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Effects of Rainwater Harvesting and Vegetation Cover in reducing Water, Soil and Nutrient Losses during Restoration of Degraded Hills in Rajasthan, India

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16.1 INTRODUCTION

Rain is the main source of water for raising forestry plantations, growing agricultural crops and the drinking water sources. However, concentration of rainfall to a few events results in runoff losses of the order of 20 to 40 per cent and influences loss of water and nutrients (Liu *et al.*, 2008). Soil erosion reduces water availability by reducing soil depth and contributing to the formation of surface soil crusts (Sarah, 2004). Formation of rills and gullies, promoted by soil erosion, increase runoff on the slopes and provide efficient pathways to drive water out of the system (Bracken and Croke, 2007). The relationship between rainfall and runoff is important for its application in adopting control measures. By knowing relationships between soil physiography, vegetation status, the hydrological behaviour of the area can be defined and the hydrological responses of the area can be easily predicted. To minimize and control water, soil and nutrients losses,water retention structures are prepared and utilized (Schröder *et al.*, 2004; Huddle *et al.*, 2011). There is direct relationship between the hydrologic functioning and both the spatial pattern and the functional diversity of perennial vegetation, that suggest that plant spatial pattern, physical crust cover, and functional diversity are linked through feedback mechanisms (Bautista *et al.*, 2007). Rain is the main source of water for raising forestry plantations, growing agricultural crops and the drinking water sources. Rainfall is low and erratic in the dry region of India. Further, concentration of rainfall to a few events results in runoff losses of the order of 20 to 40 per cent. The role of soil erosion on ecosystems has been interpreted as an abiotic exploitation agent, responsible for the loss of water and nutrients (Liu *et al.*, 2007) along with germinated crops or other vegetations (Chambers, 2000). Further, soil erosion reduces water availability to plants by reducing soil depth and contributing to the formation of surface soil crusts (Pimentel *et al.*, 1995; Sarah, 2004). Formation of a network of rills promoted by soil erosion, increases runoff on the slopes and provides efficient pathways to drain water out of the system and reduces water availability at site (Favis-Mortlock *et al.*, 2000; Bracken and Croke, 2007), whereas it reduces storage capacity of the reservoirs or dams off site (Bunyasi *et al.*, 2013). The relationship between rainfall and runoff is important for its application in adopting control measures. However, it requires sufficient knowledge and a better understanding of the hydrological processes, rainfall characteristics, runoff mechanism, and the identification of runoff sources, which in turn are determined by the physical properties of the area (Shakya and Chander, 1998; Gomi *et al.*, 2008). By defining relationships between these properties, the hydrological behaviour of the area can be defined and the hydrological responses of the area could be easily predicted (Acreman and Sinclair, 1986).

Erosion negatively affects plants colonization and their performance by reducing the availability of seeds, nutrients, and water in soil. There is a need to modify one or more of the factors affecting erosion processes, i.e. slope length, slope steepness, afforestation and support practices like *bunds* or rainwater harvesting that slow runoff water or cause deposition (Kuzucu *et al.*, 2013). To minimize and control losses of water, soil and nutrients in the form of runoff losses so that the quality of water flowing should not deteriorate (Baker and Laflen, 1983; Schröder *et al.*, 2004), one can prepare different rainwater harvesting (water retention) structures (Wani, 2000) or adopt soil and water conservation measures (Czapar, 2006). For example, Contour trench (CT), Gradonie (GD), Box trench (BT) and V-ditch (VD) were prepared in a degraded hill area and runoff losses were measured in 2005, 2006, 2007 and 2009 during the monsoon period of June to October. Water samples were collected and analyzed for quantification of soil and nutrients losses and for observing the efficiencies of these RWH devices in minimizing the soil and nutrient losses from the treated area during the process of degraded hill restoration (Ivanov *et al.*, 2008; IWP, 2013) through afforestation and rainwater harvesting. The results of soil, water and nutrient losses and the effects of regenerated herbaceous vegetation on these variables are described in this manuscript.

16.2 METHODOLOGY

16.2.1 Site characteristics

Study was conducted at Bara Nandra Kho Forest Block covering an area of about 17 ha, spread over 23⁰ 25′ 27.0″ N to 23° 25′ 43.4″ N latitudes and 74° 24′ 00.5″ E to 74° 24′ 23.1″ E longitude. Altitude of the area ranged between 248 to 320 msl. The site is located 17 km south-west of Banswara (23° 32′ 28.2″ N and 74° 26′ 30.3″ E), Rajasthan, India. Air temperature varied from 4°C in January to 42°C in May. The mean minimum annual temperature during experimental period ranged from

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18.7°C in 2008 to 20.1°C in 2006, whereas mean maximum annual temperature ranged from 32.8°C in 2008 to 34.3°C in 2010 (Table 16.1). Average annual rainfall from 1993 to 2004 was 960 mm with 54 rainy days. Rainfall varied from 562.5 to 2,266.0 mm during 2005 to 2010 with average values of rainfall and number rain days of 1221 mm and 41.6, respectively (Table 16.1). Hill slopes were categorized into steep (>20 per cent), medium (10-20 per cent) and gentle (<10 per cent) slopes. The surface of steep slope was covered with crystalline gravels and pebbles of varying size with randomly growing *Lantana camara* L. and *Themada quadrivelvis*(L.) Kuntze and *Apluda mutica* L. grasses. Medium slope had light textured sandy loam soils of shallow depth and was mostly covered by *Prosopis juliflora*(Sw.) DC. With some *L. camara* shrub and *Aristida funiculata* Trin. & Rupr. and *Heteropogon contortus*(L.) P. Beauv. ex Roem. & Schult. grasses. Soils in gentle slope were loamy to clay loam in texture and shallow to deep in soil depth. This area was dominantly covered by *P. juliflora* and *L. camara* bushes and the grasses like *Dichanthium* spp. and *Cenchrus* spp. Soil pH ranged between 6.34 and 7.02. Average SOC, available NH_4-N, NO_3-N and PO_4-P of the site were 0.76 per cent, 22.15 mg kg^{-1}, 2.50 mg kg^{-1} and 4.51 mg kg^{-1}, respectively (Singh, 2012).

16.2.2 Experimental design

The experiment was laid in a complete randomized block design in five replications because of hillocks of varying height and aspects associated with different drainage lines. Major emphasis was given to have a plot of equal size though varied in shape to adjust between the hill slopes and the drainage lines. Seventy-five plots each of 700 sq.m area were laid in <10 per cent, 10-20 per cent and >20 per cent slopes distributed in about 17 ha area covering almost all aspects. Each plot was separated by individual boundary of trench (2,025 sq.cm cross section area, 45 cm × 45 cm) to prevent water flow into the plots from the other areas or plots and for diverting the flowing water toward the drainage lines. Four rainwater harvesting structure viz. contour trench (CT), gradonie (GD), box trench (BT) and V-ditch (VD) of 30 running meter length were prepared to harvest rainwater in the plots. In addition there were control plots without any rainwater harvesting structures (Singh, 2009). Contour trenches and Box trenches were excavated at different contour levels to conserve the runoff water and the trenches were 45 cm × 45 cm in cross section. Box trenches were 15 in number and 2 m in length, whereas contour trenches were continuous in nature. Gradonie and V-ditches were across the contour and 1,800 sq.cm cross section area, but differences were only in vertical cut of 30 cm height. In the V-ditch the vertical cut was downside of the slope in VD, whereas in gradonie ditch the cut was upside of the slope (to reduce velocity of surface runoff water). The excavated soil was always kept downside of the dugout. A mixed plantation of *Acacia catechu* (L.f.) Willd, *Azadirachta indica* A. Juss., *Dendrocalamus strictus* (Roxb.) Nees, *Emblica officinalis* Gaertn., *Holoptelia integrifolia* (Roxb.), *Syzigium cumini* (L.) Skeels, and *Zizyphus mauritiana* Lam. was prepared in August 2005. Thirty five seedlings of these species were planted in a 45 cm × 45 cm × 45 cm pit size, i.e. 500 plants per ha.

16.2.3 Runoff measuring devices and water loss measurement

Plots were fixed on area basis so that runoff water should drain from a single point, where the runoff measuring device was installed. Looking into the sociology of the area, the runoff loss measurements was done by runoff collection in the tanks of capacity 1,000 litres (Miller, 1994). Excavations of tanks, erection of tank walls and their plastering were done to avoid any seepage loss from the tanks. The tanks were constructed at the water draining point and were cautiously made to avoid any water flow from outside the area. A brick wall of dimension 250 cm (length) ×45 cm (height) × 30cm (width) was erected and 20 pipes of 50 mm diameter (19 pvc and one central GI pipe) were fixed along the complete length of the wall at equal intervals in September 2005 (Figure 16.1). Nineteen pipes drained water outside of the plots and the collection tanks, whereas the central one drained its water in the collection tank. Thus, $1/20^{th}$ part of runoff was collected in the tank (Ullah *et al*., 1972). The quantity of water flowing through the central pipe and the other pipes was standardized and was considered in calculating the total runoff. Three rows of baffles in alternate sequence at 10 cm intervals and 8 cm height were erected parallel to the above-mentioned wall to make water flow uniform and minimize flow rate as well as the flow variability of runoff water in the drainage pipes. Water discharge was measured at different time intervals during rain

Table 16.1: Rainfall received with number of rainy days near the experimental site in Banswara district, Rajasthan during 2005-2009

Year	Rain days	Rainfall during monsoon (June-October) and annual (mm)						
		June	July	August	September	October	Total	Annual
2005	42	82.6	290.0	169.1	483.5	-	1025.2	1026.7
2006	63	148.4	648.6	630.3	489.1	44.0	1960.4	2266.0
2007	44	102.0	232.0	565.0	254.0	-	1153.0	1391.0
2008	29	101.0	192.3	129.5	74.0	-	496.8	562.5
2009	30	69.0	457.0	333.0	-	-	859.0	859.0
Average	41.6	100.6	364.0	365.4	325.2	44	1098.9	1221.0

Figure 16.1: Preparation of runoff measuring device (left) and plantation activity (right) at the experimental site in August 2005.

fall during September 2005 to September 2009. Total amount of runoff was calculated as percentage of the total rainfall received in the plot (FAO, 1985).

16.2.4 Water sampling and analysis

Water samples were collected from the runoff collection tanks. The whole water was stirred thoroughly to homogenise the sediments settled at the tank bottom and water samples were collected from the half of the height of the water table, i.e., in the centre of the tank (Ciesiolka *et al.*, 2004). Water from the different sampling time was mixed together to form a composite sample of many rains. Water samples collected were brought to the laboratory, filtered through Whatman 42 filter paper (OMA, 1990). Each sample was analyzed for pH, electrical conductivity (EC) and total dissolved solid. Total dissolved salts (TDS), total solids (TS) and total suspended solids (TSS, i.e., soil) were determined gravimetrically. Nitrogen (NO_3-N and NH_4-N) and phosphorus (PO_4-P) in the collected runoff water were analyzed calorimetrically following standard procedure (Jackson, 1973) using UV-Visible (Shimadzu) spectrophotometer.

16.2.5 Statistical analysis

Data were analyzed statistically using SPSS version 8.0 statistical package. Since data on height and dry biomass of herbaceous vegetation were recorded six times (in October each year), these data were analyzed using Repeated Measure ANOVA considering year as the 'Tests of within-subjects effects' and slope and RWH treatments as the 'Tests of between-subjects effects'. Plant survival, growth (height and collar diameter) and mean annual increment (separately for each species) data were analyzed using a two-way ANOVA. Above-mentioned parameters were the dependent variables and slope and RWH treatments were the fixed factors. Duncan Multiple Range Tests (DMRT) was applied to group homogeneous subsets of slope and rainwater harvesting treatments at the $P< 0.05$ levels. To obtain relations among rainfall, runoff water, soil and nutrient loss and number of herbaceous species and their diversity regression relations were observed.

16.3 RESULTS

16.3.1 Runoff coefficient and conservation effects

In 2005 overall runoff was 5.63 per cent of the rainfall. Runoff coefficient was highest in >20 per cent slope, whereas lowest runoff was from <10 per cent slope area. Gradonie (GD) structure was found most effective, while BT structure was observed least effective in reducing runoff coefficient among the RWH treatment(Table 16.2). Annual runoff was 669.1 m^3 ha^{-1} from >20 per cent slope to 466.3 m^3 ha^{-1} from <10 per cent slope area. The annual runoff was 612.2 m^3 $ha^{-1}$from the control plots, and 551.3 m^3 ha^{-1}, 427.1 m^3 ha^{-1}, 687.4 m^3 ha^{-1} and 576.8 m^3 ha^{-1} from CT, GD, BT and VD plots, respectively, among the RWH treatments. In 2006 average runoff (9 observations) ranged between 4.56 per cent and 11.79 per cent. The lowest runoff was 3 per cent on August 29, whereas the highest runoff was 15.1 per cent on 6th August 2006 (Table 16.2). Such variations appeared to be dependent upon rainfall intensity, duration and saturation of the soil that facilitate surface runoff. Highest amount of runoff was from 10-20 per cent slope area with relatively coarser textured soil, but it did not differ with runoff from >20 per cent slope area (Gomo *et al*., 2008). MartõÂnez-Mena *et al*. (1998) observed greater runoff coefficient (9 per cent) and lower runoff threshold (3.6 mm) in the fine textured and poorly permeable soils of low organic carbon content as compared to more permeable, coarser textured soils of medium organic carbon content (53 per cent, and 8 mm, respectively). Zhao *et al*. (2013) observed time lag in runoff initiation time, which was longer in the shallow hoeing and contour ploughing treatments than in the zero tilling treatment. However, these authors did not observe significant differences in the total runoff yields among these treatments, though sediment loss was significantly lesser in the shallow hoeing and contour ploughing treatments than in the zero tilling treatment. Rain

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Table 16.2: Average runoff coefficient (per cent) and annual runoff (m^3 ha^{-1}) water in different years affected by varying slopes and rainwater harvesting treatments.

Slope	Treatment	2005		2006		2007		2009		Av.of 4 years (%)
		(%)	Annual	(%)	Annual	(%)	Annual	(%)	Annual	
<10 %	Control	5.27	537.9	9.28	1810.1	18.00	2061.4	15.07	1294.3	11.64
	C. Trench	4.66	479.3	6.95	1361.7	11.25	1296.7	9.90	832.7	7.91
	Gradonie	2.52	260.0	7.22	1423.1	15.55	1802.8	10.95	940.5	9.06
	Box Trench	7.28	745.6	4.56	892.1	11.46	1319.1	7.35	631.1	7.63
	V-Ditch	2.27	231.8	4.58	896.3	10.41	1198.5	4.50	386.3	5.21
10-20 %	Control	5.95	609.3	11.79	2310.7	21.32	2458.5	13.07	1122.9	12.49
	C. Trench	3.13	326.1	9.16	1809.2	17.62	2047.1	7.92	680.3	9.15
	Gradonie	6.06	621.4	10.90	2124.9	17.90	2047.4	11.81	1014.5	11.61
	Box Trench	7.53	767.0	10.85	2141.2	21.52	2491.6	13.02	1118.3	13.07
	V-Ditch	6.28	646.9	8.95	1758.3	16.27	1876.1	13.66	1173.3	10.99
>20 %	Control	7.15	715.1	10.41	2017.1	13.21	1498.3	12.30	1056.6	9.82
	C. Trench	8.61	872.4	7.76	1469.4	12.10	1323.6	11.06	949.5	9.42
	Gradonie	4.45	446.5	11.04	2160.0	12.91	1494.7	10.36	889.6	9.75
	Box Trench	5.23	535.0	10.48	2037.9	16.97	1936.4	10.66	915.5	11.31
	V-Ditch	7.87	783.0	8.09	1551.1	11.03	1243.4	12.51	1074.9	10.19

intensity appears as the major rainfall parameter controlling the runoff response in a micro-catchment of fine textured soil with low infiltration rate and with a poor plant cover, whereas total rainfall is more closely correlated with runoff in coarser textured, highly permeable soils with a denser plant cover (MartõÂnez-Mena *et al*., 1998, Kovar *et al*., 2011). Runoff coefficient was 10.5 per cent in control, 7.2 per cent from VD, 8.0 per cent from CT, 8.6 per cent from BT and 9.7 per cent from GD plots, which are equivalent to annual runoff of 2046.3 m^3 ha^{-1}, 1401.9 m^3 ha^{-1},1546.1, 1690.4 m^3 ha^{-1}and 1902.7 m^3 ha^{-1}, for the respective RWH treatment.

Runoff measurements in 2007 show runoff coefficient (average of eight observations) of 11.0 per cent to 21.5 per cent with an average value of 15.2 per cent for the area. Runoff coefficient for individual eight observations were 1.16 per cent, 4.02 per cent, 18.72 per cent, 31.0 per cent, 23.58 per cent, 11.74 per cent, 19.43 per cent and 12.22 per cent, respectively, on July 1st, 7th, 9th, 11th and 12th and August 6th, 8th and 22nd. This indicated a wide range of variations in runoff losses depending upon the intensity and quantity of rainfall. Despite low rainfall on 11th and 12th July 2007 as compared to that on 9th July, high runoff coefficient on former dates was due to continuous rain that caused saturation of the soil profile and resulted into a greater runoff. Bugan *et al*. (2012) observed that streamflow is driven by quickflow, i.e. overland flow and interflow, with minimal contribution from groundwater, and is also more dependent on the rainfall distribution in time rather than on the annual volume. Repeated Measure Analysis (all the observations) indicated significant effect of rainfall duration and intensity on the runoff. Significant ($P<0.01$) event × slope and event × treatments interactions indicates that runoff from a particular slope or RWH treatment depended upon the rainfall and the soil saturation as well as efficiency of RWH structure in reducing runoff. For example rainfall on a saturated area facilitates surface runoff (Liu *et al*., 2008). Among the slopes, runoff was lowest ($P<0.05$) from either <10 per cent slope (i.e., 7th July, 9th July, 11th July, 12th July, 6th August and 8th August 2007) or >20 per cent slope area (i.e., 1st July and 22nd August 2007). The highest amount of runoff was from 10-20 per cent slope area. However, differences in runoff losses between <10 per cent slope and >20 per cent slope were not significant during 9th July to 8th August 2007. This indicates two types of runoff generation: (i) infiltration-excess overland flow in the more degraded areas with low organic carbon content and low infiltrability; and (ii) a saturation-excess overland flow in the less degraded areas with high organic carbon content, high infiltrability and a dense plant cover. On an average lowest runoff was from >20 per cent slope area (i.e., 13.25 per cent), though it did not differ significantly ($P>0.05$) with the runoff from <10 per cent slope area. The highest runoff was from 10-20 per cent slope area with runoff coefficient of 18.93 per cent (i.e. 1509.8 m^3 ha^{-1}). It was due to higher infiltration rate in >20 per cent slope as compared to other slope though variations due to soil heterogeneity also influencing surface runoff (Liangand Xie, 2001). Among the treatments, runoff coefficient was lowest in V-ditch plots (12.57 per cent) as compared to 17.51 per cent in control, 16.65 per cent in BT, 15.45 per cent in GD and 14.00 per cent in CT plots. This indicated an average annual water loss from 1439.3 m^3 ha^{-1} in VD plots to 1915.7 m^3 ha^{-1} from BT plots (2006.1 m^3 ha^{-1} from the control plots) in 2007 (Table 16.2).

In two measurements made in 2009 during July and August, the runoff coefficients were 12.81 per cent (i.e., 147.0 m^3 ha^{-1}) and 9.05 per cent (i.e., 68.9 m^3 ha^{-1}) across slopes and RWH treatments. This indicated a decreasing trend in runoff with time and corresponding vegetation growth. The water loss did not differ significantly due to both slopes and treatments (Table 16.2). Though runoff was lowest in <10 per cent slope in both July and August 2009, but the highest amount of runoff was recorded from 10-20 per cent slope in July 2009 and >20 per cent slope in August 2009. Such variations appeared to be due to the influence of micro-topography, presence of vegetation and soil heterogeneity. Results of (Chen *et al*. (2013) indicate important roles of seal soil layer, micro-topography and vegetation in dry land runoff processes, where seal soil layer controls runoff generation; vegetation patches affect overland flow by enhancing local infiltration rates; and micro-topography had a small impact on the total amount of runoff, but shapes the spatial pattern of the overland flow. In this the presence of vegetation patches amplified the effect of micro-topography by increasing spatial variability of infiltration and runoff (Chen *et al*., 2013). Among RWH treatments, the runoff was highest from the control plots at both the events. Lowest water loss was from the CT plots in July 2009 and in VD plots in August 2009. Average loss was 171.3 m^3 ha^{-1} from <10 per cent slope to 214.2 m^3 ha^{-1} from 10-20 per cent slope, whereas it ranged from 172.1 m^3 ha^{-1} for CT plots to 242.7 m^3 ha^{-1} for the control plots, with an average loss of 196.8 m^3 ha^{-1} from the area. Annual loss for the year 2009 ranged from 386.3 for VD plots in <10 per cent slope to 1173.3 m^3 ha^{-1} for the control plots in 10-20 per cent slope, with an average value of 938.7 m^3 ha^{-1} for the area.

Average of four years observations indicated runoff coefficient of 10.46 per cent. The lowest (P<0.05) runoff was from <10 per cent slope area (8.72 per cent), whereas the highest runoff (12.21 per cent) was from 10-20 per cent slope area. Runoff from >20 per cent slope areas was 10.45 per cent. Lesser runoff from >20 per cent slope area was probably due to higher infiltration rate and coarser surface reducing surface runoff and facilitating infiltration of water into soil. However, the runoff recorded in 2007 and the observation during initial rainfall in 2006 showed lesser runoff from >20 per cent slope as compared to <10 per cent slope. However, the observations recorded during July onwards particularly after regular rain or rainfall of high intensity showed greater runoff from >20 per cent slope area as compared to <10 per cent slope area. Though there is a distinct relationship between slope and runoff coefficient, but it was not observed as one would expect, because steeper slope (>20 per cent) provided lesser runoff as compared to 10-20 per cent slope area. This was probably due to greater surface roughness because of presence of pebbles influencing surface runoff (Zhao *et al.*, 2013). The observations of Bayabil (2009) also indicated a decrease in runoff coefficient as slope increases that imply that areas with the steepest slope in the watershed have the least runoff coefficient as compared with mid-slope and gentle-slope areas. This strengthens the concept of saturation excess runoff from gentle slope areas and appeared to be the major runoff mechanism. Further, areas of compaction and low soil organic matter also reduce infiltration and water retention and exacerbate runoff and erosion (Singh, 2012; Singh *et al*., 2012). Observations of Silgram *et al*., (2010) indicated 5.5-15.8 per cent of rainfall as runoff, and losses of 0.8-2.9 kg ha^{-1} phosphorus and 0.3-4.8 ton ha^{-1} sediment along tram line (a trench favouring runoff), whereas, the loss was only 0·2–1·7 per cent rainfall as runoff, 0.0-0.2 kg P ha^{-1} and 0.003-0.3 ton ha^{-1} sediment from treatments without tram lines or those where tram lines had been disrupted. This indicates that a terracing or a small disruption in tram line could control runoff and nutrient loss significantly, whereas bare soil surfaces exposed to heavy rain lead to formation of rills and facilitated runoff (Silgram *et al*., 2010). Among the treatments, highest (P<0.05) runoff (12.29 per cent) was from the control plots, whereas the lowest runoff was from V-ditch plots (i.e., 9.27 per cent)> this indicated that V-ditch facilitated water distribution in surface soil layer reducing surface runoff. It was followed by contour trench (i.e., 9.57 per cent), which facilitated water infiltration in deep soil profile. Most effective rainwater harvesting treatments for controlling runoff losses was V-ditch in <10 per cent slope and contour trench in 10-20 and >20 per cent slope area. In general, trenches increase rainwater harvesting by breaking the slope of the ground and therefore reducing the velocity of water runoff. By decreasing runoff, rainwater harvesting devices enhanced water infiltration and prevented soil erosion. Though contour trenches are reported to be applied to all soil types and are not dependent on slope or rainfall conditions (Sussman, 2007), but most of the rainwater harvesting devices became less effective at more frequent rainfall and higher amount of rainfall and runoff losses (Czapar *et al*., 2006).

17.3.2 Sediment yield

Sediment yield varied (P<0.01) widely depending upon rainfall intensity as well as saturation of soil through regular rain for more than a day (Year × slope interaction, P<0.01). In the five observations recorded during the study period highest sediment yield (kg soil per cubic meter water) was recorded from 10-20 per cent slope in most of the observations except in August 2007 and July 2009, when the sediment yield was highest from <10 per cent slope (Table 16.3). The sediment yield was lowest in >20 per cent slope, where it ranged from 0.21 to 2.58 kg soil m^{-3} water. Highest sediment yield was 1.6 tons ha^{-1} from 10-20 per cent slope in July 2006 and the lowest was 8.3 kg ha^{-1} from the same slope in August 2007. This variation was probably associated with herbaceous vegetation cover and diversity among different years. While recording observations on infiltration rate, runoff and sediment yield under simulated rainfall experiments(Joshi and Tambe, 2010) found grass-cover as the most effective measure in inducing infiltration and in turn minimizing runoff and sediment yield. Liu *et al*. (1994) observed a linear relation between soil loss and slope angle according to the equation: S (soil loss) = 21.91 sin theta -0.96, where theta is the slope angle and S is the slope steepness factors normalized to 9 per cent. Their results showed lesser soil loss at high slopes than does the relationship used in the Universal Soil Loss Equation, but a greater soil loss than predicted by the Revised Universal Soil Loss Equation for steep slopes (Liu *et al*., 1994). Further, sediment yield was highest in September 2005 and lowest in July 2009, indicating a decreasing trend in soil loss and was due to increased growth of tree/shrub species and the associated herbaceous vegetation growing in the area (Joshi and Tambe, 2010). Lal (1976) observed that erosion increases with slope according to an exponential curve of 1.2 on modified ferralitic soil enriched with gravel (alfisol) when the soil is bare, but the soil loss is independent of slope (from 1 to 15 per cent) if crop residues are left on the surface. This indicates that

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Table 16.3: Sediment yield in water collected in the measuring tanks under the influence of slope and rainwater harvesting devices.

Slope	RWH treatment	Sediment yield (kg soil m^{-3} water)					Annual soil loss (tone ha^{-1})				Mean
		Sept 2005	July 2006	July 2007	Aug 2007	July 2009	2005	2006	2007	2009	(t ha^{-1} Y^{-1})
<10 %	Control	3.94	2.02	0.66	0.40	0.28	1.90	3.25	1.39	0.31	1.88
	C. Trench	2.77	1.78	0.73	0.16	0.36	0.82	3.89	0.57	0.41	1.57
	Gradonie	3.66	1.59	0.47	0.14	0.15	0.82	2.21	0.54	0.17	0.93
	Box Trench	2.09	2.80	0.81	0.83	0.21	1.72	2.54	1.26	0.12	1.41
	V-ditch	2.90	1.92	1.61	0.37	0.08	0.84	2.00	1.47	0.04	1.30
10-20 %	Control	8.49	4.10	0.83	0.07	0.11	5.01	10.34	1.21	0.13	4.44
	C. Trench	1.59	2.13	0.43	0.21	0.18	0.57	4.64	0.72	0.14	1.57
	Gradonie	2.59	2.39	0.25	0.14	0.10	1.81	6.14	0.48	0.11	2.11
	Box Trench	1.78	3.32	0.30	0.13	0.12	1.35	8.74	0.63	0.13	3.05
	V-ditch	2.48	1.91	0.42	0.18	0.26	1.39	4.06	0.65	0.33	1.84
>20 %	Control	0.95	1.92	0.41	0.30	0.22	1.06	4.48	0.60	0.33	1.74
	C. Trench	0.65	2.53	0.18	0.08	0.16	0.65	4.31	0.23	0.15	1.79
	Gradonie	1.78	2.27	0.14	0.09	0.05	0.76	4.87	0.22	0.04	2.52
	Box Trench	2.33	2.41	0.44	0.29	0.19	0.51	5.71	0.84	0.28	1.97
	V-ditch	0.36	3.80	0.31	0.19	0.38	0.43	6.78	0.43	0.49	2.68

runoff as such depend more on the hydrodynamic properties of the soil rather than on the slope itself (Lal, 1976; Roose, 1971; Avenard and Roose, 1972).

Although slope has a powerful influence on erosion, but high erosion and runoff on gentle slopes indicates that this phenomenon can occur without any need for a steep slope and the action of rain is enough for this process to begin with (Fauck 1956, Fournier 1967). Enhanced growth of herbaceous vegetation from July to September reduced sediment yield in August as compared to that in July (Schlesinger *et al*., 2000). Highest sediment yield was from the control plots in September 2005, BT plots in July 2006 and August 2007; and contour trench plots in July 2007. Lowest sediment yield was recorded in water flowing out from GD plot in July 2006, July 2007 and August 2007, whereas it was lowest in contour trench in September 2005. In most of the observations, lowest sediment yield was from GD plots in <10 per cent slope area except in July 2009, when the sediment yield was lowest in V-ditch plots. In 10-20 per cent slope area, the lowest sediment yield was from V-ditch plots in July 2006 and August 2007 and from GD plots in July 2007 and 2009, whereas in >20 per cent slope area the lowest sediment yield was from GD plots.

An overall sediment yield was 4.99 tons ha^{-1} in 2007 to 0.21 tons ha^{-1} in 2009 with an average sediment yield of 2.05 tons soil ha^{-1} $year^{-1}$ (kg m^{-3} × water loss in m^3 annually) across the area. Highest sediment yield in September 2005 was due to initial effects of site preparation and designing of RWH devices (Costantini and Loch, 2002), but highest total sediment yield in July 2006 was associated with highest amount of runoff. However, a decreasing trend in sediment yield was observed from 2007 onward and was because of increased vegetation cover as well as vegetation diversity in the area under conservation of soil and water (Li *et al*., 2013). El-Atta and Aref (2009) observed improved rainwater harvesting and growth performance of *Juniperus procera* on maintained terraces along hill slopes, whereas abandoning and damage of terraces produced more soil loss, increased surface runoff and bulk density, reduced infiltration and less growth of *Juniperus*. Average soil loss ranged between 2.60 tons ha^{-1} $year^{-1}$ ($P<0.05$) from the 10-20 per cent and 1.42 tons ha^{-1} $year^{-1}$ from <10 per cent slope (Table 16.3). The sediment load was 2.69 tons ha^{-1} $year^{-1}$ in the runoff from the control plots; where it ranged from 1.64 tons ha^{-1} $year^{-1}$ in water flowing from CT plots to 2.15 tons ha^{-1} $year^{-1}$ in water flowing from the BT plots. This indicates that contour trench (CT) is more efficient in controlling soil loss from the area, followed by GD structure. Interestingly, sediment yield was negatively correlated to species richness ($r=-0.231$, $P<0.05$) and species diversity ($r=-0.265$, $P<0.05$) of herbaceous vegetation in 2009 indicating that increased species richness/ diversity reduced sediment yield in runoff water similar to the observations of (Pohl *et al*., 2009). Shrestha *et al*. (2010) also recorded a negative correlation between vegetation diversity and soil erosion. However, soil loss was positively related to annual runoff loss ($r=0.299$, $P<0.01$) i.e., highest rainfall favours greater runoff as well as soil loss. However, vegetation cover and rainfall intensity are two important factors that affect soil erosion and nutrients losses, which can be minimized by managing ground cover (Zhang*et al*., 2011, Atucha *et al*., 2013).

17.3.3 Quality of runoff water

Measured pH of runoff water during 2005 to 2009 neither differed due to slopes nor due to rainwater harvesting treatments, but electrical conductivity (EC) varied ($P<0.05$) due to slopes only. Water pH was highest for the water of 10-20 per cent slope area except in July 2006, when pH was highest for the water collected from <10 per cent slope area. The water pH was lowest in <10 per cent slope area in general, but it was lowest in 10-20

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per cent slope area in July 2006 and August 2009 and >20 per cent slope area in August 2007 (Table 16.4). Among the RWH treatments, runoff water pH was lowest for the water collected from V-ditch plots in September 2005, BT plots in July 2006, 2007 and 2009 and of GD plots in August 2007. The pH was highest of the water of BT plots in September 2005, GD in 2006, CT plots in 2007 and control plot in 2009. Slope × RWH treatment interaction indicated lowest pH of water of BT plots in <10 per cent slope, GD plots in 10-20 per cent slope area and V-ditch plots in >20 per cent slope area. Such variations were probably related to sediments in water and the rocks from which the soil is derived influencing the growing vegetation with advancement of the monsoon (Nalubega and Nakawunde, 1995; Li *et al.*, 2013). Ugolini *et al.* (2001) found out that rock fragments from sandstone and siltstone were a source of high concentrations of exchangeable calcium, potassium and magnesium that support the growth of grass (e.g. *Agrostis* sp). While comparing with the rainfall water, Tang *et al.* (2011) observed that overland flow increased pH and decreased EC while stream waters increased pH and EC, though there were no significant differences in pH and EC among the stream waters during the rainfall. The electrical conductivity was greater ($P<0.05$ in August 2007) in the water collected from the <10 per cent slope area as compared to the other slopes (except August 2009, when it was greater in the water of >20 per cent slope than in other slopes).

