a significant improvement in physical, chemical and biological parameters of soil, which may be due to increase in SOC, recycling of nutrients through leaf litter and favorable conditions for bio-chemical processes (Sanchez, 1987; Nair, 1993). Increase in SOC in agroforestry plots over pure crop might be due to comparatively resistant organic carbon added through tree pruning / leaf letter and more root biomass yielded by trees (Ram Newaj *et al*., 2007; Prasad *et al*., 2015). Maximum available P in zero pruning plot may be due to the fact that increase in microbial biomass with dehydrogenase activity in agroforestry plots appears to have triggered biochemical process and transformation of nutrients in soil (Prasad *et al*., 2016).

Table 1. Impact of tree pruning on soil health indicator (0-30cm) values of *A. procera* based Agroforestry system system

Parameters	Treatments						
	Pure crop	Pure tree	Zero Pruning	50% pruning	70% pruning	Mean	LSD (P<0.05)
Bulk density (g/cm^3)	1.44	1.47	1.42	1.41	1.43	1.45	0.03
Water holding capacity (%)	13.83	13.63	15.03	15.42	16.30	14.84	3.14
Porosity (%)	29.63	32.70	34.06	35.28	34.92	33.32	3.08
pH	6.99	6.38	6.20	6.44	6.30	6.47	0.21
EC (dS/m)	0.34	0.20	0.19	0.15	0.18	0.21	Ns
SOC (%)	0.52	0.67	0.76	0.72	0.67	0.67	0.10
CEC (Cmol p+/kg)	11.63	13.13	13.23	15.00	15.17	13.63	2.39
Available N (kg/ha)	150.33	164.50	203.00	205.42	181.50	180.95	50.08
Available P (kg/ha)	11.32	14.34	20.01	19.03	18.37	16.61	3.49
Available K (kg/ha)	113.17	139.37	145.33	137.50	140.67	135.21	Ns
Microbial biomass (ug/g)	127.47	146.40	169.00	197.60	200.67	168.23	43.44
Dehydrogenase activity (ug TPF/g/day)	37.05	76.73	60.13	72.36	60.23	61.30	37.05

Soil Quality Index

Soil quality indicator values were normalized on 0 to 1 scale using linear scoring function and equation 1 and 2. After deciding the shape of anticipated response ('More is better'; 'Less is better' or 'Optimum') the minimum and maximum threshold values were assigned for each indicator (Table 2). From functional score SQI was calculated for all plots. As revealed from Table 2, the calculated SQI was maximum in 50 % pruning plots and minimum in pure crop plot. All agroforestry plots yielded more SQI indicating improvement in soil health. Over the base line reference SQI, the improvement in SQI ranged from 21.47 % in pure crop to 46.08% in zero pruning plot with mean value of 39.06%. The improvement over pure crop brought by agroforestry plots ranged from 19.65% in pure tree to 31.34% in zero pruning plot (Table 3). In comparison lower base line reference SQI, the quality index was found in order: Pure crop< Pure tree< 70% pruning< 50% pruning< zero pruning. The order of SQI over pure crop was in order: zero pruning> 50% pruning> 70% pruning> pure tree.

Use of SQI value based on summarized soil properties to assess soil quality of agricultural and forest ecosystems is well established. Use of index value based summarized soil properties have been used and suggested to assess soil quality of agricultural systems (Doran and Parkin, 1996; Kang *et al*., 2005). While evaluating sustainability of rice-wheat cropping system on a Vertisol in India, Mohanty *et al*. (2005) developed a soil quality index (SQI) based on bulk density (BD), penetration resistance (PR), water stable aggregates (WSA) and soil organic matter (OM) and concluded that SQI values of 0.84–0.92, 0.88–0.93 and 0.86–0.92 were optimum for rice, wheat and the combined system of rice + wheat, respectively. Sharma and Arora (2010) developed relative soil quality and production efficiency indices for maize-wheat in agro-climatic conditions of Himalayan ecosystem involving soil and climatic variables. Similar to agricultural systems, SQI has also been used to assess forest soil health. To assess trends in forest soil health under forest inventory analysis (FIA), a single value SQI integrating 19 physical and chemical properties of soil has been developed by Amacher *et al*. (2007) to monitor changes in soil

Table 2. Soil health indicator (0-30cm) values and their functional scores in soil of *A. procera* based agroforestry system

Indicator	Threshold		Reference/ value	Function	Score	Treatments				
	lower	Upper	Baseline		Reference	Pure crop	Pure tree	Zero pruning	50% pruning	70% pruning
Bulk density (g/cm^3)	1.3	2.1	1.66	Less is better	0.55	0.83	0.79	0.85	0.76	0.83
Water holding capacity (%)	10	25	12	more is better	0.13	0.26	0.24	0.34	0.36	0.42
Porosity (%)	20	80	31	optimum	0.18	0.19	0.21	0.23	0.26	0.25
pH	5.5	8.5	6.5	optimum	0.33	0.50	0.71	0.77	0.69	0.73
EC (dS/m)	0.2	4	0.5	Less is better	0.92	0.96	1.00	1.00	1.00	1.00
SOC (%)	0.2	1	0.4	more is better	0.25	0.40	0.59	0.70	0.65	0.59
CEC (Cmol P+/kg)	5	25	10	more is better	0.25	0.33	0.41	0.41	0.50	0.51
Available N (kg/ha)	80	250	140	more is better	0.35	0.41	0.50	0.72	0.74	0.60
Available P (kg/ha)	8	25	10	more is better	0.12	0.20	0.37	0.71	0.65	0.61
Available K (kg/ha)	100	300	140	more is better	0.20	0.07	0.20	0.23	0.19	0.20
Microbial biomass (ug/g)	50	400	75	more is better	0.07	0.22	0.28	0.34	0.42	0.43
Dehydrogenase activity (ug TPF/g/day)	25	275	50	more is better	0.10	0.05	0.21	0.14	0.19	0.14
SQI					0.29	0.37	0.46	0.54	0.52	0.53

properties of forest soil with time. They assigned an index value to each soil property and all individual index values were summed up to obtain a SQI. The SQI values were developed for six FIA plots of the United States. The average SQI values varied from 43% to 67% for different FIA plots. The lower values of SQI observed in present study indicate that soil used for agroforestry experiment was degraded and agroforestry practices brought improvement ranging from 19.65 to 31.34% over pure crop plot which, proves the hypothesis that practicing agroforestry with proper tree management restores degraded land and improves soil quality (Table 3).

CONCLUSION

The results of the study, apart from its scientific value, will have practical implications in bridging the gap in using SQI value based on summarized soil properties to assess soil quality of various agroforestry systems. Further, our findings proved the hypothesis that agroforestry is vital for restoration and revitalization of poor and marginal land resource. The low value of base line (reference) SQI (0.29) indicate that the soil health of Bundelkand region is poor and practice of agroforestry holds the potential to improve soil quality ranging from 19.7 to 31.3% after 10 years. The better effect of tree pruning on SQI confirms that the pruning of tree components in any agroforestry system is crucial for sustainability of land resource and productivity.

Table 3. Effects of tree pruning on soil quality index of *A. procera* based agroforestry system

Treatments	Soil Quality Index	% Over baseline	% over pure crop
Baseline (Reference)	0.29	-	-
Pure crop	0.37	21.47	-
Pure tree	0.46	36.90	19.65
Zero Pruning	0.54	46.08	31.34
50% Pruning	0.53	45.78	30.96
70% Pruning	0.52	45.06	30.04
Mean		39.06	28.00

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Comparative study of reference evapotranspiration estimation methods including Artificial Neural Network for dry sub-humid agro-ecological region

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ABSTRACT

In the present study, an attempt has been made to compare the reference evapotranspiration (ET_o), computed by eight different methods, namely, Penman-Monteith, Modified Penman-Monteith, Hargreaves-Samani, Irmak, Hargreaves, Valiantzas, ANN and FAO(24) model for the dry sub-humid agro-ecological region (Varanasi). An attempt was also made to find out utility of artificial neural networks (ANN) for estimation of ET_0 with minimum input. Feed forward network has been used for prediction of ETo using resilient back-propagation method and the architecture 2-2-1(having parameters T_{mean} and solar radiation) was found to be the best one. The average annual evapotranspiration (by Penman–Monteith method) for Varanasi was found to be 1447.4 mm. When compared among the different methods for estimation of reference evapotranspiration with Penman-Monteith method, the FAO-24 and Hargraves-Samani (3) under estimate, however, Modified Penman-Monteith, Hargreaves-Samani, Irmak, Hargreaves, Valiantzas over-estimate and ANN closely estimates reference evapotranspiration.

Key words: Reference evapotranspiration, ANN, Trends, Penman-Monteith method

INTRODUCTION

Reference evapotranspiration (ET_o) is an important parameter of the hydrologic cycle and its accurate estimation is important for many studies, such as hydrologic water balance, irrigation scheduling, water resources planning-management and for hydrologic and climatic studies. Evapotranspiration (ET) is the combined process of evaporation from the soil and plant surfaces and transpiration through the stomata of the plant surface. The evapotranspiration rate from a reference surface having no shortage of water is called the reference crop evapotranspiration (ET_o). The reference surface is a hypothetical grass with specific characteristics. The concept of the reference evapotranspiration was introduced to study the evaporative demand independent from crop type, crop development and management practices. The only factors affecting ET_o are climatic parameters and can be computed from weather data. Many equations are used to estimate ETo and can be divided into two main groups, those that are physically based like Penman, Penman-Monteith model, etc. and those that are empirical based like Hargreaves, Hargreaves-Samani, Blaney-Criddle model, etc. but the comparison between the results of these methods reveals a wide divergence (Doorenbos and Pruitt, 1977). ET_o expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider the crop characteristics and soil factors. The FAO Penman Monteith method is the most reliable method for determining ET_o as it explicitly incorporates both physiological and aerodynamic parameters. It is a method with strong likelihood of correctly predicting ET_o in a wide range of locations and climates and has provision for application even when some data is missing. Artificial neural network (ANN) technique has drawn the attention of many researchers because of the nature of being efficient and having nonlinear modeling of complex systems. Many studies have been done on the reliability of ANNs for estimating ET_o. Kisi (2007) compared the potential of different ANN techniques and empirical methods in reference evapotranspiration

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estimation. In the present study, an attempt has been made to estimate the reference evapotranspiration by different known methods with the objective to reduce the input weather parameters (due to no availability of various weather data) without losing the qualitative result.

MATERIALS AND METHODS

Study area

Meteorological data from the observatory of Institute of Agricultural sciences, BHU, Varanasi (Latitude: 25.26 N, Longitude: 82.99E and Altitude: 80.71 m) were collected and analysed for the purpose of this study. The observatory is situated in the dry sub humid agro ecological region (BHU, Varanasi). The meteorological data i.e. maximum temperature (T_{max}), minimum temperature (T_{min}), maximum relative humidity (RH_{max}), minimum relative humidity (RH_{min}), sunshine hour, wind speed, rainfall and pan evaporation of period of 29 years (1986-2014) were used for present study. FAO has recommended the Penman-Monteith method for estimation of reference evapotranspiration as it is a close, simple representation of the physical and physiological factors governing the evapotranspiration process. But, this method requires various meteorological parameters that are usually not available in most meteorological stations. Here, some other standard methods like FAO-24 (Pan) model, Modified PM method, Hargreaves method, Hargreaves Samani method, Valiantzas method, Irmak method, ANN, etc are tested for estimation of ET_0. ANN was also tested and input parameters were optimized. The different methods of estimation of reference evapotranspiration as mentioned above with the required input parameters are discussed below.

FAO-56 (Penman Monteith) method

The Penman Monteith method is considered as standard because it has ranked first for both humid and arid regions (Allen *et al.*, 1998). The equation that is used for calculating the reference evapotranspiration is given below:

$$ET_0 = \frac{0.408\Delta(Rn-G)+\gamma\frac{900}{T+273}u2(es-ea)}{\Delta+\gamma(1+0.34u2)} \quad (1)$$

where,

ET_o = Reference evapotranspiration [mm day^{-1}]

R_n = Net radiation at the crop surface [MJm^{-2} day^{-1}]

G = Soil heat flux density [MJ m^{-2} day^{-1}]

T = Mean of daily air temperature [°C]

u_2 = Wind speed at 2 m height [m s^{-1}]

e_s = Saturation vapour pressure [kPa]

e_a = Actual vapour pressure [kPa]

Δ = Slope vapour pressure curve [kPa °C $^{-1}$]

λ = Psychrometric constant [kPa °C^{-1}].

The parameters: air temperature, sunshine duration, wind speed and relative humidity are taken directly from the meteorological station and are used to estimate other parameters such as the net radiation, slope of saturation vapour pressure curve, psychrometric constant, etc.

Modified Penman Monteith method

Due to difficulties in getting data, particularly solar radiation, wind speed etc. Valiantzas (2006) suggested the simplified algebraic formula for Penman's equation, which requires commonly available data of mean temperature, solar radiation, mean relative humidity and wind speed.

$$ET_0 = 0.051(1-\alpha)Rs(T+9.5)^{0.5} - 2.4\left(\frac{Rs}{Ra}\right)^2 + 0.048(T+20)\left(1-\frac{RHmean}{100}\right)(Fu-0.5) \text{---- (2)} \quad (2)$$

where, T is the mean air temperature for the examined time interval (^{0}c), Q is the reflection coefficient or albedo with typical value of the albedo for a grass cover is 0.23, Ra is the extraterrestrial radiation (MJm^{2}d^{-1}), RH_{mean} is the mean relative humidity for the examined time interval(%) and $f_u=a_u+(b_u*U)$, where $a_u=1$, $b_u=0.54$.

FAO-24 (Pan) model

Evaporation from pan (USWB Class A Land Pan) is due to combined effect of temperature, relative humidity, wind speed, sunshine hour, etc. It is used in case of limited data condition. The reference evapotranspiration as given by FAO (Pan) model is given by:

$$ET_o = E_{pan} * K_p \quad (3)$$

where, ET_o = Reference evapotranspiration, (mm day^{-1})

E_{pan} = Pan evaporation, (mm day^{-1})

K_p = Pan coefficient (0.7)

Hargreaves method

Hargreaves (1975) suggested equation for reference evapotranspiration based on solar radiation, maximum temperature and minimum temperature as follows:

$$ET_0 = 0.0135 * 0.408Rs\,(T+17.8) \quad (4)$$

Hargreaves Samani method

The extraterrestrial radiation based equation of Hargreaves and Samani (1985) requiring only the data for Ra, T_{max} and T_{min} is as follows:

$$ET_0 = 0.408 * 0.0023(T + 17.8)(Tmax - Tmin)^{.5}\ Ra \quad (5)$$

Valiantzas method

A simplified form of modified PM equation requiring only solar radiation (R_s), T_{mean}-, RH_{mean} takes the following form (Valiantzas, 2013).

$$ET_0 = 0.0393Rs(T + 9.5)^{.5} - 0.19Rs^{.6}\phi^{.15} + 0.078(T + 20)\left(1 - \frac{RHmean}{100}\right) \quad (6)$$

Irmak method

Irmak *et al*. (2003) developed following simplified equation for estimation of ETo using solar radiation and mean temperature.

$$ET_0 = -0.611 + 0.149Rs + 0.079T \quad (7)$$

Artificial Neural Network

Artificial Neural Network (ANN) offers a relatively quick and flexible means of modelling. It gives complex nonlinear relationship among the dependent and independent variables, due to which it has received enormous interest by researcher and widely used for calculation of evaporation under limited weather data. An ANN is a computer model, composed of individual processing elements called units or neurons and they are highly interconnected and operate in parallel, these elements are inspired by biological nervous systems. In this study, the neural networks are adjusted or trained with a series of inputs so that a particular input leads to a specific target output from the training data set. In the ANN analysis MLP type of feed-forward neural network with back propagation learning algorithm is applied with input layer, hidden layer and output layer. Basically, it is a gradient descent technique to minimize the squared error between the calculated and predicted outputs. In this study, since the purpose of this study was the estimation of ETo, the ANN has only one output variable. The output of a neuron is decided by an activation function. There are a number of activation functions that can be used in ANNs, such as step, sigmoid, threshold, linear, etc. The sigmoid activation function [*f*(*x*)] commonly used, can be formulated mathematically as:

$$f(x) = \frac{1}{1 + e^{-x}}$$

The database was divided into three subsets: 65% of data are used in the training phase, 20% in the testing phase; 15% for validation. The first set is for determining the weights and biases of the network, the second one is for evaluating the weights and biases and to decide when to stop training and the last data set is for validating the weights and biases to verify the effectiveness of the stopping criterion and to estimate the expected network operation on new data sets. The idea behind this division is to overcome the over fitting problem. The PM estimated daily ET_0 values were employed as substitute for measured ET_0 data and used as target output. Results showed that increasing the number of neurons in hidden layer did not improve the ANN results as reported by Kisi (2006), but too many neurons may lead to the over fitting. So the number of hidden nodes in the ANN architecture was identified by trial and error (Moghaddamnia *et al.*, 2009). These computed ET0 values were used to train the ANN models. Various architectures and input combinations of the models were compared for crop evapotranspiration. The input variables considered in the input layer decrease gradually according to their reduced sensitivity i.e. T_{mean}>VPD >R_S > U_2as suggested by Anupriya *et al.* (2014) by calculating a sensitivity coefficient of ETo to each climate variable (Irmak *et al.*, 2006). Input parameters decrease from four to one and their effect on predicted ET_o is analyzed.

Accuracy criteria

Accuracy tests were performed to evaluate the reference evapotranspiration estimated by different methods by the statistical analysis, as shown in table in next page.

RESULTS AND DISCUSSION

Food and Agriculture Organization (FAO) has suggested that the Penman-Monteith method is the standard method for estimation of potential evapotranspiration. The average annual evapotranspiration for Varanasi is found to be 1447.4 mm and the average daily evapotranspiration is found to be 3.96 mm / day by the above method. The daily average reference evapotranspiration varies from minimum 1.65 mm / day to maximum 6.77 mm / day. Anupriya *et al.* (2014) has suggested that $T_{mean,}$ Vapour Pressure Deficit (VPD), solar radiation (R_S) and wind speed (U_2) are the parameters which are most sensitive in the decreasing order towards reference evapotranspiration. Artificial Neural Network technique was utilised with the different

Performance Criteria	Formula	Remarks
Mean Square Error (MSE)	$MSE = \frac{1}{N}\sum_1^N (Pi - Ei)^2$	An MSE of zero, means that the 'Pi' predicts observation of the parameter 'Ei' with perfect accuracy.
Root Mean square error (RMSE)	$RMSE = \sqrt{\frac{\sum_1^N (Pi-Ei)^2}{N}}$	Flemming (1975)
Coefficient of correlation (r)	$r = \frac{\sum_i (Pi - \bar{P})(Ei - \bar{E})}{\sqrt{\sum_i (Pi - \bar{P})^2 \sum_i (Ei - \bar{E})^2}}$	It always lies between -1 to +1, if r =1, the correlation coefficient is perfect and positive and if r = -1, then it is perfect and negative.
Coefficient of determination (r^2)	$r^2 = \frac{\{\sum_i (Pi-\bar{P})(Ei-\bar{E})\}^2}{\sum_i (Pi-\bar{P})^2 \sum_i (Ei-\bar{E})^2}$	Coefficient of determination (r^2) is a statistical measure of how well the regression line approximates the real data points. An r^2 of 1 indicates that the line of regression is of best fit.

where, P_i = Predicted ETo, E_i = Estimated ET_o, N = Number of observation

combination of these four sensitive parameters as input for estimation of reference evapotranspiration. To find out the best ANN architecture, providing near accurate estimation of evapotranspiration with limited climatic data, first of all the optimum number of nodes in hidden layer for each ANN architecture were decided by running the ANN analysis to a number of times until a significantly least relative error is found in the holdout. The best ANN architecture was chosen and evaluated among various ANN architectures with different number of neurons in hidden layer. Table 1, represent the results obtained from ANN of feed forward with learning algorithm of back propagation (BP) type. For statistical comparison of performance of these ANN architectures, the predicted evapotranspiration by these neural networks were compared with the estimates provided by the FAO-56(PM) evaporation model. The detail performance evaluation is briefed in the Table 1.