Electrical conductivity (EC) - a measure of dissolved salts in solution is very much related to total dissolved salts in the water. Marion and Babcock (1976) also developed an equation (17.1) relating EC (dS m^{-1}) of the soil solution to the total dissolved salt (TDS) concentration (mmol L^{-1}), and to ionic concentration (C) (mmol L^{-1}). However, one limitation to the use of EC as an indicator of TDS is that EC does not respond to the presence of uncharged dissolved substances, such as silica, a common weathering product from igneous rock (Moore *et al.*, 2008).

$$\text{Log TDS} = 0.990 + \log \text{EC} \qquad (16.1)$$

In the present study, EC was lowest for the water flowing from 10-20 per cent slope area except in July 2006, when it was lowest in the water of <10 per cent slope area and appeared to be associated with quantity of runoff. Among the RWH treatments, highest EC was observed in the water flowing from control plots in September 2005 and July 2006, which yielded higher runoff and resulted in greater erosion under high intensity rainfall and dissolution of salts in water. However, the rock composition also determines the chemistry of the soil and ultimately the water flowing over it. For example, limestone leads to higher EC because of the dissolution of carbonate minerals by surface flowing water. The highest EC of the water flowing from the CT plots in other observations was probably due to less runoff but relatively greater concentration of salts in soil depending upon the RWH structures and the rock from which the soil has been formed. As lowering the concentration of salt by maximizing the amount of fresh water inflow or runoff to dilute salt concentration is a technique to reduce salinity of the dam water (Westrup, 2009). However, EC can also be influenced by the presence of fine sediment (Fenn, 1987). Further, total salt load also varies under different land uses because different land uses influence runoff amounts differently and consequently salt loads too (Ghadiri *et al.*, 2004). Lowest salinity (EC) was observed in the water flowing from V-ditch plots in September 2005, GD plots in July 2006, control plots in July 2007 and 2009, BT plots in August 2007 and CT plots in

Table 16.4: Water pH and electrical conductivity collected from the runoff measuring tanks under the influence of slope and rainwater harvesting devices.

Slope	RWH device	pH					EC (dSm^{-1})				
		Sep 05	July 06	July 07	Aug. 07	July 09	Sep 05	July 06	July 07	Aug 07	July 09
<10 %	Control	*7.75*	*8.41*	*7.56*	*7.51*	*7.22*	*0.34*	*0.38*	*0.20*	*0.43*	*0.59*
	C.trench	*7.68*	*8.28*	*7.45*	*7.56*	*7.13*	*0.32*	*0.32*	*0.60*	*0.31*	*0.71*
	Gradonie	*7.71*	*8.48*	*7.41*	*7.42*	*7.10*	*0.28*	*0.34*	*0.16*	*0.25*	*0.67*
	B.trench	*7.86*	*8.08*	*7.29*	*7.32*	*6.93*	*0.29*	*0.35*	*0.20*	*0.32*	*0.79*
	V-ditch	*7.56*	*8.05*	*7.45*	*7.37*	*7.15*	*0.30*	*0.35*	*0.26*	*0.31*	*0.49*
10-20 %	Control	*8.31*	*7.80*	*7.91*	*7.35*	*7.30*	*0.33*	*0.41*	*0.13*	*0.15*	*0.55*
	C.trench	*7.82*	*8.01*	*8.00*	*7.60*	*7.27*	*0.21*	*0.33*	*0.21*	*0.36*	*0.45*
	Gradonie	*7.86*	*7.80*	*7.29*	*7.38*	*7.22*	*0.27*	*0.36*	*0.15*	*0.25*	*0.54*
	B.trench	*8.23*	*7.85*	*7.59*	*7.57*	*7.26*	*0.26*	*0.29*	*0.11*	*0.17*	*0.59*
	V-ditch	***7.76***	*7.92*	*7.39*	*7.90*	*7.22*	*0.27*	*0.34*	*0.19*	*0.27*	*0.41*
>20 %	Control	*7.44*	*8.19*	*7.66*	*7.27*	*7.15*	*0.35*	*0.48*	*0.24*	*0.35*	*0.41*
	C.trench	*8.03*	*7.91*	*7.96*	*7.62*	*7.15*	*0.29*	*0.37*	*0.19*	*0.29*	*0.41*
	Gradonie	*8.43*	*8.41*	*7.98*	*7.43*	*7.16*	*0.29*	*0.35*	*0.16*	*0.29*	*0.45*
	B.trench	*7.89*	*8.10*	*7.80*	*7.40*	*7.12*	*0.30*	*0.36*	*0.25*	*0.29*	*0.40*
	V-ditch	*7.60*	*8.19*	*7.49*	*7.50*	*7.06*	*0.34*	*0.47*	*0.22*	*0.38*	*0.45*

August 2009. This indicates wide variations that depended upon rainfall intensity, total runoff and consequently the efficiency of the RWH structure in reducing runoff and the salt content. The study of Gilley *et al*. (2012) indicates that runoff losses of ammonium nitrogen (NH_4-N), total nitrogen, and nitrate nitrogen are all correlated to easily obtained soil EC measurements. All measured water quality parameters were significantly influenced by runoff rate indicating that runoff rate, and not the amount of unconsolidated surface materials significantly influences nutrient losses in runoff (Gilley *et al*., 2012). Interaction term of slope × treatments for average of all the data indicated lowest EC of the water collected from V-ditch plots in <10 per cent slope, CT plot in 10-20 per cent slope and GD plots in >20 per cent slope areas indicating the efficiency of these RWH structure in the respective slope categories in terms of reducing salt concentration of the runoff water.

16.3.4 Reduction in Nutrient loss

Losses of dissolved nutrients (i.e. N, P, K, Ca, Mg, Na, Cl, and SO_4) in runoff depend not only on the total amount of runoff but also on the concentrations of each nutrient lost through water from a particular area as well as on the vegetation composition and structure (Townsend and Atkinson, 2013). Nitrogen loss from agricultural land accounts for over half of nitrogen entering surface waters (DEFRA, 2004). Because of high solubility nitrate leaches readily from soils into water table and enters directly to water bodies by runoff and through atmospheric deposition(DEFRA, 2004; Mercer *et al*., 2011). However, growing vegetation plays an important role in reducing nutrient loss and thus water quality (Schlesinger *et al*., 2000) observed runoff at a lower threshold of rainfall in a shrubland than in grassland, where the runoff coefficient averaged to 18.6 per cent in shrubland over a seven-year period. However, in grassland plots, runoff coefficient was 5 per cent to 6.3 per cent of incident precipitation (Schlesinger *et al*., 2000). Thus nutrient losses from the shrub land plots were greater than from grassland plots (N losses averaging 0.33 kg ha^{-1} yr^{-1} vs. 0.15 kg ha^{-1} yr^{-1}, respectively, during a three-year period). This indicates that herbaceous vegetation is more effective in reducing runoff and nutrient losses, whereas it can also be minimized by suitable soil and water conservation measures (Rice and Horgan, 2011; Atucha *et al*., 2013).

16.3.4.1 Phosphorus (PO_4-P)

The pathway for phosphates entering into water bodies is through soil erosion and overland flow particularly phosphates attached to the soil particles (Donnison, 2011). Water dissolved PO_4-P indicated significant intra and inter-annual variations as in the rainfall. Event × slope and event × treatment interactions were significant indicating that PO_4-P loss, which depended on the slope and rainwater harvesting treatments (i.e. quantity of runoff) also varied with intensity of rainfall.(Edwards *et al*., 2000) showed that the magnitude of PO_4-Ploss was related to the proximity of preceding rainfall. Hence, antecedent soil moisture affects PO_4-P transport (McDowell and Sharpley, 2002). Tests of between subject effect indicated significant ($P<0.05$) variation in water soluble PO_4-P due to slope (Table 16.5), where soil available PO_4-P in different slopes influenced its availability in the runoff water (Cox and Hendrick, 2000; Fang *et al*., 2002; Torbert *et al*., 2002). However, phosphorus fixation capability, soil organic matter, pH and active Fe and Al content of the soils also influence total PO_4-P loss through runoff (Gao *et al*., 2001). Runoff water either across the soil surface or via subsurface flow can contain significant amount of dissolved PO_4-P. As moving water across the soil surface interacts with a thin layer of soil, during which PO_4-P is extracted from the soil and plant material and dissolved in the runoff water and released further to the drainage or water bodies (Randal *et al*., 1998; Sistani *et al*., 2009). While studying correlation of sediment and phosphorus loss (total phosphorus(TP), dissolved phosphorus (DP) and dissolved reactive phosphorus (DRP) compared to different physical soil parameters (Schiotz *et al*. 2006)observed a dependency of soil loss to runoff while total phosphorus was correlated with both the soil loss and total runoff, in which carbon and initial soil conditions are important parameters in determining runoff and soil loss. Among slope, PO_4-P was highest in the water collected from >20 per cent slope area ($P<0.05$ in July 2007 and August 2007). However, lowest PO_4-P was in the water collected from 10-20 per cent slope area in September 2005 and July 2006, whereas it was lowest in the water collected from <10 per cent slope area in July and August 2007. Though there was a reduction in loss of PO_4-P under soil and water conservation through rainwater harvesting treatments, but the variations in soil soluble PO_4-P in runoff water due to RWH was insignificant. Lowest PO_4-P availability was in runoff water of GD/V-ditch plots in September 2005 and July 2006, whereas it was lowest in the control plots in July and August 2007 and July 2009. The highest available PO_4-P was in the water of CT plots ($P<0.05$ in August 2007) except in July 2006 (in GD) and 2007 and 2009 (V-ditch plots). This was probably due to less runoff from CT plots resulting in an increase in PO_4-P concentration though vegetative cover is one of the major determinants of the concentration of PO_4-P in runoff. However, slope × RWH treatment interaction indicated lowest PO_4-P in the water collected from BT plots in all the slopes except in July 2009, when it was lowest in the water of the control plots. The study of (Udawatta *et al*., 2004)showed that the differences in observed PO_4-Plosses among three adjacent watersheds over aseven year period were caused by differences in runoff volume, maximum flow rate, runoff duration, and the presence or absence of vegetative ground cover. Timing of precipitation is also recognized as another important determinant of the concentration of PO_4-P in runoff because rainfall provides the major source of energy for particle detachment and transport. A six-year study carried out by (Quinton *et al*., 2001) also revealed that smaller rainfall events accounted for a greater proportion of PO_4-P loss than infrequent larger events.

Annual loss of PO_4-P through runoff water was highest (618.20g ha^{-1} $year^{-1}$), which decreased to lowest value in 2009. Average PO_4-P loss ranged from 274.76 g ha^{-1} $year^{-1}$ from<10 per cent slope to 487.51 g ha^{-1} $year^{-1}$ from 10-20 per cent slope areas. Positive correlations of water soluble PO_4-P with sediment yield ($r=0.319$, $P<0.01$), runoff in 2006 ($r=0.259$, $P<0.05$) and water soluble NH_4-N ($r=0.369$, $P<0.01$) indicated that soil erosion and associated nutrients transport is driven by surface runoff, which is generated disproportionately from soils that have low infiltration capacity as a consequence of factors like high clay

Table 16.5: Influence of slope categories and rainwater harvesting devices on PO_4-P loss through runoff during rehabilitation of degraded hills. Values are mean of five replications.

Slope	RWH device	PO_4-P (g m^{-3})					PO_4-P (g ha^{-1} $year^{-1}$)				
		Sep 05	July 06	July 07	Aug 07	July 09	2005	2006	2007	2009	Mean
<10 %	Control	0.14	0.13	0.17	0.23	0.08	66.51	680.46	536.25	84.36	414.85
	C.Trench	0.18	0.18	0.17	0.28	0.06	74.30	342.75	334.69	54.27	217.32
	Gradonie	0.17	0.16	0.15	0.28	0.07	44.06	492.08	473.27	52.53	265.49
	B.Trench	0.20	0.20	0.14	0.25	0.23	177.85	279.12	301.49	202.68	242.01
	V-Ditch	0.15	0.14	0.17	0.28	0.14	37.75	280.12	324.58	93.23	234.14
10-20 %	Control	0.15	0.14	0.21	0.35	0.05	88.94	1331.74	806.89	54.17	740.43
	C.Trench	0.21	0.20	0.25	0.46	0.08	80.27	461.77	895.08	41.52	419.34
	Gradonie	0.17	0.17	0.23	0.33	0.07	129.44	477.68	692.30	70.57	383.65
	B.Trench	0.14	0.14	0.24	0.36	0.05	111.16	580.73	908.61	46.52	458.28
	V-Ditch	0.16	0.17	0.21	0.34	0.12	100.15	453.61	629.38	136.42	437.82
>20 %	Control	0.31	0.31	0.33	0.31	0.11	353.46	550.41	509.08	130.42	402.01
	C.Trench	0.15	0.16	0.31	0.46	0.18	154.08	428.95	598.34	154.97	409.28
	Gradonie	0.14	0.14	0.38	0.42	0.20	78.74	1048.37	750.78	132.10	646.20
	B.Trench	0.14	0.14	0.28	0.44	0.07	55.57	398.81	826.24	51.19	391.00
	V-Ditch	0.21	0.21	0.45	0.43	0.23	268.56	481.20	646.10	288.23	484.74

content, surface crusting or shallow bedrock. However, literature indicates that phosphorus transport in runoff tends to increase with increasing phosphorus concentration (at the soil surface) and increasing runoff (Sharpley *et al*., 2003). Water soluble PO_4-P loss was highest from the control plots, whereas the loss of PO_4-P through runoff decreases under RWH. Loss of PO_4-P ranged from 348.65 g ha^{-1} $year^{-1}$ from the plots with CT structure to 435.11 g ha^{-1} $year^{-1}$ from the plots with GD structure. The order of RWH treatments in reducing PO_4-P loss was Control>GD>VD>BT>CT. This indicates that PO_4-P loss depends upon the volume of runoff as the primary determinant of nutrient loss (Melland *et al*., 2008) but it also depends upon the intensity of rainfall as well as on the RWH treatment and associated herbaceous vegetation. Thus practices like rainwater harvesting or other soil and water conservation measures that reduce phosphorus concentrations in the soil surface and/or reduce surface runoff are most effective in controlling PO_4-P transport and its loss.

16.3.4.2 Ammonium nitrogen (NH_4-N)

Concentration of NH_4-N in runoff indicated significant ($P<0.01$) intra and inter annual variation. Tests of between subject effect indicated non-significant ($P>0.05$) variation in water NH_4-N due to both slope and rainwater harvesting treatments (Table 16.6). Among the slope across RWH treatments, NH_4-N concentration was highest in the water collected from 10-20 per cent slope area in September 2005 and July 2006 and 2009, whereas it was highest in the water collected from >20 per cent slope area in July and August 2007. Among the RWH treatments, highest concentration of NH_4-N was in the water collected from the control plots except in August 2007 and July 2009, when concentration of NH_4-N was highest in the water collected from BT and GD plots, respectively. Lowest NH_4-N concentration was observed in the water collected from GD plots in September 2005 and July 2007 and 2009, whereas the concentration of NH_4-N was lowest in the water collected from V-ditch plots in July 2006 and August 2007. Slope × RWH treatment interaction indicated that water NH_4-N was lowest in the water collected from CT plots in <10 per cent slope, GD plots in 10-20 per cent slope area and V-ditch plots in >20 per cent slope area. Variations in NH_4-N concentration in water collected from a particular plot/ treatment or the slope appeared to be due to difference availability of NH_4-N in the soil and vegetation characteristics. (Zhang *et al*., 2011) determined that the runoff loss of dissolved organic N was related not only to N application rate, but also to soil total N and organic carbon, whereas the runoff loss of NH_4-N was mainly related to soil available NH_4-N, but not related to N application rate.

However, availability of nitrogen fixing species like *Zornea gibbosa* or *Indigofera* spp. or the utilization pattern of soil nutrients by the growing vegetation during the monsoon period in the present study appeared important factors influencing concentrations of NH_4-N in runoff water. Thus vegetation dynamics is one of the key factors in quantifying and interpreting the hydrological and erosional response of the land use/cover and soil erosion pattern and suggests that soil and nutrient losses can be minimized by changing land use and increasing the ground cover (Nunes *et al*., 2011). Loss of NH_4-N showed a pattern similar to PO_4-P loss and varied from 3.11 kg ha^{-1} $year^{-1}$ in 2007 to 0.96 kg ha^{-1} $year^{-1}$ in 2009 and seems to be associated with soil loss, i.e. erosion pattern.(Zheng *et al*., 2004) observed different nutrient enrichment ratios for organic matter, total nitrogen, ammonium nitrogen and available Pin eroded sediment where available P had the highest enrichment ratios, followed by ammonium nitrogen and were closely related to sediment concentration and erosion patterns. Average data of all four years indicated 1.40 kg ha^{-1}

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Table 16.6: Influence of slope categories and rainwater harvesting treatments on loss of NH_4-N through runoff during rehabilitation of degraded hills. Values are mean of five replications.

Slope	RWH Device	NH_4-N (g m^{-3})					NH_4-N (g ha^{-1} $year^{-1}$)				
		Sept. 05	July 06	July 07	Aug. 07	July 09	2005	2006	2007	209	Mean
<10 %	Control	1.07	0.89	1.37	1.60	0.66	574.82	1861.62	3529.05	635.91	1866.50
	C.Trench	1.28	0.95	1.48	1.13	0.64	594.25	1707.20	1850.54	420.10	1191.78
	Gradonie	0.60	1.00	0.96	1.86	0.77	153.30	1529.56	2728.93	946.83	1337.26
	B.Trench	1.26	0.74	1.34	2.07	1.66	886.49	765.55	2776.87	1391.87	1444.76
	V-Ditch	1.77	0.92	1.53	0.67	1.79	508.49	1134.03	1606.56	674.69	1149.31
1 0 - 2 0 %	Control	1.88	1.38	1.76	0.94	1.46	1074.57	3421.62	3728.13	1570.36	2467.17
	C.Trench	0.89	1.06	1.22	2.02	1.28	343.20	2257.21	3871.71	1043.72	2111.81
	Gradonie	1.43	1.09	0.79	1.18	0.97	1070.34	2529.66	2506.4	799.86	1841.72
	B.Trench	1.43	1.18	1.10	1.53	1.12	928.49	2916.34	3917.47	1105.12	2302.57
	V-Ditch	1.37	0.92	1.12	1.66	1.82	867.24	2030.35	3296.81	1149.94	2432.39
>20 %	Control	2.22	1.22	1.71	2.15	0.69	2483.15	2871.01	3229.21	776.22	2283.28
	C.Trench	1.42	0.78	1.33	2.96	0.89	1430.02	1344.59	3122.17	808..42	1879.81
	Gradonie	1.17	1.15	1.42	2.36	0.36	639.34	2864.32	3282.05	241.12	2255.52
	B.Trench	0.91	0.87	2.16	2.20	0.66	380.43	2217.40	4106.26	623.94	2406.51
	V-Ditch	1.13	1.07	1.30	1.60	1.41	1410.88	1808.38	2143.78	1370.95	1844.37

$year^{-1}$ ($P<0.05$) loss of NH_4-N from <10 per cent slope. The loss was 2.23 kg ha^{-1} $year^{-1}$ from 10-20 per cent slope area, and almost equal loss from >20 per cent slope area as from 10-20 per cent slope across the RWH treatments. Among RWH treatments, loss of NH_4-N in runoff water was 2.2 kg ha^{-1} $year^{-1}$ from the control plots, whereas the lowest amount of NH_4-N loss was from the CT plots. This indicated that contour trench is best RWH structure in reducing the loss of NH_4-N. The order of RWH structures in terms of NH_4-N loss was CT<VD<GD<BT<control.

16.3.4.3 Nitrate nitrogen (NO_3-N)

Concentration of NO_3-N in runoff water varied ($P<0.01$) significantly between the years as well as the day of sampling in a month/year. Significant event × slope interaction indicated that concentration of NO_3-N depended on the soil available NO_3-N in different slope and dissolution of NO_3-N in the runoff water. Tests of between subject effect indicated non-significant ($P>0.05$) variation in NO_3-N concentration due to both slopes and RWH treatments (Table 16.7). Among the slopes, NO_3-N concentration was highest in the water collected from <10 per cent slope area ($P<0.05$ in August 2007), whereas it was highest in the water collected from 10-20 per cent slope area in September 2005, July 2006 ($P<0.05$) and 2009. Lowest concentration of NO_3-N was in the water collected from control plots in September 2005, July 2007 and 2009, whereas it was lowest in >20 per cent slope area in July 2006 and in 10-20 per cent slope area in August 2007. Average of slopes for the treatments indicated highest concentration of NO_3-N in the water flowing from control plots in September 2005 and July 2006, V-ditch plots ($P<0.05$) in 2006 and CT plots in August 2007. Lowest NO_3-N concentration was in the water flowing from GD plots in September 2005 and July 2006, CT plots in July 2007, BT plots in August 2007 and control plots in July 2009. Such variation in NO_3-N concentration in runoff water was due to availability of water in soil influencing NO_3-N concentration in surface runoff or free drainage as well as utilization and enrichment (Figure 16.2) by the growing plants and the herbaceous vegetation(Elwell and Stocking, 1976; Francis and Thornes, 1990; Bochet and Garcıa-Fayos, 2004). Sharma (1999) observed an increasing trend in nitrogen loss through leaching and run off with increase in soil nitrogen (may be through application of nitrogen) and was significantly influenced by the nature of the soil, the amount of rainfall received and the method of cultivation in the area. Slope × RWH treatment interaction indicated that concentration of NO_3-N was lowest in the water collected from BT plots in <10 per cent slope, V-ditch plots in 10-20 per cent slope area and GD plots in >20 per cent slope area. Though leaching losses of NO_3-N in deeper soil profile reduces its surface availability and therefore in surface runoff, but growing vegetation also reduces soil NO_3-N because of utilization in plant growth and soil erosion (Bochet and Garcıa-Fayos, 2004) by decreasing soil erodibility, effective precipitation and kinetic energy of runoff (Brandt, 1989; (Domingo *et al*., 1998); (Martınez-Mena *et al*., 2000). The NO_3-N loss was highest ($P<0.01$) in 2007 as compared to the other years, whereas the loss was lowest in 2005. Zhang *et al*. (2010) observed that saturated near-surface soil moisture had dramatic effects on NO_3-N and NH_4-N losses and water quality. Under the low fertilizer treatment, average NO_3-N concentrations in runoff water of saturated soil averaged 2.2 times greater than that of free drainage, 1.6 times greater for NH_4-N, whereas under the high fertilizer treatment, NO_3-N concentrations in runoff water from saturated soil averaged 5.7 times greater than that of free drainage, 4.3 times greater or NH_4-N (Zhang *et al*., 2010). In this nitrogen loss formed with NO_3-N is dominant during the event,

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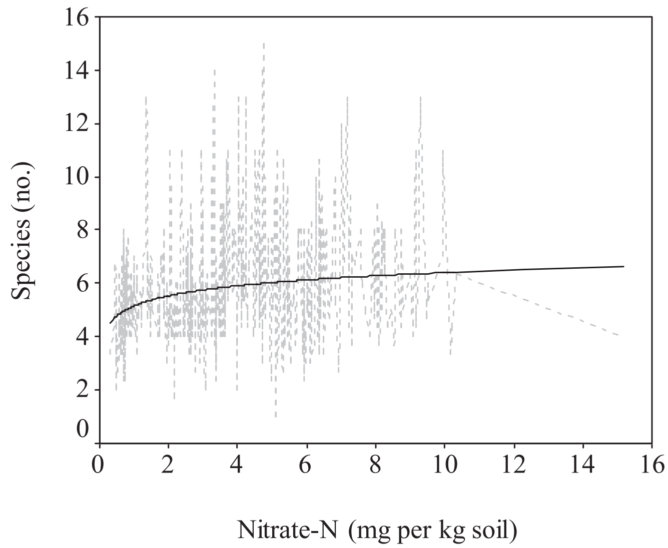
Figure 16.2: Relationships in number of herbaceous species and soil nitrate build up during rehabilitation of degraded hills.



but not NH_4-N. This indicates that saturated condition could make significant contribution to water quality problems.

However, the NO_3-N losses was relatively less in latter part of the monsoon months as compared to the former month (July) and was probably influenced by vegetation growth as well as dissolution of nutrients in the water flowing through it. Highest solubility of NO_3-N in water together with the increased nutrient status in the area during rehabilitation process also influenced NO_3-N loss in 2007 and 2009. Increase in number of species particularly the nitrogen fixing species, resulted in an increase in the soil available NO_3-N and its concentration in runoff water in 2007 enhancing total NO_3-N loss from the area (Ewell, 1986). Average loss of NO_3-N was 1.57 kg ha^{-1} $year^{-1}$ from >20 per cent slope (did not differ with NO_3-N loss from <10 per cent slope), whereas it was 2.69 $kgha^{-1}$ $year^{-1}$ from 10-20 per cent slope area.

Thus total loss depended upon both the concentration of NO_3-N in runoff water and the total runoff and most importantly the vegetation composition and structure that influence these both variables (Elrashidil *et al.*, 2005) observed the effects of land use on NO_3-N loss, where average the loss by runoff was 1.9 kg ha^{-1} yr^{-1} for both fallow and cropped soils, but it was greater than that in the grassland (1.27 kg ha^{-1} yr^{-1}). Variation in NO_3-N loss in runoff was not significant among the RWH treatments, but the loss was highest (i.e., 2.18 kg ha^{-1} $year^{-1}$) from the control plots. Box trench was observed most efficient in controlling NO_3-N loss (1.85 kg ha^{-1} $year^{-1}$). The order of RWH structures in reducing NO_3-N loss was BT>CT>GD>VD>control.

16.3.5 Herbaceous species diversity

Soil depth and nutrients availability (particularly nitrogen) strongly influence above ground net primary productivity and plant species composition (Baer *et al.*, 2003). Initially greater availability of soil water and disturbance (site preparation and afforestation) influenced mineralization and enhanced nutrients availability promoted regeneration of a greater number of species. After 2007, there was a gradual decrease in number of species per unit area providing a humped-shape pattern. (Grime, 1979)

Table 16.7: Influence of slope categories and rainwater harvesting structure on loss of NO_4-N through runoff during rehabilitation of degraded hills. Values are mean of five replications.

Slope	RWH device	NO_3-N (g m^{-3})					NO_3-N (g ha^{-1} $year^{-1}$)				
		Sep 05	July 06	July 07	Aug 07	July 09	2005	2006	2007	2009	Mean
S1	Control	0.23	0.34	1.09	2.47	2.49	126.49	648.15	4403.71	1413.81	1855.83
	C.Trench	0.29	0.34	1.23	3.11	2.95	134.88	561.54	3394.98	1480.44	1453.98
	Gradonie	0.13	0.31	1.64	3.67	2.43	32.87	550.31	5650.60	1594.58	1957.09
	B.Trench	0.29	0.34	1.07	2.25	2.68	196.15	336.59	2651.56	937.17	1117.07
	V-Ditch	0.39	0.33	2.51	3.21	2.32	111.56	343.26	4229.07	474.06	1691.82
S2	Control	0.43	0.41	3.90	1.07	3.27	246.96	1099.19	7349.13	1807.80	3016.45
	C.Trench	0.20	0.34	3.57	1.99	3.72	74.87	737.80	6498.21	1254.91	2521.62
	Gradonie	0.31	0.34	4.11	0.94	2.00	234.73	785.88	60.91.17	1062.79	2414.92
	B.Trench	0.31	0.29	4.11	1.44	2.67	203.68	746.51	8274.77	1357.28	2885.43
	V-Ditch	0.30	0.31	4.12	0.73	3.51	189.75	619.05	5628.60	2201.68	2635.96
S3	Control	0.49	0.28	2.13	1.29	2.49	544.17	626.05	3341.22	1411.73	1670.28
	C.Trench	0.31	0.22	1.34	2.31	3.87	312.92	363.49	2889.70	1689.80	1585.19
	Gradonie	0.26	0.26	1.79	1.12	2.60	141.66	656.33	2637.01	907.87	1303.10
	B.Trench	0.20	0.25	1.20	1.48	2.80	83.00	580.44	3127.23	1457.38	1538.40
	V-Ditch	0.25	0.25	3.06	1.55	2.53	309.34	460.71	3639.27	1410.34	1729.70

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described this pattern that few species are able to tolerate extreme conditions of nutrient deficiency, but as resources increase, more species can survive and hence species richness increases. However, at higher nutrient levels, few highly competitive species become dominant, suppressing the other species influencing vegetation composition and diversity (Grime, 1979).

Average data on number of species, Menhinick's diversity index (D_{Mn}), Shanon-Weiner diversity index (H'), species evenness (e') and species dominance (D) for 5 years (2005 to 2009) indicated highest number of species, H' and e' in<10 per cent slope and lowest in >20 per cent indicating their relations with soil available water, organic carbon and nutrients (particularly soil water), which was relatively greater in <10 per cent and >20 per cent slope as compared to 10-20 per cent slope (Table 16.8). The D_{Mn} and D were highest in >20 per cent slope but their lowest values were in 10-20 per cent slope and <10 per cent slope, respectively. Therefore, number of species, H' and e' showed a decreasing trend in their values with increase in slope gradient. However, species dominance showed an increasing trend with increase in slope gradient ($r=0.146$, $P<0.05$), a reverse trend of soil water and nutrients suggesting the genetic characteristics of the species suitably adapted to such resource deficient environments. The early naturalists Linnaeus, Willdenow, von Humboldt, Darwin and Wallace observed that number of species decreased from low to high latitudes. On their explorations of tropical mountains– von Humboldt and Darwin predominately in the South American Andes, and Wallace in Southeast Asian islands – observed the same trend for elevation, i.e. the number of species appeared to decrease from low to high elevations (Lomolino, 2001).This indicated that it is not only the soil water but also nutrients availability play important role in promoting and sustaining number of species

Table 16.8: Average values of number of species (m^{-2}) and the different diversities indices of herbaceous vegetation influenced by natural slope gradient and rainwater harvesting treatments.

Slope	RWH treatment	Species	D_{Mn}	H'	e'	D
<10 %	Control	5.72	0.33	1.51	0.71	0.42
	Contour trench	6.32	0.42	1.60	0.76	0.36
	Gradonie	6.44	0.39	1.66	0.76	0.38
	Box trench	6.00	0.37	1.43	0.73	0.39
	V-ditch	6.35	7.12	1.50	0.73	0.37
10-20 %	Control	5.76	0.40	1.42	0.72	0.44
	Contour trench	5.68	0.37	1.41	0.76	0.39
	Gradonie	5.67	0.34	1.51	0.75	0.43
	Box trench	5.91	0.36	1.39	0.72	0.39
	V-ditch	5.51	0.29	1.54	0.69	0.48
>20 %	Control	5.41	0.39	1.35	0.69	0.46
	Contour trench	5.45	0.35	1.35	0.71	0.46
	Gradonie	5.84	0.45	1.35	0.69	0.44
	Box trench	5.88	0.42	1.42	0.73	0.39
	V-ditch	5.80	0.35	1.36	0.64	0.51

Table 16.9: Correlation coefficients (r) of indicating relationships between water, soil and nutrient losses.

Variables	Annual loss of soil, water and nutrient				
	Water runoff	Soil loss	PO_4-P	NH_4-N	NO_3-N
Water runoff	-	0.350**	0.539**	0.521**	0.667**
Soil loss		-	0.342**	0.316**	0.308**
PO_4-P loss	0.539**	0.342**	-	0.411**	0.487**
NH_4-N loss	0.521**	0.316**	0.411**	-	0.394**
NO_3-N loss	0.667**	0.308**	0.487**	0.394**	-
Species Number	NS	-0.276*	-0.264*	-0.282*	NS
D_{Mn}	-0.261*	-0.231*	-0.369**	-0.382**	-0.279
Species diversity	NS	-0.265*	-0.258*	NS	NS

****, Significant at P<0.01; *, significant at P<0.05; and NS, not-significant (P>0.05)**

as indicated by number of species in 10-20 per cent slope with lowest soil water content among the slope gradient. This can be explained on the basis of exponential increase in number of species with soil NO_3-N concentration (Fig 16.3), though there may be chances of variations in species response to different nutrients and soil water availability. Among the RWH treatments, number of species, D_{Mn} and H' indicated their highest values in gradonie plots, whereas species evenness was highest in CT plots and species dominance was highest in VD plots. Control plots showed lowest number of species and indicates its relation with soil water, which was lowest in the control plots. This indicates the influence of soil water is an important soil resource for plant growth in rise of number of species (Verma and Sagar, 2011). However, VD plots showed lowest values of D_{Mn} and e' but highest values of species dominance. Slope × RWH treatment interaction was significant, where highest values of D_{Mn} was in CT plots in <10 per cent slope, control plots in 10-20 per cent slope and in BT plots in >20 per cent slope.

Such variability in species richness may partly be explained by environmental and resource heterogeneity, though (Austin *et al.*, 1996) observed that tree species richness is only slightly (positively) related to soil nutrients. However, the effects faster depletion of soil water (reduced soil water availability) negatively affected species richness in VD plot was similar to the observation of O'Brien (1993). Highest value of Shanon-Weiner diversity index in GD/CT plots and the lowest value in the VD plots indicated the negative effects of water deficit on diversity of herbaceous species. However, lowest value of e' in VD plots (VD<control<BT<G<CT) was indicative of competitive reduction of abundance of other species (Rajaniemi, 2011).Slope × RWH treatment was not significant, though it was highest in GD plots in <10 per cent slope and in CT plots ($P<0.05$) in 10-20 per cent slope and >20 per cent slope areas. Highest value of average species dominance in VD plots and the lowest in BT plots (order of RWH for species dominance as BT<CT<G<Control<VD) indicated the dominance of most adaptive species under reduced soil water availability or other stresses particularly the C_4 plants.

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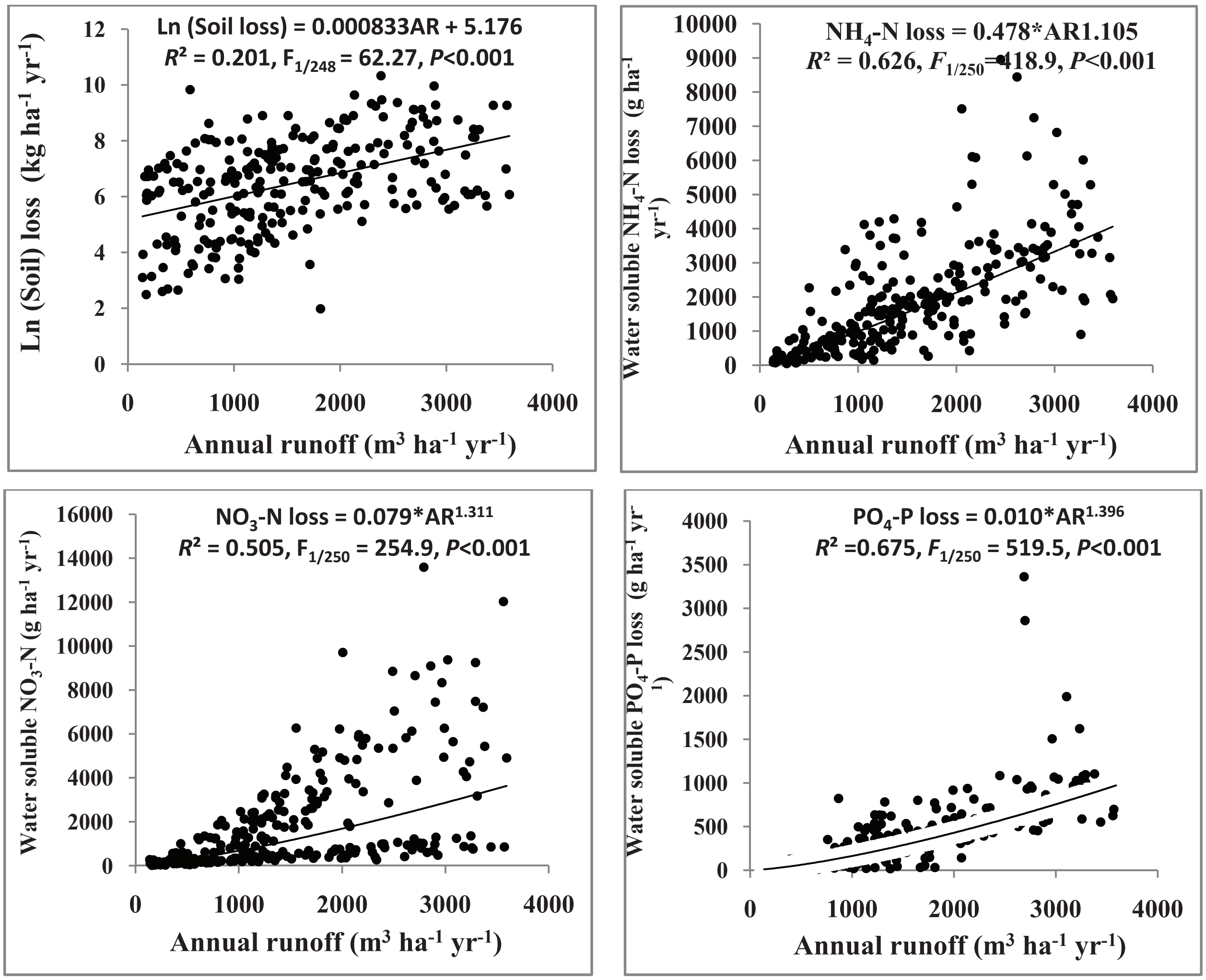
Figure 16.3: Relationships between annual runoff and corresponding losses of soil, NH_4-N, NO_3-N and PO_4-P nutrients losses.



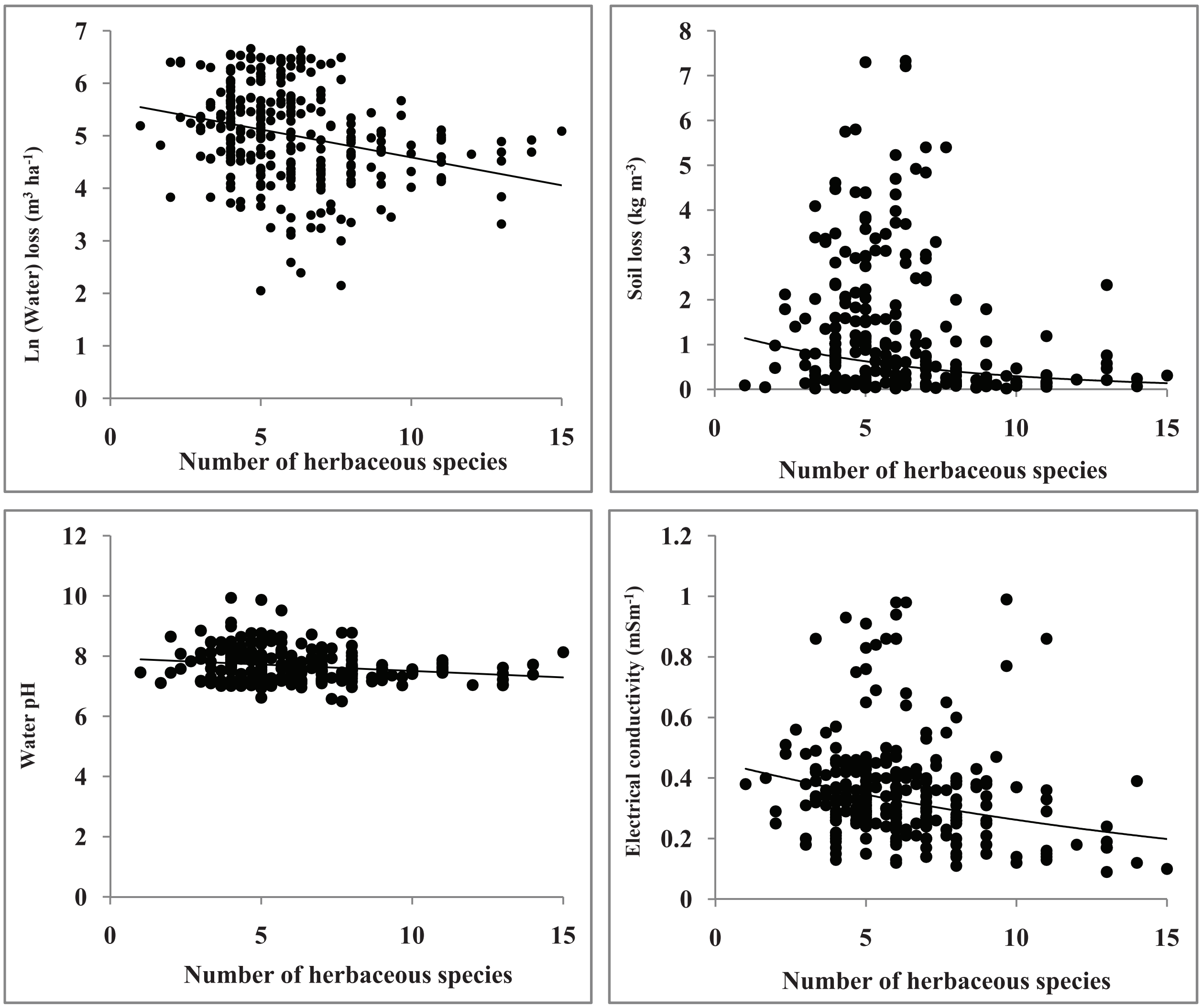
16.3.6 Relationship between water and diversity variables

Hill slope gradient showed positive relationship with loss of PO_4-P through runoff (r=0.151, P<0.05). The slope gradient influenced the nutrient loss by runoff and velocity on sloping land. As the slope gradient decreased, the nutrient loss decreased because of the increase in infiltration and soil texture, porosity, and water content that influence the motion of soil water and the transfer and form of nutrients in the soil (Li *et al*., 2006). Annual runoff was correlated to species evenness negatively (r=-0.149, P<0.05) and annual losses of soil, NH_4-N, NO_3-N and PO_4-P (r=0.332, 0.670, 0.550 and 0.712, respectively, P<0.01) positively (Table 16.9).

The annual soil loss showed positive relationship with pH of runoff water (r=0.172, P<0.05), annual loss of water (r=0.332, P<0.01), NH_4-N (r=0.159, P<0.05) and PO_4-P (r=0.243, P<0.01), and negative relation to NO_3-N loss (r=0.185, P<0.01). However, losses of NH_4-N (r=0.271, P<0.01), NO_3-N (r=0.271, P<0.01), and PO_4-P (r=0.128, P<0.05) were positively related to species dominance. This indicates that decreased diversity in an area may be harmful for water quality as well as soil health (Schulz and Mooney, 1993). High plant diversity and vegetative coverage influences the infiltration coefficient of rainwater into subsurface soil as well as runoff flow velocity and leads to increased ecosystem productivity by more completely, and/or efficiently, exploiting soil resources like nutrients and water (Li *et al*., 2006). Therefore, different sloping lands need to be managed separately by use of suitable rainwater harvesting and conservation measures.

Though weakly related, the annual loss of soil through runoff (i.e. sediment yield) increased exponentially with increase in surface runoff, whereas annual loss of NH_4-N, (R^2=0.626, P<0.001), NO_3-N (R^2= 0.505, P<0.001) and PO_4-P (R^2=0.675, P<0.001) were related to annual runoff by a power factor of 1.105, 1.311 and 1.396, respectively (Figure 16.3). This indicates that increased amount of runoff increases in the amount of soil and nutrients losses. This could be more when rainfall intensity will be increase. Reduction or removal of protective vegetation

Figure 16.4: Relationship of number of herbaceous species with annual runoff, soil loss (event), water pH and water electrical conductivity.



covers leads soil bare for long period of times and promotes surface runoff and reduces the ability of soil to carry out its essential functions of nutrient retention. Buda *et al*. (2008) observed relatively small nutrient losses(despite high nutrient concentrations in runoff water) during storms occurring on residual soils and generating small volumes of infiltration-excess surface runoff. In contrast, much greater nutrient losses occurred from foot-slope position, which produced much larger volumes of saturation-excess surface runoff causing dilution of nutrient concentrations significantly (Buda *et al*., 2008).

Natural log of annual runoff decreased linearly with increase in number of herbaceous species, whereas event loss of soil loss indicated negative exponential relation (Figure 16.4). Water pH decreased linearly, while electrical conductivity of water showed negative exponential relationship with number of herbaceous species. This indicates the importance of herbaceous species in reducing surface runoff, soil erosion and losses of NH_4-N and PO_4-P (Zhenhong, 2004). Diverse communities appeared to be more efficient at capturing nutrients, light, and other limiting resources and help conserve soil and water.

However, loss of NO_3-N showed positive relationship with number of herbaceous species and was probably related to increased number of nitrogen fixing species that enhanced soil available NO_3-N (Fig 17.2) promoting its losses through runoff. Bartley *et al.* (2006) demonstrated that vegetation cover and hill slope characteristics have very different water and sediment yields depending upon the arrangement of the cover patches on the hill slope. These authors have observed that hill slopes with relatively high vegetation cover, but with small patches bare of vegetation can have between 6 and 9 times more runoff, and up to 60 times more sediment loss than similar hill slopes that do not contain large bare patches (Bartley *et al*., 2006).

16.4 CONCLUSION

Total amount of rainfall and its intensity influenced total runoff and nutrient concentrations in the runoff. Effects of soil texture and vegetation composition and structure appeared more influential as compared to the effects of slope gradient as indicated by greater runoff from 10-20 per cent slope area. However, slope gradient influenced the nutrient loss significantly because decrease in slope gradient increases infiltration and decreases water and nutrient loss. Here soil texture, porosity, and water content influenced the velocity of soil water and the transfer of nutrients in the soil. Vegetative cover influenced the runoff, though stoniness on the hill slopes in >20 per cent slope also reduced surface runoff most of the times, i.e. except when saturation excess surface runoff occurred (i.e., September 2005). Rainwater harvesting devices were able to reduce runoff losses indicated by runoff coefficient ranging from 9.3 per cent in VD plots to 12.3 per cent in the control plots, where VD structure found most efficient. However, highest runoff (14.63 per cent) from 10-20 per cent slope area with relatively light textured and shallow soils as compared to 10.22 per cent from <10 per cent slope and 12.90 per cent from>20 per cent slope areas necessitate special attention.

Conservation measures substantially reduced soil and nutrient losses from the area however; it had relatively little impact on inorganic nitrogen losses, i.e. NO_3-N. Changing fertilization quantity, adjusting vegetation coverage and suitable soil and water conservation practice on different sloping lands may better control runoff and nutrient losses. Phosphorus loss is mainly associated with erosion and runoff and one can reduce the PO_4-P loss by reducing sediment loss in runoff (Gillingham and Thorrold, 2000; Daverade *et al*., 2003). Hence soils and sites, which are more prone to erosion and runoff losses, need to be closely managed to avoid phosphorus loss. V-ditch was found effective in <10 per cent slope area and can be beneficial in developing rangelands with increased herbaceous growth. Contour trench is effective in all slopes particularly in small and medium sized storms, effectiveness decreased a little as annual rainfall and slope increases. However, these structures found effective in reducing runoff and erosion from smaller and more frequent events, but seemed to be relatively less effective as the amount of precipitation and runoff increases particularly the GD and BT structures. To minimize this, the intensity of RWH devices may be increased. Negative relationships between water and nutrient losses and number of herbaceous species indicate that one can reduce runoff and nutrient losses by increasing vegetation cover particularly herbaceous vegetation. Increased vegetation cover through afforestation and protection by adopting rainwater harvesting appeared better in reducing soil, water and nutrient losses as well as improving the quality of water flowing from the area.

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17

Forest in Context of Soil and Water Conservation, Augmentation of Water Resources and Sustainable Productivity

Saibal Dasgupta, Tajinder Pal Singh and Pratap Narain

17.1 INTRODUCTION

Food, nutrition and water security for ever growing population are emerging as a global priorities of 21st century in face of fierce global competition for food, water, declining natural resources and ecosystem services. In this context Sustainable Land and Ecosystem Management (SLEM) is vital, considering phenomenal all-round development resulting in degradation of land, water and forest resources. Water and forests are fundamental basis of life. Impacts of forests on hydrological regime through influences on rainfall, interception, runoff, soil erosion, moisture conservation, ground water recharge and dry season flow have to be understood under contextual setting beyond traditional hydrology. Soil and water conservation in context of forests begins from soil working that is the pre-planting stage and continues through the life cycle of the tree. Smart forest management is needed for regulating the hydrological cycle to ensure everlasting availability of fresh water and ground water recharge, which are emerging key issues particularly in water scarce dry areas.

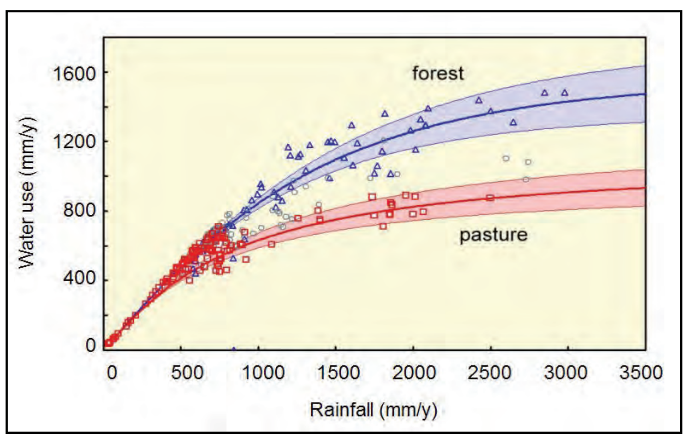
Popular myths that forests perform extremely critical watershed functions, as they enhance rainfall, act as "sponges" that prevent floods during the monsoon and release water during dry season, and prevent soil erosion has been contested by the growing knowledge of higher consumption of water by trees compared to other vegetation such as grass (Calder 1979; Scott and Lesch 1997; Finlayson 1998). Forest canopy is required to be managed to optimize the opportunity time of infiltration and outflow from the dense forests. Broad leaf forests accentuate soil erosion by coalescence of raindrops which acquire terminal velocity by falling from high trees. In such forests, leaf litter and understorey also play dominant role in reducing the beating action of rain drops and reduction of soil erosion. Management of under storey and leaf litter has immense bearing on the water and sediment yields from such forests. Soil and water conservation and forest management on landscape basis have cascading effect in the zone of influence impacting the productivity of land and ecosystem services. These perceptions and emerging issues pertaining to 'Water and Forests' are required to be addressed through long term hydrological data series and simulation modeling beyond traditional hydrology.

17.1.1 Key issues for hydrological Impact of forests

Evapotranspiration and infiltration juxtaposed with soil profile moisture storage are the key issues governing impacts of forests on ground water recharge and dry season flow. In tropical regions, forests are reported to reduce dry-season flows except in degraded forested catchments where extra infiltration outweighs the extra ET-losses from forests (IUFRO, 2007).There are concrete evidences that good forests particularly the energy plantations use more water due to greater leaf surface area (LAI), deeper roots and greater aerodynamic roughness than grasses or crops. Hence, tree and forest water use (ET) is typically higher resulting in lower surface runoff, groundwater recharge and water yields (Figure17.1; Zhang *et al.*, 2001)Where large-scale forest planting is contemplated in tropical regions for climate change mitigation or energy needs, it is essential to ensure that it does not accentuate water shortages (IUFRO, 2007).

The annual flow for the initial 2-3 years increases proportionally with degree of forest removal. Studies in Tanzania have revealed that without soil degradation: deforestation leads to increases in dry-season flows due to the lower water use of annual crops relative to forest. These results, however, should be cautiously generalized for degraded habitat across the globe. Land

Figure 17.1: Water use under forest and pasture lands



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degradation, followed by deforestation reduces dry-season flows due to increased water losses due to wet-season runoff .Water shortage at one of the wettest places on Earth (Cherrapunji, NE India) is due to lost infiltration opportunity resulting in entire loss of water as runoff in to Bay of Bengal. After treeplanting, the net balance of the changes in these two processes–increased evapo-transpiration due to forestation of fast growing species and reduced infiltration and higher runoff due to land degradation–will determine the net hydrological impact and dry season base flow as modified by soil depth /soil water storage opportunity.

Positive trade-off between improved vegetation, water use and infiltration after reforesting of degraded lands appears possible. However the improvement was found to be greatest in high rainfall areas of south China and Leyte Philippines, where streams have been reported to become perennial after 15 years of plantations (Brurijnzeel, 2013).

Forests can mitigate small and local floods but do not appear to influence either extreme floods or those at the large catchment scale, well-managed natural forests exert filtration effect, protect drinking-water supplies, reduce pollutants, obstruct runoff pathways more in riparian zones, reduce erosion and sediment outflows. While mitigating air pollution in urban/ industrial areas by capturing sulphur and nitrogeneous gases, trees might be a cause of acid rains in industrial belts (IUFRO, 2007).

17.1.2 Impact of soil and water conservation and best management practices

Mechanical and biological conservation measures in the deforested area, degraded lands and agricultural fields impact runoff losses, infiltration and ground water recharge. Studies in foothills of Himalayas at Central Soil and Water Conservation Research Institute, Selaqui (Shastri and Dhruvnarayana, 1986) have revealed that when a sal (*Shorea robusta*) watershed was put to agricultural use, the volumes and peak rates of runoff increased by 15 per cent and 72 per cent, respectively. Treatment of agricultural watershed with field bunds and brushwood check dams reduced the volumes and peak rates of runoff by 86 per cent and 62 per cent and soil loss by 94 per cent. The watershed lags time increased by 15 minutes, and recession time by 350 minutes (Figure 17.2).

17.2 METHODOLOGY

Under the Sustainable Land and Ecosystem Management (SLEM) project, two studies were undertaken investigate water and forest interactions with special reference to hydrological impacts.

A community driven project on SLEM through integrated watershed management, joint forest management and sustainable livelihood development was initiated in Central India; Betul, Chhindwara, Siddhi and Umaria districts of Madhya Pradesh. The project envisaged sustainable watershed management of forest and non-forest land, rehabilitation of degraded bamboo forest and improvement of productivity of rain-fed lands. An area of 3,000 ha was treated with soil and water conservation measures like vegetative, brushwood and crate wire check dams, contour trenches, and plantations of *aonla* (*Emblica officinalis*), *mahua*, (*Madhuca longifolia*), *neem* (*Azadiricta indica*) species. Dinnanath and *Stylo hamata* grasses were established on the sides of contour trenches. An area of 789 ha of degraded bamboo forests was rehabilitated involving poor tribal families living on degraded marginal lands on forest fringes. This provided them a monthly income of Rs 2,500 per family in lieu of the work done for rehabilitation and co-management of degraded bamboo forest. These families were also involved in making incense sticks or *kadi* from discarded bamboo obtained from forest department at a notional price. They also grew seasonal vegetables for their use and selling in the local market. In addition, energy plantations were raised in 220 ha using *subabool (Leucaena leucocephala), neem*, (*Azadiricta indica*) citrus species and an area of 190 ha was covered with fuel-fodder tree species to provide fuel wood to the locals and reducing pressure on the forests. Horticulture, medicinal and aromatic plants (2,20,000 in number) were also distributed to the beneficiaries for development of kitchen gardens and homesteads for their use and selling in the local market.

In another study, 20 micro watersheds, located close to the agricultural frontier with high erosion indices and an impoverished socio-economy, covering an area of 60,000 ha were selected in the mid-Himalayan region at 700 to 2,000 m elevation in Uttarakhand. Soil conservation works on non-arable land, forest regeneration, pasture/ silvi-pasture development, contour bunds, vegetative barriers and ground water

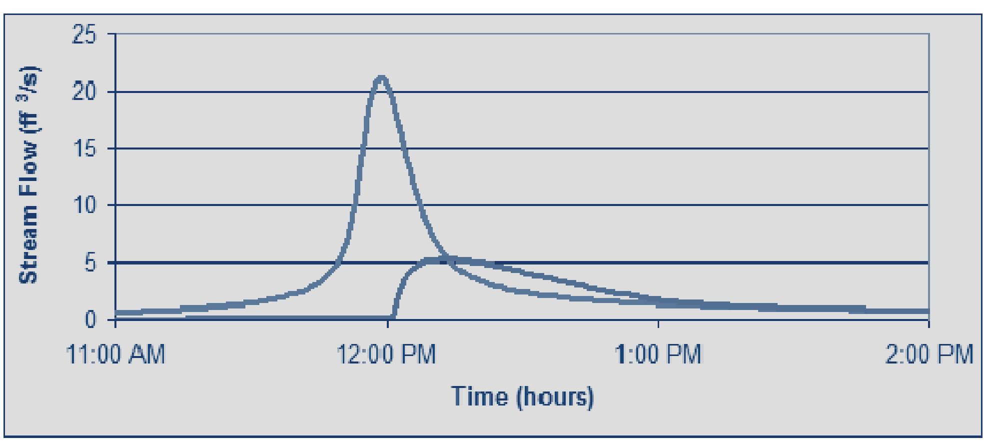

Figure 17.2: Impact of agriculture and conservation measures on peak rate of runoff recession

augmentation through rain water harvesting in ponds were the main interventions. The approach envisaged bottom-up, needs-based community watershed planning and local governance in execution. Watershed outputs were measured by performance indicators in terms of sustainability, adoption of innovative technologies for enhancing water availability, reduction in community dependency on forest for fuel wood and marketing medicinal and aromatic plants through Self Help Groups (SHGs). Afforested with Bauhinia*(Bauhinia spp.)*, Alder (*Alnus spp.)*, Oak (*Quercus spp.)*, *Ficus religiosa*, *Grevia optiva*, *Albezzia lebbeck*, *Toona ciliata* species were performed on 203 ha in reserved forest and 627 ha in other places. Aided natural regeneration and cultural operations were carried out in 115 ha oak plantation in patches, where ever possible.

Drainage line treatment comprised of vegetative brushwood check dams (491) on first order streams supported with conservation species like *Agave*, dry stone check dams (21,183 cum) and wire check dams (50,836 cum) in the upper and middle catchments. In SLEM area, 89,130 contour trenches (3 m x 0.5m x 0.5m) were dug and two rows of fodder or lemon grass along with two broad leaved tree species were planted on the lower side of such trenches. Diversion drains (10,675 cum) and cement crate wire and dry cross barriers and retaining walls (8,630.25 cum) were constructed. River bank protection was carried out by construction of crate wire (18,988 cum).

In order to study the impact of soil and water conservation, silt observations were recorded at fortnightly interval from January to December (2007-2009) in three representative streams at lower reaches of the watershed in Haldwani Division of Nainital District. For this purpose, silt observation meter was utilized, which works on the principle of photometry. The light emitted by the light emitting diode (LED) is received by a sensor. The suspended silt in the water hinders direct movement of light, which is read by the sensor Silt observations are expressed as Nephelometric Turbidity Units (NTU). Calibration by the standards of known turbidity, the observed values can be converted to the silt load of the stream water.

17.3 RESULTS

In the state of Madhya Pradesh, watershed interventions helped increase productivity, reduce peak rates of discharge, soil loss and improve the environment. The degraded bamboo forest has been successfully rehabilitated. The economic analysis based on seven-years project life and 12 per cent discount rate yielded a Net Present Value (NPV) of Rs 28,820 and Benefit:Cost Ratio (B:C) of 1.28:1 at Internal Rate of Return (IRR) of 21.4 per cent.The investment can be recovered within a period of six years. Apart from rehabilitation of bamboo forests, employment generation, poverty alleviation, improvement of socio-economic conditions of tribal, control of land degradation, improvement in bio-diversity and ecological benefits were long term gains through the project.

In case of Uttarakhand watershed, interventions such as drainage line treatment and soil and moisture conservation measures have protected 182 ha agricultural land (Table 17.1), which yielded a profit of Rs 38.2 lakh and reduced soil loss of 93,370 tonnes (Anonymous, 2012).Two ground water recharge ponds, having catchment area of 7 ha and water storage of 7.5 lakh litres constructed near the ridge line in district Nainital stored runoff water and at restricted expansion of gullies locally called *(Gadera)* downstream, recharged ground water and rejuvenated springs (*Naula*) for drinking purpose. At another site, an old spring at the verge of drying with a discharge rate of 7 litres per minute recorded an increase discharge rate of nearly 11 litres per minute and the stream started flowing for longer duration due to the land treatment.

The major benefits of SLEM on forest watersheds revealed hydrological regulation (groundwater recharge), low-flow augmentation, flood moderation and soil conservation. The effect of soil and water conservation in the forest fringe areas and contiguous agricultural land have resulted in remarkable improvement of surface water resources, augmentation of ground water and base flow, which emerged as springs in lower reaches. The surplus water was collected in an irrigation tank and utilized for supplemental irrigation of nearly 3 ha of vegetables which are then sold by the self-help groups. This has improved the livelihood of people in the SLEM watersheds.

The groundwater level is extremely sensitive to each year's rainfall. The geological conditions dominated over all other factors, and influence of forest cover on recharge may be minimal. Recharging of the permanent groundwater level and other linked aquifers seem to happen primarily when the stream floods in response to a heavy rainfall event. In a drought year, the low

Table 17.1: Impact on Soil and Water conservation works and drainage line treatment

Treatment	Quantity	Soil loss reduction (cum)	Total soil reduction (estimated)
Veg. Check dam (No.)	491	0.25	122.75
Stone Check dam (cum)	72018.41	1	72018.41
Diversion Drain (cum)	10675.05	0.1	1067.505
Contour Trenches (No.)	89130	0.75	66847.5
Total Soil reduction in cum (estimated)			140056.2
1 Cum of soil loss reduction due to soil protection			0.0013
Total area of agriculture top soil protected			182.07 ha
1cum of soil loss			1.5 tonnes
Total soil loss reduced			93370.8 tonnes

groundwater level prevents extraction beyond a point, forcing the farmers to switch on to less water requiring crops and reduced ground water use. A good year can result in the doubling of net incomes from agriculture as compared to a low rainfall year. The hydrological studies conducted in the Western Ghats (Anonymous, 2007) support the hypothesis. It suggests that the deeper aquifer in Arepalya is well connected with the shallow aquifer, and hence the recharge entering the latter is quickly available to bore wells tapped by the farmers. Indeed, it appears that the major recharge is taking place not in the hilly catchment but in the streambed in the flatter valley portion, which is highly porous consisting of several meter thick layers of accrued sediment. Thus the groundwater in wells rises significantly with valley floods. These studies also suggest that considerable recharge to groundwater is possible under relatively undisturbed dense evergreen forests, in spite of high predicted evapo-transpiration. The "Calder-Ian" fear that such dense forest might be transpiring large fractions of the rainfall and hence leading to depletion of stream flows seems to have little relevance in the Western Ghats, where soil hydraulic conductivity is generally very high, high rainfall is concentrated into 4-5 months, and ecosystems have adapted to moisture stress during the dry season by encouraging more deciduous behaviour in the trees. This hypothesis may also be true for Uttarakhand regions receiving high rainfall with sandy porous geomorphology.

A pragmatic SLEM approach is, therefore, indispensable for smart forest management envisaging soil and water conservation for augmentation of water resources, sustainable productivity and ecosystem services, which can be articulated through sustainable integrated management of resources on landscape or watershed basis. Complementary land-use, in which land is allotted to that form of use, in which it would produce most and deteriorate least, has to be adopted based on the principle of Land Use Capability Classification, which is not strictly adhered to due high population pressure and demand on the land resources.

17.3.1 Impact of soil and conservation in a hilly watershed

The measurement of silt load in one of the streams indicated that with passage of time silt load gets reduced drastically (Figure 17.3). This might be due to reduction of runoff velocity by adoption of soil and water conservation interventions, which promote deposition of the silt in the watershed itself. Adoption of cultural, vegetative, mechanical and structural, such as vegetative barrier, alley cropping, contour farming, strip cropping, plantation/afforestation, graded bunding, contour trenching, nala bunding, retaining wall, diversion drains, loose boulder/gabion check dams, etc., retain silt behind the structures and restrict its movement outside the catchment area. Higher obstruction to the surface runoff by the growing trees, rainfall interception, improved infiltration in drier soil profile and litter effect are other forest influences impacting runoff in the wet season as well as dry season flow from the watershed.

17.3.2 Beyond traditional hydrology

Scientific support to popular myths that forests perform extremely critical watershed functions, as they enhance rainfall, act as "sponges" that prevent floods during monsoon and release water during dry season, and prevent soil erosion in spite of high water consumption is required to be investigated particularly for tropical physiographical regions. Simulation modeling for adoption of Best Management Practices in priority/critical areas of watershed, management of tree canopy, the understory and litter for regulating hydrological functions of forests is required to be developed. Pandey *et al*. (2009) have applied the WEPP model for prioritization of critical areas and evaluated some of the best management practices for a small hilly watershed (Karso) of India. CO_2-fertilization effect-plants can utilize more CO_2 to make carbohydrates (as CO_2 concentrations have increased by about 5 per cent per decade over the past 20 years, the rates of water-use efficiency increased by about 30 per cent a year) through natural adaptation regulated by stomata openings (*Nature*, July 24, 2013; Bryan Walsh). Long term data based on hydrology from different Ministries is required to generate a robust data base for developing simulation models to carry the thinking beyond traditional hydrology.