The ANN architecture 4-3-1 estimated evapotranspiration with maximum accuracy, i.e. relative error (Holdout) = 0.001, MSE = 0.003 mm day^{-1}, RMSE = 0.053 mm day^{-1}, r = 0.992 and r^2 = 0.985. But, this architecture requires four input parameters. While the ANN architecture 2-2-1 requires only two input parameters i.e., T_{mean}, solar radiation (R_s) and estimate evapotranspiration quite accurately with less error i.e., relative error (Holdout)= 0.005, MSE =0.017 mm day^{-1}, RMSE = 0.130 mm day^{-1}, r = 0.988 and r^2= 0.976. Therefore,

Table 1. Comparison of various neural network predicted ET_o data with FAO-56 (PM) estimated ET_o

ANN architecture	4-3-1	3-3-1	*2-2-1*	1-9-1	3-5-1	2-6-1	2-3-1
Inputs	T_{mean}, Solar radiation, VPD, U_2	T_{mean}, Solar radiation (R_s), VPD	T_{mean}, Solar radiation (R_s)	T_{mean}	Solar radiation (R_s), (VPD, U_2)	T_{mean}, U_2	Solar radiation (R_s), VPD
No of neurons							
Input	4	3	2	1	3	2	2
Hidden	1	1	1	1	1	1	1
Output	1	1	1	1	1	1	1
Nodes in hidden layer	3	3	2	9	5	6	3
MSE	0.003	0.015	0.017	0.624	0.024	0.129	0.185
RMSE	0.053	0.124	0.130	0.790	0.156	0.359	0.430
Coefficient of correlation (r)	0.992	0.989	0.988	0.920	0.985	0.959	0.944
Coefficient of determination (r^2)	0.985	0.978	0.976	0.846	0.970	0.920	0.892
Relative Error (Holdout)	0.001	0.006	0.005	0.089	0.009	0.034	0.061

where, T_{mean}= Daily mean temperature (°C), Solar radiation (R_s) on daily basis, Vapour Pressure Deficit (VPD) = e_s-e_a, U_2= Wind speed daily basis

ANN architecture 2-2-1 was chosen for comparison with other empirical methods of evapotranspiration estimation. Fig. 1 is a general architecture (2-2-1) of a feed forward neural network consisting of one input layer, one hidden layers and one output layer and found to be the best one among other architectures under consideration. The comparison of estimated ET_o values by different 9 methods including ANN (2-2-1) is represented in Table 2 on ten days basis for providing clear view of reference evapotranspiration by different methods. It is found that mean daily ET_o estimated by methods like PM, Hargreaves, Irmak, HS-5 and ANN lies in the close proximity. However, annual average ET_o obtained from Hargreaves and Irmak method are almost same. Graphical representation

Table 2. Comparison of the results obtained from various ET_o estimation methods

Month	No. of days	Average ETo (mm / day) estimated on ten days basis by different methods							
		Pan	P-M	Hargreaves	Irmak	HS	Modified PM	Valiantzas	ANN
JAN	I (10)	1.04	1.69	1.97	2.29	2.42	2.00	2.30	1.83
	II(10)	1.26	1.97	2.22	2.54	2.63	2.30	2.65	1.99
	III(11)	1.43	2.28	2.55	2.87	2.94	2.65	3.06	2.28
FEB	I(10)	1.62	2.54	2.95	3.18	3.24	2.92	3.36	2.57
	II(10)	1.90	2.92	3.22	3.43	3.58	3.30	3.71	2.87
	III(8)	2.22	3.30	3.64	3.77	3.98	3.76	4.23	3.37
MAR	I(10)	2.56	3.76	4.04	4.09	4.49	4.33	4.85	3.82
	II(10)	3.03	4.20	4.41	4.35	5.11	4.78	5.24	4.10
	III(11)	3.86	4.83	4.90	4.68	5.85	5.51	6.01	4.63
APR	I(10)	4.59	5.39	5.46	5.05	6.54	6.09	6.79	5.22
	II(10)	5.13	5.69	5.58	5.15	6.98	6.54	7.08	5.60
	III(10)	5.59	6.06	5.98	5.40	7.10	6.89	7.36	6.08
MAY	I(10)	5.42	6.29	6.14	5.49	6.99	7.05	7.36	6.26
	II(10)	5.64	6.36	6.19	5.51	7.15	7.08	7.33	6.39
	III(11)	5.48	6.39	6.14	5.50	7.14	7.01	7.18	6.44
JUN	I(10)	5.80	6.45	6.22	5.53	7.13	7.09	7.23	6.55
	II(10)	5.35	5.91	5.67	5.19	6.20	6.45	6.34	5.97
	III(10)	4.23	4.89	4.60	4.55	5.60	5.16	4.93	4.74
JUL	I(10)	3.73	4.66	4.39	4.46	5.19	4.86	4.62	4.54
	II(10)	3.21	4.33	4.14	4.28	4.77	4.43	4.12	4.20
	III(11)	3.19	4.49	4.39	4.42	4.55	4.66	4.34	4.38
AUG	I(10)	3.08	4.42	4.40	4.45	4.46	4.57	4.34	4.43
	II(10)	2.68	4.00	3.99	4.18	4.22	4.10	3.88	4.00
	III(11)	2.93	4.28	4.32	4.41	4.28	4.38	4.25	4.35
SEPT	I(10)	3.02	4.17	4.34	4.33	4.14	4.25	4.15	4.19
	II(10)	2.73	3.93	4.07	4.19	3.97	4.05	4.00	3.96
	III(10)	2.61	3.98	4.27	4.30	4.00	4.13	4.23	4.08
OCT	I(10)	2.49	3.78	4.25	4.30	4.00	4.06	4.39	4.03
	II(10)	2.25	3.47	4.01	4.10	4.03	3.82	4.30	3.62
	III(11)	2.02	3.07	3.74	3.91	3.95	3.55	4.24	3.24
NOV	I(10)	1.92	2.74	3.34	3.63	3.79	3.25	3.97	2.70
	II(10)	1.84	2.45	3.06	3.38	3.45	2.99	3.72	2.37
	III(10)	1.54	2.25	2.85	3.17	3.22	2.76	3.47	2.23
DEC	I(10)	1.37	2.06	2.59	2.93	3.00	2.55	3.23	2.07
	II(10)	1.24	1.92	2.33	2.72	2.76	2.35	2.90	1.89
	III(11)	1.16	1.75	2.08	2.45	2.58	2.12	2.55	1.79
ET_o(mm)	Annual avg.	1107.10	1447.41	1505.51	1502.38	1677.61	1600.15	1700.01	1448.27
	Daily average	3.03	3.97	4.12	4.12	4.6	4.38	4.66	3.97

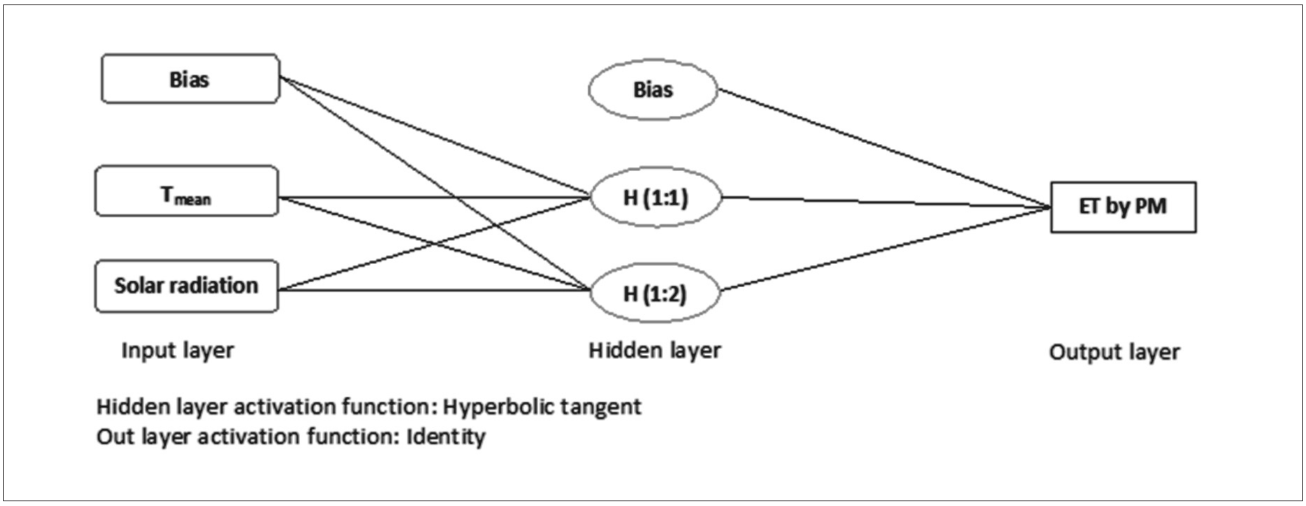

Fig. 1. Architecture (2-2-1) of feed forward neural network with one hidden layer

of average ET_o by different methods on monthly basis is shown in Fig 2. It shows maximum ET_o during month of May and lowest during month of Dec-Jan. When compared among the different methods for estimation of reference evapotranspiration with standard Penman-Monteith method, it is found that Pan (FAO-24) under estimate and Modified Penman-Monteith, Hargreaves-Samani, Irmak, Hargreaves, Valiantzas overestimate however ANN closely estimates reference evapotranspiration.

Long term changes in evaporation and potential evapotranspiration can have profound implications for hydrological process as well as for agricultural crop performance. Large changes in the evapotranspiration demand would change the water requirement and water balance in the crop growing seasons. Trend analysis as shown in Fig. 3 depicts the decreasing trend. It has also observed that annual reference crop evapotranspiration varies from 1553.02 mm (year 1993) to 1383.58 mm (year 2013). Similar trends were also observed by Rao and Wani (2011) for semi-arid climate of ICRISAT, Hyderabad.

Pan evaporation data is available at almost all metrological observatories. An attempt was made to correlate these Pan data with other estimation methods. The results of statistical analysis (Table 3) shows that Penman- Monteith method have a close relationship with Pan method having MSE= 0.968, RMSE= 0.984 and coefficient of correlation (r) = 0.977 followed by ANN having MSE= 1.002, RMSE= 1.001 and coefficient of correlation (r) = 0.971. Similar pattern was also found by Kale *et al.* (2013). A single linear regression (y = mx + c) for each estimation was also accomplished by plotting the scatter plot for the test data with respect to data obtained from FAO-24 estimations and is depicted in Fig. 4 to 10.

Table 3. Statistical comparison of ET_o estimated by different methods with ET_o estimated by FAO-24 (Pan) model

ET_o estimation methods	MSE	RMSE	Coefficient of correlation (r)	Coefficient of determination (r^2)	Conversion Equation from Pan model to others	C (y intercept)
Penman-Monteith	0.968	0.984	0.977	0.955	Y_1 = 0.9591X + 1.056	1.056
Hargreaves	1.397	1.182	0.960	0.922	Y_2 = 0.8051X + 1.683	1.683
Irmak	1.649	1.284	0.940	0.884	Y_3 = 0.5877 X + 2.334	2.334
Hargreaves-Samani	2.534	1.592	0.979	0.959	Y_4 = 0.973 X + 1.645	1.645
Mod PM	1.899	1.378	0.985	0.970	Y_5 = 1.0309 X + 1.257	1.257
Valiantzas	2.852	1.689	0.952	0.907	Y_6 = 0.9663 X + 1.727	1.727
ANN	1.002	1.001	0.971	0.942	Y_7 = 0.9457 X + 1.100	1.100

where, X = Estimated ETo by Pan method and Y_1, Y_2, Y_3, Y4, Y5, Y6 and Y_7 are estimated ETo by Penman- Monteith, Hargreaves, Irmak, Hargreaves samani, Modified PM, Valiantzas and ANN methods, respectively.

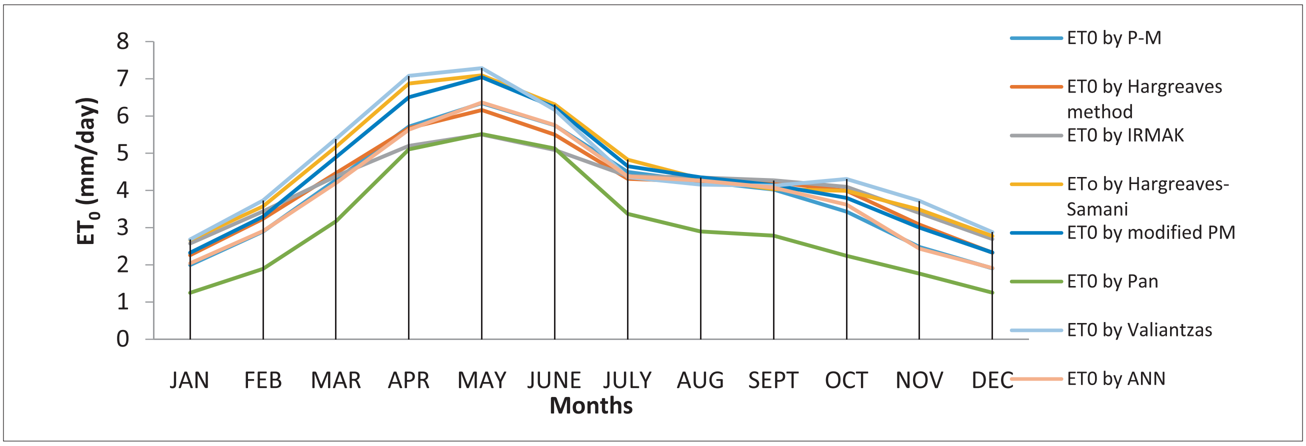

Fig. 2. Monthly average reference evapotranspiration (ET_o) by different 8 methods