According to Indian National Forest Policy, 1952, it is

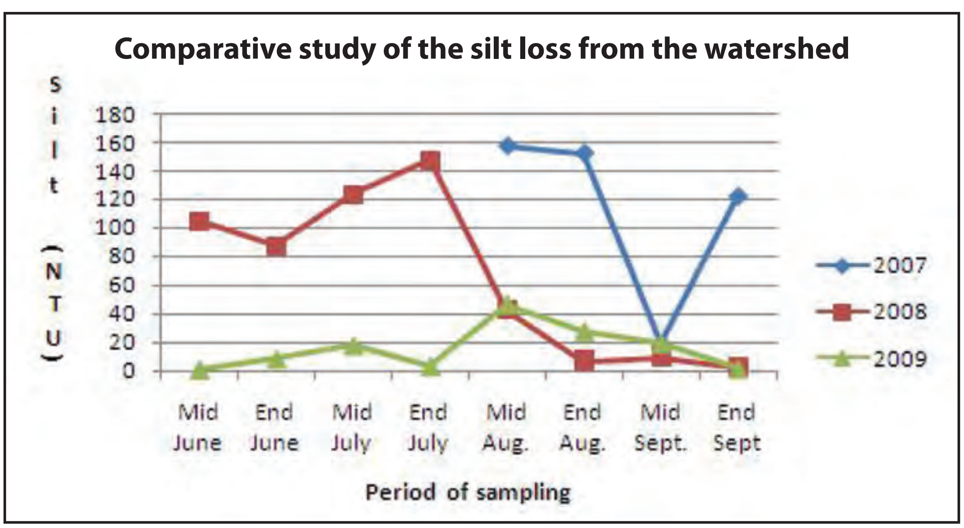

Figure 17.3: Impact of conservation measures on silt loss in Khujetigad watershed, Haldwani, Nainital

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mandatory that India has one-third of land under forests. About 60 per cent land is to be kept under forests for protective functions in hills prone to erosion and 20 per cent in plains. Forest and tree cover of the country is 78.29 M ha (23.81 per cent), which includes 9 M ha (2.76 per cent of TGA) tree cover through Tree Outside Forest (TOF). Potential production of wood and fuelwood from TOF is 14-16 times that of annual estimated production from the forests (SFR, 2011). Behaviour of TOF vis-a-vis forests needs to be examined?

ACKNOWLEDGEMENTS

Authors are grateful to the Project Director of Uttarakhand Decentralized Watershed Management Project, Government of Uttarakhand and Government of Madhya Pradesh, for utilization of information under the GEF-SLEM Projects.

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18

Managing Forests for Water and Soil Moisture to attain Full Growth Potential by the Vegetation in the Hilly Terrain of Garhwal Himalayas

B.M. Dimri, M.K. Gupta and A.K. Raina

18.1 INTRODUCTION

The contrast between the seemingly lifeless rocks and boulders in hilly terrain and lush green canopy of forests is the result of the growth conditions provided by soil for plants to establish and flourish. Forest soils in hills have an essential role to perform in maintaining the life support system in the region and the Uttarakhand Himalayas are also a major source of watersheds of major rivers. Forests have a very important function in the maintenance of favourable soil conditions on one hand and in regulating the flow velocity of rivers on the other. Therefore, the management of soil moisture is becoming increasingly important with better knowledge of soil fertility practices and growth of plants. It is one of the most important soil properties for maintaining good plant growth. Moisture not only acts as a vehicle for ion transport but also provides favourable conditions for soil chemical action and development of the activities of microorganisms.

Due to the escalating demand on forest produce from conifer forests of Garhwal hills, the pressure on these fragile forests is mounting continuously. Vast denudation of these forests in areas like upper Yamuna forests of Uttarkashi district has destabilized the hills causing soil loss and leaving the slopes with frequent rock outcrops. Out of nearly 5,300 million tonnes of soil (app. 16 t ha^{-1}) lost by erosion annually, considerable amounts are lost from the deforested hilly areas. Vegetation once lost may give rise to succession of some other vegetation types of low economic value but the soil loss is irreversible. The nature takes about 300 years to produce a 25 mm layer of soil under normal tropical conditions. Presence of forests can reduce the erosive losses of material from forest floor by checking the velocity of falling rains. Deodar can intercept up to 25 per cent of rainfall (Singh *et al.,* 1983). Removal of tree cover, therefore, decreased soil moisture store, disturbed soil aggregates along with porosity and decreased soil water retention due to lack of litter on the forest floor (Negi, 1981). The organic matter and the root system improve the soil structure; increase the infiltration of water and water holding capacity of the soil (Marshall and Holmes, 1988; Kang *et al*., 1996; Jiang, 1997; Teresaecheverria and Martinez, 2001). The importance of moisture retention and quantity relationship lies in the fact that it may change due to the effect of altitudes and seasons. The various soil moisture constants in the present study were determined and have been discussed as influence by different altitudes and seasons.

This study was conducted in the upper Yamuna Forest Division of Garhwal Himalaya to determine the soil moisture at different altitudes and seasons. The different soil moisture was studied as maximum water holding capacity, field capacity, wilting points and available water capacity at different altitudes and seasons for attention of researchers, scientists and field managers for performance and maintenance of soil conditions and good health of forests for their management.

18.2 METHODOLOGY

This study was carried out in Mungersanti range of upper Yamuna Forest Division of Garhwal Himalayas and the forests are located in West Uttarkashi district and North and North eastern part of Dehra Dun district lie between latitudes 30°24'N and longitudes 77° 56' and 78°35'E. The sites received fair distribution of precipitation and moderate to low heat and the spring and autumn seasons were considered suitable for the study. These forests were categorized as Himalayan moist temperate forests as a major group and lower western Himalayan temperate, Ban and Moru oak (*Quercus leucotrichophora – Q. floribunda*), moist deodar *(Cedrus deodara)*, western mixed coniferous and western Himalayan upper oak – fir forests as type group by Champion and Seth (1968). These forests are moist temperate forests of western Himalayan region with mean annual rainfall ranging from 650mm to 1,100mm and the rainfall is well spread out throughout the year. Main precipitation is through rainfall in summer, monsoon and snowfall in winters. The maximum temperature was recorded as 31°C in August and minimum temperature was -1.5°C in January for the study period. The western mixed coniferous forests have been described as the most attractive in the Himalayas with mixture of spruce, fir, kail pine and deodar and varying intermix of evergreen and deciduous broad leaf trees. Study area showed reasonably well distributed ground flora. Four sites were selected in the study area which varied in altitude and species composition. These have dominant species such as Chir pine (*Pinus roxburghii*) at 1,800m, Deodar–Kail pine (*Cedrus deodara– P. wallichiana*) at 2,100m, Ban–Moru oak (*Quercus leucotrichophora –Q. floribunda*) at 2,400m and Silver fir–Spruce (*Abies pindrow – Picea smithiana*) at 2,700m altitudes. Four altitudes zones were selected with these dominant species to test the performance through soil and vegetation interaction, since soil moisture and water availability

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on given site are related to tree growth and health of the natural forest to a great extent. Soil profiles were exposed at different altitudes and soil samples were collected at each altitude with predetermined depth ranges of 0-15cm, 15-30cm, 30-60cm, 60-90cm, 90-120cm and 120-150cm. Soil samples were processed as per procedure described by Jackson (1967). The maximum water holding capacity (MWHC) was determined by using the standard procedure described by Piper (1966), field capacity (FC) by using pressure plate extractor described by Black (1965) and wilting point (WP) by pressure plate extractor (Richards and Weaver, 1943) as described by Singh (1980) and available water capacity (AWC) was calculated from the difference between wilting point (WP) and field capacity (FC) moisture.

18.3 RESULTS

The management of soil moisture is becoming increasingly important with better knowledge of fertility practices and growth of plants. It is one of the most important soil properties for maintaining good plant growth. Since moisture not only acts as a vehicle for ion transport, but also provides favourable conditions for soil chemical action and development of the activities of microorganisms. The importance of moisture holding and content relationship lies in the fact that it may change due to the effect of altitudes and seasons. The various soil moisture constants in the present study were determined and have been discussed as influence by different altitudes and seasons. These forests are facing a good deal of biotic interference, especially in the lower altitudes of Deodar–Kail and Chir pine forests. However, this has been assumed to be an existing reality and a given condition in the study. The different soil moisture were studied as maximum water holding capacity (MWHC), field capacity (FC), wilting points (WP) and available water capacity (AWC) at different altitudes and seasons.

18.3.1 Maximum Water Holding Capacity

Maximum water holding capacity (MWHC) is the amount of water which soil could hold at completely saturated state. MWHC moisture covers both macro and micro pores. The principal factors affecting the water holding capacity of soils are texture, structure and organic matter. Water is held not only by the soil as film but also between particles because of surface tension of the water and intermolecular forces within the water. The air in the soil is completely replaced by water and the tension with which moisture is held by soil at MWHC is near to nothing. MWHC gives fair idea about soil holding of maximum water and the air circulating porosity. The MWHC for all the altitudes and seasons was determined and data are presented in Table 18.1.

18.3.2 Effects of Altitudes at MWHC

Maximum water holding capacity (MWHC) decreased with increasing soil depth in spring and autumn seasons. At 2,700m altitude, MWHC varied in different soil depths from 75.46 per cent to 43.70 per cent in spring and 83.14 per cent to 45.21 per cent in autumn season. MWHC decreased down the profile with increasing soil depth with significant negative correlation for spring ($r = -0.90^*$) and autumn ($r = -0.87^*$). MWHC ranged in different soil depths from 61.13 per cent to 38.49 per cent in spring season and 68.07 per cent to 41.10 per cent in autumn at 2,400m altitude. MWHC decreased down the soil profile with increasing soil depth with significant negative correlation for spring and autumn season ($r = -0.91^{**}$). MWHC ranged in different soil depths from 54.13 per cent to 37.47 per cent in spring season and 65.53 per cent to 40.62 per cent in autumn at 2,100m altitude. MWHC decreased with increasing soil depth in the profile with significant negative correlation for spring ($r = -0.93^{**}$) and autumn ($r = -0.83^*$). MWHC in different soil depths ranged from 50.98 per cent to 36.05 per cent in spring and 64.07 per cent to 39.17 per cent in autumn at 1,800m altitude. MWHC showed decrease down the profile with increasing soil depths with significant negative correlation for spring ($r = -0.91^{**}$) and autumn ($r = -0.83^*$).

18.3.3 Specific Effects of Altitudes and Seasons on MWHC

In order to know the specific effects of altitudes and seasons, values were worked out and presented in Table 18.2. The MWHC at all altitudes and seasons decreased down the profile with increasing soil depth. At 2,700m altitude, MWHC was highest followed by 2,400m, 2,100m and 1,800m altitudes. There was higher moisture content at MWHC in autumn season than in spring. Higher moisture content at MWHC in surface soil than downwards was an expected trend since porosity of soil surface layers tend to remain high compared with sub-surface layers. It

Table 18.1: Maximum water holding capacity (per cent) in different seasons and altitudes

Sl. No.	Soil Depth (cm)	Altitude (m)							
		2700		2400		2100		1800	
		Seasons							
		Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn
1	0-15	75.46	83.14	61.13	68.07	54.13	65.53	50.98	64.07
2	15-30	64.80	67.70	51.35	58.60	47.39	51.97	44.27	50.33
3	30-60	53.85	54.34	46.56	49.81	44.53	45.70	41.40	44.06
4	60-90	47.51	48.39	42.95	45.95	40.72	43.76	39.62	42.88
5	90-120	46.00	47.17	41.39	43.50	39.54	42.75	37.80	40.84
6	120- 150	43.70	45.21	38.49	41.10	37.47	40.62	36.05	39.17

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Table 18.2: Specific effect of seasons and altitudes on maximum water holding capacity (per cent)

Sl. No.	Soil Depth (cm)	Altitude (with integration of seasons)				Season (with integration of altitudes)	
		2700m	2400m	2100m	1800m	Spring	Autumn
1	0-15	79.30	64.60	59.83	57.52	60.42	70.20
2	15-30	66.25	54.97	49.68	47.30	51.95	57.15
3	30-60	54.09	48.18	45.11	42.73	46.58	48.47
4	60-90	47.95	44.43	42.24	41.25	42.70	45.24
5	90-120	46.58	42.44	41.14	39.32	41.18	43.56
6	120- 150	44.45	39.79	39.04	37.61	38.92	41.52

Table 18.3: Field capacity moisture (per cent) in different seasons and altitudes

Sl. No.	Soil Depth (cm)	Altitude (m)							
		2700		2400		2100		1800	
		Seasons							
		Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn
1	0-15	39.36	42.19	31.18	37.59	28.54	35.78	26.69	34.67
2	15-30	34.61	36.81	26.49	30.43	24.49	27.15	22.83	26.23
3	30-60	28.13	29.68	25.17	27.19	23.36	25.47	21.17	24.16
4	60-90	25.17	27.47	22.04	24.77	21.13	23.18	19.83	21.97
5	90-120	23.84	25.21	21.41	23.45	20.44	21.88	19.08	21.04
6	120- 150	22.29	24.34	20.12	22.29	18.67	20.97	18.31	20.13

is especially so of macro-pores due to the action of soil forming process like leaching of finer particles to sub-surface layers. Presence of soil humus made a significant difference in creating a pattern of differences in moisture at MWHC at different altitudes and seasons. The water holding capacity and moisture equivalent values are fairly high especially in upper horizon as per the findings of Khan *et al*. (1961); Verma, (1973). Favourable influences of soil organic matter on MWHC have been reported by Mathur and Bhatnagar (1964); Shamanna *et al*. (1967).

The organic matter increased water holding capacity, cation exchange capacity and served as reservoir of nutrients as reported by Hoyle (1973). The higher percentage of soil organic carbon improves the overall soil environment and the water holding capacity (Bhattacharyya *et al*., 2007). The MWHC tended to be high in forested soils than relatively exposed poor organic matter in agricultural soil as evidenced by Mathur *et al.* (1984). Silver fir and spruce forests soil have good water holding capacity because of their high organic matter content as reported by Taylor *et al.* (1934). Hilly terrain may show good deal of variation in MWHC at short distances Khan and Yadav (1962). The upper layers of soil profiles showed high soil moisture retaining capacity because of enrichment of soil with humus which showed high hydrophyllic nature of MWHC have also been reported by Yadav (1963).

18.3.4 Field Capacity Moisture

Field capacity moisture has a good deal of influence on the growth performance of trees and in maintenance of dynamic nutrient cycling in forest ecosystem. Soil moisture retention at field capacity (FC) or 1/3 atmosphere moisture, was determined for different altitudes and seasons and presented in Table 18.3.

18.3.5 Effect of Altitudes on FC Moisture

Field capacity moisture percent shows a decline with increasing soil depth in spring and autumn seasons. At 2,700m, FC moisture ranged in different soil depths from 39.36 per cent to 22.29 per cent in spring and 42.19 per cent to 24.34 per cent in autumn. FC moisture decreased down the profile with increasing soil depth with significant negative correlation for spring (r = - 0.92**) and autumn (r = - 0.91**).

At 2,400m, FC moisture percentage ranged in different soil depths from 31.18 per cent to 20.12 per cent in spring and 37.59 per cent to 22.29 per cent in autumn. FC moisture decreased down the profile with increasing soil depth with significant negative correlation for spring (r = - 0.93**) and autumn (r = - 0.89*). At 2,100m, FC moisture ranged in different soil depths from 28.54 per cent to 18.67 per cent in spring and 35.78 per cent to 20.97 per cent in autumn. FC moisture decreased down the profile with increasing soil depth with significant negative correlation for spring (r = - 0.94**) and autumn (r = - 0.85*). At 1,800m, FC moisture ranged in different soil depths from 26.69 per cent to 18.31 per cent in spring and 34.67 per cent to 20.13 per cent in autumn. FC moisture decreased down the profile with increasing soil depth with significant negative correlation for spring (r = - 0.90*) and autumn (r = - 0.84*).

18.3.6 Specific effects of altitudes and seasons on FC moisture

In order to observe the specific effects of altitudes and seasons, the values were worked out and are presented in Table 18.4. There was decrease in FC moisture with increasing soil depth.

At 2,700m altitude retained higher moisture at FC than 2,400m, 2,100m and 1,800m altitudes. At 2,700m altitude, the site showed better soil moisture retention than other three altitude sites. A good aeration pores and moisture storage as found in the case at 2,700m altitude was significant since it maintained a good air–water balance for the plants. The seasons also showed similar effect on FC moisture retention. There was higher FC moisture in autumn as compared to spring. This was because of higher rainfall interception which has a bearing on higher moisture retention by the soil. The moisture content at FC also increased as the soil became finer in texture. Lower altitude (1,800m) reflected the influence of forest floor on soil water movement and retention by the soil. Greater the exposure, lesser was retention of moisture in the soil.

Field capacity moisture has a good deal of influence on the growth performance of trees and in maintenance of dynamic nutrient cycling in forest ecosystems. The degree of variation in soil moisture is also dependent on type and amount of vegetative cover. The depletion pattern of soil moisture through different seasons could be helpful in determining the moisture needs of the growing forest at different periods of time Jha *et al*. (1981). The findings on soil moisture at FC obtained in this study are in conformity with results reported by Jha and Rathore (1980), Jha *et al.* (1984) and Guimmayen (1978).

18.3.7 Wilting Point moisture

Plant growing in soil will absorb water and reduce the quantity of moisture remaining in the soil. The soil–water phenomenon assumes criticality when the soil moisture becomes limiting during dry months in a forest situation. The limiting moisture availability in soil makes the plant root exert greater energy to extract a given amount of water compared with soil at FC moisture. As the soil dries out plants will begin to show the effects of reduced soil moisture uptake. During the day time they will tend to wilt, especially if temperatures are high and if there is some wind movement. At first this daytime wilting will be associated with renewed night time turgor, ultimately the rate of the supply of water to the plants will be so slow that the plant will remain wilted day and night. The plants now exist in permanently wilted condition. At this stage the soil moisture content at which plants show permanent wilting is called wilting point (WP) moisture. This can be worked out experimentally by putting soil at 15 atm. pressure. The moisture content in soil at 15 atms expressed as percentage is called WP moisture percentage. The WP moisture was observed in the soil at different altitudes and seasons and data obtained are presented in Table 18.5.

18.3.8 Effect of altitude on WP moisture

The data on wilting point (WP) moisture percentage shows a decreasing trend with increasing soil depth in spring and autumn seasons. At 2,700m, WP moisture ranged from 20.38 per cent to 11.74 per cent in spring and 22.34 per cent to 12.52 per cent in autumn at different soil depths. WP moisture decreased with increasing soil depth with significant negative correlation for spring (r = - 0.94**) and autumn (r = - 0.95**). At 2,400m, WP moisture percentage ranged from 16.89 per cent to 10.61 per cent in spring and 19.71 per cent to 11.82 per cent in autumn. WP moisture decreased down the profile with increasing soil depth

Table 18.4: Specific effect of seasons and altitudes on Field Capacity moisture (per cent)

Sl. No.	Soil Depth (cm)	Altitude (with integration of seasons)				Season (with integration of altitudes)	
		2700m	2400m	2100m	1800m	Spring	Autumn
1	0-15	40.77	34.38	32.16	30.68	31.44	37.55
2	15-30	35.71	28.46	25.82	24.53	27.10	30.15
3	30-60	28.90	26.18	24.41	22.66	24.45	26.62
4	60-90	26.32	23.40	22.15	20.90	22.04	24.28
5	90-120	24.52	22.43	21.16	20.06	21.19	22.89
6	120- 150	23.31	21.20	19.82	19.22	19.84	21.93

Table 18.5: Wilting point moisture (per cent) in different seasons and altitudes

Sl. No.	Soil Depth (cm)	Altitude (m)							
		2700		2400		2100		1800	
		Seasons							
		Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn
1	0-15	20.38	22.34	16.89	19.71	15.67	18.97	14.13	18.12
2	15-30	18.72	20.16	14.12	16.32	13.06	14.64	12.63	14.25
3	30-60	15.19	16.57	13.38	14.78	12.14	13.96	11.16	13.17
4	60-90	13.26	14.89	12.17	13.14	11.46	12.37	10.28	11.68
5	90-120	12.13	13.36	11.78	12.27	10.97	11.34	9.71	11.04
6	120- 150	11.74	12.52	10.61	11.82	9.23	10.93	9.03	10.61

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with significant negative correlation for spring (r = - 0.92**) and autumn (r = - 0.91**). At 2,100m, WP moisture ranged from 15.67 per cent to 9.23 per cent in spring and 18.97 per cent to 10.93 per cent in autumn at different depths. WP moisture decreased with increasing soil depth with significant negative correlation for spring (r = - 0.93**) and autumn (r = - 0.89*). At 1,800m, WP moisture ranged from 14.13 per cent to 9.03 per cent in spring and 18.12 per cent to 10.61 per cent in autumn in different depths. WP moisture decreased down the profile with increasing soil depth with significant negative correlation for spring (r = - 0.95**) and autumn (r = - 0.88*).

18.3.9 Specific effects of altitudes and seasons on WP moisture

In order to observe the specific effects of altitudes and seasons, the values were worked out and are presented in Table 18.6. The WP moisture showed uniform decrease from top soil layer of the profile down to the lowest one at different altitudes and seasons. At 2,700m altitude WP moisture was highest in all depths compared with at 2,400m, 2,100m and 1,800m altitudes. For other seasons too WP moisture showed decline down the soil profile. The values in autumn were greater at all soil depths than in spring. The WP moisture showed significant negative correlation with soil profile depth at all altitudes and seasons. In general, plants cannot extract moisture at this stage because the roots are unable to counter the force at 15 atms with which WP moisture is held by the soil particles. Obviously, such an amount of water present in the soils is not available to plants. The soil moisture must be maintained considerably above the wilting point if plants are to grow and function normally. The moisture content in the soil at WP shows variation depending upon the soil conditions.

The WP moisture in a soil enriched with such substances should tend to be higher than in humus poor soil. A good aeration pores and moisture storage as found in the case of silty loam soil is of practical significance since it maintains a good air–water balance for the plants (Jha and Rathore, 1980). The moisture content at FC and WP increased as soil became finer in texture. However, this increase in moisture content was not of the same magnitude at these constants. The gradient in the WP moisture obtained at different altitudes and seasons shows conformity with the above concept. Similar observations were made by Jha *et al.* (1984) in the forests in Himachal Pradesh. The high level of WP moisture in the humus enriched soils may not serve very useful purpose for main species but it could still be useful for other living systems in soil plant relationship at different altitudes.

18.3.10 Available water capacity

The available moisture is generally considered as that held between the field capacity (FC) and wilting point (WP). Most of the plants use this moisture and it is termed as available water capacity (AWC). The moisture between these two constants is not equally available. As the soil dries up from a state of field capacity to wilting point the availability of water diminishes nonlinearly. The data on available water capacity (AWC) obtained at different altitudes and seasons are presented in Table 18.7.

18.3.11 Effect of altitudes on AWC

The data on available water capacity (AWC) showed a decline with soil profile in spring and autumn seasons. At 2,700m, AWC

Table 18.6: Specific effect of seasons and altitudes on Wilting point moisture (per cent)

Sl. No.	Soil Depth (cm)	Altitude (with integration of seasons)				Season (with integration of altitudes)	
		2700m	2400m	2100m	1800m	Spring	Autumn
1	0-15	21.36	18.30	17.32	16.12	16.76	19.78
2	15-30	19.44	15.22	13.85	13.44	14.63	16.34
3	30-60	15.88	14.08	13.05	12.16	12.96	14.62
4	60-90	14.07	12.65	11.91	10.98	11.79	13.02
5	90-120	12.74	12.02	11.15	10.37	11.14	12.00
6	120- 150	12.13	11.21	10.08	9.82	10.15	11.47

Table 18.7: Available water capacity (per cent) in different seasons and altitudes

Sl. No.	Soil Depth (cm)	Altitude (m)							
		2700		2400		2100		1800	
		Seasons							
		Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn
1	0-15	18.98	19.85	14.29	17.88	12.87	16.81	12.56	16.55
2	15-30	15.89	16.65	12.37	14.11	11.43	12.51	10.20	11.98
3	30-60	12.94	13.11	11.79	12.41	11.22	11.51	10.01	10.99
4	60-90	11.91	12.58	9.87	11.63	9.67	10.81	9.55	10.29
5	90-120	11.71	11.85	9.63	11.18	9.47	10.54	9.37	10.00
6	120- 150	10.55	11.82	9.51	10.47	9.44	10.04	9.28	9.52

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Table 18.8: Specific effect of seasons and altitudes on Available water capacity (per cent)

Sl No.	Soil Depth (cm)	Altitude (with integration of seasons)				Season (with integration of altitudes)	
		2700m	2400m	2100m	1800m	Spring	Autumn
1	0-15	19.41	16.08	14.84	14.55	14.67	17.77
2	15-30	16.27	13.24	11.97	11.09	12.47	13.81
3	30-60	13.02	12.10	11.36	10.50	11.49	12.00
4	60-90	12.24	10.75	10.24	9.92	10.25	11.32
5	90-120	11.78	10.40	10.00	9.68	10.04	10.89
6	120- 150	11.18	9.99	9.74	9.40	9.69	10.46

ranged from 18.98 per cent to 10.55 per cent in spring and 19.85 per cent to 11.82 per cent in autumn in different soil depth. AWC decreased with increasing soil depth with significant negative correlation for spring (r = -0.89*) and autumn (r = -0.85*). At 2,400m, AWC ranged from 14.29 per cent to 9.51 per cent in spring and 17.88 per cent to 10.47 per cent in autumn in different depth. AWC decreased down the soil profile with increasing depth with significant negative correlation for spring (r = -0.91**) and autumn (r = -0.86*). At 2,100m, AWC ranged from 12.87 per cent to 9.44 per cent in spring and 16.81 per cent to 10.04 per cent in autumn in different depths. AWC decreased down the soil profile with increasing depth with significant negative correlation for spring (r = -0.91**) and non-significant correlation for autumn season. At 1,800m, the AWC decreased down the soil profile with increasing depth. AWC ranged from 12.56 per cent to 9.28 per cent in spring and 16.55 per cent to 9.52 per cent in autumn in different soil depths. The correlation was not found significant with depth for the seasons.

18.3.12 Specific effects of altitudes and seasons on AWC

In order to observe the specific effects of altitudes and seasons, the values were worked out and presented in Table 18.8. There was a general decrease in the AWC down the soil profile at different altitudes. The AWC was higher at 2,700m altitude compared to 2,400m, 2,100m and 1,800m altitudes. The contrast especially in the top layers was clear at 2,700m and 2,400m altitudes compared to 2,100m and 1,800m. The AWC showed decline in the soil profile for spring and autumn seasons. The values in autumn were relatively more compared to spring in different depths because of higher incorporation of humus in wetter season. From the data it appears that the availability of water is not greatly influenced by higher accumulation of soil humus at 2,700m altitude compared to other altitudes. The availability of water in the top layers was better than lower layers at all altitudes and seasons. The AWC showed significant negative correlation with soil profile depth at 2,700m and 2,400m altitudes, while it showed non-significant correlation at 1,800m and 2,100m altitudes (autumn season only).

The availability of water was better in top layer compared with lower layers. The soil layers were influenced markedly by available water and its movement in the soil. Hardpans or impervious layers slow down the rate of movement of water drastically and also impede the root interception. They sometimes restrict root growth and effectively reduce the soil depth from which moisture is drawn. Soil moisture loss from forest soil is an irreversible process and this loss depends critically on the stand characteristics, etc. Estimates of AWC have been made in the laboratory based on the established concepts of Veihmeyer and Hendrickson (1949). The AWC improved in the conditions where forest disturbances was less, the exposure was less, top soil was covered with litter resulting in high absorption of incident rainfall and high soil moisture retention. Removal of forest due to forest fire or cutting of trees increase water yield because of reduced interception and transpiration losses (Bosch and Hewlett, 1982; Jones and Post, 2004; Brown *et al*., 2005). Higher the soil inorganic fraction, lesser was AWC observed. AWC did not show increase with soil humus enrichment because of the fact that presence of soil humus or its accumulation tends to increase the FC and WP percentage than so much the difference between the two soil moisture constants.

The observations in the present study such as significant negative correlation with soil depth, narrow contrast in AWC at different altitudes and seasons especially in top layers are in line with the known concepts. The available moisture capacity of the soil increased from sandy loam to silty loam and also clay soil showed higher available moisture than sandy loam soil reported by Jha and Rathore (1980). The similar trend was observed by Abrol and Bhumbla (1969); Salter and William (1965). The AWC estimates reported by Jha *et al.* (1984) confirm these findings. The available moisture storage capacity of soils determines to a great extent their usefulness in practical forestry. This capacity is often the buffer between an adverse climatic conditions and productivity of forests.

18.4 CONCLUSION

Moisture not only acts as a vehicle for ion transport but also provides favourable condition for soil chemical action and development of the activities of microorganisms. The importance of moisture holding and content relationship lies in the fact that it may change due to the effect of altitudes and seasons. The various soil moisture constants in the present study were determined and have been discussed as influence by different altitudes and seasons. A study was conducted in upper Yamuna Forest Division of Garhwal Himalaya to determine the soil moisture at different altitudes and seasons. The altitudes lie between 1,800–2,700m above msl. The maximum water holding capacity (MWHC), field capacity (FC), wilting point (WP) and available water capacity

(AWC) at all altitudes and seasons decreased down the profile with increasing soil depth. At 2,700m altitude, MWHC, FC, WP and AWC was higher followed by at 2,400m, 2,100m and 1,800m altitude. A good aeration and moisture storage as found in case at 2,700m altitude was of significance. The available moisture is generally considered as that held between the FC and WP. Wilting point moisture is an indication of soil moisture depletion and in general, plants cannot extract moisture at this stage because roots are unable to counter the force of 15 atm. with which WP moisture is held by the soil particles. Obviously, such an amount of water present in the soils is not available to plants. From the study it appears that the availability of water is not greatly influenced by higher accumulation of soil humus at 2,700m altitude compared to other altitudes. The availability of water in the top layers was better than lower layers at all altitudes and seasons. Higher the soil inorganic fraction, lesser was AWC observed.

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19

Influence of Invasion of Lantana camara and its Removal on Infiltration Capacity of Soil in Tropical Deciduous Forest of Rajaji National Park- A Preliminary Observation

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19.1 INTRODUCTION

Invasion by non-native exotic species in alien environment poses a major threat to native plant communities and alters fundamental structure and functions of ecosystems. It poses one of the most severe threats to biodiversity resulting major changes in vegetation at global level (Vitousek *et al.*, 1996; Mack *et al.*, 2000) and is detrimental to ecological integrity and economics of the invaded area (Pimentel *et al.,* 2001). Nearly 18 per cent of the Indian flora is constituted by adventive alien of whom 55 per cent are American (Nayar, 1977). *Lantana camara*, *Parthenium hysterophorus* and *Ageratum conyzoides* of American origin weeds are the most problematic in our country (Kohli *et al.,* 2004). *Lantana camara* was introduced into India in 1809 as an ornamental hedge in Calcutta's garden (Kohli, 2006). It isbeing shade tolerant prefers to grow under the canopy of forest tree or plantations and is also common in pastures, grasslands, along river banks and road sides and even agricultural lands. Rajaji National Park (RNP), Uttarakhand has extensively been invaded by the *Lantana camara* from the past few years. Invasion has occurred all over the forests engulfing all the vegetation communities. The management of the national park by the removal of *Lantana* has been initiated by the park authorities since 2007 and it is being done manually through uprooting. Infiltration studies conducted under different land use conditions recorded lowest infiltration rate under agriculture land and highest under forest (Tejwani *et al.*, 1975). Patnaik and Virdi (1962) reported such findings from the Doon valley and its adjoining uplands in the western Himalaya and Shiwaliks. Compaction to the forest floor leads in reduction of porosity and increase in bulk density of soil (Ram *et al.*, 1993). Trampling by the livestock affects physical attributes of soil (Gupta, 1983). Root biomass of the plants also affects the physico-chemical attributes of the soil (Russel, 1977). Yadav *et al.* (2005) reported infiltration characteristics in Shiwalik lower Himalaya hills at different aspects and topography. The loss of biodiversity and depletion of other natural resources due to invasion of exotic species in general and change in habitats and destruction of food web in National Park and Sanctuaries have been addressed by many authors, but studies pertaining to impact of invasion of *Lantana camara* and its removal on infiltration capacity of forest soil is negligible. Therefore, the present study has been undertaken to evaluate the impact of invasion of *Lantana camara* and its removal on infiltration capacity of soil in tropical moist deciduous forest ecosystem of RNP.

19.2 METHODOLOGY

19.2.1 Study site

Rajaji National Park (RNP) was established in 1983 and is spread over an area of 820.42 sq.km. The area falls between 77^{0}57'7"E and 78^{0}23'36"E longitude and 29^{0}52'41"N and 30^{0}15'56"N latitude and its elevation range from 1,300-1,500m amsl. The average annual rainfall of the area is approximately 2,000-2,200 mm. The soils of the area are very poor and consist of sandstone, gravel and conglomerate. The vegetation of the RNP is classified under northern tropical moist deciduous forest (Champion and Seth, 1968) which is grouped under different vegetation communities i.e. sal, mixed, riverine, pine, scrublands and grasslands. The dominant tree species in mixed vegetation communities are *Ehretia laevis, Holarrhenaantidysenterica, Lagerstroemia parviflora*, *Mallotus philippensis*, *Miliusa velutina Anogeissus latifolia*, etc. Under shrubs dominant species are *Lantana camara*, *Adhatoda zeylinica*, *Colebrookia oppositifolia*, *Murraya koenigii*, etc.

19.2.2 Phytosociological study

Nested quadrats of 10x10m, 3x3m, and 1x1m size, respectively, for recording trees, shrubs and herbs were laid out under *Lantana* invaded and four years old *Lantana* removal sites for determination of phytosociological attributes of trees, shrubs and herbs (Misra, 1968; Shannon and Wiener, 1963).

19.2.3 Soil physico-chemical analysis

Soil samples were collected from different study sites at the depth of 0-30 cm for analysis of bulk density, organic carbon (per cent) and organic matter (per cent) (Jackson, 1957).

19.2.4 Infiltration study

The infiltration study was conducted during the winter in November-December 2011 with double concentric ring

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infiltrometer as used by Brechtel (1976), Yadav (1976), Soni *et al.* (1985) and Yadav and Vasistha (1989).

19.3 RESULTS

Phytosociological attributes of trees, shrubs and herbs under *Lantana* invaded sites (LIS) and *Lantana* removal sites (LRS) are given in Table 19.1.

Table 19.1: Phytosociological attributes of trees, shrubs and herbs under *Lantana* invaded and removal sites in tropical deciduous forest of Rajaji National Park

Attributes	Plant forms	Forest floor conditions	
		Lantana Invaded Sites (LIS)	*Lantana* Removal Sites (LRS)
Density ha^{-1}	Tree	670	690
	Shrubs	1,678	1,455
	Herbs	19,700	61,300
Species Richness	Tree	10	10
	Shrubs	8	7
	Herbs	13	15
Species Diversity Index (H′)	Tree	1.83	1.68
	Shrubs	1.16	1.31
	Herbs	1.78	2.30
Dominant species with Importance Value Index	Tree	*Ehretia laevis* (60.38)	*Ehretia laevis* (130.59)
	Shrubs	*Lantana camara* (58.76)	*Adhatoda zeylinica* (184.87)
	Herbs	*Chloris dolichostachya* (84.86)	*Stellaria media* (76.59)

Results of study reveals that trees density (ha^{-1}) under LIS and LRS were 670 and 690, respectively. Similarly shrubs density (ha^{-1}) under LIS and LRS were respectively 1,678 and 1,455, whereas herbs density (ha^{-1}) was 19,700 and 61,300, respectively in LIS and LRS. *Lantana* removal enhanced density of herbaceous species which is in confirmation of the findings of Babu *et al.* (2009). Richness of the herbaceous species was also recorded more in LRS than LIS. Similarly, diversity index of shrubs and herb species was again more in LRS than LIS. Under LIS and LRS *Ehretia laevis* was dominant tree being of higher IVI value 60.38 and 130.95 respectively. *Lantana camara* was dominant (IVI 158.76) under LIS whereas *Adhatoda zeylinica* (IVI 184.87) was dominant under LRS. As a result of removal of *Lantana,* there was drastic change in understory vegetation composition. *Lantana* which was recorded as dominant shrub species in invaded sites has been replaced by native understorey vegetation of *Adathoda zeylinica* which confirm the findings of Flory and Clay (2009). *Chloris dolichostachya* (IVI 84.86) and *Stellaria media* (IVI 76.59) were dominant grass and herb species under LIS and LRS, respectively. Bulk density of soil under LIS and LRS was 1.338 and 1.134gcm^{3,} respectively, whereas organic carbon was 0.369 and 0.469 per cent, respectively (Table 19.2).

Table 19.2: Physico-chemical attributes of soil under *Lantana* invaded and removal sites in tropical deciduous forest of Rajaji National Park

Soil attributes	Forest Floor Condition	
	Lantana Invaded sites	*Lantana* Removal sites
Bulk Density (g/cc)	1.338	1.134
Organic Carbon (%)	0.369	0.469
Organic Matter (%)	0.634	0.806

The infiltration rate (cm^2 hr-^{1}) of soil under LIS is mentioned under Table 19.3. Results reveal that infiltration rate (cm hr^{-1}) at the initial (0-1 minute) stage was 120.0, whereas within 1-5 minutes, it drastically dropped to 42.0 cm hr^{-1}. Results indicate that infiltration rate decreases as time increases and within 75-105 and 105-135 minutes, movement of water into soil shows similar trend. Infiltration rate (cm hr^{-1}) of soil under LRS at the initial (0-1 minute) stage was recorded at 132 and it was 72.0 within 1-5 minutes while at different time intervals up to 165 minutes it exhibited more or less decreasing trend. Under LRS soil infiltration rates fall under very rapid classification, whereas under LIS soil falls under moderately rapid classification (Kohnke, 1968). Under LRS soil infiltration rate (cm hr^{-1}) within 0-1, 1-5, 5-15, 15-30, 30-50, 50-75, 75-105 and 105-135 minutes was, 10 per cent, 71 per cent, 168 per cent, 162 per cent, 271 per cent, 300 per cent, 358 per cent and 328 per cent more than LIS soil. Under LRS the higher infiltration rate may be due to the higher density of herbaceous plants and their root density (Russel, 1977; Ram and Jana, 1997).

Table 19.3: Infiltration capacity of soil under *Lantana* invaded sites in tropical deciduous forest ecosystem

Elapsed time in minute	Infiltration amount (lowering in water level in cm)	Accumulated infiltration amount (cm)	Infiltration rate (cm hr^{-1})
0-1	2.0	2.0	120.0
1-5	3.5	5.5	42.0
5-15	2.8	8.3	16.8
15-30	3.0	11.3	12.0
30-50	3.5	14.8	10.5
50-75	3.7	18.5	8.4
75-105	3.5	22.0	7.0
105-135	3.5	25.0	7.0

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Table 19.4: Infiltration capacity of soil under *Lantana* removal sites in tropical deciduous forest ecosystem

Elapsed time in minute	Infiltration amount (lowering in water level in cm)	Accumulated infiltration amount (cm)	Infiltration rate (cm hr^{-1})	Infiltration increase (per cent) than *Lantana* invaded sites
0-1	2.2	2.2	132.0	10
1-5	6.0	8.2	72.0	71
5-15	7.5	15.7	45.0	168
15-30	10.5	26.2	31.5	162
30-50	13.0	39.2	39.0	271
50-75	14.0	53.2	33.6	300
75-105	15.0	68.2	32.1	358
105-135	15.0	83.2	30.0	328
135-165	15.0	98.2	30.0	-

The lower bulk density and higher organic carbon and organic matter seemed to be other factors responsible for enhancing infiltration rate in LRS than LIS (Lee, 2005) (Table 19.4). Average final infiltration rate under LRS soil was 28 cm hr^{-1} whereas it was 8 cm hr^{-1} under LIS soil. Though these are preliminary observations however the results are indicating the impact of invasion of exotic species on water regulation of forest ecosystem. Zavalete (2000) also found that water holding capacity of many waterways in the South Western United States have been found decreasing due to invasion of invading species leading to more frequent and extensive flooding. Overall results indicate that *Lantana* removal from Rajaji National Park improved biological diversity of the forest understory vis -a-vis improved hydrological status too.

ACKNOWLEDGMENT

The authors are thankful to the Director, RNP for providing facilities for undertaking the present study.

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20

Physico-chemical Properties of Soil and Identification of Rocks from Riverbank of Tons, In and Around FRI Campus, Dehradun

Sudipto Bhowmik and Dr. A.K. Raina

20.1 INTRODUCTION

The present investigation was taken up on the banks of the River Tons which flows behind the west side of the Forest Research Institute campus. The site also includes a small island in the middle of the river. The sites were chosen within the area between the bridge over the river and the IMA campus. This area was selected not only to understand the relationship between the soil and the rocks from that area, but also to open further scope for the investigation in the fields of soil fertility, landscape, vegetation, biodiversity, aquatic ecology, the impact of water on soil and nutrients and erosion caused by the river, etc.

Soil contains the nutrients which are important for plant growth. These nutrients come from parent materials and decaying parts of dead organic materials. So it is important to know about the nutrients present in the soil, for better understanding the vegetation and the biodiversity of a certain area. At the same time the understanding of the interrelation between the parent rock and physicochemical properties of the soil is important. These types of studies help us to know petrographic origin of soil, nutrient reserve and different other physical and chemical properties of soil at a certain place. This information can be utilized while doing afforestation, or any restoration work in that area.

Moreover identification of rocks can help in documentation of earth history of the place, and also can be used to further studies of individual characteristics of the specimen. Knowledge on the chemical, physical and mineralogical properties of rocks helps in understanding the erosion of rocks, how it affects soil properties and the processes of soil formation. Since the rocks are collected from the river bank, they can lead us to know about the characteristics of the places where the river originated and the places through which it has flowed. In this case, the rocks may also be used to get knowledge on geology of Himalaya.

Metamorphic rocks can indicate the process of metamorphism, which may help to know the climatic or environmental conditions which the rocks had undergone, which have brought the changes in their physical and chemical properties. This can also help us in studies of climatic change in this area. Sedimentary rocks can help understand the paleo-geographical conditions due to which the rocks are formed and the era when they formed. Also they may indicate conditions and agents responsible for the deposition of constituent material, the extent of denudation. The transportation mode of the material can also be known.

In this study the amount of macro-elements like nitrogen, phosphorous and potassium, and micro-elements as Cu, Zn, Mn, Cr has been calculated, the structure of the soil has also been identified. This can help in understanding the growth of different plant communities in this region, and also to determine if any new species can be introduced in this region. It can also help understand if there is any need to improve the presence of any of the nutrients mentioned above for ecological and economical gain.These data on soils and rocks can also be used to know about impact of climate and vegetation on this region.

20.2 METHODOLOGY

For this project, soil samples were collected from five areas from the banks of the Tons river, which lies between 30^{0}21'07.25"N, 77^{0}59'32.86"E to 30^{0}21'07.49"N, 77^{0}59'22.65" E, which are listed below. The elevation of the area ranges from 611m to 621m. Different types of rocks were collected randomly from these areas. The rocks were identified, the soil samples were air dried, then ground through cyclotec sample mill and screened through 2mm sieve as per procedures described by Jackson (1967). The properties of soil were determined with help of methods described by Black (1965) and Jackson (1967). The values of pH of the soil samples were determined by the pH-meter. Values of amount of Cu, Zn, Mn, Cr in soil samples were determined by atomic absorption spectrophotometer.

20.3 RESULT

First of all the pH is determined to know whether the soil is acidic or basic. According to Thompson(1975), by strict definition, any pH below 7.0 is acid and above 7.0 is alkaline, but more practically a small zone near 7.0 is considered neutral. The descriptive terms for soil pH according to him are given below;

pH	**Descriptive Term**
less than 5.5	strongly acid
5.5-6.0	medium acid
6.0-6.5	slightly acid
6.5-7.0	very slightly acid
7.0-7.5	very slightly alkaline
7.5-8.0	slightly alkaline

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8.0-8.5	medium alkaline
More than 8.5	strongly alkaline

The acidic nature of soil depends on many factors. "Soil becomes acidic when considerable portions of the exchangeable cations are hydrogen, H^+, and various forms of hydrated aluminum"(Donahue, Miller, Shickluna, 1983). "Alkaline soils (pH >7) are very common in semiarid and arid climates. Calcareous soils cover more than 25 per cent of the earth surface. Their content of free $CaCO_3$ in upper horizon varies from a few per cent to 95 per cent" (Marschner,1986). According to Thompson, pH has less or no direct effect on plant growth, but its indirect effects are numerous and potent, and the most universal effect is nutritional. Mineralization of nitrogen and sulfur is fastest between pH 6 and 8, above pH 8 the source of sulfur is mineral rather than organic. Soil of pH between 6.5 and 7.5 is best for phosphorus availability. Total potassium declines when a soil is leached and becomes acid. In high-lime or high alkaline soils the metallic cations of manganese, iron, copper and zinc decrease in solubility. Boron may be leached at very low pH, at very high pH its solubility is low. Molybdenum is precipitated by iron and aluminum at low pH values. So once the nature of soil is determined then the reasons behind the acidic or basic nature of soil can be identified. According to Thompson most soils have pH values between 4 and 8.

Determination of the amount of organic matter present in the soil was also carried out. This helps in understanding the water holding capacity, buffering, erosion of soil, plant growth in this soil, ecology of soil and soil micro-organisms, since these all are controlled by presence of organic matter and organic carbon in soil. "Chemically, organic matter in the soil is the source of nearly all nitrogen, 5-60 per cent of the phosphorus, perhaps up to 80 per cent of the sulphur, and a large part of boron and molybdenum used by plants in a given season when crop is not fertilized"(Donahue *et al.*, 1983). According to them, benefits of soil organic matter along with supply of above mentioned nutrients are;

1) Organic matter supplies directly or indirectly through microbial action the major soil aggregate-forming cements, particularly polysaccharides.
2) Organic matter furnishes the cation exchange capacity often up to 30-70 per cent.
3) Organic matter increase water contents at field capacity and in sandy soil also increases the flow of soil and water through soil by producing larger pores in soil due to soil aggregation.
4) Organic matter acts as a chelate and makes more than one bond with metals like iron, zinc, copper, manganese and thus by forming soluble chelates it increases the mobility of micronutrients in soil, and increases their availability to plants.
5) Organic matter supplies carbon to many microbes in soil.
6) Organic matter reduces soil erosion, prevents moisture loss, controls the soil temperature also.

Determination of presence of N, P, K was carried as of some trace materials. This helps in determination of plants which can survive and whether they are local or exotic. This can also help in studies of controlling erosion and conservation of biodiversity. Nitrogen (N) is one of the three most important factors in soil that controls plant growth. It is a constituent of chlorophyll, proteins and nucleic acid. Phosphorus (P) is present cell nuclei, ATP, ADP or other energy storage and transfer chemicals. Potassium (K) helps in plant action and enzyme transformation. So studying these macro elements are very essential (Donahue *et al.*, 1983).

According to Thompson and Fredrick (1975), the amount of nitrogen absorbed by plants is maximum when the plant is young and gradually declines with age. Nitrogen deficiency may affect growth by slowing it, and affected plant may appear spindly, stunted, and pale in comparison with healthy plants. Oversupply of nitrogen generally produces a dark green, succulent vegetative growth, at the expense of seed production. In Indian soils, N varies from 0.02 per cent to 0.12 per cent (Fundamentals of Soil Science, 2002).

Phosphorus is a component of every living cell and tends to be concentrated in seeds and in the growing points of plants (Thompson and Fredrick, 1975). Phosphorus is present in soil in both organic and inorganic form. The organic phosphorus is not available to plants until the organic matter is partly decomposed. The inorganic phosphorus comes from fluorapattite ($Ca_5 (PO_4)_3F$). Phosphorus is available in soil in forms H_3PO_4, $H_2PO_4^-$, HPO_4^{2-}, PO_4^{3-}. Among them $H_2PO_4^-$ is most readily absorbed by plants. HPO_4^- may also be used. PO_4^- is available at very high pH; H_3PO_4 is available at very low pH so it is less significant for plant nutrition. Phosphorous varies in Indian soils from 100 to 2000 ppm (0.02-0.5 per cent). In calcareous soil, calcite acts as absorbent site for P and impure calcites and those of high specific surface result in more absorption of P and rapid formation of Ca-P precipitates (Fundamentals of Soil Science, 2002).

According to Thompson and Fredrick (1975), potassium does not enter into covalent bonds of organic compounds as do nitrogen, phosphorous and sulfur, but they remain as active ions within living plant cell, and leaches out of dead organic matter. Main sources of potassium in soil are muscovite mica, biotite mica, and orthoclase feldspar. Most soil contains 1-5 lb of potassium dissolved in soil solution. Plant roots can absorb potassium either by exchange of another cation (eg. H^+) or along with anions such as NO_3^- or $H_2PO_4^-$. Potassium ion balance maintains the electrical neutrality in both soil and plants. The compounds containing most K as structural elements of minerals are feldspar and mica (Fundamentals of Soil Science, 2002). The divalent copper ion (Cu^{2+}) is strongly bound in to humic and fulvic acids, forming copper-organic matter complexes (Stevenson and Fitch, 1981). Because of high affinity of Cu^{2+} for various ligands (amino acids,phenols, and synthetic chelators), even in nutrient solutions added Cu^{2+} may be rapidly complexed (Graham, 1979). Copper is present in three different forms in blue proteins, non-blue proteins and multi-copper proteins, in chloroplasts within plastocyanin and chloroplast enzymes. In copper-zinc SOD (Superoxide Dismutase), the copper atom is involved in the mechanism of detoxification of O_2 generated in photo-respiration.

According to Maschner (1986), due to Cu deficiency, grain, seed and fruit formation is much more than vegetative growth. Copper deficiency causes impaired lignification of cell wall, causing characteristics distortion of young leaves, bending and twigs. According to Brown and Clark, (1977), Mizuno (1982) in plants suffering from copper deficiency the content of soluble carbohydrates is considerably lower than normal during the

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vegetative state. Copper deficiency may result to decrease in phenoplase. According to Blingy and Douce (1977), in copper deficiency cells, a drastic decrease in cyto-chrome oxidize activity was without effect on the respiration rate, indicating that this enzyme might be present in large excess in the mitochondria. Sources of copper are chalcocite (Cu_2S), covellite (CuS), cuprite (Cu_2O), malachite [$Cu_2(OH)_2CO_3$], chrysocolla ($CuSiO_3.2H_2O$) and azurite [$Cu_3(OH)_2(Co_3)_2$]; it is present in nature as sulphides, oxides, hydroxy carbonates, silicates (Fundamentals of Soil Science, 2002).

According to Marschner (1986), Zn is an important micronutrient. Zinc acts either as a metal component of enzymes or as a functional, structural or regulatory cofactor of a large number of enzymes. The zinc-containing enzymes are alcohol dehydrogenases, Cu-Zn superoxide dismutage, carbonic anhydrase and RNA polymerase. Zn is also important for activation of enzymes as dehydrogenases, aldolases, isomerases, trans-phosphorylases, RNA and DNA polymerase. In highly weathered acid soils, zinc deficiency may occur. In calcareous soils, Zn deficiency is associated with iron deficiency. In dicotyledons, it causes stunted growth to shortening internodes and drastic decrease in leaf size. Deficiency of Zn causes red, spotlike discoloration, chlorosis and necrosis. Zn deficiency can affect gross metabolic changes by declining alcohol dehydrogenase activity. Zn deficiency also affects activities of various enzymes of the CO_2 assimilation pathway, most affected is the decline in the activity of fructose-1-6-bisphosphatase, also the rate of photosynthesis is reduced. In zinc deficient plants, the protein synthesis and protein content is also drastically reduced, also rate of RNA degradation is reduced. According to Donahue *et al*. (1983), zinc is mostly immobile in most soils. Zinc deficiencies can be expected in basic and calcareous soils, particularly if topsoil has been eroded, zinc may be also less in coarse sands, heavy phosphate applied land and exposed subsoils. Its availability in soil surface is 0.08-20.5 ppm; its sources are sphalerite(ZnS), smithsonite($ZnCO_3$), hemimorphite [$Zn_4(OH)_2Si_2O_7.H_2O$] and Zn is available as sulphides, oxides, carbonates and silicates (Fundamentals of Soil Science, 2002).

Of the micronutrient transition metals (manganese, iron, copper, zinc and molybdenum), manganese has the lowest complex stability constant and thus forms the weakest bonds (Clarkson and Hanson, 1980). Manganese activates a number of enzymes invitro, particularly decarboxylases and dehydrogenases of the tricarboxylic acid cycle. Mn as a mineral nutrient is tightly bound to mettaloproteins, where it acts as a structural constituent and as an active binding site (Marschner, 1986). Mn has its most important activity in photosynthetic O_2 evolution, and a few enzymes contain Mn. Manganese can replace magnesium in invitro reaction and activate enzyme more effectively. Mn is a structural constitutent of ribosome (Lyttleton, 1960) and also activates RNA polymerase. Under field conditions manganese deficiency is usually confined to plants growing in highly tropical soils or high-pH soils with large organic matter content (Farley Draycott,1973). Manganese deficient leaves exhibit exceptional high IAA oxidase activity (Morgan *et al*., 1976). Deficiency of manganese results in drastic reduction of soluble carbohydrates in roots. The rate of elongation seems to respond more rapidly to manganese deficiency (Marschner, 1986). In manganese-deficient plants, the formation of lateral roots ceases completely (Abbott, 1967). Range of Mn in surface soil is 37-1150000 ppm and the available range 0.60-164 ppm (Fundamentals of Soil Science, 2002).The mineral sources of Mn are pyrolusite (MnO_2), manganite (MnOOH), rhodochrosite ($MnCO_3$), rhodonite ($MnSiO_3$). Its major forms in nature are oxide silicate and carbonates. According to Aubert and Pinta (1977), the total chromium content of soil ranges from traces to 3,000-4,000 ppm, the mean ranging from 100 to 300 ppm.

- The pH ranges from within the range 7.5-8.6, which indicates the soil is alkaline. According to table given by Thompson; sample 1, sample 2, sample 3 and sample 4 are slightly alkaline whereas sample 5 is highly alkaline.
- Since pH is high in soil samples so movement of K^+ ions to soil colloidal surfaces and becoming susceptible to fixation should be easier in these areas.
- Alkalinity of soil samples indicates the presence of free $CaCO_3$ in the upper horizon of the soil, which may vary from a few per cent to 95 per cent. According to Marschner (1986), this indicates the role of limestones in supplying calcium carbonate to soil.
- Since phosphorous availability is best in soils of pH between 6.5-7.5, phosphorous should be best available to plants in regions from where soil sample 1 and 2 had been collected.
- Mineralization of nitrogen should be fast in all five regions since the pH required for the fastest mineralization of nitrogen and sulfur ranges between pH 6-8.
- Due to high pH, boron solubility should be lessin these areas.
- Since pH of the soil is high, the uptake of manganese by the plants in this region should be low.
- The amount of nitrogen in soil ranges from 0.00448 per cent to 0.01568 per cent. Though N in soil can vary from 0.02 per cent

Table 20.1: Result of analysis of the soil samples.

Sample No.	pH	Organic carbon (per cent)	Organic matter (per cent)	N (per cent)	K (per cent)	P (per cent)	Cu (ppm)	Zn (ppm)	Mn (ppm)	Cr (ppm)
1	7.5	0.3	0.5172	0.01568	0.014	0.0011	1.082	0.286	2.970	6.722
2	7.5	0.4	0.6896	0.00504	0.018	0.0008	1.119	0.162	3.194	2.305
3	7.6	0.26	0.4482	0.00448	0.008	0.0006	0.969	0.102	3.474	2.305
4	7.6	0.22	0.3793	0.00728	0.007	0.0013	1.019	0.147	3.138	4.199
5	8.6	0.18	0.3103	0.00504	0.007	0.0012	1.044	0.159	3.194	6.722

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to 0.44 per cent. In Indian soils, it varies from 0.04 per cent to 0.12 per cent. The amount of nitrogen in these soil samples fall in this range. The reason behind the very low nitrogen level is most probably the prevailing higher temperature of the Indian tropical climate.

- Since high pH and presence of limestone indicates presence of free $CaCO_3$, uptake of K^+ ions by plants may be reduced here.
- Since potassium is higher in sample 2, thereafter in sample 1, sample 3, sample 4 and sample 5 in decreasing order of presence of nitrogen, it can be considered that presence of feldspar and mica also decreases following this order.
- The phosphorous present in this samples are very low.

The rocks collected from the site have been identified as-

1. Limestone
2. Oolitic limestone
3. Pisolitic limestone
4. Quartzite
5. Travertine
6. Shale
7. Dolomite
8. Banded limestone
9. Slate
10. Marble
11. Sandstone
12. Boulders
13. Pebbles
14. Cobbles
15. Conglomerate

20.3.1 Sedimentary Rocks

20.3.1.1 Limestone

According to Tyrrell, the limestones are composed of chiefly calcite and presence of varying amount of impurities give rise to varieties as sandy, clayey, glauconitic, ferruginous, phosphatic or bituminous. Limestones may form by either by biochemical processing, consisting of a great variety of organic fragments or by inorganic precipitation and being deposited from the first as solid rock, but they are hard to distinguish from each other. Animals like foraminifera, corals, crinoids, mollusca, crustacean and plant like calcareous algae are mostly responsible for the formation of biochemical limestone. Calcium carbonate is precipitated in form of calcite in warm current areas of sea and ocean which provides warm water, high alkalinity, supersaturation and abundance of sulphate ion in solution. The shells that form limestones have either aragonite or calcite form of calcium carbonate. Aragonite can convert into calcite under normal temperature and pressure to get a more stable crystal structure. Ferroan dolomites and ferroan calcites generally act as cementing agent in limestone. Phosphatic minerals, autigenicquartz,autigenicalbite,micro-pheruitic pyrite, clay mineral as kandite and illite groups, glauconite may also be present in limestones.

20.3.1.2 Oolitic Limestone

This is a sedimentary rock.According to Pellant (2000) oolitic limestone originates in warm, shallow and strongly agitated marine conditions. The constant action of tides, currents and waves encourages the precipitation of calcium carbonate around quartz grains. This type of limestone contains high degree of calcium carbonate, small amount of quartz and other detrital materials. Fossils, specifically of invertebrates are common. These rocks are composed of closely packed ooliths called oolites, which are spheroidal or ellipsoidal structures built of concentric layers, usually composed of calcite, ooliths have a typically light coloured rock matrix which can be easily seen with naked eye.

20.3.1.3 Pisolitic Limestone

This is a sedimentary rock. According to Pellant (2000), pisoliticlimestones originate in moderately shallow marine conditions, these environments favour the precipitation of calcite and this type of conditions were common in Mesozoic era. Pisolitic limestone is similar to oolitic limestone, but it contains pisoliths which are larger and more irregular structures than ooliths, and may be up to pea size. When calcite precipitates around a nucleus as a sand grain or a fragment of a shell then pisoliths are formed. The cementing material is calcite. Pisolitic limestone is are coarse-grained rock, with pisoliths whose sizes are mostly same. Pisoliths are often flattened. Fossils including many invertebrates are common in this limestone.

20.3.1.4 Travertine

This is also a sedimentary rock. According to Pellant (2000), this rock is frequently associated with springs rising from deep seated sources, which results in many hot springs, especially in volcanic regions, giving rise to travertine by deposition of solid calcium carbonate. Travertine consists almost pure calcium carbonate, it may also contain some detrital quartz and clay. Fossils are virtually absent in this rock. It is a light-coloured rock, unless it contains iron compounds or other impurities. Travertine deposits are often rounded, botryoidal and banded structures. It is formed with small crystals of calcite that bind together other sediment particles. In many situations travertine occurs in strata. Travertine is often bedded.

20.3.1.5 Dolomite

According to Pellant (2000), this sedimentary rock is formed in marine environments, which are mostly believed to be of secondary origin, replacing original limestone. It contains high proportion of dolomite mineral,along with detrital minerals and secondary silica (chert). The mineral dolomite is magnesium carbonate. Dolomites are usually darker than other limestones. It is less fossiliferous. It has even crystalline texture. The dolomite masses are often compact and earthy.

20.3.1.6 Sandstone

According to Pellant (2000), sandstones are extremely common rocks which form from a great variety of geological situations. The majority of sandstones are accumulated in either water, usually marine or as wind-blown deposits in arid continental areas. Sandstones are predominantly made up of quartz grains, but often contain feldspar, mica or other minerals. Silica, calcite or iron oxides may cement the grains. Sandstones are medium grained rocks with well sorted grains. The grains can be angular or rounded. They may contain invertebrate, vertebrate or plant fossils. They may also contain sufficient amount of glauconite,

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that may impart green tinge in fresh rock, which may be replaced by brown red staining in weathered rocks due to breakdown of glauconite. Heavy minerals may also be present.

20.3.1.7 Shale

According to Tyrrell, shale is a form of compact argillaceous rock material. According to Pellant (2000), shale consists of a mixture of clay minerals together with detrital quartz, feldspar and mica, and the black shales are rich with carbonaceous matter, with common presence of pyrite and gypsum. The pyrite content suggests the formation of this rock in deep still water. The formation of black shale and black mud takes place in seas with strong oxygen deficiency. These are fine grained, finely laminated, splits easily along bedding planes and may contain fossils of planktonic forms.

20.3.1.8 Conglomerate

Conglomerates are made up of fragments that have undergone considerable transport in water and have consequently become more or less rounded. Since these fragments have survived the vicissitudes of transport and have been worn down and rounded, these are more durable than fundamental fragments of other rudaceous rocks. According to Mansfield(1906), the principal types of conglomerates are of marine, fluviatile, estuarine, lacustrine and glacial in origin. Most abundant conglomerates are of fluviatile type. According to Pellant, quartz conglomerates consist of light coloured quartz fragments of finer index and the matrix usually comprises of sand,silt, small rock fragments and iron oxides that often cemented by silica or calcite. Quartz conglomerate can form in places where there is sufficient energy to move larger fragment, including beaches and river systems. Whereas the polygenetic conglomerate contains fragments derived from igneous metamorphic and sedimentary origins and individual particles cemented by various chemical including iron oxides, quartz, calcite, the grains are rounded or sub-rounded. These are formed in high energy environments as powerful water currents. Fossils are rare in conglomerate.

20.3.2 Metamorphic rocks

Slate: This is a metamorphic rock. According to Tyrrell, production of slate is the chief effect of cataclastic metamorphism of argillaceous rock. Slate splits or cleaves readily along smooth, flat, closely-spaced surfaces of weak cohesion, usually developed at an angle to the original bedding. Slates consists mainly finely-divided micaceous minerals, including chlorite, with subordinate quartz and feldspars and all minerals are flattened and elongated in the plane of cleavage.

Marble: This is a metamorphic rock. According to Tyrell, if calcite is heated under pressure, dissociation is hindered and instead of following the reaction;

$$CaCO_3 = CaO + CO_2$$

The carbon dioxide is retained and the mineral merely recrystallizes as crystalline limestone or marble, which is a granoblastic aggregate.

Quartzite: According to Tyrrell, it is a metamorphic rock formed when quartz and feldspar sandstones are affected by sufficient degree of heat and are recrystallized into granoblastic aggregates of these minerals, with their clastic characters completely obliterated. It often shows a peculiar vitreous lustre.

Pebbles, Clover and Boulders: According to the table given by Holmes, boulders, cobbles and pebbles all belong to main group rudites. Boulders are fragments of diameter greater than 200mm (8 inches), cobbles are between 200mm (8 inches) and 50mm (2 inches), pebbles are between 50mm (2inches) and 10mm (2/5 inches).

Hence after identifying the rocks it can be said that;

- Among these rocks all rocks except quartzite, slate and marble are sedimentary rocks. These three are metamorphic rocks.
- All limestones are important sources of calcite which makes the soil calcareous. They may also supply quartz clay and some other detrital minerals.
- Dolomite is a source of mineral dolomite, secondary silica and other detrital minerals. Sandstones may contribute quartz, feldspar, mica, iron oxides and calcite.
- Shales can supply clay minerals, detrital quartz, mica, silica, carbonaceous matter. They also may contain pyrite and gypsum.
- Conglomerate may contain sand,silt, small rock fragments and iron oxides,quartz, calcite etc.
- Among the metamorphic rocks slates are sources of micaceous minerals, chlorite, quartz and feldspar. Marble is the source of CaO. Quartzite may supply quartz and feldspar.
- This study indicates that the most of the rocks present in the area are sources of quartz. All limestones, are sources of $CacO_3$, so the soil is calcium rich. Mica, feldspar, silica etc. are also to be supplied by these rocks.
- The origin of the River Tons is in the Himalayas, and it has flowed through different regions of this mountain chain. Since limestone, dolomite and shale, which originated due to precipitation of materials in different regions of oceans or seas, their availability in the bank of the Tons supports the concept of origin of Himalaya from the Tethys ocean.
- The presence of limestone and marble, sandstone and quartzite at same place indicates that limestone and sandstone, which are sedimentary rocks, have undergone heating effect and converted into metamorphic rocks such as marble and quartzite, respectively.

20.4 CONCLUSION

The research work helps to understand the relation between the physicochemical properties of soil and different types of rocks found in the river bank of the Tons. This will help for further works in afforestation with ecological and economic benefits, biodiversity conservation. It will help in further studies on erosion caused by water to soil and rocks. This work helped to understand local geology and also help in understanding of types of vegetation which can be sustained in this area.

The data can also indicate level of erosion caused by water, and also can help understand loss of soil nutrients due to water flow. Further research can be done to understand seasonal change of amount of minerals in the soil. The identification of rocks helps to know the geological processes which they had gone through. They also help in understanding the history of the region, and in extrapolating the nutrients supplied to the soil by the rocks, which

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may be a subject of further investigation. The study of soils and rocks help in better understanding of their inter-relation. From the result of the study, the presence of other nutrients and properties of soil that have not been studied, can be assumed.

ACKNOWLEDGEMENT

I acknowledge with profound gratitude my indebtedness to my supervisor Dr. A.K. Raina, Scientist–F, Forest Soil and Land Reclamation Division, Forest Research Institute, Dehradun (Uttarakhand) for suggesting solutions to my problems and guiding me during the entire course of preparation of this term paper.

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Role of Forests in Watershed Management for Livelihood Security and Prevention of Land Degradation under the SLEM Project

Saibal Dasgupta, Tajinder Pal Singh and Rashmi Bajaj

21.1 INTRODUCTION

Extreme weather events, climate change and the need for adaptation strategies, growing problems of water scarcity, environmental degradation, food insecurity and poor livelihood conditions and human health point towards water, water-related ecosystems and watersheds and interrelationships between forests and water. The availability and quality of water in many regions of the world is more and more threatened by overuse, misuse and pollution, and it is increasingly recognized that both are strongly influenced by forests. Moreover, climate change is altering forest's role in regulating water flows and influencing the availability of water resources (Bergkamp *et al.*, 2003).