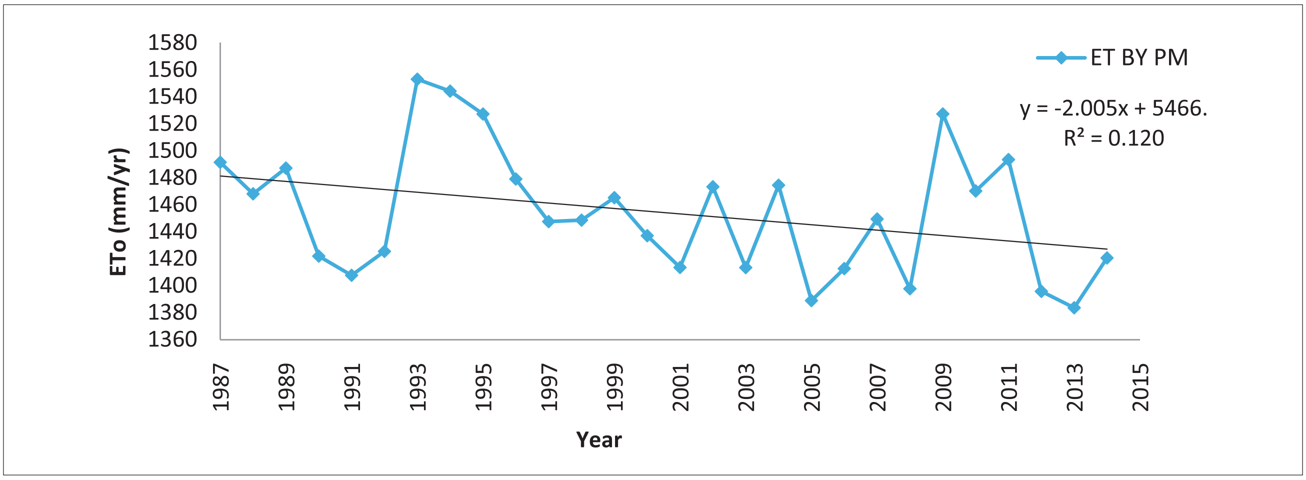

Fig. 3. Trend in reference crop evapotranspiration (ET_o) at Varanasi, UP

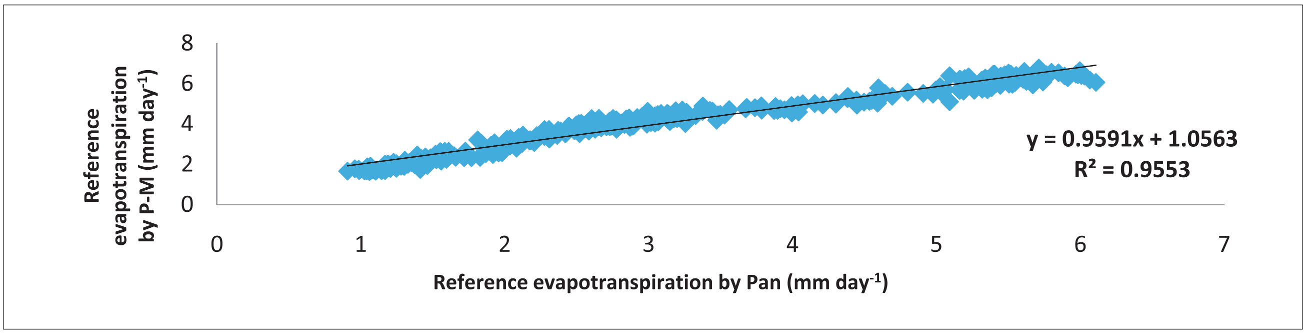

Fig. 4. Reference evapotranspiration by Pan Vs P-M

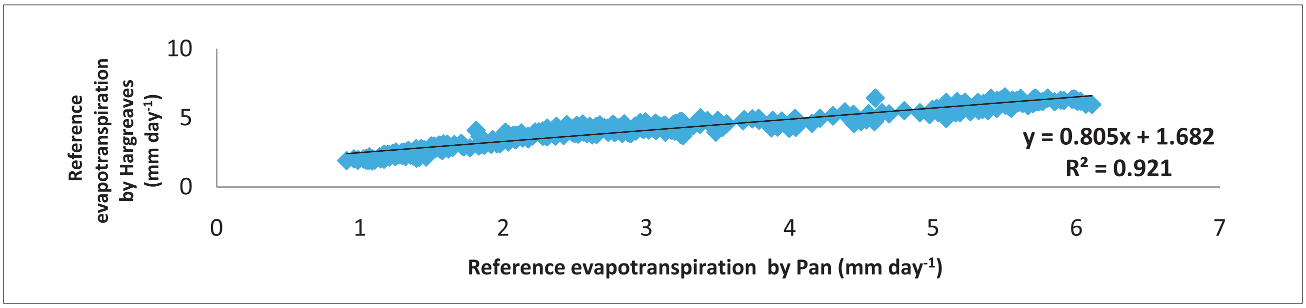

Fig. 5. Reference evapotranspiration by Pan Vs Hargreaves method

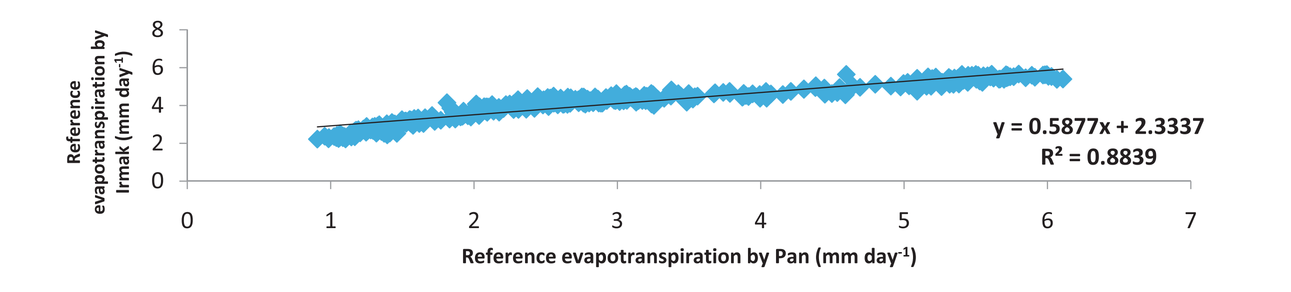

Fig. 6. Reference evapotranspiration by PAN Vs IRMAK

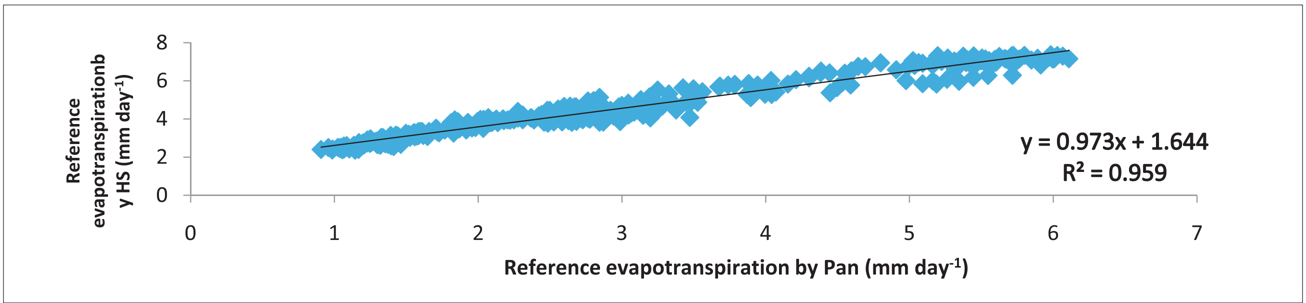

Fig. 7. Reference evapotranspiration by Pan Vs Hargreaves-Samani

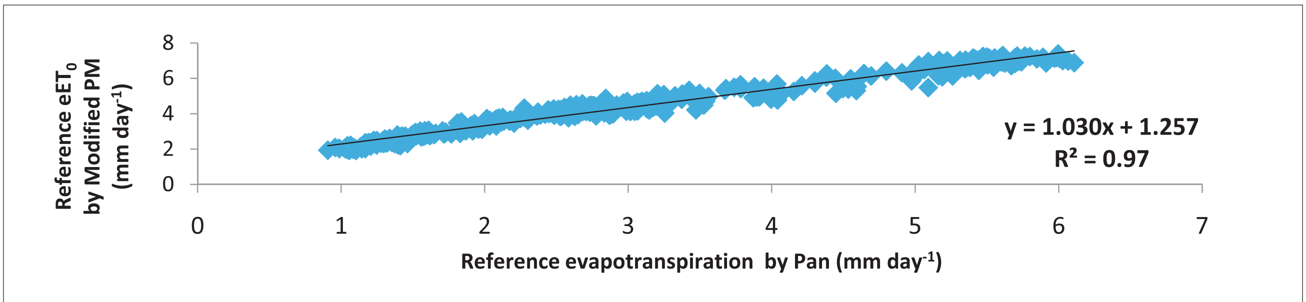

Fig. 8. Reference evapotranspiration by Pan Vs Modified PM

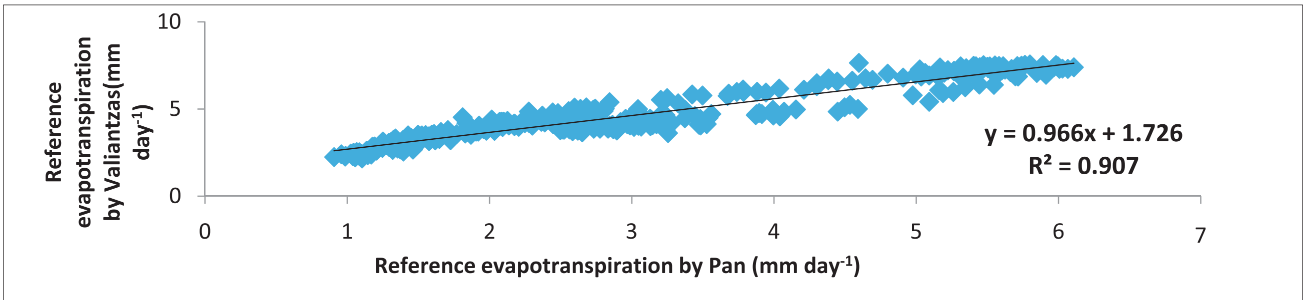

Fig.9. Reference evapotranspiration by Pan Vs Valiantzas

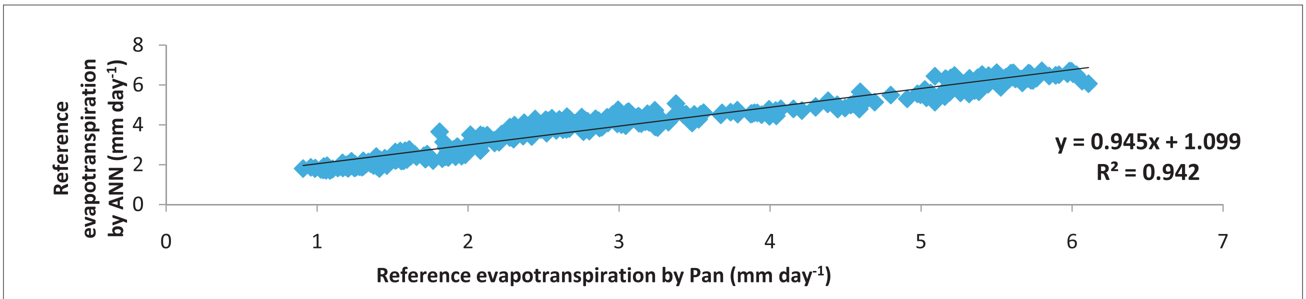

Fig. 10. Reference evapotranspiration by Pan Vs ANN

CONCLUSION

Estimation of the crop evapotranspiration is very useful for crop planning in dry Sub-humid Agro-ecological region. In case of limited weather data, Artificial Neural Network (architecture: 2-2-1) with input parameters mean temperature and solar radiation (R_s) estimate the reference evapotranspiration very accurately. The Pan data can be correlated with penman Monteith method high degree of correlation.

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Efficient use of jute agro textiles as soil conditioner to increase chilli productivity on Inceptisol of West Bengal

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ABSTRACT

A field experiment was conducted at the University farm of Regional Research Station, New Alluvial zone of Bidhan Chandra Krishi Viswavidyalaya, Gayespur under Nadia district of West Bengal which is situated at 22^0 58' 31'' N L, 88^0 26' 20'' E L, with an altitude at 10.9 m above the mean sea level to investigate the effect of various strength (gram per meter square) of jute agro textiles on change of soil properties on chilli yield. Five treatment combinations *viz*. T_1 - farmers practices (control), T_2 - 200 GSM jute agro textiles, T_3- 400 GSM jute agro textiles, T_4 - 600 GSM jute agro textiles and T_5- 800 GSM jute agro textiles were spread before transplanting of chilli seedlings along with the levels of N-P-K at 50-25-25 kg / ha and in RBD design with four réplications. Initials and final soil samples were analyzed for relevant physical and chemical properties by following standard methods. The yields of crop were found 10.00, 16.26, 17.57, 14.02 and 12.00t / ha respectively in T_1, T_2, T_3, T_4 and T_5. The yield of crop was increased 7.57t / ha (75.7%) under 400 GSM jute agro textiles over – farmers practices (control). The result showed the decreased bulk density and increased porosity under all treatments. They also improved moisture use efficiency, in general, by 96.5% over control. Decreasing bulk density with simultaneous increasing of porosity under jute agro textile treatments also improved the moisture retention capacity in soil. Better aggregation and their stabilization as well as chilli yield occurred with applied T_3 - 400 GSM jute agro textiles treatments.

Key words: Jute agro textiles, bulk density, porosity and moisture use efficiency.

INTRODUCTION

Jute agro geo-textiles as surface cover materials have various potentials for maintaining soil quality and protecting the soil against any form of degradation. Naturally occurring jute agro geo-textiles are eco-friendly and biodegradable products which act as surface cover materials and useful ameliorative to eliminate soil related constraints to crop production (Yong *et al*., 2000; Pain *et al*., 2013). It also helps to protect the most vital natural resources against various degradation processes and promotes vegetative cover through accelerated seed germination and seedling emergence (Bhattacharya *et al*., 2010). Adequate information on the efficiencies of jute agro textiles as soil conditioners towards improving crop productivity are lacking.

Chilli is an important cash crop in India and is grown for its pungent fruits, which are used both as green and ripe. Green chillies are rich in Vitamin A and C, minerals and protein. Dry chillies are also rich in Vitamin A and D. It is an essential item for almost every Indian dishes and also used as sauces, chutneys and pickles and medicinal purposes. India as the largest producer of chillies in the world. Its production level covers around 1.1 million tons annually. The major cultivated regions of chilli in India are AP, Karnataka, Maharashtra, UP, Punjab, TN, Rajasthan, Orissa, West Bengal and M.P. of which Andhra Pradesh alone commands about 46% of the production. However, the productivity of the crop gradually decreases due to declining soil fertility status and inadequate availabilities of water as well as non-availability of good quality seeds.

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Keeping in view the above considerations, the present study was undertaken to compare the efficiencies of different strength (gram per meter square) of jute agro textiles on soil quality changes and improvement of chilli yield in sub-tropical condition.

MATERIALS AND METHODS

The present investigation have been carried out at the university farm of Regional Research Station, New Alluvial Zone, Bidhan Chandra Krishi Viswavidyalaya, Gayeshpur, Nadia District, West Bengal represented by sub-tropical climatic region is situated at 22^0 58’ 31’’ N L, 88^0 26’ 20’’ E L, with an altitude at 10.9 m above the mean sea level having average rainfall of 1500 to 1600 mm / year with variation of temperatures between 10^0 to 38^0 C. The soils of the area are characterized by acidic in nature, low in organic carbon and medium in fertility status. The experiment was conducted with the treatments: T_1 : farmer’s practice (control), NPK @ 50-25-25 kg / ha; T_2 : 200 GSM jute agro textiles + NPK @ 50-25-25 kg / ha; T_3 : 400 GSM jute agro textiles + NPK @ 50-25-25 kg / ha; T_4 : 600 GSM jute agro textiles + NPK @ 50-25-25 kg / ha; T_5: 800 GSM jute agro textiles + NPK @ 50-25-25 kg / ha where GSM = gram per meter square.

All the treatments were replicated four times in RBD design with growing chilli (*Capsicum annuum)* (var. - Kajli bullet) as test crop. It was shown on 1^{st} week of February consecutively for the years of 2015 and 2016. The area of each plots were maintained by 20 sq.m with spacing of 75 cm between row to row and 75 cm between plants to plants. The recommended packages of practices were adopted for growing of the crop. Each year green chilli crops were harvested started from 1^{st} week of April upto June. Jute agro textiles were laid during the transplanting of chilli seedlings (Fig. 1). Bulk density and porosity of soil and soil moisture contents of surface layer at 7 days interval from entire growth period were determined by gravimetric method by Black (1965). The size distribution of aggregates in soil was evaluated by the methods as proposed by Piper (1966). The pH, organic carbon, availabilities of phosphorous and potassium were determined by the standard procedure of Jackson (1965). Cost benefit ratios was calculated by the ratio of total economic return (Rs) and total cost (Rs). Moisture use efficiency was calculated by the relationship as: MUE (kg / mm / ha) = Total yield (kg / ha) / Consumptive use of water (mm). Necessary stastical analysis was worked out to interpret the effects of treatments as suggested by Gomez and Gomez (1984).

Fig 1. Two month aged chilli crop with jute agro textiles

RESULTS AND DISCUSSION

Chilli yield

The results of effects of different strength of jute agro textiles on yields of chilli presented in Table 1 and (Fig. 2). Response of green chilli yield over control due to treatments were 6.26 ton / ha (62.5%), 7.57 ton / ha (75.7%), 4.02 ton / ha (40.2%) and 2.00 ton / ha (20.00%) and dry chilli yield were 1.38 ton / ha (61.61%), 1.74 ton / ha (77.68%), 0.91 ton / ha (40.63%) and 0.41 ton / ha (18.30%), respectively in 200 GSM jute agro textiles, 400 GSM jute agro

Table 1. Effect of different strength of jute agro textiles on chilli yield, MUE and BC ratio

Treatments	Green Yield (ton / ha)	Dry Yield (ton / ha)	Moisture use efficiency (kg / ha / mm)	Benefit Cost ratio (B:C)
(T_1) Control (farmers practices)	10.00	2.24	35.6	1.2:1
(T_2) 200 GSM jute agro textiles	16.26	3.62	60.0	2.2:1
(T_3) 400 GSM jute agro textiles	17.57	3.98	67.5	2.4:1
(T_4)600 GSM jute agro textiles	14.02	3.15	66.3	2.1:1
(T_5) 800 GSM jute agro textiles	12.00	2.65	64.61	2.0:1
SE(m)$\pm$	0.16	0.03	0.01	
CD(0.05)	0.50	0.10	0.03	

Fig. 2. Three month aged chilli crop with fruits

textiles, 600 GSM jute agro textiles and 800 GSM jute agro textiles. The significantly highest ($P<0.05$) green and dry chilli yield crop were observed in 400 GSM jute agro textiles. The benefit cost ratio of chilli crop also maximum on 400 GSM jute agro textiles. The results revealed that the maximum chilli yield under 400 GSM jute agro textiles probably due to proper root growth towards uninterrupted availability of nutrients through continuous supply of moisture and air. The above results find supported by Paza (2007).

Physical and chemical properties of soil

The results of the effects of different strength of jute agro textiles on the changes of physical and chemical properties of soil are presented in Table 2. Bulk density of soil were decreased by 0.07(5.15%), 0.08(5.88%), 0.1(7.35%) and 0.13(9.56%) with simultaneous increased of porosity by 6.9(17.00%), 9.0(22.17%), 8.2(20.20%) and 6.1(15.02%) respectively in 200 GSM jute agro textiles, 400 GSM jute agro textiles, 600 GSM jute agro textiles and 800 GSM jute agro textiles over control. The results further indicated that significantly increased availability of nitrogen, phosphorous and potassium. The results also reveal the increment of organic carbon by 0.09(13.64%), 0.23(34.85%), 0.31(46.97%) and 0.38(57.58%) respectively in 200 GSM jute agro textiles, 400 GSM jute agro textiles, 600 GSM jute agro textiles and 800 GSM jute agro textiles. The results revealed that the maximum porosity was found in 400 GSM jute agro textiles to increase aeration and root growth towards uninterrupted availability of nutrients. The above results are in agreement with those reported by Dutta and Chakraborty (1995).

Soil moisture use efficiency

Soil moisture changes at 7 days interval for the entire growing period of chilli under various strength of jute agro textiles have been depicted in Fig. 3. Soil moisture content at every stage was higher under each of the treatment over control. It was found maximum under 400 GSM jute geo textiles than other treatments. Results followed the following order of soil moisture contents: 400 GSM jute geo textiles > 600 GSM jute geo textiles > 800 GSM jute geo textiles > 200 GSM jute geo textiles > control. The changes of soil moisture content due to the treatment might be attributed by bulk

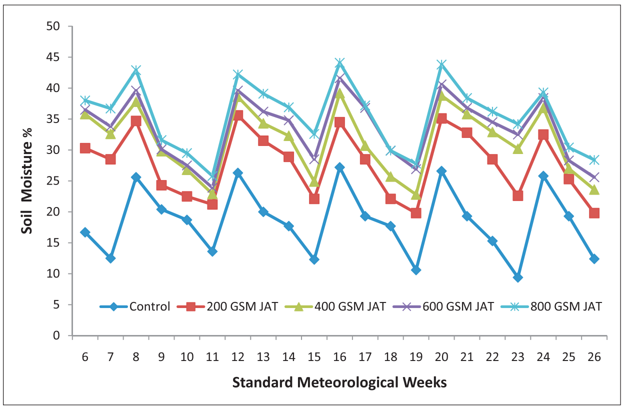

Fig. 3. Effect of various jute agro textiles management on changes of soil moisture percent

Table 2. Effect of different strength of jute agro textiles on soil physical and chemical properties

Treatments	Bulk Density (Mg/m^3)	Porosity (%)	pH (1:2)	Organic Carbon (%)	Total N (%)	Available P (kg/ha)	Available K (kg/ha)
(T_1) Control (farmers practices)	1.36	40.6	6.2	0.66	0.09	16.7	145
(T_2) 200 GSM jute agro textiles	1.29	47.5	6.4	0.75	0.18	26.9	292
(T_3) 400 GSM jute agro textiles	1.28	49.6	6.5	0.89	0.22	27.9	306
(T_4)600 GSM jute agro textiles	1.26	48.8	6.6	0.97	0.28	29.7	320
(T_5) 800 GSM jute agro textiles	1.23	46.7	6.7	1.04	0.31	30.8	332
SE(m)±	0.005	0.389	0.01	0.02	0.04	0.30	0.20
CD(0.05)	0.017	1.346	0.03	0.07	0.13	0.94	0.63

Table 3. Effect of different strength of jute agro textiles on soil structure and their stabilization

Treatments	Mean Weight Diameter (mm)	Structure Coefficient	Geometric Mean Diameter (mm)	WSA>0.25 (%)	WSA<0.25 (%)
(T_1) Control (farmers practices)	1.21	0.91	0.78	58.97	41.03
(T_2) 200 GSM jute agro textiles	1.24	1.10	0.86	72.23	27.77
(T_3) 400 GSM jute agro textiles	2.95	1.27	1.41	84.74	15.51
(T_4)600 GSM jute agro textiles	2.37	1.23	1.21	82.88	17.12
(T_5) 800 GSM jute agro textiles	2.26	1.17	1.01	79.30	20.70
SE(m)$\pm$	0.01	0.11	0.01	0.99	0.99
CD(0.05)	0.03	0.35	0.04	3.43	3.43

density and porosity in soil towards increasing moisture retention capacity of soil. The data further showed that the moisture use efficiencies of the crop, generally, increased by 81.47 % due to the treatments of jute agro textiles over control, the highest of 89.61 % which occurred under 400 GSM jute agro textiles (Table 1). The above results supported by Nag *et al.* (2008).