Forests and tree cover prevent land degradation and desertification by stabilizing soils, reducing water and wind erosion, and maintaining water and nutrient cycling in soils. Sustainable use of goods and services from forest ecosystems and the development of agro forestry systems have the potential to contribute to poverty reduction, making the rural poor less vulnerable to the impacts of desertification and land degradation. In addition, the growing problems of water scarcity, environmental degradation, food insecurity, poor livelihood conditions and human health highlight the interrelationships between forests and water.

Forested watersheds are exceptionally stable hydrological systems (FAO, 2003). The need for incorporating services from forests into larger watershed management approaches for maintaining the integrity of watersheds and landscapes is, therefore, urgent and relevant. In comparison with other land uses, healthy forests strongly influence the quantity and quality of water yielded from watersheds, discharge lower storm flow peaks and volumes for a given input of rainfall, moderate variation in stream flow during the year, stabilise soil and prevent gully and surface erosion. All of this ultimately impacts land productivity, food security and livelihood status of the population dependent on the land.

21.2 METHODOLOGY

21.2.1 Study details

This paper looks at the linkages between forests, water management and the consequent impacts on livelihoods of the poor under the SLEM (Sustainable Land and Ecosystem Management) project of GEF (Global Environment Facility). Outcomes of several projects under the Sustainable Land and Ecosystem Country Partnership Programme (SLEM-CPP) in India highlight the impact of sustainable land ecosystem management practices on livelihood security. The sustainable land and ecosystem management approach contributes directly to poverty reduction at household and community levels, in addition to maintaining land quality and ecosystem integrity. It includes increasing vegetative cover through agro-forestry, reforestation and afforestation and through ensuring sustainable extraction practices of natural resources while also maintaining the integrity of watersheds and landscapes and improving water management. Currently, six SLEM projects are being implemented in India with assistance from the World Bank, UNDP and FAO. The project sites under SLEM-CPP cover diverse ecological zones including arid, coastal and mountainous ecosystems and address diverse aspects of land and ecosystem management including coastal agriculture, shifting cultivation, watershed management, and groundwater management. The SLEM project on "Policy and Institutional Reform for Mainstreaming and Up-scaling Sustainable Land and Ecosystem Management in India" anchored at the ICFRE, Dehradun envisages identifying gaps and barriers to sustainable land management, and documenting best practices across the country, which could be up-scaled and mainstreamed.

In the SLEM programme, the multi-sectoral approach to combating land degradation also takes into account the need to conserve biodiversity and consider the implications of climate variability and change. An overall decreasing trend in land degradation is expected along with an improved protection of ecosystem functions and processes resulting in an increase in carbon stocks in the soil as well as in the vegetative cover. The expected global benefits with regard to biodiversity will be obtained both in terms of ecosystem components and services. Through enhanced conservation and sustainable use of biodiversity incorporated in the productive landscape, global benefits will in particular be related to agro-biodiversity and be obtained through agro-ecosystems managed as habitats for indigenous species and through sustainable management of vulnerable habitats such as wetlands, drylands and mountains.

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21.3 Results and discussion

Forests are critical to the eradication of poverty especially in the dry lands. They are also the first step towards healing the dry lands and protecting them from desertification and drought. India has 69 per cent of dry lands, classified as arid (15.8 per cent), semi-arid (37.6 per cent) and dry sub humid (16.5 per cent). The core activities under the SLEM projects currently operative in Madhya Pradesh, Andhra Pradesh, Uttarakhand, Nagaland, Himachal Pradesh and West Bengal include afforestation, regeneration of degraded forests by local communities, and support and training for communities to operate bio-resource based enterprises for livelihood promotion and economic empowerment. As a direct impact of the SLEM project interventions encouraging results are seen with respect to the management of natural resources and several beneficiaries showing improved livelihoods.

SLEM in Uttarakhand focuses on concerns over deterioration of water bodies, and highlights that problems of water may be resolved by the sustainable management of ecosystems. The mid-Himalayas cover about one-third of the state and covers 11 out of 13 districts of the state. The project is spread over an area of around 238,000 ha, ranging from 700m to 2,000m altitude in 76 selected micro watersheds in the middle Himalayas. About 451 Gram Panchayats (GPs) identified in 18 blocks of 11 districts are participating in this project. A total population of 254,000, living in the project area is expected to benefit from it. The SLEM project aims at the consolidation of watershed activities in 20 micro-watersheds out of 76 identified micro-watersheds in the UDWDP (Uttarakhand Decentralized Watershed Development Programme), and focuses on a select number of watersheds that are experiencing intense erosion, low socio-economic status, most of them being situated close to the agricultural frontier.

The project also focuses on controlling land degradation through the SLEM approach at watershed level, watershed planning through community participation, fostering markets for non-timber forestry products and biodiversity conservation and management through watershed planning and community participation. Through the project interventions, more than 20 micro-watersheds have been treated and land degradation controlled through forestry plantation, forest fire management, soil moisture conservation measures, water augmentation activities, revival of Water Mills (*Gharats*), cultivation of Medicinal and Aromatic Plants, etc. Decentralized Participatory Approach involving Panchayati Raj Institutions (PRIs) and village level institutions is followed and de facto financial autonomy given to PRIs in handling project funds. As a Policy initiative under the project, Van Panchayats as an institution treat Reserve Forest areas within a prescribed plan and the women Aam Sabha integrates women issues in Gram Panchayat Watershed Development Planning (GPWDP) and implementation. The physical impacts of the project show:

- About 140056 cumt of soil loss has been arrested
- Approx 182.07 ha of agriculture land has been protected
- Total Water holding capacity created :50095 (cum)
- Rejuvenation of water sources: 270 in Number

Biogas plants have also been established and about 17 households are using biogas for 8 months in a year. The biogas intervention has been able to replace fuel wood by 75 to 80 per cent. Fuel wood load from the forest has reduced from an estimated 40,950 kg to 8,830 kg. The 32,120 kg of biomass conserved is equivalent to protecting 30 trees annually and reducing more than 45 tonnes of CO_2 emission. Drudgery of women has been reduced and they are saving approximately 2.5 hrs daily. The biogas production from each plant is estimated at 488 cum equivalent to 2,010 kg of firewood valued at Rs 8,040/year. The value of slurry produced is Rs 5,256 per year. The yield of crops and vegetables has increased by 10 to 30 per cent after the application of biogas slurry.

The impact of the revival of water mills under the projects also highlights the positive results of the project intervention. It has led to a potential annual saving of 78247 L in diesel consumption. The milling capacity of the traditional watermills among the sample gharats increased to 80 to 100 kg/ day during July-October (reduced slightly in non-rainy months), and their average efficiency increased from 46.79 kg to 68.76 kg/ day per yr (31.95 per cent). The average per capita income in terms of *Bhagwari* increased from 2.25 qt. to 3.12 qt. per year (27.88 per cent). *Bhagwari* is measured in terms of monetary benefits at local value of raw material**.** The per capita income increased from Rs 3,606 to Rs 6,243 per year. The revival of the water mills has also led to an interesting convergence. The *Jai Siddhnath* SHG of *Baisani* in *Bageshwar* division has installed improved mechanized system to run rice mill and to generate electricity of 2.5 KW with the help of UREDA. This electricity is being distributed to one Junior High School and 4 households. Each household contributes Rs 100 per month to the SHG for O&M and other related works.

The SLEM project thus aims to mainstream sustainable watershed management approaches into GP watershed development plans. These plans are being integrated with watersheds lying outside the authority of GPs but under the management of the Forest Department. The plan also include appropriate fire management practices, including technological solutions for utilization and conversion of chir pine (*Pinus roxburghii*) biomass into briquettes for meeting household and other energy requirements of communities. The project has also focused on fostering markets for Non-Timber Forest Products (NTFPs) to reduce pressure and dependence on the natural resource base. The pine briquettes technology piloted successfully under UDWDP is being scaled-up. SHGs and VGs are being encouraged to take up the activity as an income generation activity.

Nagaland situated at the confluence of Indo-China and Indo-Myanmar region is endowed with great species diversity and endemism in terms of flora and fauna. Shifting cultivation, locally referred to as 'jhum', is the main form of agriculture and is most suitable for the agro climatic conditions and steep terrain. However, in recent years, shortened jhum cycle has been observed with insufficient time for restoring soil fertility, yields have declined over time, and families that were once self sufficient in foodgrains are not able to produce enough even for a few months of the year. There is little time for natural regeneration resulting in accelerated soil erosion and change in hydrological conditions of the area. The major challenge for Nagaland therefore is how to adapt this land use and production system to rising populations and changing lifestyles, while also maintaining its ecological sustainability. The SLEM project is being implemented in three districts of Nagaland: Mon, Mokokchung and Wokha cover 70 villages where shifting cultivation is rampant. The project aims to develop, demonstrate and upscale sustainable land management practices for the conservation of jhum lands in Nagaland through an ecosystem approach. Horticulture and agroforestry plantations introduced in over 11,000 hectares of land under the SLEM project in Nagaland has increased forest cover and additional income generating activities in project areas. Over 800 jhum-practicing households have benefited from introduction of integrated farm development practices that integrate crop, livestock, fishery, forestry and horticulture and reduce soil erosion. There has been an increase in average incomes of 4,000 households by 15-20 per cent annually and increase in incomes of 3,000 women by 10 per cent.

Specific agro-climatic conditions, extensive rain-shadow/ drought-prone areas, dry land farming and poverty, characterize large parts of Peninsular India. There is also intensive use and extraction of surface water and groundwater compromising regional food production, reducing rural employment and degrading natural systems. Current land use practices are already making dry land farming increasingly unviable, and studies show that climate change will further exacerbate the low and uncertain rainfall conditions in these areas. On the farms, soil erosion, declining soil fertility, low soil organic matter and reduced water holding capacity have impacted yields. Degraded farming conditions have grave social consequences including male migration, disoriented residuary families, and distorted family and community relationships. Lowland soils are also impacted by water-logging and salinity. The effect of drought or climate variability in Andhra Pradesh was found to be in terms of loss of crop production output of five major corps viz., rice, maize, sorghum, groundnut, and sunflower (World Bank, 2006). The SLEM project in Andhra Pradesh seeks to build upon the experience gained in the Andhra Pradesh Farmer Managed Groundwater Systems project (APFAMGS) project which made hydrological and hydrogeological information accessible and usable by some half-a-million farmers in a set of established hydrological units. While the APFAMGS raised the baseline in terms of groundwater management and associated land management practices in key drought-prone areas of Andhra Pradesh, the project results revealed a very changed set of environmental and socio-economic conditions that present broader opportunities for enhanced land management and climate change adaptation. The SLEM project has established a set of nine pilot initiatives (Anantapur, Chittoor, Kadapa, Kurnool, Mahbubnagar, Nalgonda and Prakasam), across the region in selected, representative hydrological units to extend this environmental knowledge and propagate alternative land and water management practices to reverse environmental degradation through locally identified climate change adaptation measures. These pilots, it is expected will establish platforms for more effective mobilization of government support and private sector services. The success achieved with groundwater based farmers will be extended to rain-fed farmers under the SLEM project while also preparing them to adapt to the risks posed by climate change. The farmers dependent on rain fed farming have been prioritized in the 650 habitations, and they are being provided capacity to gather all technical data related to rainfall, soil moisture, runoff, soil quality along with appreciation of the process of carbon sequestration at the farm level through the farmer Water School. The project expects that the field data collection would sharpen the farmer's ability to make critical and informed decisions on crop varieties, planting season, managing pest attacks, etc., to match with the emerging climate change. The data gathering will help in building alliances with different stake holders for working together to mitigate the impact. Specifically the project will generate simple improved practices for SLM moving towards broader improvements that are relevant and acceptable, combining scientific methods with traditional ones and scale up and build upon the lessons of the ongoing work in APFAMGS. This is being done through Participatory Technology Development (PTD) and Participatory Hydrological Monitoring (PHM).

The SLEM project in Madhya Pradesh aims to remove barriers to promote sustainable rural livelihoods that are ecologically sustainable. The project is implemented in nine forest divisions spread across five districts of Madhya Pradesh – Betul, Chhindwara, Sidhi, Singrauli and Umaria. These districts home to five Protected Areas harbour rich biodiversity that provide ecosystem services beyond its borders, such as water and climate regulation, and have some of the last remaining habitats for India's threatened biodiversity. They are also home to some of the poorest human populations. The selected village clusters in these districts have a forest cover of roughly 45-50 per cent of geographical area. The population is comprised of people from different ethnic groups, with significant numbers belonging to tribal groups. Tribal populations have over the generations considered the forests as their natural habitat and their dependency on forest and forest based resources has been almost 100 per cent. Land degradation and fertility loss are important causes of poverty in the project districts. More than half of tribal/rural families have less than two hectares of land and these lands are primarily rain fed, lacking irrigation facilities. The project aims to remove barriers to promoting sustainable rural livelihoods that are ecologically sustainable and provide a broader range of livelihood options for the tribal/ rural poor. Demonstration activities have been targeted on the basis of four micro-catchments/watersheds. Main activities in the project include:

a) Regeneration of degraded bamboo forests by local communities, and energy and fodder plantations.
b) Support and training communities to operate and bioresource based enterprises for livelihood promotion and economic empowerment.

Apart from these core activities, the project is also working with local communities on lac cultivation, rope making, fish production and marketing, incense manufacturing, etc., and provides support and training to communities to operate bio-resource based enterprises for livelihood promotion and economic empowerment. The SLEM approach thus focuses to remove barriers to promote sustainable rural livelihoods that are ecologically sustainable and provide a broader range of livelihood options for the tribal/rural poor. The SLEM programme conceived as a multi-stakeholder project supports adoption and implementation of sustainable land and ecosystem management, the essence of which is to apply a multi-sectoral approach to land management, biodiversity conservation and climate change/adaptation issues in several states of India.

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22

Water Stresses and Adaptation of Forest Tree Species to Climate Change

M. Al-Amin and S. Afrin

22.1 INTRODUCTION

Climate variability and change, its impact and vulnerabilities are growing a concern worldwide. Global climate change is now a reality and the change is mainly happening due to global warming. Global warming is an issue of much concern for both the developing and developed countries. Bangladesh is widely recognized to be one of the most climate vulnerable countries in the world (MoEF, 2009). The Intergovernmental Panel on Climate Change (IPCC) predicts that global temperatures will rise between 1.8^0 C and 4.0^0 C by the last decade of the 21^{st} century. The IPCC also forecasts that global warming will result in sea level rises of between 0.18 and 0.79 metres, which could increase coastal flooding and saline intrusion into aquifers and rivers across a wide belt in the south of the country, although most of the area is protected by polders. Rainfall is predicted to become both higher and more erratic, and the frequency and intensity of droughts are likely to increase, especially in the drier northern and western parts of the country.

Forests are often called lungs of earth, because forests act as an indicator of environment quality and contribute to sustainable development in a stable and productive environment (Colmore, 2003). Forests cover one third of the earth's surface and estimation is that more than two thirds of all available terrestrial species are found in the forests. The lack of moisture in soil, increasing temperature, salinity intrusion, water logging condition or flood could affects seed germination and seedling growth in plant (Thomson *et al.,* 2005).

Climate is a key factor which determines the distribution of plants and animals (Al-Amin, 2008). Global changes include mainly temperature rise, flood and water deficiency. Bangladesh will face serious consequences of biodiversity loss due to global climate change, in the form of rising temperature and altered soil moisture, is projected to decrease the yield of food crops over the next 50 years (Thomson *et al.,* 2005).

Plant function is inextricably linked to climate and atmospheric carbondioxide concentration. Climate change affects plants, focusing on several key determinants of plant growth: atmospheric CO_2, temperature, water availability and the interactions between these factors. Micro-climate affects the plant's immediate environment and so directly influences physiological processes. Though the long life-span of trees does not allow for rapid adaptation to environmental changes, forests are particularly sensitive to climate change. However, it is predicted (MoEF, 2005) that prolonged floods would severely affect growth of many timber species, while it would cause high incidence of mortality for *Artocarpus* species, which is one of the most important timber species of Bangladesh.

Adaptation entails efforts to deal (or cope) with the unavoidable impacts of climate change (due to the failure of mitigation efforts). Adaptation measures specially for forestry need to be planned well in advance of expected changes of climate in growing conditions because the forests regenerated today will have to cope with the upcoming climate conditions of at least for a number of decades, often even more than 100 years. Therefore, a need may exist to address the adaptive responses of *Artocarpus chaplasha* and recommend steps need to be taken for collection, conservation and management programmes for future vulnerable adverse climates.

22.2 METHODOLOGY

The treatments used in the experiments are: water deficit (2 ml, 5 ml, 10ml, 15 ml: normal), waterlogged (15 ml: normal, 300ml, 400ml, 500ml) with elevated temperatures as IPCC (2007) suggested (existing temperature with +1.60, +2.70, +4.00). 2 ml, 5ml and 10 ml water were sprinkled to the sample seedlings for testing growth of *A. chaplasha* in water stress condition in growth chambers. However, to investigate the growth of *A. chaplasha* in water logged condition using 300 ml, 400 ml and 500 ml water were sprinkled to the other set of sample seedlings. The effect of treatments (water stress, water logged compared to normal with existing and different elevated temperatures) on *A. chaplasha* were assessed through two adaptive parameters: Leaf angle and Leaf area which show adaptive response of plants very efficiently (Kummerrow, 1980). The following parameters were assessed:

22.2.1 Leaf angle

Protractor was used for leaf angle measurement. Data of leaf angles were recorded at every seven days interval and continued up to 17 weeks.

22.2.2 Leaf area

Leaf area was measured by using a Planimeter. The following formulae were used for calculating leaf area:

Area Calibration Constant (ACC) = Known area / Tracing result of known area.

Actual area of the unknown specimen = Tracing result of unknown object × ACC.

22.2.3 Statistical analysis

Statistical analysis was done by using statistical software Minitab 2002 version 13.2.

22.3 RESULTS

22.3.1 Leaf angle

Figure 22.1 is showing physiological stresses for water under different temperature scenarios to accommodate less evapo-transpiration in course of time (weeks: x axis).

Figure 22.1 illustrates, leaf angle in existing temperature scenario started with 72^0, however, with time (weeks) it decreases due to its physiological stress as because of loss of water from the cells in the upper surface of the leaf and may be because of leaf water deficits. Conversely, adaptive response of seedlings of *A. chaplasha* was visualized within 10 to 11 weeks through widening the angle of leaves but the rate was very slow. Subsequently, in low and mid elevated temperature scenarios the seedlings had leaf angle of 60^0 to 70^0 at the starting and in course of time (weeks) there was rapid change in leaf orientation.

The seedlings show their response to stress by the swift reduction in leaf angle and show their adaptive mechanism from week 10 to 15. Though, the seedlings under low and mid scenario develop their adaptability to water and temperature stress but showed decreasing tendency with time in the angles of leaves. Similar result was found in the high elevated temperature scenario except that the seedlings visualize their adaptive response earlier (7 week) than the other scenarios. The result indicates that, water and temperature stress, individually or combined affect the physiological processes and conditions and also may damage the adaptive mechanism of plants. This may happened because high temperature increases the rate of water loss and the use of food in respiration and water stress or deficit cause cell turgor reduction, closure of stomata and reduction in the rate of photosynthesis. Briefly the result suggested that combination of elevated temperature and water stress, may affect the growth and yield of *A. chaplasha* in the upcoming century and the species may not be able to thrive in the adverse environment.

Figure 22.2 illustrates that in existing and low elevated temperature scenario angle of the leaves were ranged from 58^0 to 60^0, at the starting point and with time (weeks) leaf angles were decreased but the rate of decrease was not sharp. The seedlings visualize their adaptive tolerance within 9 to 11 week at the both scenarios and started widening of their leaf angle. These may be because they had enough water and increasing evapo-transpiration rate The seedlings under mid elevated temperature scenario started with about 45^0 at the starting of their growth and during the consecutive show decreasing trend of the angle of leaves. However, in course of time they started their adaptive mechanism and it visualized from the 9 week and after that time the seedlings under mid elevated temperature scenario widen their angle of leaves and the rate of increasing was better.

Seedlings under high elevated temperature scenario show similar result and they started widening of leaf angle from week 6 to 7. This may be because of higher temperature compared to other scenarios. The result indicates that seedling of *A. chaplasha* may stimulate their adaptive tolerance with time and may survive in water logging condition in the next century.

Bradford and Hsiao (1982) found under water logging condition tomato, not only does the main petiole change in angle, but each leaflet also assumes a more vertical orientation. This reduces the horizontal surface area for light interception and the heat load. Epinasty and partial stomatal closure may act together to restrict water loss soon after water logging. The maintenance of high leaf permits some stomatal opening and the accompanying photosynthesis.

The observed results in the leaf angle responses of the seedlings which were with water deficit and logged treatment (Figures 22.1 and 22.2) depicted that within 9 to 10 weeks the seedlings started its adaptation mechanism for minimum utilization of water and consequently, the leaf angle again starts widen but the rate was significantly lesser then its early growth period. Similar response was found in low and mid elevated temperature scenarios, except that seedlings under water deficit treatment show a decreasing tendency in its angle of leaves compared to the others.

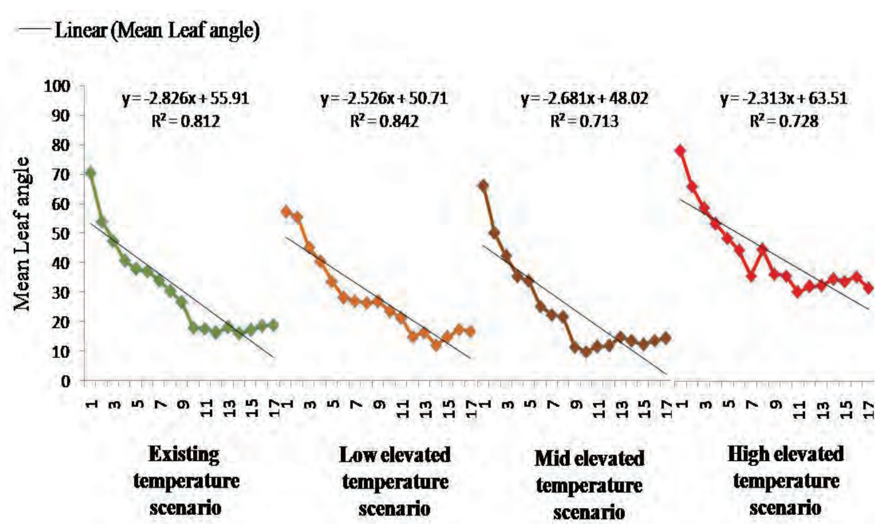

Figure 22.1: Leaf angle response of *A. chaplasha* under water deficit in different temperature scenarios

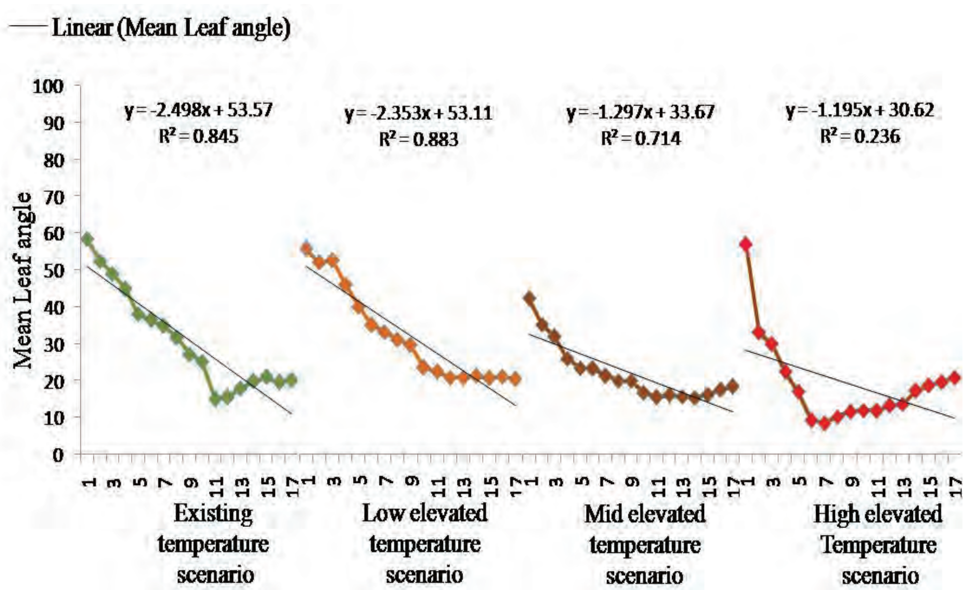

Figure 22.2: Leaf angle response of *A. chaplasha* under water logged in different temperature scenarios.

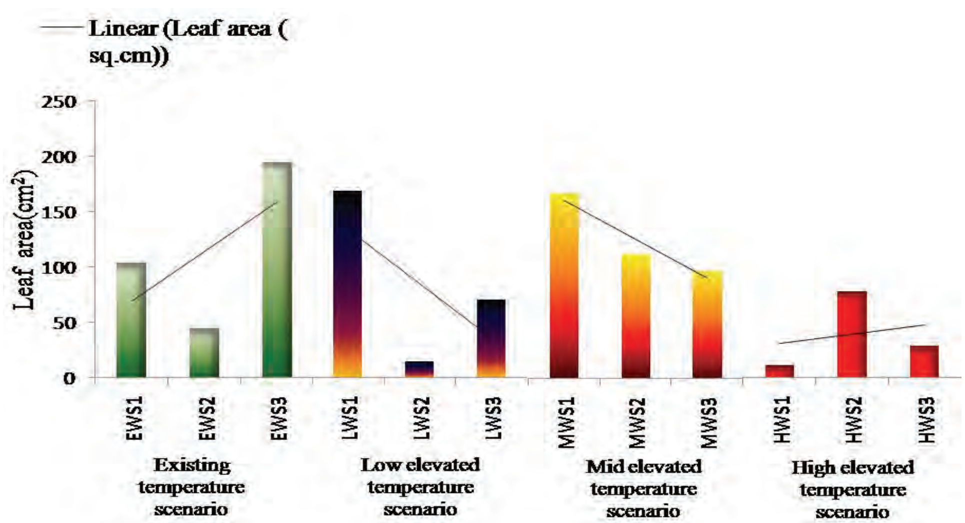

Figure 22.3: Leaf area response of *A. chaplasha* under water stress in different temperature scenarios.

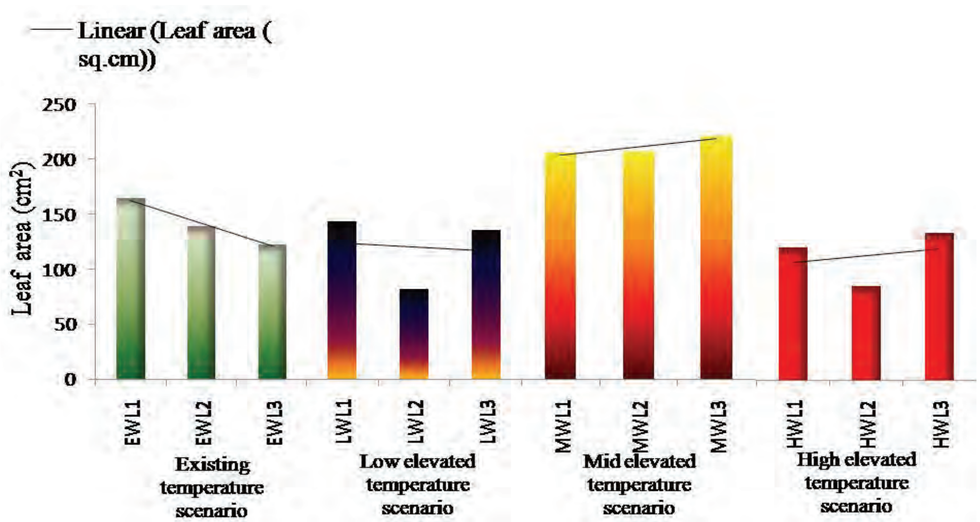

Figure 22.4: Leaf area response of A. *chaplasha* under water logged in different temperature scenarios.

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22.3.2 Leaf area

Adaptive responses of leaf area were observed within the seedlings under water stress and water logged treatments (Figures 22.3 and 22.4). Leaf area of *A. chapalasha* in water stress condition under different temperature scenarios (Figure 22.3) was higher in mid elevated temperature followed by existing temperature, low elevated temperature and then in high elevated temperature. The result indicates that in high elevated temperature and water stress affect the adaptation mechanism of leaf.

Turner (1979) reported that water stress reduces leaf area by accelerating the rate of senescence of the physiologically older leaves and through its effect on leaf shedding. Figure 22.4 illustrates leaf area of *A. chaplasha* was lower in high elevated temperature and higher in mid elevated temperature with water logging treatment compared with existing temperature and water logged scenario. The result suggested that seedlings of *A. chaplasha* may be able to show adaptive significance through increasing the area of leaf up to year 2050. That means the seedlings of *A. chaplasha* may be suitable for the near future plantation but not for the next century. The result indicates that adaptive response in leaf area of *A. chaplasha* may increase in near future but in long run *A. chaplasha* may not be able to adapt under extreme temperature and development of leaf area of the species may decrease.

Table 22.1: ANOVA for leaf angle and leaf area responses of *Artocarpus chaplasha*.

Sources of variation	F
Effect of elevated temperature and water stress on leaf angle of seedling	41.64 ***
Effect of elevated temperature and water logged on leaf angle of seedling	48.37 ***
Effect of elevated temperature and water logged on leaf area of seedlings	6.81 ***

*** indicates high level of significance

Figure 22.1 described that leaf area of seedlings of *Artocarpus chaplasha* were significantly affected by different elevated temperatures and water logged condition. However, seedlings under water stress in different temperatures do not show any significant difference. Begg (1980) suggested that reduction in leaf area is one of the most important consequences of the sensitivity of cell growth to water deficits and leaf growth is generally more sensitive to water stress than stomatal conductance and carbon dioxide assimilation, Similar result was suggested by Nautiyal *et al.* (1993) and Rahman *et al.* (2004).

22.4 CONCLUSION

The study has explored a range of stress factors that influence forest tree species and forest ecosystems, may adapt to the adverse situation. The study concluded that seedlings of *Artocarpus chaplasha* may not only adapt with the water stress condition (drought and flood) imposed by future changing climate but also achieve better growth in near future like 2030 to 2050. This situation demands that the seedlings of *Artocarpus chaplasha* may show their adaptive tolerance and develop adaptive mechanism through their physiological processes. However, in the long run (2100) the species showed an adaptation mechanism in very early stage of their life span and may survive but appear as a bushy shape. Finally, the result concludes that for overall condition *Artocarpus chaplasha* may be suitable for plantation in near future like 2030 to 2050 but not for the next century unless technological interventions like gene grafting will be provided.

ACKNOWLEDGEMENT

This paper is highly indebted to the IFESCU-USDA project titled "Identifying and developing the management techniques of suitable forest tree species of agro-ecological zones using climate change scenarios for Bangladesh" and for using the facilities to conduct the stated research.

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23

Effects of Water Availability on Gas Exchange of Different Tree Species under Controlled Conditions in Arid Region of Rajasthan, India

G. Singh, Bilas Singh and T.R. Rathod

23.1 INTRODUCTION

Plantation growth in arid and semi-arid regions is associated with soil water availability which is mostly influenced by low and erratic rainfall (Ibraimo and Munguambe, 2007; Mzezewa *et al*., 2010; Mzezewa and Gwata, 2012; Poonia and Rao, 2013). Low soil water storage capacity makes it difficult for plant life to sustain growth, giving low biomass production (Li *et al*., 2006). Reduced soil water availability adversely affects above ground processes and productivity as well as below ground processes including root growth and development (Dichio *et al*., 2000; Grabosky *et al*., 2009). Thus, water stress has injurious effect on vegetation growth, which is seen in terms of reduced growth and biomass accumulation in the plants of dry areas and needs to be managed by framing suitable policy (Hazell *et al*., 2001; El-Kharraza *et al*., 2012).

The northwestern region of India harbours naturally growing species of *Prosopis cineraria*, *Tecomella undulata*, *Ziziphus nummularia,* etc., which are comparatively slow growing under varying degree of stresses including drought (Bhuiyan and Kogan, 2010; Ramawat, 2010). This emphasized the need of introduction of comparatively fast growing species of high commercial value to meet the ever increasing demand of fodder and fuel wood. Construction of IGNP in northwestern part of Rajasthan provides abundant water supply in command areas, where the plantations and agriculture fields are often over irrigated, which results in rise of ground water table, development of salinity and water logging condition taking croplands out of agriculture production (Yeddl and Peddi, 2003; Bhakar, 2007). Since the irrigation is discontinued after four to five years, plantation suffers from acute water stress. This resulted in large-scale mortality in the plantation. This was probably due to development of shallow root system caused by over irrigation as well as faulty method of irrigation (Gupta, 1995). Thus to economize and optimize the water use efficiency, it is of paramount importance to understand the physiological functions of tree seedlings under varying levels of irrigation and quantify the water use and biomass production and understand the hydrological behaviour of different species (Bruijnzeel, 2004; Rodríguez-González *et al*., 2010; Wang *et al*., 2012).

However, to examine and understand the hydrological behaviour of plant species, one has to measure gas exchange and the physiological controls of transpiration (Roberts, 2007). As gas exchange and water transport in plants are known to be linked through stomatal regulation, photosynthesis and transpiration measurements by physiological methods would be particularly valuable and important (Brodribb, 2009; Konrad and Roth-Nebelsick, 2011). The other principal physiological measurements used are determinations of leaf stomatal conductance and leaf water relations to monitor plant water stress and its relations to hydrological behavior (Chelcy *et al*., 2007; Asbjornsen *et al*., 2011). Stomata acts as the regulators of plant water potential and maintain it at values that can be sustained by the conducting system of the trees (Sperry, 2000; Cochard *et al*., 2002; Arve *et al*., 2011), so stomata closes when plants cannot sustain the rate of water loss driven by leaf–air vapor pressure deficit (Streck, 2003; Lee, 2013). It also reduces photosynthetic rates a trade-off that influences plant function and growth, particularly under drought stress (Hubbard *et al*., 2001; Singh and Singh, 2003; Brodribb, 2009). Variations in environmental conditions including soil salinity and other stresses also have profound effects on foliage photosynthetic capacity and overall productivity (Meir *et al*., 2002; Singh and Bhati. 2003; Kirschbaum, 2004; Ninemets and Anten, 2009; Wargent *et al*., 2013). In a study, Way and Oren (2010) observed the beneficial effects of climatic warming on temperate forest species but suggested about imposed limitations on tropical vegetation if temperatures exceed >35°C. Minimum temperatures are also important if they drop below −2°C causing stomatal closure and photosynthetic efficiency (Hadley 2000; Strand *et al*., 2002).

In view of these facts, an experiment was conducted to monitor physiological function of *Eucalyptus camaldulensis*, *Dalbergia sissoo* and *Acacia nilotica* species in response to varying drought stress. These species were selected because of their important attributes, tolerance of wide range of stress and rapid growth and high yield and good quality wood as timber and fuel wood (Schmidt *et al*., 2008; Dhupper, 2012; Thumma *et al*., 2012; Bromham *et al*., 2013). The objectives of the experiment were to find out critical limit of water stress tolerance, efficient water use and to quantify water loss from seedlings of the different tree species as the hydrological behaviour in relation to gas exchange.

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23.2 METHODOLOGY

23.2.1 Site descriptions

The study was conducted at the experimental field of Arid Forest Research Institute, Jodhpur (Latitute 26°45`N, Longitude 72°03 E) in Rajasthan, India. The climate of the site is tropical and characterized by hot and dry summer, hot rainy season, warm autumn and cool winter. Summer is the most dominant season characterized by high temperature (reaches up to 48°C in month of May) spreading over March to mid July and experienced strong winds (usually 20-30 km h^{-1} and occasionally 130 km h^{-1}). The period from mid-July to September is the monsoon season, which receives most of the rainfall. The mean annual rainfall is 370 mm with 65 per cent coefficient of variation and the mean annual pan evaporation is 2,025 mm indicating high water deficit in the area. Soil of the experimental site is aridisol "coarse loamy, mixed, hyperthermic of Typic Haplocambids" as per the USDA classification. The soil texture is loamy sand (83.8 per cent), silt (11.16 per cent) and clay (5.1 per cent) and had low soil organic matter (0.14 per cent, 0.13 per cent and 0.17 per cent; soil depth of 0-25, 25-50 and 50-75 cm, respectively). The soil has a pH of 7.88, EC 0.70 dSm^{-1} and a water holding capacity of 10.67 per cent (w/w) at –0.03 MPa and 3.23 per cent at –1.5 MPa. The soil was low in KCl extractable nitrogen (10.99 mg kg^{-1}), Olsen's available phosphorous (5.46 mg kg^{-1}) and ammonium acetate extractable potassium (109 mg kg^{-1}).

23.2.2 Plantation establishment

One-year-old seedlings of *Dalbergia sissoo*, *Eucalyptus camaldulensis* and *Acacia nilotica* from a single provenance were planted in July 1998 in the infilled non-weighing type lysimeter (RCC type) of size 2m × 2m × 2m. The lysimeter tanks were simulated similar to the soil condition of a nearby field. A drainage pipe covered with glass wool was provided for proper drainage of the excess water. The planted lysimeters were distributed into five groups to maintain them at five varying irrigation treatments. Each treatment was taken in three replications and experiment was laid in Randomised Complete Block Design. There was one planted seedling in each lysimeter (Singh and Singh, 2009).

23.2.3 Soil water content and irrigation levels

Soil water content and pressure relation was developed with the help of pressure plate apparatus (Table 23.1). The experiment had five treatments comprising five different irrigation levels depending on the soil water content at different pressures. Irrigation treatments were initiated in the first week of October 1998 after proper establishment of the seedlings. At the time of treatment initiation, soil of all the lysimeters was fully saturated at field capacity by addition of water and drainage of excess water was allowed till the soil water ceased to drain down. Different irrigation levels were: 36.2 mm (W_1), 26.5 mm (W_2), 20.2 mm (W_3) and 18.1 mm (W_4) given throughout the experimental period. There was a control in which no further water was added to the tanks after initial saturation (W_5). Soil water content of top 100 cm soil layer was monitored gravimetrically after oven drying of the soil samples at 105°C temperature to a constant weight. Irrigation were based on the percent soil water content (m/m) at the pressures of –0.03 MPa (10.7 per cent), –0.05 MPa (9.9 per cent), –0.10 MPa (7.4 per cent), –0.50 MPa (5.6 per cent), –1.00 MPa (4.3 per cent), and –1.50 MPa (3.2 per cent). The seedlings were re-irrigated by addition of differences in soil water content between –0.05 to –0.10 MPa (W_1 20 mm), –0.10 to –0.50 MPa (W_2 14 mm), –0.50 to –1.00 MPa (W_3 10 mm), and –1.00 to –1.50 MPa (W_4 8 mm) when the soil water content reached 7.4, 5.6, 4.3, and 3.2 per cent in the respective treatment. No irrigation was done in the control (W_5)after maintaining it at field capacity initially (Singh and Rathod, 2010; Singh, 2011). The experiment was terminated in the last week of October 2000.

Table 23.1: Relation of suction pressure and soil water content of the soil of lysimeter and corresponding quantity of water per irrigation (mm) in 0-100 cm soil layer.

Treatment	Suction pressure (-MPa)	Soil water content (per cent)	Quantity of water per irrigation	
			(mm)	(liter)
W_1	0.05 – 0.10	9.97 – 7.56	36.2	144.8
W_2	0.10 – 0.50	7.56 – 5.79	26.5	106.0
W_3	0.50 – 1.00	5.79 – 4.44	20.2	80.8
W_4	1.00 – 1.50	4.44 – 3.23	18.1	72.4
W_5	– 0.03 – till death	10.67 – till death	325.0 (one time)	1300 (7.4m^3 soil)

23.2.4 Observation recording

Physiological variables like leaf water potential (Ψ_l), rate of photosynthesis (P_N), rate of transpiration (E) and stomatal resistance (R) were recorded when water content of the soil approached 7.4 per cent in W_1, 5.6 per cent in W_2, 4.3 per cent in W_3, and 3.2 per cent in W_4 treatment. Leaf water potential (Ψl) was recorded in triplicate at one month interval for each treatment using HR 33 T Dew Point micro-voltmeter (Logan, UT, USA). Leaf water potential was recorded between 05:00 to 07:00 from October 1998 to February 2000, before any significant transpiration was realized. The Ψ_l measurements of November 2009 and December could not be done due minor repairing problems in the instrument. Measurements of Ψ_l were conducted on the three replicate samples of each treatment per species.

P_N, E and R were recorded in triplicate at 10:00 to 11:00 in open system with portable CO_2 gas analyser, model CI-301 (CT-301 PS0; CID, Vancouver, USA) and subsequently averaged to provide a mean value for each solar time in a month. All these observations were recorded for leaves of middle canopy of the seedlings. Self shading within the cuvette was minimised by ensuring that the leaves did not overlap, particularly in the

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Table 23.2: Partitioning of water loss from the area and seedlings of different tree species irrigated at 36.2 mm level during summer months of 2002 (mulches of *C. burhia* and *A. funiculata*).

Parameters	No plant	*E. camaldulensis*	*A. nliotica*	*D. sissoo*
Plot area (m^2)	4	4	4	4
Study period	2 April - 8 June	31 March -30 May	28 March -29 May	25 March -1 June
Number of days	68	61	63	69
Number of irrigation	3	8	6	5
Total irrigation (mm)	108.6	289.6	217.2	181.0
PET* (mm)	1.60	4.75	3.45	2.62
PET (liters)	6.40	19.00	13.80	10.40
Transpiration loss (lit day^{-1})	-	12.60	7.40	4.00
Loss from open surface (lit day^{-1})	7.00	-	-	-

*PET: potential evapo-transpiration (evaporation + transpiration). Source: Singh and Rathod (2012)

seedlings of W_3, W_4, and W_5 treatments, the leaves of which were comparatively smaller than those in W_1 and W_2 treatments (Singh and Singh, 2003). Stomatal conductance (*gs*) was calculated as 1/stomatal resistance (R). Instantaneous WUE was calculated as the ratio of rate of photosynthesis (P_N) to rate of transpiration (E).

23.2.5 Statistical analysis

Physiological variables under different irrigation levels were analyzed using a one way ANOVA. Irrigation level was the fixed effect and within treatment variations were the error term. Since the data were collected for twenty four months, i.e. two year continuously the data were also analyzed by repeated measure ANOVA considering different physiological parameters as the dependent variable. Months were the between subject effects and the treatments were the within subject effects. Variations were the error term. Protected LSD was used as comparisons at a threshold P = 0.05 to test for differences among the treatments and the months. Multiple regression technique was also used to observe relationships of Ψ_l, P_N, and E with soil water availability and the environmental variables. Relationships were also observed among different physiological variables.

23.3. RESULTS AND DISCUSSION

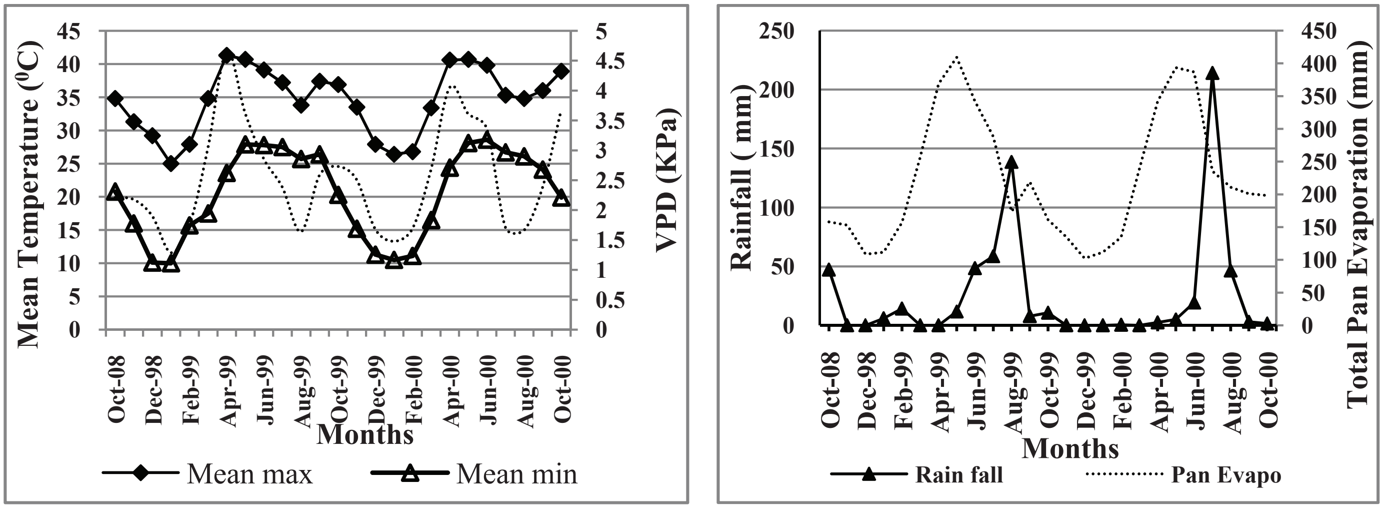
23.3.1 Irrigation frequency and total water use

Re-irrigating the seedlings when the soil water content approached to 7.56 per cent (- 0.10 MPa), 5.79 per cent (- 0.50 MPa), 4.44 per cent (- 1.00 MPa) and 3.23 per cent (- 1.50 MPa) in W_1, W_2, W_3 and W_4 treatments, respectively affected the frequency of irrigation in a year. The frequency of irrigation was highest for the seedlings of W_1 and decreased to the lowest number of irrigation in W_4 treatment (Annexure 23.1). Furthermore, frequency of irrigation increased in second year than that in the first year. Based on the observations on maintaining treatments up to the lowest soil water content in respective treatment, number of irrigations varied both due to species and the treatment (Annexure 23.1). Number of irrigations per year decreased with increase in soil water stress. It increased however with age of the plants. Total number of irrigations was 21.9, 29.2, 32.6 and 35.1 per year for one, two, three and four year old *E. camaldulensis* seedlings in W_1 treatment, respectively for example. It indicates that frequency of irrigation should be high with increase in age of the plants. Lowest number of irrigation and hence low quantity of water is required for raising *D. sissoo* plantation. There is clear seasonal variation in water requirement and irrigation frequencies (number of irrigation per year) was high in summer followed by spring and winter. It was low during winter months (Annexure 23.2).

23.3.2 Partitioning in water loss

Monitoring water loss partitioning in the form of transpiration and evaporation (during March to June 2002) after irrigation at the rate of 36.2 mm per irrigation indicated highest amount of water loss from bare soil surface and was greater as compared to soil surface covered with *Crotolaria burhia* and *Aristida funiculata* mulches. Total loss from the (4 m^2 area) plantation of *E. camalulensis* was 4.75mm day^{-1} (19 litres day^{-1}) as compared to loss of 3.45 mm day^{-1} (13.8 litres day^{-1}) from *A. nilotica* plot and 2.62 mm day^{-1} (10.4 litres day^{-1}) from *D. sissoo* plot (Table 23.2). The respective partitioning between transpiration and evaporation was 66 per cent and 34 per cent in *E. camaldulensis* plot, 54 per cent and 46 per cent in *A. nilotica* plot and 38 per cent and 62 per cent in *D. sissoo*. The loss from bare soil surface (without mulch) was 7.0 litre day^{-1}. This suggests that provision of simple mulching can saves the loss of 0.16 mm day^{-1} of soil water (Singh and Rathod, 2012).

Figure 23.1: Mean monthly maximum and minimum temperature and vapour pressure deficit (left panel) and rainfall and total pan evaporation (right panel) at the experimental site.



23.3.3 Environmental variables

Environmental variables like air temperature, vapour pressure deficit (VPD), potential evapotranspiration varied within day and months. Mean monthly minimum and maximum lower air temperatures were 10.0 °C and 25.0°C in January 1999 and increased gradually to range between 27.9°C and 40.7°C, respectively in May 1999 which was at par for air temperature in May 2000 except mean minimum air temperature (28.1°C). These temperatures increased from their lowest value at 08:00 to 13:00 hr and decreased in the evening (17:00 hs). Vapour pressure deficit increased from 1,286 Pa (389 in morning to 2,183 Pa at midday) in January to 5,115 Pa (2,943 in morning to 7,753 Pa at midday) in May (Figure 24.1, left panel). Rainfall was 636 mm and total pan evaporation was 5,598 mm during October 1998 to October 2000 showing high water deficit at the experimental site (Figure 23.1, right panel). Potential evapotranspiration fluctuated between 2.47 mm d^{-1} in December to 8.54 mm d^{-1} in May (Rao *et al*., 1971). Photosynthetically active radiation (PAR) increased from the lowest at 08:00 hr to midday (13:00 hr) and decreased during the post dawn period. Maximum PAR oscillated between 1060 μmol m^{-2} s^{-1} in January 1999 to 1933 μmol m^{-2} s^{-1} in May 1999.

23.3.4 Water relations

Predawn leaf water potential (Ψ_l) varied as a function of soil water potential (Ψ_{soil}) and vapour pressur deficit. Ψ_l varied significantly (P>0.050) among the species across the irrigation levels and years/months.Among species, *E. camaldulensis* seedlings maintained higher Ψ_l as compared to *A. nilotica* and *D. sissoo* across the treatments and number of observations. Averaging for the treatments, seedling of W_1 maintained the highest leaf water potential (Ψ_l) in the all three species (Table 23.3). With increasing soil water stress from W_1 to W_5, the drop in Ψ_l was significant (P > 0.05) among the treatment in all three species. The Ψ_l decreased by 20 per cent and 29 per cent at W_3 and W_4, whereas the reduction was up to 54 per cent at W_5 treatment in *D. sissoo* seedlings. The reduction in the Ψ_l was by 13 per cent, 22 per cent and 57 per cent in *E. camaldulensis* and 11 per cent, 17 per cent and 73 per cent in *A. nilotica* seedlings at W_3, W_4 and W_5 treatment, respectively, as compared to Ψ_l in W_1 treatment in respective species. This indcates that *D. sissoo* maintained low Ψ_l at W_3 and W_4 level of irrigation and high Ψ_l at W_5 level of irrigation when compared with the other two species.

Interestingly, *A. nilotica* maintained higher Ψ_l at W_3 and W_4 irrigation levels than in the *E. camaldulensis* and *D. sissoo*, but at W_5 level of irrigation it showed lowest. Temporal variations in Ψ_l were significant (P < 0.05) between both months as well as the species. $\Psi_l$was the highest (-1.58 MPa) in the month of January in *D. sissoo* seedlings followed by March (-1.89 MPa) and July (-1.99 MPa).It declined in themonths of April and August. $\Psi_l$was observed lowest (-3.57 MPa) in the month of June indicated negative relation to soil water stress and air temperature. DMRT indicated similar Ψ_l of March and July, July and August, August, September and April in *D. sissoo* seedlings. Seedlings of *E. camaldulensis* showed highest (-0.99 MPa) Ψ_l in month of November followed by December (-1.001 MPa), January (-1.02 MPa) and February (-1.04 MPa). The lowest Ψ_l was observed in the month of July and August (-1.31 MPa). Ψ_l of March and October, April and September or July and August did not differ (P>0.05) in *E. camaldulensis* seedlings. For *A. nilotica* seedlings Ψ_l was highest (-1.13 MPa) in January followed by December (-1.14 MPa), November (-1.15 MPa) and February (-1.15 MPa).Ψ_l was lowest in July (-1.39 MPa). DMRT indicated significant (P<0.05) difference in Ψ_l in *A. nilotica* seedlings among the months. Temporal variations in Ψ_l were lowest in *E. camaldulensis* seedlings, whereas the variations were highest in *D. sissoo* seedlings.

Table 23.3: Effect of different levels of irrigation on two years average (24 months) predawn leaf water potential (Ψ_l) of different species.

Tree species	Irrigation levels				
	W_1	W_2	W_3	W_4	W_5
D.sissoo	-2.04	-2.17	-2.37	-2.63	-3.21
	F = 271.23; P< 0.005				
E.camaldulensis	-0.90	-0.94	-1.01	-1.09	-1.44
	F = 18717.77: P< 0.005				
A. nilotica	-0.97	-1.01	-1.08	-1.14	-1.66
	F = 58027.27; P< 0.005				

Table 23.4: Average rate of photosynthesis (μmol m^{-2} s^{-1}) influenced by different levels of irrigation on the seedlings of different tree species. Values are mean of three replications.

Irrigation level	*E. camaldulensis*	*D. sissoo*	*A. nilotica*
W_1	*5.70*	3.88	4.96
W_2	*4.70*	3.33	4.00
W_3	*2.63*	2.71	2.48
W_4	*1.95*	2.10	1.77
W_5	*0.85*	1.24	0.94
F value	31.85	20.32	22.22
P value	<0.05	<0.01	<0.05

23.3.5 Gas exchange

23.3.5.1 Rate of photosynthesis

Rate of photosynthesis (P_N) differed significantly ($P<0.05$) among the irrigation levels and the species. Average across irrigation levels and years/months, *E. camaldulensis* seedlings maintained highest ($P<0.01$) rate of photosynthesis (3.17 μmol CO_2 m^{-2} s^{-1}) as compared to *D. sissoo* (2.65 μmol CO_2 m^{-2} s^{-1}) and *A. nilotica* (2.83 μmol CO_2 m^{-2} s^{-1}). However, the seedlings of *D. sissoo* in T_5 treatment had high P_N compared to other two species. P_N was highest for the seedlings in W_1 treatment for all species (Table 23.4). There was a decrease in P_N with decrease in irrigation levels from W_1 to W_5. At irrigation level W_2, there was a 17.5 per cent, 14.6 per cent and 19.4 per cent decline in mean photosynthesis rate. However, the decline in P_N was by 54.0 per cent, 30.0 per cent and 50.6 per cent at W_3 and by 66.0 per cent, 46.0 per cent and 63.2 per cent at W_4 as compared to P_N in the seedlings of W_1 treatment. In severely water stressed treatment (W_5), the photosynthetic rate registered the lowest values of 0.85, 1.10 and 0.94 μmol m^{-2} s^{-1} for the respective species. P_N increased in both growing seasons viz. February to March-April and July to September and decreased thereafter (Figure 23.2) showing lowest value during winter. Significant species × irrigation treatment ($P<0.01$) indicated that variation in P_N depended upon both the levels of irrigation as well as on the type of species.

In seedlings of W_1 treatment P_N ranged between 1.21 μmol CO_2 m^{-2} s^{-1} and 8.0 μmol CO_2 m^{-2} s^{-1} in *D. sissoo* between 2.18 μmol CO_2 m^{-2} s^{-1} and 8.90 μmol CO_2 m^{-2} s^{-1} in *E. camaldulensis* and between

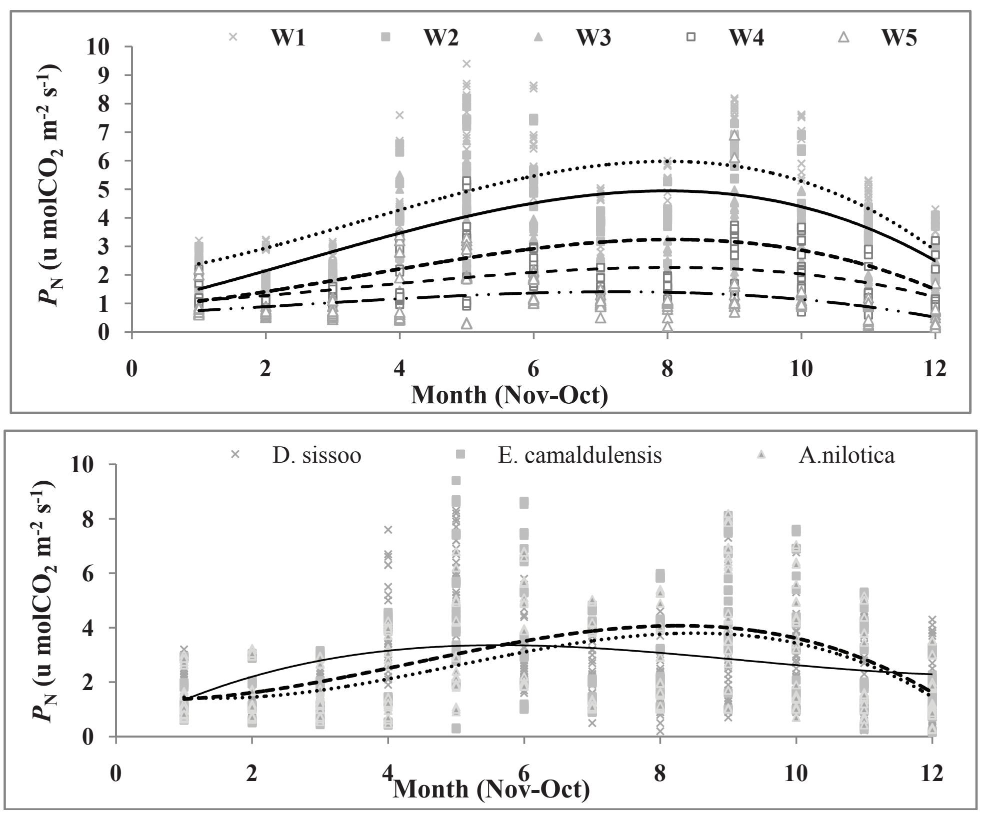


Figure 23.2: Temporal changes in rate of photosynthesis (P_N) under different levels of irrigation (top, across species) and different tree species (bottom, across irrigation levels). Observed data are indicated by points, whereas estimated ones are shown by line diagram.

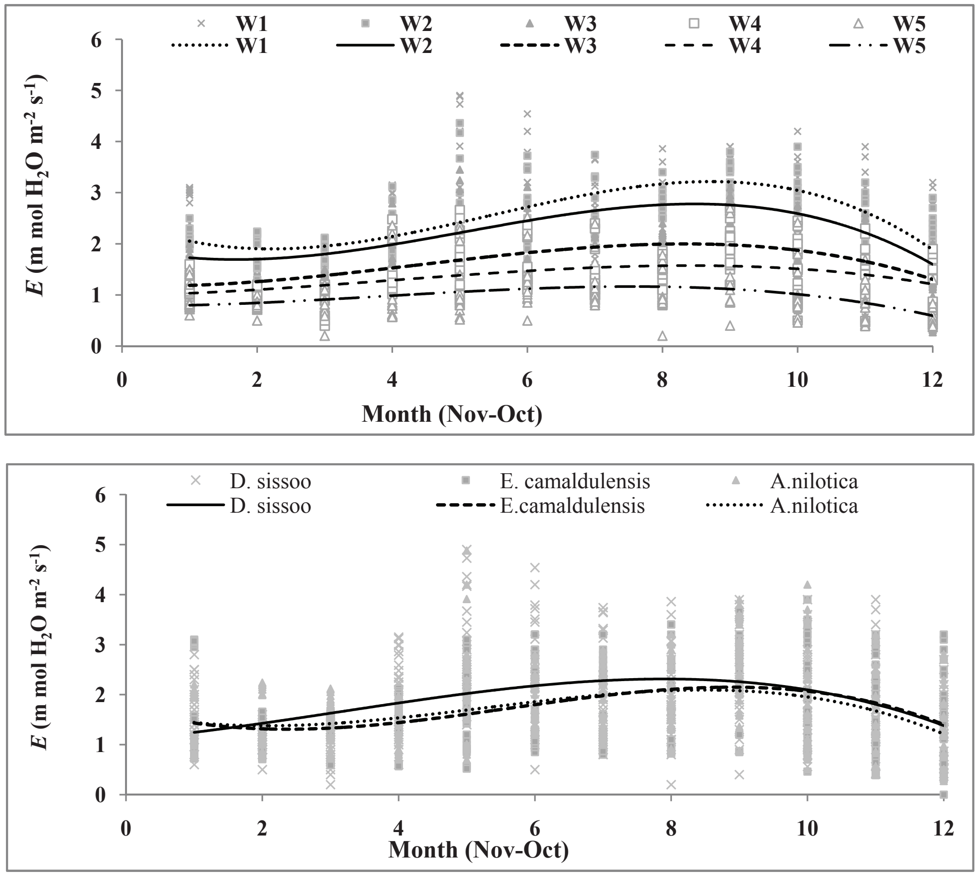


Figure 23.3: Temporal changes in rate of transpiration (*E*) at different irrigation levels (top, across species) and tree species (bottom, across irrigation levels). Observed data are indicated by points, whereas estimated ones are shown by line diagram.

1.81 and 8.00 in *A. nilotica*. Average P_N in W_1 was 3.1-fold in *D.sissoo*, 6.7-fold in *E. camaldulensis* and 5.3-fold in *A. nilotica* as compared to respective species at W_5 level. DMRT indicated that P_N differed significantly ($P<0.01$) among the months except in October, November, December and January for the seedlings of *E. camaldulensis*, in September, October, November, May and June in the seedlings of *D. sissoo* and in most of the months in the seedlings of *A. nilotica*. Seasonal variation in P_N of all three species was significant ($P<0.01$), but difference between highest and lowest values of P_N was highest at W_1 treatment and decreased with decrease in irrigation level (Figure 23.2, top). P_N was lowest during winter months of November to January and highest during monsoon period of July to September because of favourable atmospheric humidity and temperature. These species showed a bimodal pattern of changes in P_N with two maxima, one during February to April and the second in July to September. However, it varied among the species. For example highest value of P_N was in spring in the seedlings of *D. sissoo*, whereas it was highest during monsoon in the seedlings of *E. camaldulensis* and *A. nilotica* (Figure 23.2, bottom). However it has to be pointed out here that the stressed seedlings of *A. nilotica* (i.e., W_3, W_4 and W_5 treatments) maintained high rate of photosynthesis followed by *D. sissoo* and *E. camaldulensis* during the summer months. Thus based on the average photosynthetic response the irrigation levels can be grouped into three categories like W_1 and W_2,$W_3$and W_4, and W_5.

23.3.5.2 Rate of transpiration

Transpiration rate (*E*) of tree seedlings differed significantly ($P<0.05$) among the irrigation levels as well as tree species (Table 23.5). *A. nilotica* transpired with highest average rate (1.85 m mol H_2O $m^{-2}s^{-1}$) compared to *E. camaldulensis* (1.78 m mol H_2O m^{-2} s^{-1}) and *D. sissoo* (1.72 m mol m^{-2} s^{-1}). Decreased level of irrigation from W_1 to W_5 resulted in a decline in average *E* values (ranging from 2.65 m mol H_2O $m^{-2}s^{-1}$ in W_1 to 0.90 m mol H_2O $m^{-2}s^{-1}$ in W_5 treatment) across species. The highest *E* was observed in the seedlings of W_1 treatment. Increase in soil water stress reduced *E* by 12.9 per cent, 20.9 per cent and 9.6 per cent in the seedlings of W_2 treatment. The decline in rate of transpiration was 37.3 per cent, 37.2 per cent and 35.1 per cent, respectively, for the seedlings of W_3 treatment. The reduction was maximum for the severely water stressed seedlings of W_5 treatment with transpiration rate of 0.76, 1.11 and 0.83 m mol H_2O m^{-2} s^{-1}. Rate of transpiration in the seedlings of W_1 was 2.3-fold greater in *D. sissoo*, 3.6-fold greater in *E. camaldulensis* and 3.3-fold greater in *A. nilotica* as compared to the values of *E* at W_5 level in respective species. This indicates that the reduction in *E* was relatively greater up to W_3 in *D. sissoo* as compared to other two species, but later on the decline was more for the seedlings of *E. camaldulensis* (W_4 and W_5 treatments), where *A. nilotica* and *D. sissoo* maintained higher *E* in the respective treatment. This indicates conservative nature of *E. camaldulensis* in transpiring water at severe stress or during winter and liberal use of water at sufficient soil water availability or under conducive environments. Rate of transpiration also

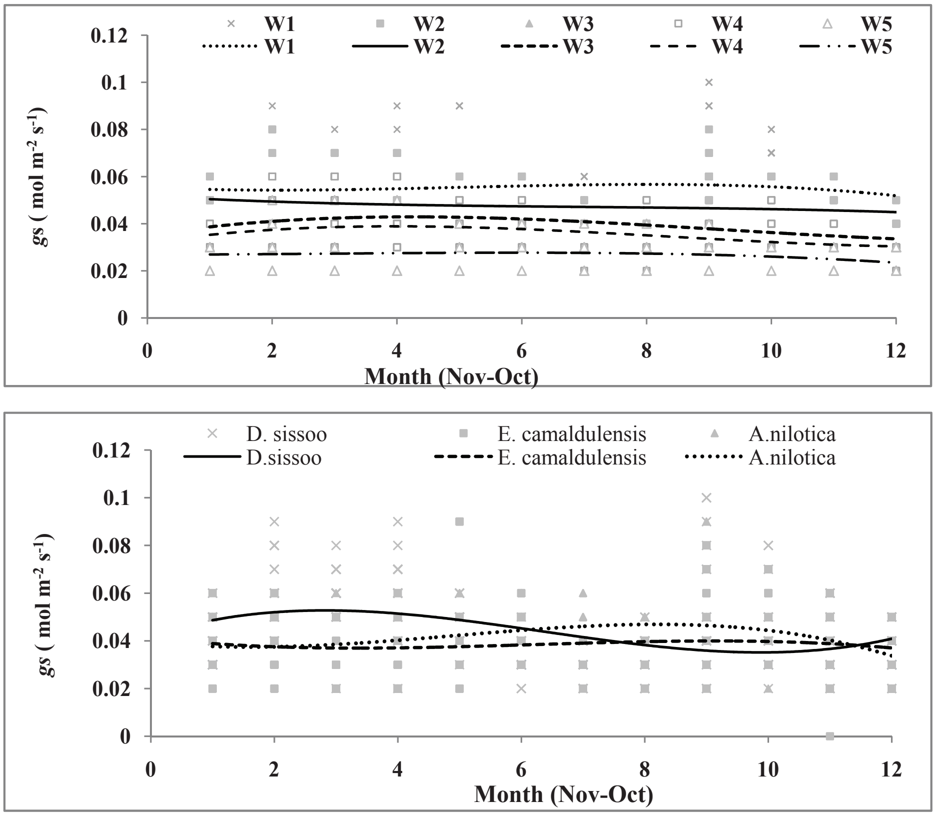


Figure 23.4: Periodical changes in stomatal conductance (*gs*) influenced by irrigation levels (top, averaged across species) and tree species (bottom, averaged across the irrigation level).

exhibited seasonal pattern, in which it showed highest *E* values either during February to April or during July to September, i.e., two maxima and two minima (Figure 23.3, observed pattern). The lowest rate of transpiration was observed during winter months of December to January, after which it showed an increasing pattern in *E*. The seasonality in *E* was more pronounced in W_1 and W_2 treatments, after which it was less evident, though *E* increased during monsoon period probably due to improved environmental conditions. Thus W_1 and W_2 fell into one group, whereas W_3 and W_4 fell into second group with very less difference with W_5 treatment. Among the species, *E. camaldulensis* and *A. nilotica* transpired with high rate during July to October, whereas *D. sissoo* transpired with high rate during spring season. Thusboth*A. nilotica* and *E. camaldulensis* followed similar pattern of transpiration, whereas *D. sissoo* followed a different pattern (Figure 23.3, bottom).