Soil aggregation

The results of the effects of jute agro textiles on the changes of various indices of soil structure and their stabilization were presented in table 3. Results clearly revealed much variation of all the indices of soil structure and their stability due to application of various treatments. The values of mean weight diameter (MWD), geometric mean diameter (GMD), structural coefficient (SC) and water stable aggregates (WSA) were found highest under 400 GSM jute agro textiles followed by 600 GSM jute agro textiles, 800 Gsm jute agro textiles, and 200 GSM jute agro textiles. These indicated that 400 GSM jute agro textiles could be effective amelioration towards improving stability of soil structure. The above results are supported by the findings of Panchal *et al.* (2002).

CONCLUSION

Efficiencies of different strength of jute agro geotextiles on the improvements of soil properties attributing yield of chilli have been investigated in the present study. Sharp improvements of bulk density, porosity, moisture use efficiency as well as better aggregation and well stabilization of soil aggregates occurred due to application of each strength of jute agro geotextiles in general, of which 400 GSM jute agro textiles showed most prominent effects on porosity and yield of chilli and benefit / cost ratio as well. The result thus leads to suggest that 400 GSM jute agro textiles could be effectively utilized for chilli cultivation as its beneficial effects towards favourable soil structure along with other soil properties and uninterrupted availability of water, nutrient and air influencing root growth which in turn improves crop production.

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Artificial Neural Network models for disaggregation of monsoon season runoff series for a hilly watershed

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ABSTRACT

This paper presents the application of artificial neural networks for disaggregating of monsoon season comprising of June, July, August and September (JJAS) months of the year runoff series and is illustrated by an application to model the river flow of Naula watershed of Ramganga river in Uttrakhand state, India. Two different seasonal ANN models were developed. In the first ANN model neural network was trained with monsoon season comprising of June, July August and September (JJAS) months of the year runoff as input and runoff (corresponding to 4 months, JJAS) of June, July, August and September month output. The ANN architecture 1-1-1-4 was found best in training and testing. In the second ANN model most active monsoon months (July and August) total runoff and relatively less active months (June and September) total runoff was used as input and runoff of July and August; June and September runoff, respectively as output. The ANN architecture 1-4-4-4-2 for June-September total and 1-4-4-2 for July-August total was found best in training and testing. Lower value of RMSE and higher value of CE was obtained for all the months for the selected architecture. The correlation coefficient between measured and simulated data series are 0.92 and 0.75 for training and testing, respectively for model 1 whereas for model 2, the values are 0.99 and 0.87 in July-August and 0.97 and 0.89 in June-September for training and testing, respectively.

Key words: Disaggregation, Neural network, Levenberg-Marquardt algorithm

INTRODUCTION

Water resources systems are complex and need systematic study with reliable data to arrive at optimal planning and management decisions. Relative shortage of runoff data at lower time scale coupled with insufficient runoff gauge demands the generation of the hydrologic sequences for the design of water resources system. Disaggregation models have been used to disaggregate annual flow series to monthly of spatially to disaggregate basin flows at some time interval to flows at individual sites at the same time interval. Artificial neural networks is adopted by the researchers (Burian *et al.*, 2000,2001; Nix and Pitt, 2001; Burain and Durran, 2002; Kumar and Raju, 2002; Singh *et al.*, 2008; Zhang *et al.*, 2008; Bhatt *et al.*, 2011; Subbaiah, 2013) in the disaggregation models.

Artificial neural networks (ANN) are semi-parametric regression estimators and are well suited as they can approximate virtually any (measurable) function up to an arbitrary degree of accuracy (Hornik *et al.*, 1989). A significant advantage of the ANN approach in system modeling is that one need not have a well-defined physical relationship for systematically converting an input to an output. Rather, all that is needed for most networks is a collection of representative examples (input-output pairs) of the desired mapping. The ANN then adapts itself to reproduce the desired output when presented with training sample input. ANN have become popular in the last decade for hydrological forecasting such as rainfall-runoff modeling, stream flow forecasting, ground water and precipitation forecasting and water quality issues (Kisi, 2004; Sahoo *et al.*, 2005; Admowski, 2007, 2008a, 2008b; Panda, 2010; Admowski and Chan, 2011).

The major objective of this paper is to investigate the potential of artificial neural networks in disaggregating monsoon season runoff series into monthly runoff series and to assess its performance. The applicability of the method is

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demonstrated by modeling river flow for Naula watershed of Ramganga river catchment for an Indian basin.

MATERIALS AND METHODS

Study area and data

The Naula watershed is the part of Ramganga river catchment upstream to Naula gauging station and is geographically located between 29°44' N and 30°5'20" N Latitude and 79°6'15" E and79°31'15" E longitude. The area of the watershed is about 1010 sq km which drains from North to South into the Bino tributary and the main Ramganga river. The Bino tributary joins then Ramganga river at the Kedar gauging station. The topography of the watershed is undulating and irregular with slope varying from moderate to steep. The minimum and maximum elevations of the watershed are 792 m and 3112 m, respectively above the mean sea level. The climate of the watershed is Himalayan sub-tropical to sub-temperate. The major portion of annual precipitation occurs in the form of rainfall from mid June to middle of September with the mean annual precipitation as 1015 mm. The rainfall generally, occurs due to South-West monsoon.

The daily rainfall and runoff data of monsoon season (1^{st} June to 30^{th} September) for the years 1979 to 1996 for Naula watershed were obtained from Ranikhet Forest Sub-Division Uttarakhand. The daily rainfall and runoff data were converted into monthly data series and monsoon season comprising of June, July August and September (JJAS) months. The monsoon season rainfall and runoff for June, July, August and September for the year 1979 to 1996 shows that overall 65.04% of monsoon season rainfall flows as runoff whereas percentage of rainfall as runoff flow is 29.17%, 51.20%, 77.60% and 112.22% in the months of June, July, August and September, respectively. Analysis of rainfall and runoff processes clearly indicates increasing trend in the percentage rainfall contribution to runoff from June to September months. There is increasing contribution of sub surface flow / delayed runoff in the September month runoff.

Model description

An artificial neural network (ANN) is a data-driven process with a flexible mathematical algorithm capable of solving complex nonlinear relationships between input and output data sets. A neural network can be described as a network of simple processing nodes or neurons, interconnected to each other in a specific order, performing simple numerical manipulations. A neural network can be used to predict future values of possibly noisy multivariate time series based on past histories. The most widely used neural network is the multilayer perceptron (MLP). In the MLP, the neurons are organized in layers, and each neuron is connected only with neurons in contiguous layers.

The Levenberg-Marquardt algorithm (LM) is a modification of the classic Newton algorithm. The goal of the LM algorithm is to search for the minimum point of a nonlinear function (*Karul et al.*, 2000). The LM algorithm performs a curve fitting on the data. The LM algorithm is designed to approach second-order training speed and accuracy without having to compute the Hessian matrix. Second-order nonlinear optimization techniques are usually faster and more reliable and it was found that the performance of the LM algorithm is superior to other training algorithms such as the conjugate gradient and gradient descent with momentum algorithms. Therefore, the LM algorithm was used to train the ANN models in this study.

Model development

To develop an ANN model, the primary objective is to optimize the architecture of the ANN that captures the relationship between the input and output variables. The development of disaggregation models using ANN involves the following steps (Srinivasulu and Jain, 2006):

(i) selection of data sets for training and testing of the model, (ii) identification of the input and output variables, (iii) normalization (scaling of the data),(iv) selection of network architecture, (v) determining the optimum number of neurons in the hidden layer, (vi) trainings of the ANN models and (vii) validation of ANN models using the selected performances evaluation statistics.

The ANN models developed in this study consisted of three layers; an input layer consisting of neurons depending on the input data vectors, hidden layer and an output layer consisting of number of neurons depending on the output vector. The seasonal inflow is taken as input. The data was split into two data sets: (1) The training set (1979-1991) and (2) the validation set (1992-1996). The first data set was used to train the model. The latter data set was used to indicate the performance of a trained ANN. In this study 70% data was taken towards training set and the remaining 30 % toward the validation set. The next step in the development of ANN model was the determination of optimum number of neurons (N) in the hidden layer. The optimum numbers of neurons in the hidden layer were indentified using a trial and error procedure by varying the number of hidden neurons from 1 to 5. Further the ANN models were trained using the Levenberg-Marquardt training algorithm and the optimum network architecture was selected based on network with minimum root mean square error (RMSE). Therefore, ANN models were adopted as the best structure combination to capture the relationship inherent in the data set under consideration. The sigmoid activation function was used as transfer function for both hidden and output layers. In this study two disaggregation models were developed.

Model 1: Monsoon season comprising of June, July August and September (JJAS) months runoff was disaggregated into June, July, August, September month's runoff (corresponding to 4 months, JJAS)

Model 2: Most active monsoon season months (July and August) total runoff was disaggregated into July and August month's runoff and relatively less active monsoon months (June and September) total runoff was disaggregated into June and September month's runoff.

The ANN architecture of 1-N-4 for model1 and 1-N-2 for model 2 was investigated. Of several network configurations tried, results from1-1-1-4 optimum architecture for model 1 and 1-4-4-4-2 for June- September and 1-4-4-2 for July-August for model 2 were used in the study.

RESULTS AND DISCUSSION

The graphical results in terms of plot of measured and simulated flows by the models for the training period for the months of June, July, August and September were considered for comparison and for one of the representative month July is shown in Fig. 1(a). Visual assessment of the simulated and measured flow shows that the trend of simulated monthly runoff by model 2 follows well the measured monthly runoff for all the years. The comparison further indicates that the performance of the both models in predicting July and August month runoff is comparable during training period except for model1 in the year 1983. It was observed that the problem of under estimating high flows and over estimating low flows by model1 for months of July and September is overcome by the model 2.

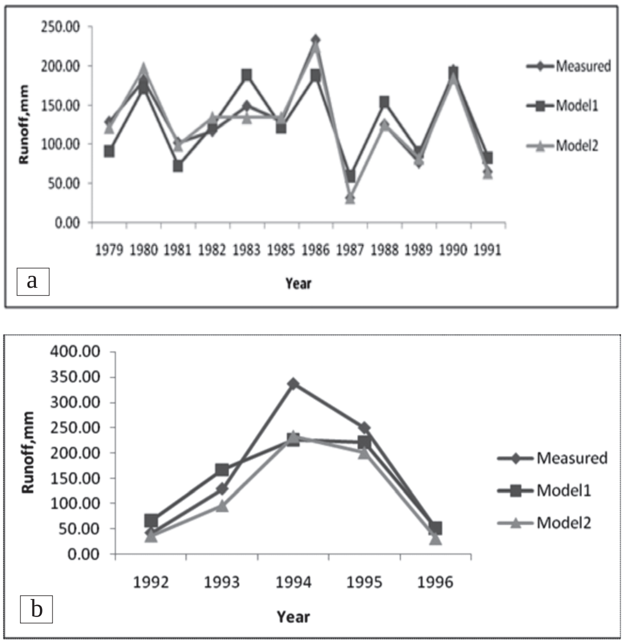

Fig. 1. Comparison between measured and simulated runoff of July month for (a) training period, (b) testing period

The monthly simulated runoffs by the models were compared with the monthly measured runoff graphically for the months of June, July, August and September, respectively. The Fig. 1(b) shows the comparison between measured and simulated runoff for July month for testing period. The Figures nicely demonstrates that models performance is in general, accurate and good, where all data points are near the line of agreement and thus show a close match throughout the testing period except 1994 year for June and August, 1993 year for August and 1993 and1995 year for the month of September. The models were not able to predict the high value of runoff correctly. It is observed that in the training data set high flows are significantly less than the low and medium flows; therefore, parameters estimated on this training set have a bias towards the low and medium flows. It was observed that flows are relatively high during the testing period. This observation substantiates comparatively not so good performance of the models during testing period. Subbaiah (2013) also observed that ANN models underestimated quite a number of moderates flows peaks by up to 32%. The value of measured runoff in the year 1993, 1994, 1995 are more than 102, 360 and 332 mm then the average runoff of 512 mm of training period. None of the years in calibration period received similar amounts of runoff as in these years which received more values of runoff covering the years in training.

The monthly simulated values of runoff were plotted against the measured values for training and testing periods for the months of June, July, August and September for model1 and the plot for the month of July for model 1 for training and testing period are shown in Fig. 2(a) and Fig. 2(b),

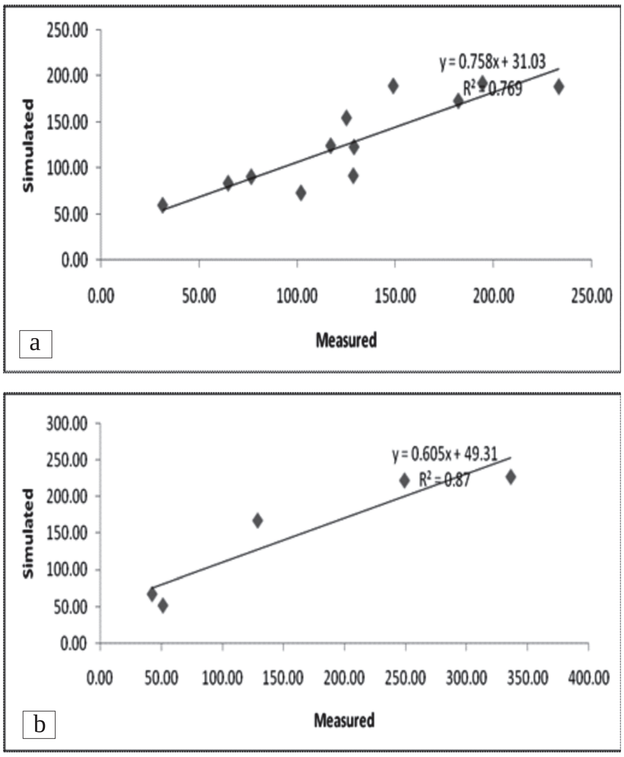

Fig. 2. Comparison of measured and simulated runoff by model 1 of July for (a) training period, (b) testing period

respectively whereas for model 2 are shown in Fig. 3(a) and Fig. 3(b), respectively. The values of R^2 shows good fit except for the months of June and September by model 1.The values of R^2 of linear fit between observed and simulated runoff for the monsoon month by the two models are given in Table 1. It is clear from the Table 1 that all the values of coefficient of determination are in the acceptable limit for the months of July and August in case of model1, the values being higher than 0.75 for training and testing period. The values of R^2 are not so good for the months of June and September in case of model1. The value of R^2 for the months of June, July, August and September in case of model 2 are more than 0.95 in case of training period and more than 0.65 in case of testing period. The values of R^2 are higher in the months of July and August. The lower value of R^2 in June and September data series were observed due to large variability. It is clear from the Table 1 that the fit of model 2 is better for all the four months during training and testing period in comparison to model 1.

Table 1. Coefficient of determination (R^2) of linear fit equation between observed and simulated runoff for training and testing periods

Training	June	July	August	Sept.
Model 1	0.114	0.769	0.772	0.20
Model 2	0.962	0.970	0.980	0.954
Testing				
Model 1	0.710	0.870	0.636	0.279
Model 2	0.708	0.982	0.950	0.649

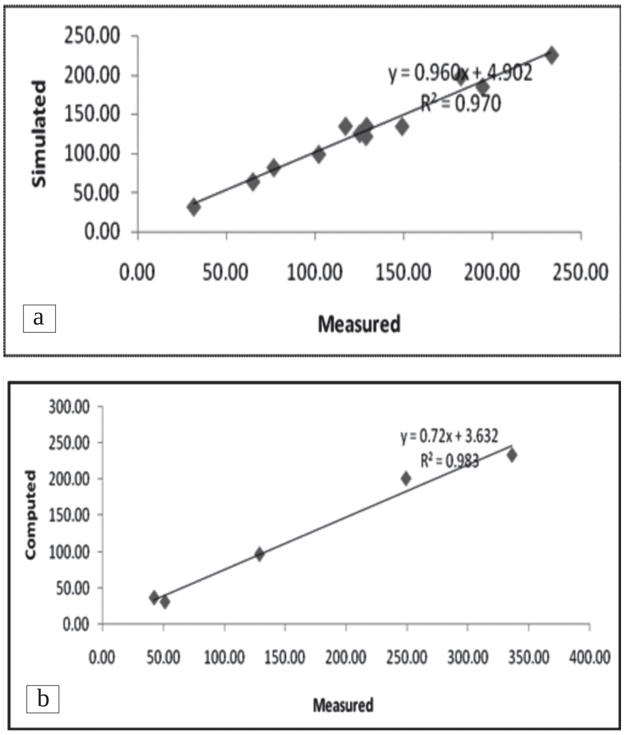

Fig. 3. Comparison of measured and simulated runoff by model2 of July for (a) training period, (b) testing period

Model evaluation criteria

Multiple performance criteria have been used by the researchers to evaluate the adequacy of ANN models in simulating rainfall-runoff processes. A rigorous evaluation of hydrologic model performance should contain at least one goodness of fit of relative error and at least one absolute error measure (Legates and MCcabe, 1999; Rajaee *et al.*, 2009). The most commonly employed measure are Root mean squared error (RMSE), Coefficient of efficiency (CE) and correlation coefficient (CORR). The correlation coefficient ranges from 0 to 1, with higher values indicating less error. The root mean square error is a measure of residual variance and is indicative of the models ability to predict high flows and ranges between 0 and " with lower value corresponds to better performance of the model. The coefficient of efficiency (Nash and Sulcliffe, 1970) determines the relative magnitude of the residual variance compared to measured data variance. The values of coefficient of efficiency range between -" to 1. The coefficient of efficiency equal to 1 being the optimal value representing the perfect fit. The coefficient of efficiency is sensitive to extreme values and might yields suboptimal results when the data set contains large outliers. The equations of RMSE, CE and CORR are as follows:

$$\text{(1)} \quad RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(R_{POWi} - R_{PPWi})^2}$$

$$\text{(2)} \quad CE = \left[1 - \frac{\sum_{i=1}^{N}(R_{POWi} - R_{PPWi})^2}{\sum_{i=1}^{N}(R_{poi} - \overline{R_{po}})^2}\right]$$

$$\text{(3)} \quad CORR = \frac{\sum_{i=1}^{N}(R_{POWi} - \overline{R_{POW}})(R_{PPWi} - \overline{R_{PPW}})}{\sqrt{\sum_{i=1}^{N}(R_{POWi} - \overline{R_{POW}})^2 \sum_{i=1}^{N}(R_{PPWi} - \overline{R_{PPW}})^2}}$$

where, R_{POWi} and R_{PPWi} are the observed and predicted values for i^{th} data set; N is the total number of observations; and R_{POW} and R_{PPW} are the mean of observed and predicted values, respectively.