Table 23.5: Effect of varying levels of irrigation on rate of transpiration (m mol H_2O m^{-2} s^{-1}) for the seedlings of different tree species. Values are mean of three replications.

Irrigation level	Eucalyptus camaldulensis	*Dalbergia sissoo*	*Acacia nilotica*
W_1	*2.71*	2.53	2.71
W_2	*2.38*	2.00	2.45
W_3	*1.70*	1.59	1.76
W_4	*1.33*	1.38	1.48
W_5	*0.76*	1.10	0.83
F value	39.74	5.06	24.96
P value	<0.05	<0.01	<0.05

23.3.5.3 Stomatal conductance

The effect of irrigation on stomatal conductance (*gs*) differed significantly (P<0.05) among the irrigation levels as well as the tree species. Average *gs* (across the irrigation levels and months) was highest in *A. nilotica*, i.e. 39.57 × 10^{-3} mol m^{-2} s^{-1} as compared to 30.56 × 10^{-3} mol m^{-2} s^{-1} for *D. sissoo* and 35.67 × 10^{-3} mol m^{-2} s^{-1} for *E. camaldulenis*. This indicates lowest value of *gs* for the seedlings of *D. sissoo* at all irrigation levels. Interestingly *E. camaldulensis* maintained almost average value of *gs* of all three species. Stomatal conductance was high when soil water availability was sufficient (W_1 and W_2 treatments) in all species (Table 23.6). It decreased gradually as soil water stress intensified particularly from W_3 onwards. As compared to the value in W_5 treatment, the increase in *gs* was 1.3-fold, 1.6-fold, 2.0-fold and 2.2 fold for the seedlings of W_4, W_3, W_2 and W_1 treatment, respectively. However, increase in *gs* ranged from 1.2-fold in W_4 to 2.6-fold in W_1 treatment in *D.sissoo*, 1.5-fold in W_4 to 2.3-fold in W_1 treatment in *E. camaldulensis* and 1.3-fold in W_1 to 1.9-fold in W1 treatment in *A. nilotica* as compared to the value in W_5 treatment. Thus lowest variability in *gs* was in *A. nilotica*, whereas it was highest in case of *D. sissoo*.

Stomatal conductance indicated a clear seasonal pattern (Fig 23.4). The variations in *gs* was significant (P<0.01) particularly during growing period of February to March and July to August in all species. The seedlings of W_1 and W_5 treatments showed highest *gs* during monsoon period of July-August after a lowest

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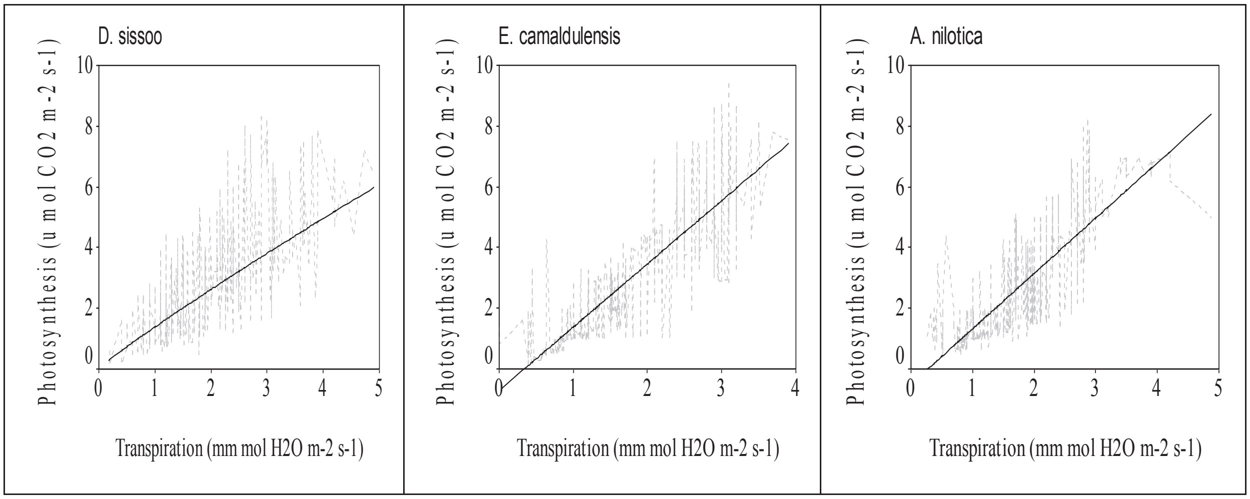
Figure 23.5: Relationships between rate of photosynthesis (P_N) and rate of transpiration (E) in different species across the irrigation levels.



value during winter. Seedlings of W_2 did not exhibit any seasonal trend in *gs*, whereas the seedlings of W_3 andW_4 treatments showed similar pattern with highest *gs* during spring (February to March). The stomatal conductance was lowest during peak summer period in both the year 1999 and 2000. This indicates that increased water availability is favourable for stomatal conductance. *D. sissoo* maintained higher *gs* during March, whereas *A. nilotica* exhibited higher *gs* during summer months of March to September, whereas *E. camaldulensis* exhibited almost same *gs* throughout the year. Thus all three species exhibited different seasonal pattern in stomatal conductance, though also influenced by availability of soil water.

Table 23.6: Effect of different levels of irrigation on the stomatal conductance ($\times 10^{-3}$mol m^{-2} s^{-1}) of *D. sissoo, E. camaldulensis*and*A. nilotica*seedlings. Values are mean of three replications.

Irrigation level	E. camaldulensis	*D. sissoo*	*A. nilotica*
W_1	48.80	45.96	50.63
W_2	42.25	39.87	46.64
W_3	34.46	28.00	40.06
W_4	31.47	21.21	34.19
W_5	21.36	17.76	26.31
F value	49.82	11.96	36.88
P value	<0.05	<0.01	<0.01

23.3.5.4 Instantaneous water use efficiency (WUE)

Instantaneous water use efficiency (WUE, P_N /E) varied (P<0.01) both due to irrigation levels as well as across tree species. Average WUE was 1.64 × 10^{-3} mol CO_2 assimilation per mol of H_2O use for *E. camaldulensis*as compared to 1.51 mol CO_2 assimilation per mol H_2O use for *D. sissoo* and 1.49 mol CO_2 assimilation per mol H_2O use for *A. nilotica* seedlings across the irrigation levels. While considering irrigation levels across species WUE decreased with increasing water stress ranging between 1.82 mol CO_2 assimilation per mol H_2O use in the seedlings of W_1 and 1.12 mol CO_2 assimilation per mol H_2O use in the seedlings of W_5 treatment. This was probably due less effect of water stress on rate of transpiration compared to rate of carbon dioxide assimilation (P_N). Interestingly WUE, which depended upon species characteristics, also depended upon soil water availability. WUE was greater for the seedlings of $W_2$and W_3 treatments as compared to the seedlings of W_1 treatment in case of *D. sissoo*, but declined in severely stressed seedlings of W_4 and W_5 treatments (Table 23.7). However, at high soil water availability in W_1 and W_2 treatments, WUE was highest for the seedlings of *E. camaldulensis* and *A. nilotica* (W_1 only) than *D. sissoo* but a reverse trend was recorded at other levels of irrigation. Thus *E. camaldulensis* was an efficient water user at highest levels of soil water availability, whereas *D. sissoo* was an efficient soil water user at mild soil water stress.

23.3.6 Relationships in different physiological variables

Rate of photosynthesis (r^2 = 0.49, 0.73 and 0.69, P<0.01, respectively *D. sissoo*, *E. camaldulensis* and *A. nilotica*) and rate of transpiration (r^2 = 0.50, 0.75 and 0.67, P<0.01, respectively *D. sissoo*, *E. camaldulensis* and *A. nilotica*) both exhibited positive correlations to quantity of irrigation levels, i.e. soil water availability. Photosynthesis rate (P_N) and transpiration rate (E) were related to each other by a power equation ($Y=1.388X^{0.9184}$; R^2=0.522, $F_{1/334}$=364.1, P<0.001) in *D. sissoo* and by linear equations in *E. camaldulensis* (Y=2.083X-0.7029; R^2=0.699, $F_{1/353}$=818.3, P<0.001) and *A. nilotica* (Y=1.824X-0.4495; R^2=0.655, $F_{1/346}$=655.5, P<0.001) species (Fig 24.5). Slope gradients of these equations indicated relatively greater variations in these physiological variables in *E. camaldulensis* (2.083) as compared to *D.* sissoo (1.388) and *A. nilotica* (1.824) with changes in soil water availability.

Rate of photosynthesis exhibited linear relationships with stomatal conductance in *D. sissoo* (Y=47.519X+0.6579; R^2=0.180, $F_{1/331}$=72.56, P<0.001) and *E. camaldulensis*

Table 23.7: Effect of varying levels of water stress on instantaneous water use efficiency ($\times 10^{-3}$ mol CO_2m assimilation per mol H_2O use) for the seedlings of different tree species.

Irrigation level	E. camaldulensis	*D. sissoo*	*A. nilotica*
W_1	*2.10*	1.53	1.83
W_2	*1.97*	1.67	1.63
W_3	*1.55*	1.70	1.39
W_4	*1.47*	1.52	1.21
W_5	*1.11*	1.13	1.13

(Y=125.70X-1.9984; R^2=0.578, $F_{1/353}$=482.4, P<0.001), whereas P_N increased exponentially with increase in stomatal conductance in case of *A. nilotica* (Y=53.428e$^{(0.211/X)}$; R^2=0.706, $F_{1/348}$=835.5, P<0.001). However, rate of transpiration was linearly related to stomatal conductance in all species, i.e. *D. sissoo* (Y=14.41X+1.2615; R^2=0.062, $F_{1/333}$=21.91, P<0.001) *E. camaldulensis* (Y=46.05X-0.0695; R^2=0.484, $F_{1/352}$=329.6, P<0.001) and *A. nilotica* (Y=54.734X-0.6162; R^2=0.577, $F_{1/346}$=471.65, P<0.001). Highest slope gradient (54.73) in *A. nilotica* followed by *E. camaldulensis* and *D. sissoo* indicates that change in rate of transpiration is high (more sensitive) in *A. nilotica* as compared to other species. Further, change P_N was relatively greater than *E* suggesting more sensitive nature of P_N as compared to E towards change in environmental variables including soil water availability. Thus effects of soil water availability/stomatal conductance was more on rate of photosynthesis than on rate of transpiration. While comparing among species increased stomatal conductance enhances P_N in order of *D. sissoo* <*E. camaldulensis* <A. *nilotica*. Similar order was observed for rate of transpiration too (Figure 23.6).

23.4. RESULT AND DISCUSSION

23.4.1 Soil water use and frequency of irrigation

Soil water stress, i.e., decreased level of irrigation impaired physiological functions and biomass production. Decreased irrigation levels from W_1 to W_5 treatments affected soil water availability, carbon assimilation and growth and phenology of the planted seedlings of *D. sissoo*, *E. camaldulensis* and *A. nilotica* (Figure 23.7). Irrigation at W_1 level maintained sufficient soil water availability but required frequent irrigation, i.e. increasing frequency of irrigation. Lam *et al*. (1994) observed that plant available soil water is linearly related to irrigation amount. High rate of soil water depletion either due to utilization by the growing seedlings or evaporation losses resulted in an increase in frequency of irrigation, though surface evaporation of water depends upon varying factors including surface cover (Van Wesemael *et al*., 1996; Singh, 2011; Singh *et al*., 2013). Reduced irrigation level decreases soil water potential affecting soil water availability negatively both for its use for seedling growth as well as surface evaporation loss because the soil water becomes more tightly held at low soil water potential (Singh and Rathod, 2012). This reduced the frequency of irrigation when plants are irrigated at low levels like W_2 onwards treatments as evident in Annexures 23.1 and 23.2. Greater frequency of irrigation as well as total water input in 13 to 24 months than those in the 1 to 12 months old planted seedlings was due to increase in water use of the growing seedlings and increased plants size under the age effects. However, total water use by 13 to 24 months old seedlings in the present study was low as compared to the reported water use of 910 to 1,220 mm per year for *D. sissoo* (Khan, 2000). This indicates that increased irrigation level not only enhances soil water use but also promotes evaporation losses enhancing frequency of irrigation, though improves growth and biomass production. The observations of Bala *et al*. (2003) also indicate significant differences in the growth parameters in the field grown seedlings of *A. nilotica* (L.) Willed. Ex del, *E. camaldulensis* Dehnb and *D. sissoo* Roxb. Ex D.C. Prodr at varying levels of irrigation. Better performance of seedlings of W_1 and W_2 treatments than those in the other treatments might be due to more availability of water with positive effects on nutrients mobility, which influenced the physiological processes and ultimately enhances growth rate and biomass production (Marion and Everett, 2006; Singh, 2009). High soil water availability facilitates nutrient accumulation, leaf growth and number of leaves which convert more solar energy and fix more CO_2 to produce more photosynthates, and thus greater growth and biomass (Ceulemans *et al*., 1993, Singh and Singh, 2003). Sufficient soil water availability in these treatments probably maintained cell turgidity that favoured leaf area expansion, increase in leaf size and the overall biomass (Souch and Stephens, 1998).

23.4.2 Soil water availability and leaf water potential

Decreased Ψ_l in the seedlings of all tree species with decreasing irrigation levels, i.e. increasing soil water stress from W_1 to W_5 treatment was similar to observations on *Quercuspubescens* Willd growing in Mediterranean climate, where this species showed strong relations with soil water availability (Tognetti *et al*., 1999). In a study, Deb *et al*. (2013) observed that stress caused by decreasing soil water at different depths were generally significantly correlated with stem water potential, where soil water depletion was higher in upper soil layer of 0–40 cm where root length density was higher than in the deeper soil layer of 40–80 cm. A difference of 0.32 to 0.64 MPa in Ψ_l during first and second year indicated the highest amount of soil water loss in *D. sissoo* species seedlings as compared to the other species suppressing stomatal conductance and rate of transpiration. Despite an average difference in Ψ_l of 1.17 MPa, the seedlings of W_5 survived for more than two years indicating its strong adaptability to soil water stress and maintenance of gas exchange (Raftoyannis and Radoglou, 2002). Such increase in difference in Ψ_l between the seedlings of W_1 to that of W_2 onwards suggests that transpiration exceeds absorption (de-Sena *et al*., 2007). However, the differences in Ψ_l between the seedlings of W_1 and W_5 for *E. camaldulensis* and *A. nilotica* were 0.54 MPa and 0.69MPa, respectively. Such differences in Ψ_l might be due to decrease in hydraulic conductance of soil-leaf continuum (increase in resistance in water flow in soil-plant-atmosphere continuum) because of decreased cell turgor (Ni and

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Figure 23.6: Effects of stomatal conductance on rate of CO_2 assimilation (P_N, left panels) and rate of transpiration (*E*, right panels) in seedlings of tree species. Top: *D. sissoo*; Middle: *E. camaldulensis*; and Bottom: *A. nilotica*.

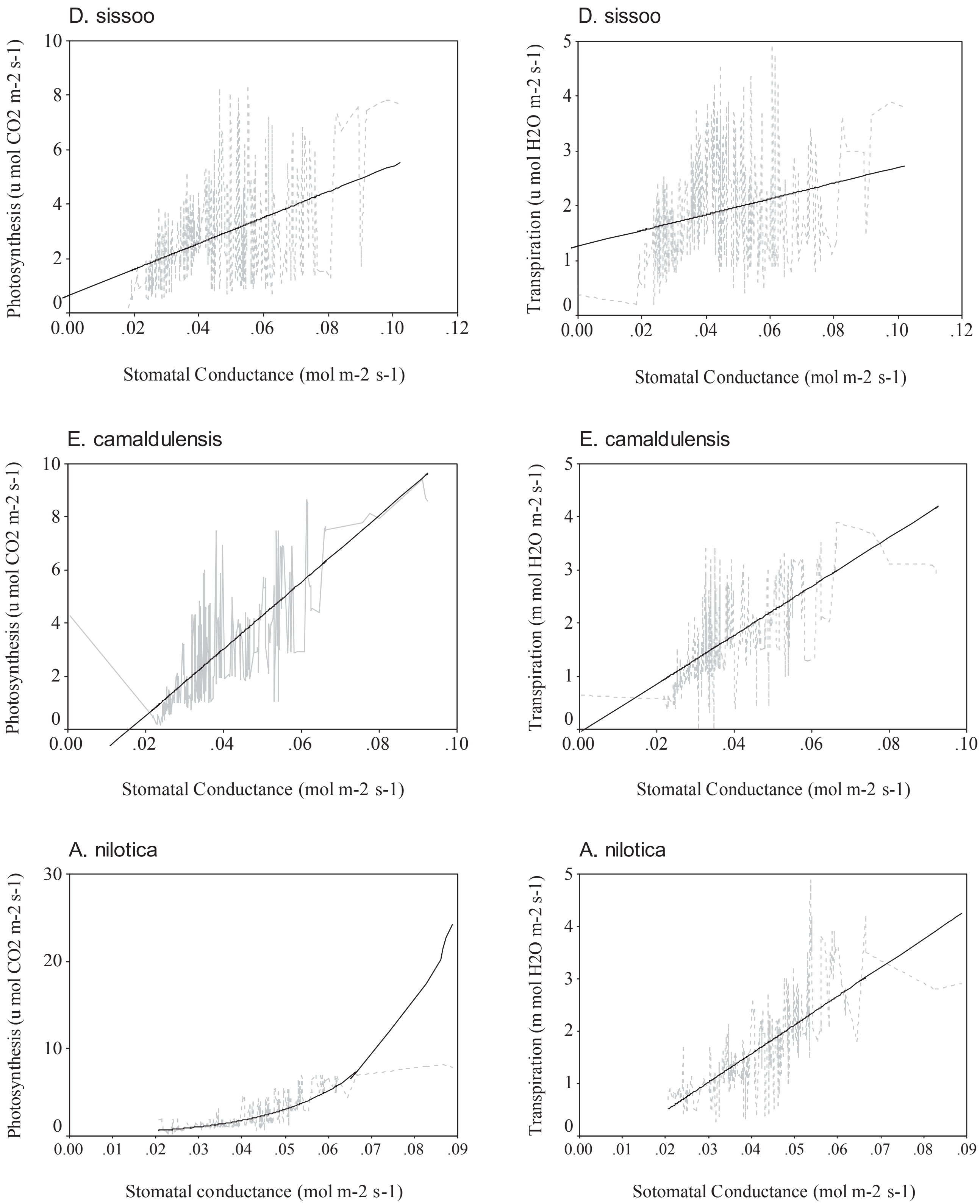

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Figure 23.7: Growth variation and phonological changes in different tree species under varying level of irrigation. Left: height growth difference in W_1 and W_5 level of irrigation in *D. sissoo*; Middle: plant of *E. camaldulensis* at W_5 and; Right: plant of *A. nilotica* at W_5 irrigation level.

Pallardy, 1990, Stiller *et al*., 2003). However, these were relatively high in *E. camaldulensis* and *A. nilotica* as compared to *D. sissoo* indicating greater adaptability of the former two species as compared to *D. sissoo* towards drought stress. Gradual decline in Ψ_1 for the seedlings of W_1 and W_2 treatments with increasing PAR and VPD from January to May indicated significant relations of these environmental factors with the seedling water status (Silva *et al*., 2003). The large daily and monthly variations in Ψ_1 in the seedlings of *D. sissoo* indicate that this species is very sensible to changes in soil water content thereby showing moderate drought tolerance. Whereas the low daily and monthly variations in Ψ_1 shows that *E. camaldulensis* and *A. nilotica* seedlings are less sensible to changes in soil water content which are more water stress tolerance as compared to *D. sissoo* seedlings. It could be due to a relative inability of the stomata to restrict water loss at low soil water availability (Miller *et al*., 1993) like that in *Q. robur* (Fort *et al*., 1997) and *Q. frainetto* (Fotelli *et al.* 2000). It is also evidenced by recovery in the growth of the seedlings of *A. nilotica* and *E. camaldulensis* in W_5 treatments when irrigated after drying to leafless conditions (Fig. 23.7).

23.4.3 Soil water and gas exchange

Highest values of P_N and E in the seedlings of W_1 and W_2 treatment of all species was related to high Ψ_1,*gs* and soil water availability. Enhanced CO_2 diffusion into mesophyll cells under increased soil water availability and g_s at -0.05 to -0.50 MPa suction pressure resulted in high CO_2 fixation, i.e. P_N compared to the seedlings of other treatments (Ni and Pallardy, 1991, Niinemets, 2012). The maximum value of g_s is closely linked to canopy photosynthetic capacity, leaf–air vapor pressure deficit, water potential gradient between soil and leaves, photosynthetically active radiation, and air temperature (Elliot and Vose, 1994). Decrease in soil water availability for the seedlings of all species in W_3 onward treatments reduced Ψ_1 significantly ($P<0.05$) affecting *gs* and other physiological variables negatively. It is also indicated by positive correlations between P_N (r^2 = 0.49, 0.73 and 0.69, $P<0.01$, respectively *D. sissoo*, *E. camaldulensis* and *A. nilotica*) and E (r^2 = 0.50, 0.75 and 0.67, $P<0.01$, respectively *D. sissoo*, *E. camaldulensis* and *A. nilotica*) with quantity of irrigation levels (Fort *et al*. 1998). However, the declining *gs* and P_N was more pronounced in the seedlings of *E. camaldulensis* and *A. nilotica* as compared to the seedlings of *D. sissoo*. Negative correlations of P_N, Ψ_1 and E with soil water stress (decreased irrigation level) also indicate higher drought tolerance behaviour in *E. camaldulensis* and *A. nilotica* seedlings as compared to *D. sissoo* seedlings (Allen *et al*., 1999). Linear relationships of P_N and E with stomatal conductance (except P_N in *A. nilotica*) clearly indicates that rate of CO_2 assimilation and rate of transpiration are very much controlled by functioning of stomata, which was related to soil water availability made by supplemental irrigation. However, relatively greater slope gradient of the equation for P_N as compared to E indicates that rate of photosynthesis is more sensitive to increased stomatal conductance (related positively to soil water availability) than the rate of transpiration. In a review Ashraf and Harris (2013) highlighted that photosynthesis is severely affected in all its phases by varying stresses, because the mechanism of photosynthesis involves various components, including photosynthetic pigments and photosystems, the electron transport system, and CO_2 reduction pathways, where any damage at any level caused by such stresses may reduce the overall photosynthetic capacity of the plant. However Yang *et al*. (2009) in their model observed that the simulated photosynthesis rates were not as sensitive to reduction in stomatal conductance as the simulated transpiration rates. Further, linear relationship between P_N and E suggests similar behaviour of these both variables towards soil water availability, their extent varied between the species depending upon the adaptability of these species towards drought stress. For example, increase in soil water availability through supplemental irrigation was more favourable for P_N as compared to E in the seedlings of *E. camaldulensis*, but with a reverse trend in the seedlings of *D.sissoo*. Low soil water availability for the seedlings of W_3 to W_5 treatments might limit evaporative leaf cooling resulting in a high leaf temperature than in the seedlings of W_1 and W_2 treatments affecting physiological functions, growth productivity of the planted seedlings (Singh and Singh, 2003). This suggests that response of both P_N and E towards increased irrigation level/soil water is for the seedlings of *E. camaldulensis* and *A. nilotica* than in the seedlings of *D. sissoo* and indicates their bio-draining efficiency.

Highest P_N in April-May and July –September months was probably due to optimum environmental factors such as air temperature, PAR and VPD, but increased air temperature, solar irradiations and vapour pressure deficit during summer months affected P_N and *E* negatively. However, highest variations in P_N as compared to *E* within the months also indicate that P_N was more sensitive to environment. Relatively lesser decrease/increase in *E* as compared to P_N with respective irrigation level suggests that *D. sissoo* seedlings failed to restrict water loss through stomata even at low soil water availability that resulted in low WUE in this species. This is supported by almost similar values of *gs* which imposes physiological limitation on transpiration in the seedlings (Waring and Landsberg, 2011). This indicates that non-stomatal factors play a major role in regulating P_N and *E* during high irradiation and high temperature (Addington *et al*., 2004; Roddy *et al*., 2013). A weak negative relation of VPD with P_N and *E* during summer months of April and May also suggests the effects of these environmental variables on gas exchange reducing the values of P_N and *E* (Moore *et al*., 2011; Waring and Landsberg, 2011).

23.4.4 Instantaneous water use efficiency

Relatively greater P_N as compared to *E* at higher soil water availability than at lesser soil water availability resulted in greater WUE at high level of irrigation. However, utilization of intercellular CO_2 by mesophyll cells, which is more directly related to photosynthesis than stomatal aperture, appeared to be the responsible factor in enhancing WUE in the seedlings of W_2 treatment of *D. sissoo* and the seedlings of W_1 treatment of *E. camaldulensis* and *A. nilotica* (Teskey *et al*., 1986, Singh and Singh 2003). Ni and Pallardy (1991) observed that decrease in concentration of intercellular CO_2 led to increase in WUE at mild water stress and was unaffected by stomatal conductance. Increase in instantaneous WUE at mild water stress and a significant decline at severe water stress support moderate drought tolerance behaviour of the species (Jimenez *et al*., 2013). However, decrease in WUE in severely stressed seedlings of W_4 and W_5 treatments particularly during April and May was due to increased air temperature, PAR, and VPD that induced water loss through transpiration, i.e., increased *E* value limiting biomass production (Miller *et al*., 1993). Decline in WUE with decreased irrigation level from W_1 to W_5 treatment seems to be due to increases in resistance gas exchange in mesophyll cells rather than the influence of stomatal conductance controlled by stomatal aperture (Pandey, 1999). Midday depression in photosynthesis because of high irradiance has also been observed in other species, where transpiration either did not decrease or dropped much less under both low and high soil water condition (Jifon and Syvertsen, 2003).

23.5. CONCLUSIONS

Soil water stress maintained by varying level of irrigation affected P_N, *E* and *gs* in the planted seedlings of *D. sissoo*, *E. camaldulensis* and *A. nilotica*. Highest value of P_N, *E* and *gs* and leaf water potential was observed for the seedlings irrigated >7.5 per cent of field capacity (W_1 treatment). However, decrease in irrigation levels increased soil water stress progressively, which resulted in a decrease in frequency of irrigation impairing photosynthesis and transpiration rates. A drastic reduction in both P_N and *E* occurred at available soil water of W_3 level. However, water stress at W_2 had no appreciable influence on stomatal conductance, but further increase in soil water stress in W_3 onwards there was a steep decrease in stomatal conductance that control gas exchange affecting P_N and *E*. . Relatively greater increase in P_N as compared to *E* with soil water availability as well as stomatal conductance indicates that rate of photosynthesis is more sensitive to environmental conditions than do rate of transpiration. This pattern in P_N and *E* affects instantaneous WUE, which was highest in the seedlings of W_1 treatment for *E. camaldulensis* and *A. nilotica* and decreased with severity of soil water stress. However, changes in rate of transpiration and photosynthesis also depended upon tree species and *E. camaldulensis* and *A. nilotica* appeared more tolerant to varying levels of soil water availability, whereas *D. sissoo* showed mild tolerance to soil water stress. Based on the observations following recommendations can be framed:

- ➢ These irrigation levels can be categorized into three groups like W_1~W_2, W_3~W_4 and W_5 in order of decreasing physiological functions and productivity.
- ➢ Highest reduction in P_N, *E* and *gs* at W_3, W_4 and W_5 irrigation levels indicates that water availability of >50 per cent (W_2 and above) field capacity is better to maintain physiological function, growth and biomass production of these species.
- ➢ Relatively faster increase in both photosynthesis and transpiration rates rate in the seedlings of *A. nilotica* and *E. camaldulensis* indicates their capacity of bio-draining soil water together with biomass production.

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Annexure 23.1: Frequency (number of irrigation year^{-1}) and quantity of irrigation and water use efficiency (WUE; g dry biomass litre^{-1} water used) of seedlings at different ages.

Age (months)	Treatment	Frequency	Irrigation quantity	Total quantity		Biomass	WUE
E. camaldulensis		(days)	(mm)	(mm)	(liter)	g plant^{-1}	
3-12*	W_1 (36.2)	21.9	791.3	1116.3	4465.2		-
	W_2 (26.5)	15.2	402.3	727.3	2909.2		-
	W_3 (20.2)	12.7	256.7	581.7	2326.8		-
	W_4 (18.1)	11.8	214.1	539.1	2156.4		-
13-24	W_1	29.2	1057.8	2174.1	8696.4	10610	1.23
	W_2	20.3	537.7	1265.0	5060.0	8960	1.77
	W_3	17.0	343.2	924.9	3699.6	3450	0.93
	W_4	15.8	286.2	825.3	3301.2	3065	0.93
Acacia nilotica							
3-12*	W_1 (36.2)	17.2	621.9	946.9	3787.6		-
	W_2 (26.5)	12.3	324.6	646.0	2584.0		-
	W_3 (20.2)	11.4	230.0	555.1	2220.4		-
	W_4 (18.1)	10.4	188.1	513.1	2052.4		-
13-24	W_1	22.8	826.5	1773.4	7093.6	6030	0.85
	W_2	16.4	434.1	1080.1	4320.4	5050	1.17
	W_3	15.2	307.4	862.5	3450.0	4150	1.20
	W_4	13.9	251.4	764.5	3058.0	3380	1.11
Dalbergia sissoo							
3-12*	W_1 (36.2)	14.4	520.6	845.6	3382.4		-
	W_2 (26.5)	11.9	316.2	637.6	2550.4		-
	W_3 (20.2)	10.5	211.5	536.5	2146.0		-
	W_4 (18.1)	9.3	167.6	492.6	1970.4		-
13-24	W_1	19.2	695.8	1541.4	6165.6	4523	0.73
	W_2	15.3	404.1	1041.7	4166.8	3955	0.95
	W_3	14.0	282.6	819.1	3276.4	1875	0.57
	W_4	12.5	226.1	718.7	2874.8	1303	0.45

*Includes 325 mm irrigation applied to maintain the soil of all the tanks at field capacity initially

Annexure 23.2: Seasonal variations in the irrigation intervals (no. of days) for the seedlings of different tree species at different age.

Age (months)	Treatment	Winter	Spring	Summer	Mean
E. camaldulensis					
3-12*	W_1 (36.2)	22.5	16.0	9.8	12.5
	W_2 (26.5)	26.8	22.8	13.2	18.0
	W_3 (20.2)	27.5	24.3	15.5	21.5
	W_4 (18.1)	28.0	27.0	19.0	23.1
13-24	W_1	22.5	16.0	9.8	12.5
	W_2	26.8	22.8	13.2	18.0
	W_3	27.5	24.3	15.5	21.5
	W_4	28.0	27.0	19.0	23.1
Acacia nilotica					
3-12*	W_1 (36.2)	27.0	20.0	12.0	16.0
	W_2 (26.5)	28.0	26.3	19.0	22.3
	W_3 (20.2)	29.0	28.3	19.7	24.0
	W_4 (18.1)	29.5	29.5	21.0	26.3
13-24	W_1	27.0	20.0	12.0	16.0
	W_2	28.0	26.3	19.0	22.3
	W_3	29.0	28.3	19.7	24.0
	W_4	29.5	29.5	21.0	26.3
Dalbergia sissoo					
3-12*	W_1 (36.2)	28.0	24.5	16.0	19.0
	W_2 (26.5)	29.0	27.7	19.0	22.9
	W_3 (20.2)	30.0	28.9	21.3	26.1
	W_4 (18.1)	31.0	31.0	27.0	29.5
13-24	W_1	28.0	24.5	16.0	19.0
	W_2	29.0	27.7	19.0	22.9
	W_3	30.0	28.9	21.3	26.1
	W_4	31.0	31.0	27.0	29.5

* Includes 325 mm irrigation applied to maintain the soil of all the tanks at field capacity initially.

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