The results in terms of various performances statistics for both the models are presented in Table 2. Analyzing the result it can be observed that in case of model 2 values of CORR, RMSE, CE are 0.99, 9.03 and 98% for June to September and 0.97, 20.99 and 94.0% for July-August during training period respectively, whereas the values are 0.87, 55.57, 68.83% for June- September and 0.89, 44.42, 77.64% for July-August for testing period respectively. Model performance of training set is very good for both the models. The model 2 which had a testing correlation coefficient of 0.87 and 0.89 and a testing Nash-Sutcliffe efficiency of 68.83 and 77.64 performed than model 1(correlation coefficient of 0.75 and Nash-Sutcliffe efficiency of 50.44). Also the model 2 which had a testing root mean square error of 55.57 and 44.42 was more accurate than model1(root mean square error of 71.04). Thus on comparing values of evaluation parameters for testing set it is evident that runoff estimated by model 2 is better than model 1, therefore, it can be said when overall performances is considered the model 2 performed better than model.

Table 2. Performance of models simulating runoff

Training	Model 1	Model 2	
		June-Sept.	July-Aug.
CORR	0.92	0.99	0.97
RMSE	33.82	9.03	20.99
CE	85.44	98.00	94.04
Testing			
CORR	0.75	0.87	0.89
RMSE	71.04	55.57	44.42
CE	50.44	68.83	77.64

CONCLUSION

This study is based in the comparative analysis for two disaggregation models. The models were used to predict runoff in Naula watershed of Ramganga river and their performance were evaluated using RMSE, CE, CORR. The lower value of RMSE and higher value of CE and CORR indicate that both the model showed good prediction accuracy for low and medium value of flows but unable to maintain same level of accuracy for higher value of flow. The results suggest that ANN models provide accurate estimates for disaggregation seasonal models to monthly scale. The model 2 performed better than model 1 when overall performances were considered.

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Institutional dynamics of Mopane woodland management in Bulilima district of Zimbabwe

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ABSTRACT

The paper discusses the institutional dynamics influencing the management of Mopane woodlands in Bulilima district of Zimbabwe. The existence of Mopani woodlands as common pool resources in Bulilima makes them vulnerable to over-exploitation. The institutions responsible for sustainable management seem very weak. Common pool resources have been condemned as environmentally unsustainable, economically unviable or socially anachronistic especially when they become *de facto* open access resources. The dismantling of local institutions in Zimbabwe came with a complete disregard of indigenous knowledge. Independent Zimbabwe inherited policies that assumed ignorance among rural users. The policies currently in operation are fuzzy, inchoate, and falling between local traditional governance systems which in themselves are not clearly defined and state control which is so far removed from the day to day management of the resources. A question therefore arises on the implications of the current institutional dynamics on Mopani tree use and management. The study thus attempted to establish the institutional dynamics relating to Mopani tree use and management in Bulilima profile the implications of such changes in the use behaviour of users and managers and establish the existing potential within the existing institutions for management of Mopani trees. As a way of gathering data this study is largely ethnographic, involving different approaches that allow for close attention such as observations, participation in the observed practices and events, in-depth interviews, narratives and archival research. Questionnaires have also been used to augment qualitative data. Findings indicate that at community level, there are a multiplicity of institutions and management structures with unclear mandates and jurisdictions. Power and knowledge dynamics influence processes of negotiating resource access by various actors. Although women have historically been sidelined in formal decision-making processes, they seem to be playing a key role in Bulilima largely because men are in Botswana and South Africa.

Key words: Common pool resources, Indigenous Knowledge, Resource Management

INTRODUCTION

Natural resource crisis in Africa has been largely linked to centralized state control far removed from the day to day management of resources (Fabricius *et al*., 2013; Eguavoen and Laube, 2010). There is an increasing consensus, evidenced by burgeoning literature in natural resource management, that the cause of resource degradation is institutional. If we get the right rules and governance structures, natural resources will be used wisely and conservation goals will be met (Acheson, 2006).

This paper discusses institutional dynamics surrounding the management of Mopani woodlands in Bulilima district of Zimbabwe. It examines the role of local level institutions, both formal and informal. In the case of Zimbabwe, the term formal or modern institutional structures refers to governance structures of the state that include the village committees (VIDCOs) and ward development committees (WADCOs) that are elected" (Nemarundwe, 2003). Institutions are thus a set of informal and formal rules that facilitate and constrain human behaviour, or define 'the rules of the game' (Bromley, 1989; North, 1990). They are considered to provide mechanisms whereby individuals can transcend social dilemmas (Acheson, 1989; Bates, 1995; Ostrom, 1990).

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MATERIALS AND METHODS

The study was carried out in Bulilima district, Matabeleland South province of Zimbabwe. Villages and wards are administrative units found in communal areas of Zimbabwe. Six or seven villages make a ward. (Madzudzo, 1997). The district has 19 wards characterised by multiple livelihood strategies that include small businesses, communal farms, small-scale mines and irrigation schemes, amongst others (ZIMSTATS, 2012). In the wards are villages that were used as units of study. The entire district lies within Natural Regions IV and V, which are characterised by short, variable rainfall seasons averaging generally below 400 mm per year and long dry winter periods (Vincent and Tomas, 1960; Magadza, 2006; Mahati *et al.*, 2008). The predominant tree species is Colophospermum Mopane (Dye and Walker, 1980; Dube, 2008).

In Fig. 1 (a) Bulilima district is shown in one big district, Bulilimamangwe, before it was divided in 2002 while in (b) Bulilima is shown as district on

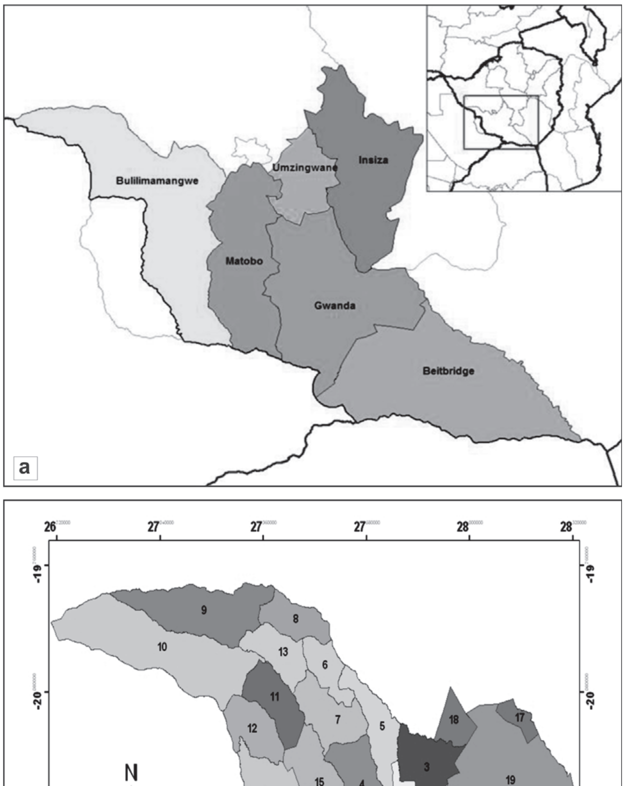

Fig. 1. Map of Matabeleland South province (a) and Ward map of Bulilima district (b).

its own after 2002. Bulilima and Mangwe districts were initially part of one big district known as Bulilimamangwe. In 2002 Bulilimamangwe district was split into three districts (Bulilima, Mangwe and Plumtree) as it was considered by the government of Zimbabwe to be administratively too large. Plumtree is the only urban district (Munyati, 2006).

Data sources

The wards selected for this study were Makhulela and Bambadzi. Within these wards, 4 villages were sampled for data collection. These were Makhulela 1 and Twayitwayi from Makhulela ward and Mbimba 1 and 2 from Bambadzi ward. These areas were selected because of the exclusive dominance of Mopani resources in these wards. Selection of two wards ensured comprehensive ethnographic study in order to understand institutional dynamics governing the management of Mopani woodlands. Triangulation methods were used to verify data collected and thus improve on its reliability and validity. Data collection thus involved various participatory techniques. A total of 6 focus group discussions were conducted. Each group was composed of between 8 and 12 respondents. The groups comprised of men and women in leadership positions, men and women who are in the natural resources committees, ordinary members of the communities, a group of traditional leaders (Sobhukus and headmen) and a group of local government representatives (WADCOs and VIDCOs). Key informants were identified based on their expert knowledge about the history of the study area, gender, wealth, ethnicity, and age and leadership position. They provided valuable information on a variety of issues that included indigenous knowledge available in management of Mopane resources, importance of Mopane resources to local communities, and issues of ownership and access to natural resources within the district. The specific informants interviewed comprised of Bulilima Chief Executive Officer (CEO), representatives of the local government which is the District Administrator (DA), responsible for the welfare of chiefs, the Village Development Committee (VIDCO) and the Ward Development Committee (WADCO) representatives, Chief Makhulela, one Sobhuku, Council chairperson, officials from government organisations such as Environmental Management Agency (EMA) and Forestry Commission, officials from Non-governmental Organisations (NGOs) operating in the district and community members selected because of their knowledge of the area, their position in the community and their wealth status in the community.

RESULTS AND DISCUSSION

Information gathered through various data collection tools revealed that both formal and informal institutions exist in Bulilima. These institutions result in various dimensions that influence decision making and knowledge production in the use and management of Mopani woodlands.

Formal Institutions (sometimes referred to as modern)

Understanding formal institutions affecting Mopani woodlands in Bulilima district cannot be fully comprehended without discussing the institutional policy governing woodland resources in Zimbabwe. Studies on this policy (Mandondo, 2000a; Sithole, 1999; Mukamuri, 1995; Murombedzi, 1991; Murphree, 1991; Mapedza, 2007; Mandondo 2000; Kwashirai, 2009) indicate that there has been a concerted effort in Zimbabwe to move from state centred approaches towards decentralisation and participatory resource management. The idea was to empower local communities and encourage them to be part of resource management within their communities. Noble as the idea has been, the reality on the ground indicate that not much has been achieved in terms of ensuring local participation and natural resource access. Formal institutions have been highlighted as perpetrators of the colonial system of natural resource governance (Mapeza, 2007; Kwashirai, 2009).

The principal legislative provisions governing woodlands in the communal areas are the Forest Act (1982), the Communal Lands Forest Produce Act (1987) and the Rural District Councils Act (1988). Nemarundwe (2003) noted that The Forest Act of (1982) governs the establishment and protection of state forests while the Communal Lands Forestry Produce Act (1987) prohibits the commercialisation of forest products in all communal areas. The Rural District Councils Act (1988) gives district councils powers to act as the local planning and development authorities and enact legally binding land use and conservation by-laws that apply to areas under their jurisdiction *(ibid).*

The Forestry Commission, through the Communal Lands Forestry Produce Act (1987), regulates and monitors the use of all woodland in the district. Mopani woodland, being the dominant specie in the area, is given special attention. Focus group discussions conducted in the study areas revealed that the Forestry Commission is very active in enforcing its regulations on the use of Mopani woodlands. Locals are not allowed to cut down Mopani woodlands for firewood or commercial purposes yet outsiders can exploit any woodland resource through use of permits acquired either from the Forestry Commission or the Rural District Council (RDC). This is a classic case of government policies disempowering the locals. During the colonial era, mining contractors extracted wood from native reserves with the blessing of Commissioners who offered timber to the miners at concessionary rates in affirmative recognition of the mining industry's contribution to overall development (Scoones and Matose, 1993). The natives were not allowed similar privileges for their own resources. In the post-colonial Zimbabwe, nothing seems to have changed except replacing white colonisers with black colonisers.

Outsiders who acquire permits from the RDC to exploit Mopani woodlands and other resources for commercial use are allowed to harvest freely. The fees that are paid for permits accrue to the RDC and Forestry Commission and rarely do they develop the communities where the resources come from. Community members are therefore disempowered by the national legislation in the form of the Communal Lands Forestry Produce Act (1987). The community members also highlighted that some of their resources are extracted clandestinely late at night. There are allegations from the locals that those who exploit natural resources at night would have bribed officials from the police, RDC or Forestry Commission hence they are never arrested.

Bulilima RDC also influences the management of natural resources in the district through the Communal Areas Management Programme for Indigenous Resources (CAMPFIRE). CAMPFIRE is an organisation run by the RDC to manage the district's natural resources for the benefit of the local communities. Interviews with CAMPFIRE officials and local community members revealed that although CAPMFIRE is meant to monitor all the resources including Mopani woodland, it only concentrates on the management of elephants because they have higher returns. Through the CAMPFIRE, the RDC generates income from trophy hunting by international hunters. According to CAMPFIRE regulations, this income should be channelled back to communities. Reality on the ground however indicates that most of the revenue collected is used by the RDC to meet its internal expenses. It is evident that the system of natural resource governance still favours the elite. Decentralisation was done to disperse power from the central government only to centre it on local powerful institutions not the communities themselves.

Environment Conservation Committee (ECC), the Village Development Committees (VIDCOs), the Ward Development Committees (WADCOs), elected councillors and traditional authorities also provide regulatory institutions that purport to monitor the use of natural resources in the district. The ECC is a committee elected by the community members to monitor the use of natural resources. This was one of the innovative ways of trying to bring the issue of resource governance to the local people. This committee is a brain child of the RDC. However evidence on the ground indicated that the committee exists only by name as it is one of the most passive organisations within the communities. It lacks necessary powers to enforce its by-laws. The committee reports to the RDC even though the council seemingly does not offer much support. Women constitute the highest number in this committee, a scenario that perhaps suggest its lack of influence on natural resource governance in the area.

The testimony above seems to be a common perception among several other members of this committee in the different wards. The fact that men shun this committee significantly diminishes its powers of influence. In a patriarchal society where men make the rules and dominate in all forums outside the home, decisions about natural resource management are left to them.

VIDCOs and WADCOs are local government entities created to foster developed at a local level. They are relevant in this discussion because over the years they have provided a different dimension to natural resource governance and development in Matabeleland region[1]. They owe their existence to the Prime Minister's directive of 1984 which also saw the establishment of the posts of Provincial Governors; the latter being appointed on loyalty to the ruling party by the Prime Minister (Mabhena, 2010). In state rhetoric VIDCOs were there to promote local decision making and should be viewed as structures promoting democratic governance. In some circles however, the formation of VIDCOs was regarded as a Zimbabwe African Union Patriotic Front (ZANU PF) mechanism for controlling Matabeleland (Stoneman and Cliffe, 1989). Madondo (2000) further concurs and argue that the infiltration of VIDCOs and WADCOs by the ruling ZANU-PF party has seen them carry the stigma of politically sponsored institutions that have no clear bases in history, or mere grassroots extensions of the ruling party. Focus group discussions with the locals revealed that these institutions still perform the same role as they used to before though their activity is now less pronounced. This could be because ZANU PF no longer fears that serious political opposition can come from Matabeleland region. Nevertheless, discussions showed that these two entities are partisan in nature and in some cases are clearly reserved for ZANU PF members. At the helm of the VIDCOs and WADCOs are elected councillors who champion party agendas. Interviews with the two councillors from the two wards under study (one from ZANU PF and the other from Movement for Democratic Change (MDC)) revealed that natural resource access purely political. For members of the ruling ZANU PF party, use of Mopani woodlands for whatever purpose is usually met with less ridicule by the powers that be compared to those perceived to be of the opposition party. However similar favours are usually denied those perceived to be of the opposition party.

Traditional institutions of chiefs, headman and kraal-head constitute a somewhat interesting institution in the history of natural resource management in Zimbabwe. Its legimation has been primary derived from customary beliefs with considerable support from both colonial and post-colonial governments. Traditional leaders' influence on natural resource management has always been at the mercy of the ruling government of the time. Chiefs have been constantly empowered and disempowered to suit the policies and agendas of the governments in power (*ibid*). The fact that their appointment, though customary, is influenced by the ruling party makes them an extension of state control at a local level. It is not surprising that traditional leaders are therefore

[1]Village Development Committees (VIDCOs) and Ward Development Committees (WADCOs) were created as a way of controlling resources and development in Matabeleland region by the then ZANU dominated government in 80s. These Institutions were a result of a protracted power struggle in the Matabeleland region of Zimbabwe which culminated into military operations on unarmed civilians. The operation is popularly known as Gukurahundi in Zimbabwe and resulted in the death of more than 20 000 civilians (Mabhena, 2010)

unpopular to those who do not support the ruling party. Nevertheless, they are empowered to enforce rules and exact fines on those who indiscriminately cut down Mopani woodlands. Group discussions however revealed that these fines are administered in a partisan manner depending on which political party you are affiliated to and are at the discretion of the chief or headman. In most cases the collected fines are siphoned by the RDC, a scenario that Madondo (2000) refers to as a typical case of higher level authorities decentralising costs but retaining control of benefit. The fines rarely benefit the local communities of Bulilima.

Informal institutions

Informal institutions sometimes referred to as traditional or indigenous, do exist and to a certain extent plays a key role in the sustainable management of Mopani woodlands in Bulilima. While traditional leadership (chiefs, headman and kraal heads) represent an extended arm of the local government that enforces all environmental planning and conservation by-laws, it also serves as the custodian of traditional or indigenous rules that govern the use of natural resources within the communities. Traditional management, as informal institutions are often referred to, are based on customary rights to resources. These rights base their legitimacy on historical existence of the local people who claim them within a certain geographic area. People of Makhulela and Bambadzi claim to have moved been pushed into these areas by the white colonial government in the early 1950s. They have since developed ways of interacting with their ecological environment, which is dominated by Mopani woodland species. Over the year they have learnt to sustainably use the woodland. In one of the focus group discussion with women, it was revealed that Mopani tree commands some respect within the communities because it provides other products such as Mopani worms, which are much more valuable. Almost every year, the locals harvest Mopani worms from Mopani woodlands. The worms are a significant source of livelihood. There is a belief amongst the community members that Mopani worms are a gift from the 'Gods' hence in every Mopani worm season, a few elderly people chosen to take some of the worms to the shrine known as Daka. It is here that they thank the ancestral spirits for providing them with food and they also ask for more rains. Daka therefore is a very important institution in the management of Mopani resources. It is imperative that policies aimed at natural resource management at a local level consider such traditional institutions since they influence local people's perceptions on selection and integration of externalities into the local practices (Yelsang, 2014).

Interviews with Chief Makhulela centred on traditional beliefs and norms as a way of conserving natural resources in the area. The chief believed that local people with their roots in the area generally respect and understand that resources such as big Mopani trees should not be cut unless for very special purposes. Outsiders, especially those who have been recently resettled under the Fast Track Land Reform Programme (FTLRP) do not have such respect for the trees. FTLRRP is a form of land redistribution in Zimbabwe which began in July 2000 through the Land Reform and Resettlement Programme Phase 11. It envisaged acquiring 5 million hectares and resettling new farmers on all acquired land (Murombedzi, 2005; Barry, 2004; Hammar and Raptopoulos, 2003).

The newly resettled locals, who live in nearby villages, seem to be protected by institutions more powerful than the traditional institutions followed by the locals. Perhaps it is a question of customary rights being seen as inferior to statutory rights. The discussions revealed that people from resettlements indiscriminately cut down trees disrespecting the social co-existence between the locals in Mbimba and their ecology.

CONCLUSION

The study analysed institutional dynamics surrounding the management of Mopani woodlands in Bulilima district of Zimbabwe. The focus was on two wards, Makhulela and Bambadzi, because they have an abundance of Mopani woodland. Makhulela 1 and Mbimba were selected as villages where data was collected. The study revealed that the management of natural resources and in this case Mopani woodland is influenced by both formal and informal institutions. The two sets of institutions do not always function smoothly and in most instances formal institutions tend to override traditional institutions to the detriment of the resources. It was established that generally formal institutions are more powerful as they enjoy political backing. However their power does not translate to sustainable management of Mopani woodland as local people who have always survived within their woodlands felt that they always had the right to use the resources as the community deems fit. Conflicts were inevitable resulting in general unpopularity of the Chiefs in this area. Chiefs are seen as oppressors because part of their duty is to fine those they consider to be breaking environmental laws as prescribed in the council by-laws.

It is however important to note that while modern institutions are there to stay, resource sustainability can be enhanced if there is fusion of ideologies from both formal and informal settings. Local institutions still have the opportunity when it comes to natural resource management. This is so because, the use of customary laws by traditional institutions is relevant to the people because they still believe in them. Communities from both wards under study believe that appeasing the 'Gods' by giving them some of their harvest, be it crops or Mopani worms, brings more rain and more resources.

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Soil carbon stocks in natural and man-made agri-horti-silvipastural land use systems in dry zones of Southern India

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ABSTRACT

A study was undertaken to assess the soil carbon stocks in 0-50 cm soil depth, under natural and man-made land use systems in the eastern dry zones of Karnataka in India. The carbon (C) stocks in soils ranged from 26.46 t ha^{-1} in dry land agricultural systems (without manure) to 89.20 t ha^{-1} in a mixed forest. Among natural systems, mixed forest (89.20 t ha^{-1}) and ungrazed grassland (71.78 t ha^{-1}) recorded higher levels of C stock than other systems, while grazing in grassland and litter removal in teak plantations correlated to reduced carbon stocks to 39.32 and 32.74 t ha^{-1}, respectively. Intensively managed horticultural systems namely, grapes plantation (85.52 t ha^{-1}) and pomegranate plantation (78.78 t ha^{-1}) maintained higher levels of C stock. However, agricultural systems recorded moderate to lower levels. Total carbon stocks in top 0-50 cm soils of agricultural systems was in the order: irrigated lands with manure application (52.77 t ha^{-1}) > irrigated lands without manure application (44.47 t ha^{-1}) > dry lands with manure application (37.79 t ha^{-1}) > dry lands without manure application (26.46 t ha^{-1}). It was observed that adoption of appropriate soil and crop management practices such as conservation tillage, good irrigation, incorporation of crop residues and application of manure etc. could enhance soil C pool by reducing existing carbon loss and promoting C accumulation in the soil.

Key words: Soil carbon, land use systems, residue recycling, forest, horticulture, grassland.

INTRODUCTION

Evidences are mounting that better soil management practices could contribute substantially to the mitigation of atmospheric carbon dioxide emissions (Yan *et al.*, 2005; Xu *et al.*, 2011). Conversion of natural ecosystems to agriculture in the last century has contributed to the extent of one sixth of atmospheric greenhouse gases through reduction in standing (vegetation) carbon (C) and soil C stocks (Tilman *et al.*, 2002).

Soil C constitutes a major pool in global C cycle (Scharlemann *et al.*, 2014). It is estimated that the Soils contain about 1550 Pg organic carbon and 950 Pg inorganic carbon in the upper 1m of soil layer (Lal, 2004). It is also well established that these trends could be reversed through management and land use changes (Robertson *et al.*, 2015). The carbon stored in soil of an ecosystem is controlled by the quality and quantity of biomass added and its loss through decomposition. The rate of C accumulation or loss from soil is determined by the quantity of recyclable biomass-C, temperature, rainfall, soil moisture content and management induced disturbances (Delon *et al.*, 2015; Mills *et al.*, 2014; Bhardwaj *et al.*, 2016). The carbon content is generally higher in the surface layer than deeper sub-surface layers as much of the plant and animal dead material reach the surface directly. Finally, the rate of C accumulation in soil is significantly controlled by the net balance between inputs and outputs per unit time (Fang *et al.*, 2015). Adoption of suitable management practices viz., conservation tillage, good irrigation practices, incorporation of crop residues, manure application etc. can enhance soil C pool by decreasing C losses and encouraging its sequestration in soil (Jarecki and Lal, 2003; Bhagat *et al.*, 2003). Important soil functions that are affected by agricultural land use are primary

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productivity, carbon storage and cycling, nutrients cycling and water purification and regulation (Bouma *et al.*, 2014; Schulte *et al.*, 2014).

Thus, soil can act as a large terrestrial sink of atmospheric CO_2 but the storage of C in soil is affected by the land use: crops / plant species, tillage and crop management, residue removal and incorporation and irrigation practices. Knowing the effect of these variables helps in land use planning as well as in accounting of C stocks at regional level. Keeping these in view, a study was undertaken in the Eastern dry zone of Karnataka in India to assess the soil carbon stocks (0-50 cm soil) under different land use systems, both natural and manmade, comprising of forests, grasslands, horticultural and agricultural systems.

MATERIALS AND METHODS

Study Area and land use systems

The soils of the study area originated from granite and gneiss, and are classified as Kaolinitic, isohyperthermic, belonging to Typic Kandiustalf. The study area is situated at a latitude of 12° 58' N and longitude of 77° 35' E at an elevation of about 930 MSL. The climate that prevailed was cool summer and warm winter with bimodal distribution pattern and a mean annual rainfall of 844 mm.

The forest systems comprised of mixed forest (>20 tree species) and a teak plantation. The grassland systems studied consisted of two natural grassland patches with and without grazing, and one man made napier patch. Horticultural systems included mango plantations with complete in situ litter turnover, and intensively managed grapes and pomegranate plantations. Agricultural systems comprised of both irrigated and dryland systems, with and without farmyard manure (FYM) along with recommended doses of fertilizers. Detailed descriptions of each land use system are given in Table 1.

Quantification of biomass produced and recycled

Quantity of biomass produced, removed and recycled were determined separately for each land use system. In grassland systems, the above ground biomass was harvested from one square meter while the below ground biomass was removed by digging and the roots were washed thoroughly and dried. Quantity of biomass was expressed on dry weight basis. Similarly, in grazed and napier grasslands the stubble and root biomass left after grazing / harvest were quantified. Biomass quantification was restricted only to annual litter turnover in forest systems as the methodology for annual root biomass estimations are not available. The litter samples were collected from one square meter area at a regular interval to get the annual

Table 1. Details of the studied land use systems.

Land use systems	Vegetation	System	Management Practices	Biomass Removed
Grassland Systems				
Ungrazed	Grasses	Natural	None	None
Grazed	Grasses	Natural	G	Grasses
Napier	Grasses	Manmade	C, F, H	Grasses
Forest Systems				
Mixed	Trees, Bushes	Natural	None	None
Teak	Teak	Manmade	Litter Removal	Litter
Horticultural Systems				
Grapes	Grapes	Manmade	C, IR, P, W, F, M, H	Fruits + Cane
Pomegranate	Pomegranate	Manmade	C, IR, P, W, F, M, H	Fruits
Mango	Mango	Manmade	C, P, F, H	Fruits
Agricultural Systems				
Irrigated Plots (Fert. + FYM)	Finger Millet + Corn	Manmade	C, IR, M, F, H, W, P	Grain + Straw
Irrigated Plots (Only Fert.)	Finger Millet + Corn	Manmade	C, IR, F, H, W, P	Grain + Straw
Dryland Plots (Fert. + FYM)	Finger Millet	Manmade	C, M, F, H, W, P	Grain +Straw
Dryland Plots (Only Fert.)	Finger Millet	Manmade	C, F, H, W, P	Grain + Straw

Cultivation (C); Irrigation (IR); Weedicide (W); Pesticides (P); Fertilization (F); Manuring (M); Harvesting (H); Grazing (G).

turnover (Shylaja *et al.*, 1993).

The biomass produced in horticultural systems was quantified by collecting the litter samples from one square meter and recording the annual fruit yield. Annual root biomass was not estimated in these systems, as the destructive method of sampling would result in large economic losses. In agricultural systems, the quantity of fodder and grain produced were used from the actual yield data and the biomass left in the field after the harvest of the crop was determined as detailed in grasslands.

Soil sampling and estimation of soil-C stocks

Three sampling sites were chosen for each land use system. In each site, soil samples were collected from 3 different spots at 0-15, 15-30 and 30-50 cm depths and the samples were pooled to get composite samples for each depth separately. These composite soil samples (depth wise) were air dried and passed through 2 mm sieve for further analyses. The soil present in 0-50 cm layer was determined by measuring the bulk density of soils for three depths separately and the carbon content for the collected soil samples were determined by adopting modified Walkley and Black (1934) wet oxidation method. Soil carbon stock was estimated by considering the soil bulk density and fine fractions.

Statistical analysis

All parameters were tested using a one-way analysis of variance (ANOVA) and separation of means was subjected to Tukey's honestly significant difference test (Steel and Torrie, 1960). Correlation analysis was conducted to identify relationships between the measured parameters. All tests were performed at 0.05 significance level.

RESULTS AND DISCUSSION

Biomass produced and recycled

The data on the quantity of biomass produced, removed and recycled annually among different land uses systems are given in Table 2.

Biomass Production: Among 12 different land use types, pomegranate orchards recorded the least biomass production with 3.6 t ha^{-1}, while irrigated agricultural systems with two crops of finger millet and maize, supplemented with manures and fertilizers, produced 30.0 t ha^{-1} of biomass. In grassland systems, the annual biomass production ranged from 6.0 - 13.8 t ha^{-1} with least production in grazed land and the highest in napier grassland. Irrigated agricultural systems recorded very high biomass production compared to dryland systems. The moisture limitations in dryland restricted the cropping to only one crop per year, which was able

Table 2. Quantity of in-situ and ex-situ annual biomass turnover (t ha^{-1}) among different land use systems.

Land use system	*Biomass Produced	‡Biomass Removed	§Residue BM Recycled	FYM added	†Net OM Recycled
Grassland Systems					
Ungrazed	6.7	0.0	6.7	0.0	6.7
Grazed	6.0	3.5	2.5	0.0	2.5
Napier	13.8	7.0	6.8	0.0	6.8
Forest Systems					
Mixed#	6.7	0.0	6.7	0.0	6.7
Teak#	5.2	4.2	1.0	0.0	1.0
Horticultural Systems					
Grape#	7.2	7.1	0.1	50.0	50.1
Pomegranate#	3.6	2.4	1.2	12.5	13.7
Mango#	5.4	1.0	4.4	0.0	4.4
Agricultural Systems					
Irrigated (FYM + Fert.)	30.0	20.0	10.0	15.0	25.0
Irrigated (Fert. Alone)	24.9	17.5	7.5	0.0	7.5
Dryland (FYM +Fert.)	17.1	10.5	6.6	10.0	16.6
Dryland (Fert. Alone)	8.2	3.4	4.8	0.0	4.8

***** *Biomass produced* included litter, fruit, grain, straw and root; **‡** *biomass removed* included grain, fodder, litter and fruit; **§** *Residue biomass recycled* included roots and stubble in annuals and only litter (leaves + twigs) in perennial trees; **†** *Net organic matter (OM) recycled* = Residue BM recycled + FYM added; # Below ground BM produced / recycled not considered.

to produce 8.2 and 17.1 t ha^{-1} of biomass. The litter biomass (fallen leaves and stems) ranged from 3.6 - 7.2 t ha^{-1} among land use systems with perennial trees. Natural mixed forest recorded 7.2 t of litter biomass, while teak plantations produced 5.2 t of litter per hectare. In case of horticultural systems, the above ground biomass produced in grape and mango orchards were 7.2 t ha^{-1} and 5.4 t ha^{-1}, respectively.

Residue biomass recycled

Land management practices adopted in a given system determine extent of the biomass recycling. There was no removal of biomass in the non-grazed grasslands and mixed forests, and hence, all the biomass produced was allowed to recycle. While in grazed land, 3.5 t ha^{-1} of grass biomass were removed as fodder and hence, only 2.5 t ha^{-1} of biomass was allowed to recycle in the form of stubble and roots. Among irrigated agricultural systems, biomass was removed (grain and fodder) to an extent of 20.0 t ha^{-1} in fertilizer and FYM treated plots and 17.5 t ha^{-1} in no-FYM plots (only fertilizer). Thus, the quantity of biomass allowed to recycle was 10.0 and 7.5 t ha^{-1}, respectively. However, the moisture limitations in dryland restricted the turnover to 6.6 and 4.8 t ha^{-1}, respectively in plots with fertilizer plus manure and fertilizer alone plots. Among tree based perennial systems, mixed forest recorded an in situ biomass turnover of 6.7 t ha^{-1}. Litter removal in teak plantations, to prevent fire damages, resulted in a biomass turnover of mere 1.0 t ha^{-1}. Extraction of fruits was the major source of biomass removal in horticultural systems except in grapes, where the biomass was also removed in the form of canes and leaves during pruning operations. Thus, the management practices adopted in a given system and the quantity of biomass recycled is likely to have an influence on the net soil carbon stocks.

Net organic matter recycled

In manmade agricultural and horticultural systems, unlike the natural ones, organic matter was added in the form of compost/manure to maintain yield and quality. Thus, the net organic matter recycled would be the sum of residue biomass and manure. The net organic matter recycled was as high as 50.1 t ha^{-1} in grape orchard and it was low in pomegranate plots with a net turnover of 13.7 t ha^{-1}. However, there was no addition of manure to mango and thus the biomass recycled was equal to the net organic matter recycled. In FYM treated agricultural systems, irrigated lands recorded a net biomass turnover of 25.0 t ha^{-1} while, dryland system recorded 16.6 t ha^{-1}. However, the net biomass recycled among no-FYM plots (only fertilizer applied), in both irrigated and dryland agricultural systems, were equal to that of residue biomass recycled. Application of organic sources enhances all the pools of soil carbon (Khursheed *et al.*, 2013) indicating recycling of organic matter. Similarly, the net biomass recycling was unchanged in ungrazed grassland and forest systems as there was no addition of organic matter from external sources.

Soil carbon stocks

The data on seasonal changes in soil organic-C under different land use systems at various depths are given in Table 3. The amount of total soil carbon stocks present in 0-50 cm of soil layer is depicted diagrammatically in Fig. 1. The surface soils (0-15 cm) of all land use systems in all the three seasons recorded highest soil organic-C. In general, the soil organic-C was higher in winter season and lower in summer.

Carbon present in these soils is mostly organic in nature and is present in the form of humus coat over soil particles. It decreased with depth in all the treatments and it differed significantly among treatments as well as seasons (Table 3). There are no records of elemental carbon in these soils as

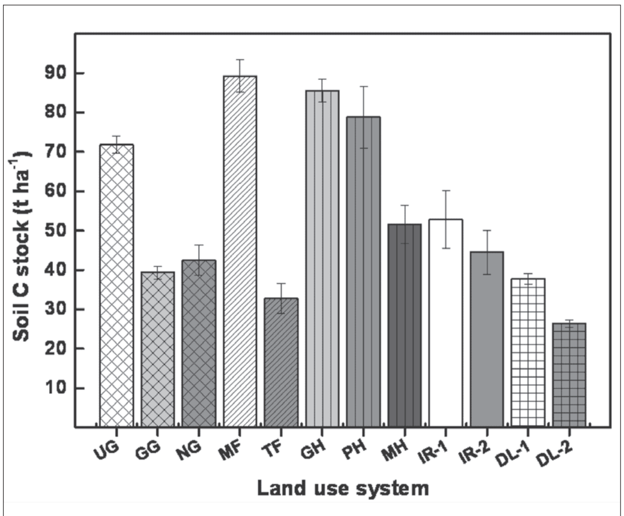

Fig. 1. Soil carbon stocks among different land use systems. UG = Ungrazed grasses, GG = Grazed grasses, NG = Napier grass, MF = Mixed forest, TF = Teak Forest, GH = Horticultural plantation-Grape, PH = Horticultural plantation-Pomegranate, MH = Horticultural plantation-Mango, IR-1 = Irrigated agricultural system with FYM and fertilizer, IR-2 = Irrigated agricultural system with fertilizer alone, DL-1 = Dryland agricultural system with FYM and fertilizer, and DL-2 = Dryland agricultural system with fertilizer alone.

Table 3. Seasonal changes in soil organic carbon (*per cent*) under different land use systems.

Land use system	Winter	Summer	Rainy
SOIL ORGANIC CARBON (%)			
Grassland Systems			
Ungrazed	1.27	1.28	1.17
Grazed	0.56	0.52	0.60
Napier	0.62	0.71	0.52
Forest Systems			
Mixed	1.85	1.58	1.68
Teak	0.38	0.56	0.45
Horticultural Systems			
Grape	1.41	1.39	1.28
Pomegranate	1.32	1.40	1.01
Mango	0.67	0.89	0.69
Agricultural Systems			
Irrigated (FYM +Fert)	0.96	0.59	0.79
Irrigated (Fert. Alone)	0.74	0.51	0.64
Dryland (FYM +Fert)	0.62	0.52	0.54
Dryland (Fert. Alone)	0.35	0.38	0.39

The values indicated are the mean of three depths.

there are no natural deposits of coal / coke.

Higher level of carbon was recorded in mixed forest patches (2.91 %) during rainy season and lowest was observed during summer in dryland agricultural plots with no FYM. Among the systems, based on mean depths and season, the ungrazed control plot (1.24 %), grapes (1.36 %), pomegranate orchards (1.24 %) and mixed forests (1.70 %) systems recorded more than 1.0 % of soil organic-C. Moderate levels of soil organic-C were observed among other systems except teak plantations (0.46 %) and dryland plots receiving only fertilizers (0.38 %). The variations in soil organic-C among different land use systems would be attributed to the net biomass turnover and land management practices adopted in the system (Post and Kwon, 2000). Influence of management practices and biomass addition / turnover on soil carbon stocks is well documented (Liao *et al.*, 2010).

The amount of soil carbon present in the form of humus is a function of bulk density and soil organic-C content. It was determined using the soil volume and its corresponding soil organic-C contents. The amount of carbon stored in the top 0-50 cm soil layer ranged from 32.7 t ha^{-1} in teak plantations to 89.5 t ha^{-1} in mixed forest. Similarly, the soil carbon stock in ungrazed grassland (71.8 t ha^{-1}) was higher than grazed (39.3 t ha^{-1}) and napier (42.5 t ha^{-1}) grasslands. The data also indicate that the quantity of carbon stored in horticultural systems was much higher than the disturbed forest and grassland ecosystems. The amount of soil carbon present in top 0-50 cm soil layer was 85.5, 78.8 and 51.6 t ha^{-1} in grapes, pomegranate and mango systems respectively. Interestingly, the soil carbon stocks was almost near to that of disturbed natural systems and lesser than horticultural systems. Irrigated agricultural systems had stored 52.8 t ha^{-1} in FYM and fertilizer treated plots compared to 44.5 t ha^{-1} in fertilizer alone treated plots. Similar trend was observed in dryland agricultural systems with much lesser quantities of humus carbon. The corresponding values in dryland agricultural systems were 37.8 t ha^{-1} (with manure and fertilizer) and 26.5 t ha^{-1} (with fertilizer alone).

Soil organic-C of any ecosystem is determined by the quality and quantity of C-inputs through biomass addition (Liu *et al.*, 2014) and its loss through decomposition (Zhu *et al.*, 2014, Toosi *et al.*, 2014). Larger the biomass turnover higher would be the soil organic carbon. Large carbon stocks were observed in natural forest and ungrazed grasslands and it could be attributed to high biomass turnover and no disturbances. However, manmade napier and grazed grasslands recorded much lower carbon stocks than ungrazed plots. Reduction in soil organic-C in napier grasslands could be due to regular cultivation practices adopted (Panagos *et al.*, 2015) and higher soil temperature as the surface was not covered most of the time (Hopkins *et al.*, 2014). Litter removal in teak plantation to prevent fire damages might have severely reduced the soil carbon stocks.

Agroforestry system results in leaf litter fall that recycles the C as well as nutrients to the soil (Solanki and Arora, 2015). This suggests that the cultivation and removal of surface cover would reduce soil carbon through enhanced decomposition rates (Sayer, 2006; Leff *et al.*, 2012; Fekete *et al.*, 2014).

CONCLUSION

The carbon preserved in the form of humus on soil particles could be used effectively as a mean to sequester atmospheric CO_2 and hence in mitigating global warming effects. The amount of carbon stored is determined by the quality and quantity of biomass added and its loss through decomposition. Deforestation, expansion of agriculture, shifting cultivation, irrigation etc. would lead to oxidation of organic matter in soil. These processes would result in CO_2 release, leading to increased concentration of CO_2 in the atmosphere. However, substantial carbon accumulation can also occur in soil with increase in biomass turnover and reduction in mechanical disturbances. Thus, adoption of conservation tillage, good irrigation practices, crop residue incorporation, manure application etc. could enhance soil carbon to a great extent by decreasing the loss of existing carbon mass and encouraging carbon accumulation. Results of the present study clearly indicate that there is a great scope to mitigate atmospheric CO_2 through better land management practices.

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Watershed based drainage morphometric analysis using Geographical Information System and Remote Sensing of Kashmir Valley

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ABSTRACT

Geographical Information System (GIS) has emerged as an efficient tool in delineation of drainage pattern of watershed, planning and management. GIS and image processing techniques can be employed for the identification of morphological features and analyzing properties of basin. The morphometric parameters of basin can address linear, areal and relief aspects. The present study was conducted to evaluate morphometric parameters of Wanpura micro-watersheds of Kashmir Valley. The morphometric parameters were determined to understand the nature, landscape development and hydrologic responses of watershed. Strahler's stream ordering revealed a total 877 number of streams belonging to different orders with the highest order of 4. Drainage network of the basin was of dendritic type, which indicates the homogeneity in texture. The low value of drainage density (5.48) indicates that the region is composed of permeable sub-surface materials, dense vegetation and low mountainous relief causing lower surface runoff, and a lower level of degree of dissection. Low value of bifurcation ratio (1.79) shows that there is little control of structure on the drainage pattern. Low infiltration number value (0.0111 km / km^4) indicates the high infiltration capacity of the soil which confirms to the huge vegetative cover of the watershed. This study would help to utilize the resources for sustainable development of the basin area

Key words: Morphometric parameters, Dal catchment, Watershed Planning, GIS

INTRODUCTION

The morphometric analysis of a watershed is an essential first step toward the basic understanding of watershed dynamics (Kumar *et al.*, 2015). Development of a drainage system and the flowing pattern of a water channel over space and time are influenced by several variables such as geology, geomorphology, structural components, soil, and vegetation of the area through which the water flows (Rekha *et al.*, 2011). Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms (Giusti and Schneider, 1965; Agarwal, 1998; Reddy *et al.*, 2002; Rudraiah *et al.*, 2008; Malik *et al.*, 2011). A major emphasis in geomorphology over the past several decades has been on the development of quantitative physiographic methods to describe the evolution and behavior of surface drainage networks (Horton, 1945; Abrahams, 1984). Morphometric analysis of a watershed provides a quantitative description of the drainage system which is an important aspect of the characterization of watersheds (Strahler, 1964). The quantitative analysis of morphometric parameters is useful in regional flood frequency analysis, hydrologic modeling, drainage basin evaluation, watershed prioritization for soil and water conservation and natural resources management at watershed level.

Drainage characteristics of many river basins and sub basins in different parts of the globe have been studied using conventional methods (Horton, 1945; Strahler, 1957, 1964; Krishnamurthy *et al.*, 1996). GIS techniques are now a day used for assessing various terrain and morphometric parameters of the drainage basins and watersheds,

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as they provide a flexible environment and a powerful tool for the manipulation and analysis of spatial information (Leopold and Miller, 1956; Pareta and Pareta, 2012). Quantitative analysis of hydrological unit and channel networks has been developed from morphometric analysis of a watershed provides a quantitative description of the drainage system which is an important aspect of the characterization of watersheds (Strahler, 1964). The quantitative analysis of morphometric parameters is found to be of immense utility in regional flood frequency analysis, hydrologic modeling, drainage basin evaluation watershed prioritization for soil and water conservation and natural resources management at watershed level. However, Horton's laws (Harton's, 1945) were subsequently modified and developed by several geo-morphologist, most notably by Leopold and Miller, 1956; Melton, 1958; Scheidegger, 1965; Schumm, 1956; Shreve, 1967; and Strahler, 1952, 1957. Morphometric parameters are mainly depending upon lithology, bed rock and geological structures. Many researchers have carried out morphometric analysis and prioritization of the watersheds using remote sensing and GIS techniques (Pandey *et al*., 2004; Malik *et al*., 2011; Pareta *et al*., 2011; Panhalkar *et al*., 2012; Kanth *et al*., 2012; Pingale *et al*., 2012; Iqbal *et al*., 2014, Hajam *et al*., 2013; Bharadwaj *et al*., 2014). In the present study an attempt has been made to assess various morphometric parameters of Wanpura watershed using modern geospatial tool. This study

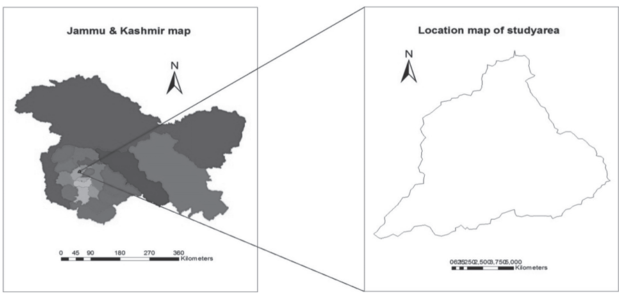

Fig. 1. Location of study area

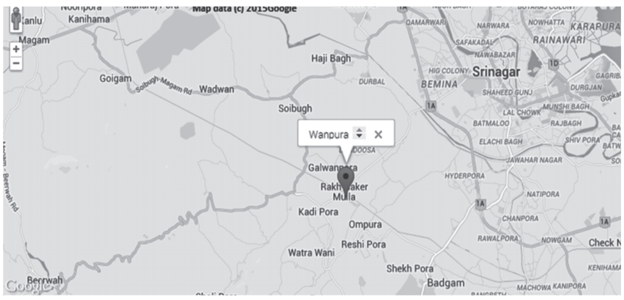

Fig. 2. Map of the study area

represents a better understanding of hydrologic behavior of the watershed parameters.

MATERIALS AND METHODS

Study area

The Wanpura watershed is located $74^0$40' 12.37" to 74^0 46' 22.86" N longitude and 33^0 57' 5.26" to 34^0 1' 51.4" E latitude. The watershed has an area of approx. 433.25km². The details of the study area are shown in Fig. 1 and 2.

For the morphometric analysis of Wanpura watershed, the data used for the codification of watersheds is Survey of India Topo-sheets, 1961 on a scale of 1:50,000th. The digitization and delineation of the watershed is done in ArcGIS 10.2 system. Various morphometric parameters along with formula are summarized in Table 1.

Construction of a digital data base

The first step is the transformation of the soft copy into digital form. This process is accomplished in various steps as given below.

Geo-referencing

The thematic maps like Base map (Micro-watershed map), Drainage map, Land use / Land cover map which are in a photographic TIFF (Tagged image file format) format are first registered to a Universal Geographical Coordinate system. The Geometric Correction tool of Data preparation module in ARC GIS 10.2 is used for registering the maps in a projection system. For registration Ground control points (GCP's) at the intersection of latitude & longitude lines have been selected. The thematic maps are initially projected on Geographical lat / long coordinate system.

Digitization (Geo-coding)

The second step involved is the on screen vectorization of various themes like, drainage, land use / land cover, etc in the form of feature data line, polygon and point. Thus a shape file format of various vector themes has been prepared by the process of digitization. This process of digitization was done in Arc GIS 10.2. All the streams have been digitized from Survey of India Topo-sheets, 1961 on a scale of 1:50,000th. Strahler's system of stream analysis being the simplest most used system and, hence the same has been adopted for the Watershed Management using Geospatial Techniques. The drainage of study area is shown in Fig. 3. The land use land capability classification map (LULC) also play important role in digitization process. The

Table 1. Morphometric properties of the study watershed

S. No.	Parameter	Formula	Description
1.	Stream Order (Horton, 1945)	Hierarchical Rank	
2.	Bifurcation Ratio (Rb) (Horton, 1945)	Rb= Nu / Nu+1	Nu = No of streams of order u Nu+1 = No of streams of order u+1
3.	Stream Length	$\bar{L}_u = \frac{\sum_{i=1}^{N} L_u}{N_u}$	Lu = Length of stream of order u
4.	Stream Length Ratio (RL) (Horton, 1945)	$RL = \bar{L}_u / \bar{L}_u\ -1$	= Average length of stream of order u -1 = Average length of stream of order u-1
5.	Form Factor (Rf)	Rf= A / Lb2	Lb = Length of basin
6.	Basin Shape Factor (Horton, 1942)	Sb= Lb2 / A	
7.	Circulatory Ratio (Rc)	$RC = \frac{A}{Ac} = \frac{4A\pi}{P^2}$	AC = Area of circle having equal perimeter as the perimeter of watershed P = Perimeter of watershed
8.	Elongation Ratio (Re) (Schumm, 1956)	$Re = \frac{D_c}{L_{bm}} = \frac{2\times\sqrt{A/\pi}}{L_b}$	DC = Diameter of circle with the same area as the watershed
9.	Drainage Density (Dd) (Schumm, 1956)	$D_d = \frac{\sum_{i=1}^{K}\sum_{i=1}^{N} L_u}{A}$	K = Principal order = highest order stream
10.	Constant of Channel Maintenance (C)	$C = \frac{1}{D_d} = \frac{A}{\sum_{i=1}^{K}\sum_{i=1}^{N} L_u}$	
11.	Stream Frequency (F)	$F = \frac{\sum_{i=1}^{K} N_u}{A_k}$	Ak = Basin area of principal order (K)
12.	Relief (H)		(Elevation of basin mouth) – (Elevation of highest point on the basin perimeter).
13.	Relative relief (RR)	RR = H / Lp×100	H = Watershed relief Lp = Length of perimeter
14.	Relief ratio (Rr) (Schumm, 1956)	Rr= H / Lb	
15.	Ruggedness number (RN)	RN = H×Dd	
16.	Geometric number	G No. = H×Dd / Sg	Sg = Slope of ground surface
17.	Time of concentration (Tc)	Tc = 0.0195 L0.77 S-0.385	L = Length of channel reach S = Average slope of the channel reach

LULC map of study area is shown in Fig. 4.

In the present study the generation of a 20 m interval DEM involves the following steps.

a) The contour map on the scale of 1:50,000 prepared manually from Survey of India Topo-sheets, 1961, were digitized with the digitizer tool in ArcGis 10.2 software. The contour lines were digitized at a contour interval of 20 m.

b) The attributes stored in the attribute table. Further the point heights which represented the peaks (highest values) were also registered. Thus a digitized contour file in a shape file format (vector) with height (Z) attribute database was generated.

c) The vectorized contours imported and converted to Arc Coverage format using import / export module of ArcGIS 10.2. The next step involves the surfacing of the contours in data preparation module.

d) Finally the DEM is prepared by providing the Z attributes in a raster format. The DEM is generally viewed and rendered to various operations for better visualization in the virtual GIS module of ArcGIS10.2. The most important among

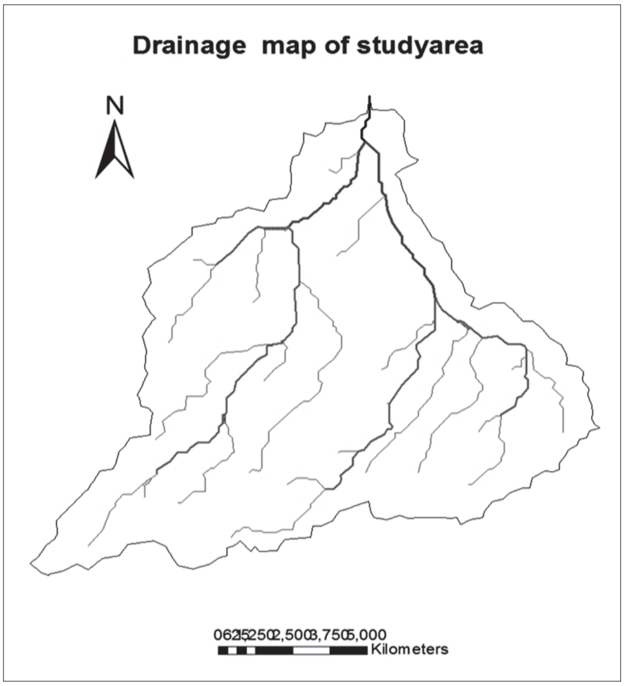

Fig. 3. Drainage map of the study area

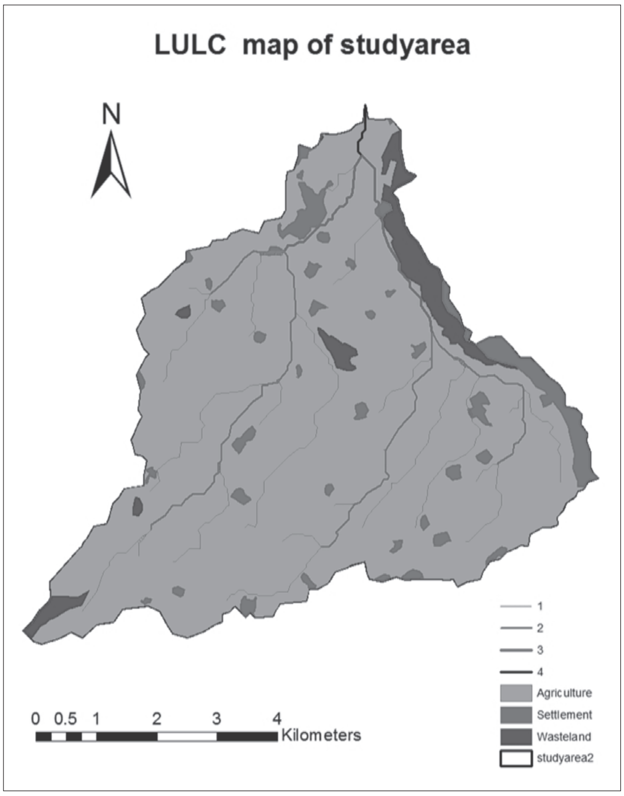

Fig. 4. LULC map of study area generation of digital elevation model (DEM)

these operations is the merging of the DEM with the satellite imagery which offered a great help in land use/ land cover classification process. The DEM map of study area is shown in Fig. 5.

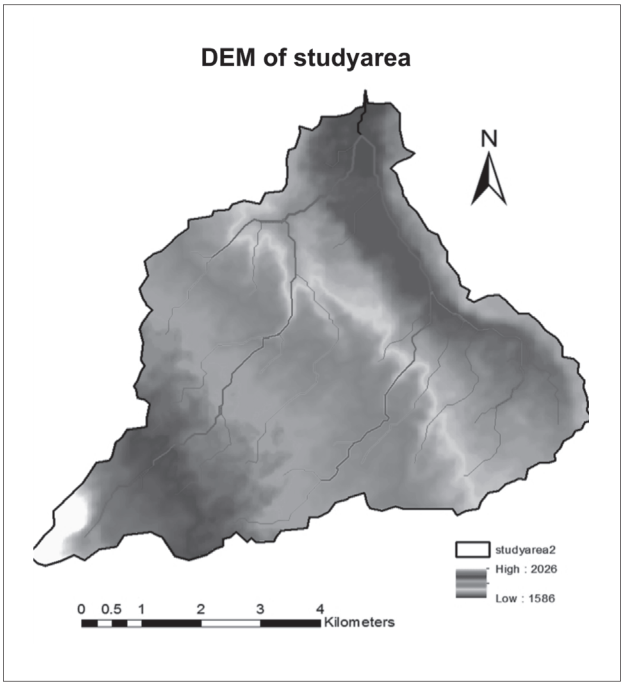

Fig. 5. DEM of the study area

Generation of slope map

DEM has been utilized to produce the Slope Map.This map was produced by converting the DEM in grid format and using the model builder module of ArcGIS 10.2.The slope map of study area is shown in Fig. 6.

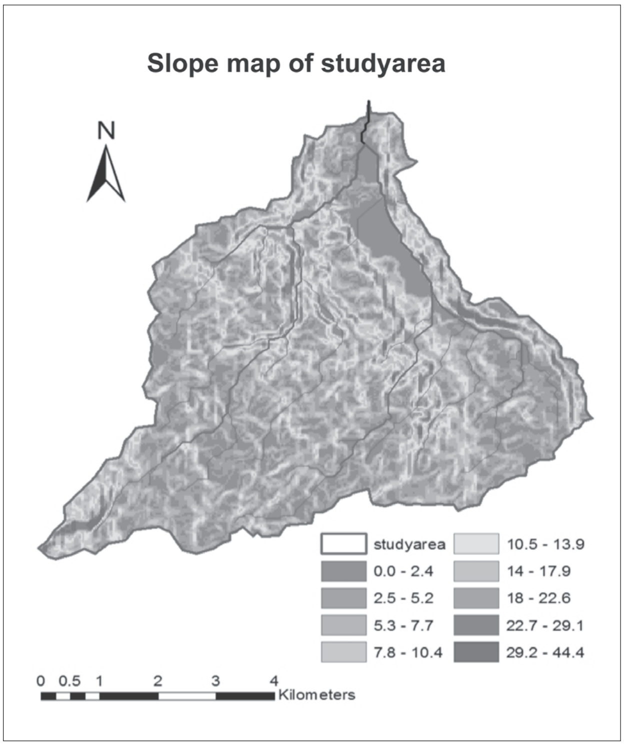

Fig. 6. Slope of the study area

RESULTS AND DISCUSSION

The most important parameter in the drainage basin analysis is ordering, whereby the hierarchal position of the streams is designated. The details of streams are illustrated in Table 2. Following Strahler's scheme, it is evident from Table 2 that the watershed has 877 number of streams out of which 468 belong to 1st order, 197 are of 2nd order, 85 are of 3rd order, and 127 are of 4th order. The first order streams of the watershed were highest in number and it decreased as the order Increased. Hence, Horton's laws are in conformity. Length of streams of different orders, and their respective mean length are given in Table 2. It is revealed from Table 2 that the drainage network of the watershed is characterized by total length 3.375 km. The length of stream segments up to 4th order measured and the total length as well as mean stream length (L_u) of each order was also computed. The mean stream lengths of stream increase with the increase of the order.

Table 2. Stream numbers of respective orders

S. No.	Stream order	Stream number	Total stream length (m)	Average stream length (L_u) (m)
1.	N1	468	210996	450.85
2.	N2	197	142859	725.17
3.	N3	85	46696	549.36
4.	N4	127	82522	649.78
Total stream length = 2375.16m				

Bifurcation ratios within a given region tend to decrease with increasing order because as order increases the percentage of streams that coalesce into a higher order tributary also increases. The hypothesis that the bifurcation ratios within a given region tend to decrease with increasing order does hold well except the bifurcation ratio of 3rdand 4th order where it registers the lowest bifurcation ratio of 0.67 in any order. The bifurcation ratio will not be exactly same from one order to the next order because of possibility of the changes in the watershed geometry and lithology but will tend to be consistent throughout the series. The mean bifurcation ratio in the watershed comparatively was registered a stable trend. It ranges from 0.67 (lowest) to 2.38 (highest). The mean bifurcation ratio of watershed was found 1.79. The low bifurcation ration indicates that the watershed has not been subjected to distortion as high bifurcation ratio (> 5) indicates the distorted drainage pattern which exists in the regions of steeply dipping rock strata, where narrow valleys are confined between the ridges. The low bifurcation ratio also confirms to the roundness of the watershed as elongated watershed have higher bifurcation ratio.

The Stream length ratio (R_l) values of watershed at different levels of hierarchy have been determined. The mean stream length ratio in watershed comparatively registers a stable trend. It ranges from 0.76 (lowest) to 1.61 (highest). The mean stream length ratio of watershed is 1.18.

Drainage density (D_d) indicates the closeness of spacing between channels and is a measure of the total length of the stream segment of all orders per unit area. It is affected by factors such as resistance to weathering, permeability of rock formation, climate, vegetation etc. The drainage density value of Wanpura watershed is 5.482 m/km^2which is very low which indicates that the watershed is mostly covered by vegetative cover and has low relief. In general, low values of D_d are the characteristics of regions underlain by highly permeable material with vegetative cover and low relief. Whereas, high values of D_d indicate regions of weak and impermeable subsurface material, sparse vegetation and mountainous relief (Nautiyal, 1994). Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture. These conditions are attested by the LULC map and slope may of the area which depict that most of the area is under the cover of vegetation and average slope lies in the range of 2.5 -5.2%. The low value of density also depicts the permeable nature of the soil which indicates that most part of the precipitation will penetrate into the soil and lesser amount will contribute to the runoff.

Constant of channel maintenance (C) indicates the surface area required to sustain unit length of stream segment. The value of C that corresponds to the study area has been found to be 0.182km^2/m, i.e. 0.182 km^2 of stream exists in unit length of watershed. This indicates the less stream network and high vegetation.

Stream frequency (F) is the total number of stream segments of all orders per unit area (Horton, 1932). F values indicate positive correlation with the drainage density of watersheds suggesting increase in stream population with respect to increase in drainage density. It is associated with lithology, degree of slope, stage of fluvial cycle and amount of surface runoff. High stream frequency is related to impermeable sub-surface material, sparse vegetation, high relief conditions and low infiltration capacity. The value of stream frequency for watershed was found 2.024 / km^2. This low stream frequency indicates permeable sub-surface material, dense vegetation, low relief conditions and high infiltration capacity.

Infiltration number (I_f) plays significant role in observing the infiltration character of basin.

It bears an inverse relation with the infiltration capacity of the basin. The infiltration number of the watershed was found 0.01 km / km^4 which are very low indicating the high infiltration capacity of the soil of the watershed.

Drainage texture (R_t) is the total number of stream segments of all orders per perimeter of the area (Horton, 1945). The drainage texture value of watershed was found 5.898 / km indicating moderate drainage texture in the watershed. It indicates the relative spacing of the drainage segments. Hence, the spacing prevalent between the segments of the streams is moderate.

Areal aspects of drainage basin parameters average value is summarized in Table 3.

Table 3. Areal aspects of drainage basin

S. No.	Morphological Parameters	Calculated value
1.	Drainage density	5.482 m / km^2
2.	Constant of channel maintenance	0.182 km^2 / m
3.	Stream Frequency	2.024 km^{-2}
4.	Infiltration number	0.0111 km / km^4
5.	Drainage texture	5.898 / km

Shape parameters

Miller (1953) defined a dimensionless circularity ratio (R_c) as the ratio of basin area to the area of circle having the same perimeter as the basin. The circulatory ratio less than 1 indicates the deviation of the watershed from the circular shape. The circulatory (R_c) is influenced by the length and frequency of streams, geological structures, land use / land cover, climate, relief and slope of the basin. The circularity ratio (0.25) of the basin corroborates the Miller's range which indicates that the basin is elongated in shape, low discharge of runoff and highly permeability of the subsoil condition. Circulatory Ratio is helpful for assessment of flood hazard. Higher the (R_c) value, higher is the flood hazard at a peak time at the outlet point. Low value of (R_c) indicates that the risk of flood is low at the peak value of precipitation. Coefficient (C_c) is used to express the relationship of the hydrologic basin with that of a circular basin having the same area as the hydrologic basin. A circular basin is the most hazardous from a drainage stand point because it will yield the shortest time of concentration before peak flow occurs in the basin. The value of (Cc) in the study area was found 0.164 which also confirms to the deviation of the watershed from the circular shape.

Basin relief (H) refers to the elevation difference between the basin outlet and the highest point located at the perimeter of the basin. The highest elevation corresponds to the elevation of 2026m while as the lowest elevation corresponds to 1586m.

Relief ratio (R_f) defined as the ratio of horizontal distance along the longest dimension of the basin parallel to the principal drainage line (Schumn, 1956). It measures the overall steepness of a drainage basin and is an indicator of the intensity of erosion processes operating on the slopes of the basin. Relief ratio normally increases with decreasing drainage area and size of a given drainage basin (Gottschalk, 1964). The value of relief ratio for Wanpura watershed came out to be 0.0374 indicating gentle slope. Relief controls the rate of conversion of potential to kinetic energy of water draining through the basin. The value of ruggedness number came out to be 0.0024 which is very low indicating gentle slope. The different relief parameters of basin relief, relief ratio, relative relief, Ruggedness number were found as 440m, 0.0374, 3.74%, and 0.0024, respectively.

CONCLUSION

The GIS technique has proved to be an accurate and efficient tool in drainage delineation and watershed management. The study has shown that the watershed is in conformity with the Horton's law of stream numbers and law of stream lengths. It was observed that there is a decrease in stream frequency as the stream order increases. Drainage network of the drainage basin exhibits as mainly dendritic type which indicates the homogeneity in texture. The low value of drainage density (5.48) indicates that the region is composed of permeable sub-surface materials, dense vegetation and low mountainous relief causing lower surface runoff, and a lower level of degree of dissection. Low value of bifurcation ratio (1.79) shows that there is little control of structure on the drainage pattern. The drainage pattern has not been distorted by the geological formations. Low value of drainage density (5.482 m / km^2) indicates that the watershed is mostly covered by vegetative cover and has low relief. The low value of density also depicts the permeable nature of the soil which indicates that most part of the precipitation will penetrate into the soil and lesser amount will contribute to the runoff. Hence, this micro- watershed may be taken for conservation measures by planners and decision makers. Further, the morphometric parameters evaluated using GIS have helped us to understand various terrain parameters such as nature of bedrock, infiltration capacity and surface run-off. The advance application of GIS techniques has led to the estimation of morphometric analysis based on different parameters, which helps in watershed planning and management.

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Short Communication

Effect of long term application of organic and inorganic nutrient sources on soil moisture and yield of maize under rainfed conditions

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ABSTRACT

A study was conducted to ascertain the long term impact of use of organic and inorganic sources of nutrients on soil moisture and maize productivity. It was observed that the soil organic C content ranged from 1.9g kg^{-1} to 5.4g kg^{-1} in surface and 1.6g kg^{-1} to 4.7g kg^{-1} in sub-surface soils. The available soil moisture percentage was significantly higher in FYM applied plots (T_6) and T_5over the rest of treatments with the values of 17.30 and 17.12 per cent at surface and 17.96 and 18.89 per cent at sub surface, respectively. Highest maize yield was recorded in treatment T_5 (23q ha^{-1}) where both organic and inorganic sources were integrated, which is statistically significant and at par with treatment T_7 (100%RDF through inorganics).

Key words: FYM, Organic, Inorganic, Rainfed, Maize

INTRODUCTION

The soils of Jammu and Kashmir have potential for cultivation of maize crop. Many inter-related factors, both natural and managerial, cause decline in yield of maize and soil fertility. This decline may be due to the absence of definite management system. As heavy feeder of nutrients, maize productivity is largely dependent on nutrient management of soil. Therefore, a good fertile soil is needed for maize to express its yield potential. The use of mineral fertilizers in maize (*Zea mays L.*) has generally been restricted to only a few farmers endowed with resources. The majority of the small holder farmers in the *kandi* region of Jammu division, on the other hand, are lacking the financial resources to purchase sufficient mineral fertilizers to replace the soil nutrients exhausted. Inorganic fertilizers are an important management input to achieve good crop yields especially in systems where soils are nutrient deficient and the main goal is to increase crop productivity (Haynes and Naidu, 1998).

Organic manures are not only supplying plant nutrients but also improve the soil quality indicators *viz.* physical, chemical and biological (Arshad and Martin, 2002; Sharma and Arora, 2010). Some of the primary effects of use of organic fertilizers are increase in soil organic matter, improved soil properties for crop growth (Arora and Hadda, 2003; Saha *et al.*, 2008;) and increase in nutrient status over a longer period of time, increased CEC and improved soil biological activity (Woomer and Swift, 1994; Khursheed *et al.*, 2012). The integrated use of organic and inorganic nutrients source is beneficial to enhance soil properties by increasing labile soil carbon fraction and maintain the crop yields (Kharche *et al.*, 2013) as well as also helps in increasing moisture holding capacity of the soils.

This increased capacity to hold moisture is especially important because of the moisture deficit conditions that prevail in the *kandi* region of Jammu (Arora and Hadda, 2008; Sharma and Arora, 2015). A study, therefore, was conducted to study the effect of inorganic and organic sources of nutrients on availability of soil moisture and yield of maize.

The present investigation was carried out in *kharif*, 2013 at Dry Land Research Sub-station Rakh Dhiansar, (SKUAST-J) Jammu in a field experiment that have initial data from 1996. The experiment was laid out during *kharif*, 2013 at Dry Land Research Sub-station, Rakh Dhiansar, Bari Brahamna, (SKUAST-J) with treatments: T_1-

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Control; T_2- 100% Recommended N:P:K (60:40:20 kg ha^{-1}); T_3- 50% Recommended N:P:K (30:20:10 kg ha^{-1}); T_4- 50% Recommended N:P:K + 50% Nitrogen through crop residue, T_5- 50% Recommended N:P:K + 50% Nitrogen through FYM; T_6- FYM @ 10t ha^{-1}; T_7- 100% Recommended N:P:K + 20 kg $ZnSO_4$ ha^{-1}

Half dose of nitrogen fertilizer with full dose of phosphorus and potassium as per treatments was applied at the time of sowing by band placement method after mixing all the three fertilizers. The remaining nitrogen was applied at the pre-tasseling stage (60 days after sowing). Farmyard manure @10 t ha^{-1} was applied and mixed in the moist soil 15 days before sowing. The gross size of each plot was 21 m^2 and net plot was 15 m^2. The sowing of the maize local composite var. *Mansar* was done by dibbling in the rows 30 cm apart, each plot having 3 rows. The number of plants in each plot was 83. The experiment was replicated thrice. To analyze the various physico- chemical properties, soil samples from surface (0-15 cm) and sub-surface (15-30 cm) were collected at the harvest stage of crop and finally stored in polythene bags for analysis. The soil samples was analyzed for pH, electrical conductivity, organic carbon, available N, P and K, percent sand, silt and clay, bulk density, water holding capacity, available moisture percentage, aggregate stability, N, P, K content in grains and straw. Soil organic carbon content was determined by Walkely and Black (1934).

From the perusal of Table 1, it is observed that in treatment T_6, there was significant increase in soil moisture percentage with the values of 17.30 % and 17.96 % in surface and sub- surface soils, respectively which was statistically at par with T_6 and differ significantly with T_4, T_7, T_2, T_3 and T_1. The percentage of organic carbon content in soil ranges from 1.9g kg^{-1} to 5.4g kg^{-1} in soil surface and 1.6g kg^{-1} to 4.7g kg^{-1} in sub-surface soils. The higher percentage of carbon noticed in treatments T_5 and T_6 both at surface and sub-surface of soil which are statistically significant and at par with each other. Soil organic carbon increased from 3.6g kg^{-1} in initial year to 5.4g kg^{-1} at soil surface in treatment T_5 (Table 1). However, the value of organic carbon decreased to 1.9 g kg^{-1} in control when compare with initial value of 3.6g kg^{-1}. Highest value of maize yield was recorded in treatment T_5 (23q ha^{-1}) which was statistically significant and at par with treatment T_7. The data presented in Table 2, reveal that available yield of maize increased from 15q ha^{-1} in initial year (1996) to 23q ha^{-1} in treatment T_5. However, the yield of maize decreased to 10.48q ha^{-1} in control. The percent increase in the yield over control varied from 66.98 to 119.46. The percent yield increase was highest in treatment T_5 with the value of 119.46 and it decreased further in treatment T_3 with the lowest value of 66.98. The available soil moisture percentage was significantly higher in treatments T_6 and T_5 over the rest of treatments with the values of 17.30 and 17.12 % at surface and 17.96 and 18.89 % at sub surface soil layers, respectively. This is mainly due to the improved organic carbon content of soil in FYM treated plots (Singh *et al.*, 2003). The higher root biomass produced by the application of FYM and inorganic fertilizers increased the level of macro-organic matter particularly in the surface soil layers (Singh *et al.*, 2003).

The percentage of carbon concentration of soil ranges from 1.9 g kg^{-1} to 5.4 g kg^{-1} at soil surface and 1.6 g kg^{-1} to 4.7 g kg^{-1} at sub surface of soil. The significantly highest percentage of carbon was

Table 1. Status of available moisture percentage and soil organic carbon content

Treatments	Available moisture percentage (%)		Organic carbon (g kg^{-1})	
	Surface	Sub -surface	Surface	Sub- surface
T_1- Control	9.01^a	9.59^a	1.9^a	1.6^a
T_2- 100% Recommended N:P:K (60:40:20 kg ha^{-1})	14.43^c	15.98^c	3.8^c	2.5^c
T_3- 50% Recommended N:P:K (30:20:10 kg ha^{-1})	13.60^b	14.27^b	2.7^b	2.2^b
T_4- 50% Recommended N:P:K + 50% Nitrogen through crop residue	16.21^d	16.76^d	4.4^d	3.6^d
T_5- 50% Recommended N:P:K + 50% Nitrogen through FYM	17.12^e	18.89^e	5.4^e	4.7^f
T_6- FYM @10t ha^{-1}	17.30^e	17.96^e	4.8^d	4.1^e
T_7- 100% Recommended N:P:K + 20 kg $ZnSO_4$ ha^{-1}	14.15^c	15.49^c	4.5^d	3.8^d
Initial value*			3.6	

Values of treatments with the same letter are statistically at par and value with different letter differ with each other. ;
*Initial value pertains to year 1996

Table 2. Yield of maize crop as influenced by treatments

Treatments	Yield (q ha^{-1})	(%) Increase in yield
T_1- Control	10.48^a	-
T_2- 100% Recommended N:P:K (60:40:20 kg ha^{-1})	20.00^c	90.83
T_3- 50% Recommended N:P:K (30:20:10 kg ha^{-1})	17.50^b	66.98
T_4- 50% Recommended N:P:K + 50% Nitrogen through crop residue	18.07 ^{b}	72.42
T_5- 50% Recommended N:P:K + 50% Nitrogen through FYM	23.00^d	119.46
T_6- FYM@10t ha^{-1}	18.63^{ab}	77.76
T_7- 100% Recommended N:P:K + 20 kg $ZnSO_4$ ha^{-1}	21.82^d	108.20

Values of treatments with the same letter are statistically at par and values with different letters differ significantly with each other. ;*Initial value pertains to year 1996

noticed in surface and sub surface soil from T_5 treatment. Increased doses of organic manures in treatment T_6 along with decreased doses of chemical fertilizers in treatment T_5 improved soil organic carbon in comparison to application of chemical fertilizer alone in long term experiment. The increase in organic carbon might be due to direct addition of organic source of nutrients (FYM) and less mineralization due to wide C: N ratio material. Sathish *et al*. (2011) found an improvement (>7.0 g kg^{-1}) of soil organic carbon in treatment receiving or both the sources of nutrients (organic and inorganic) which may be attributed to higher contribution of biomass to the soil in the form of FYM, which upon decomposition might have resulted in enhanced organic carbon content of the soil (Kukreja *et al.*, 1991; Khursheed *et al*., 2012). The increase in organic carbon content in the surface soil as compared to the subsurface soil was mainly due to the accumulation of organic residues over a period of time (Singh *et al*., 1999; Tiwari *et al*., 2002).

The beneficial effect of FYM in comparison to chemical fertilizers on yield might be due to the additional supply of nutrients as well as improvement in overall physio-chemical properties of soil (Datt and Sharma, 2003). It could also be attributed to the fact after decomposition and mineralization of applied FYM supply more available nutrients directly to plant and also had solubilizing effect on fixed form of nutrients. Similar improvement in yield of maize due to integrated use of FYM with chemical fertilizers was noted by Kaur *et al.* (2008). The yield of maize crops indicates an improvement in the efficiency of NPK fertilizers when used in conjunction with FYM (Narain *et al*., 1990).The study concluded that a available moisture percentage also significantly increased in FYM receiving plots in T_6 and T_5 both in soil surface with the mean values of 17.30 per cent and 17.12 per cent and sub surface with the mean values of 17.96 per cent and 18.89 per cent respectively. The low available moisture percentage of soil recorded in T_1 (control) both in surface as well as sub surface with the mean values of 9.01 per cent and 9.59 per cent respectively. Values of treatments with the same letter are statistically at par and values with different letters differ significantly with each other. ;*Initial value pertains to year 1996

In general, the grain and stover yield was higher in 2012-2013 was recorded in integrated nutrient management practices T_5 with the value of 23q ha^{-1}. Addition of supplementary ingredients *viz*. FYM, zinc sulphate progressively increased the proteins content in grains. However, pronounced effect on yield was observed due to the effect of organic and inorganic sources of nutrients recorded in T_5 as compared to the sole application fertilizers in other treatments.

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