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Soil Moisture and Groundwater Dynamics under Biodrainage Vegetation in a Waterlogged Land

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ABSTRACT

A field experiment was conducted during September 2016 to March 2017 to study the soil moisture and groundwater dynamics underneath four biodrainage vegetation in a waterlogged land of lower Indo-Gangetic plain of West Bengal. Four natural vegetation flora viz., Kadamba (Neolamarckia cadamba), Eucalyptus (Eucalyptus sp.), Lamboo (Dysoxylum sp.) and Banana (Musa sp.) including a non-vegetated area as control were selected for evaluation. The results of the study showed that all four biodrainage plantations had differential potential in extracting and depleting soil water from deeper soil layers and decline in groundwater table. However, the canopy of Eucalyptus vegetation has higher efficiency in exhausting the surplus soil water from deeper layers and lowering the elevated groundwater table than underneath Lamboo, Banana and kadamba vegetation. Thus, the low-cost monoculture biodrainage potential species like Eucalyptus as partial substitution or complementary association to and/ in conjunction with conventional subsurface drainage could be commissioned with suitable plant geometry to combat the sustained waterlogging and environmental hazards and maintain the desired soil water regimes for timely agricultural crop production in rabi season.

Key words: *Biodrainage, Waterlogging, Water table, Soil mosture, Land reclamation.*

INTRODUCTION

High rainfall and runoff accumulation, heavy textured deep soil, hard pan, impeded natural drainage, excess irrigation, shallow water table, seepage from canal and adverse land physiographic conditions are the major reasons for sustained waterlogging problem[14]. The standard remedial measures to address the issue have often focused on conventional engineering approaches such as surface and subsurface drainage techniques which are capital intensive and involves higher operation and maintenance cost. The disposal of drainage effluents is also infeasible due to flat to concave topography and drainage outfall problems. Biodrainage is the vertical drainage of soil water using specific types of fast growing tree vegetation with high evapotranspiration demand and is considered an economically viable alternative option in dealing with the drainage congestion and environment hazards[5,8,11].

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The plant system forms a root to shoot conduit which helps in pumping of excess soil water using bio-energy through deep-rooted plants. This results in a reversal of the rising trend of groundwater table, followed by a water table decline with time[12]. The tree once established can withdraw water from deeper layers due to their deep root system. This imposes removal of water vertically upward direction into the open atmosphere as evapotranspiration through vegetation and evaporation from soil surface[1]. The technique also renders a favourable water balance such that the groundwater table is maintained at a desired level below the root zone of the agricultural crops by balancing recharge/discharge processes. As a result, fields can be worked out in time for crop cultivation in the spaces between the tree rows to give additional returns to farmers. Biodrainage is remunerative, as it requires only a small initial investment for planting the vegetation, and when established, the system could produce higher economic returns through fuel wood, timber and fodder harvested, besides improvement in soil health and carbon sequestration[15,18].

A great deal of research has been conducted in many countries of the world to evaluate the effectiveness of different trees, bushes and crops to control waterlogging[3,12,14]. If trees tolerant to waterlogging are introduced in the problematic areas, these can easily assist in controlling water stagnation and rising water table. However, there is scarcity of information on the comparative biodrainage potential of different tree and vegetation species. Keeping these points in background, the present study was conducted to assess the soil moisture and groundwater dynamics in a land-locked waterlogged area as influenced by different vegetation species with elapsed time.

MATERIAL AND METHODS

Principles of Biodrainage

Bio-drainage is an effective tool to control rising trend of groundwater table especially in the area where traditional subsurface drainage is not practically feasible to remove surplus soil water. This is the least expensive and more environmentally friendly method of land reclamation without effluent disposal problem. Biodrainage relies on vegetation, rather than mechanical means, to remove excess water through high consumptive water use by the plants. It involves growing certain categories of plants that habitually draw their main water supply directly from the groundwater and transpire luxuriantly to the open atmosphere. The biodrainage, if properly designed and implemented, can reduce the elevated groundwater table of an area prone to sustained waterlogging and canal seepage. Biodrainage is a good substitute of expensive subsurface drainage. It improves ecology of the area and provides various ranges of costly fuel wood, timber and fodder harvested and additionally sequesters carbon in the biomass[12,15].

Heuperman *et al*.[9] in a study found an evidence of water table lowering by trees both in irrigation and dry land area in Victoria. In a northern Victorian irrigation area an 8 year-old eucalyptus plantation lowered the water table by 2 m or more and reduced the piezometric head in the underlying aquifer by up to 1.5 m. Similarly, at several dry land sites, progressively greater and more rapid lowering of the water table was observed as planted trees grew to occupy the site more fully by Morris[13]. A 6-year old eucalyptus plants in a 4-ha area in Pakistan under canal irrigation was studied by Chaudhry *et al*.[2] who reported a deeper depth of water table in the area under eucalyptus plantation and a reduced groundwater table in the regions away from the plantation. Heuperman and Kapoor[8] estimated that the average annual rate of transpiration was 3446 mm from a 25-ha plantation of *Eucalyptus camaldulensis, Acacia nilotica, Prosopis cineraria, Ziziphus spp.*, in Rajasthan. They approximated that forest plantations covering only 10% of the area can be able to transpire the estimated annual ground water recharge of 2.6 billion cubic meter (BCM) which can provide satisfactory insurance against waterlogging hazard. Dash *et al*.[5] demonstrated that the different tree species, their growth rate, growing stage, density of plants and other soil and climatic conditions may affect biodrainage potential of tree species. Chabra and Thakur[3] observed that eucalyptus and bamboo are excellent species for removing excess water and controlling water stagnation in land-locked low-lying areas and disposal of waste waters through land application. To monitor water table fluctuations immediately beneath the plantations due to evapotranspirational-drainage (ED), Rani *et al*.[17] observed that tree species like *Eucalyptus tereticornis* clone-10 and *Eucalyptus* hybrid are fast EDs primarily due to their ability to display large leaf area as compared to slow EDs like *Terminalia arjuna* and *Pongamia pinnata* where leaf area development is poor. Ram *et al*.[16] assessed the biodrainage potential of *Eucalyptus tereticornis* for reclamation of shallow groundwater table areas of semi-arid regions with alluvial sandy loam soils and recommended the closely spaced parallel plantations of *Eucalyptus tereticornis* which acts as bio-pumps for the reclamation of waterlogged areas. Bala *et al*.[1] recorded that *eucalyptus sp*. has high potential in lowering of groundwater table, besides increasing soil organic carbon, electrical conductivity, NH_4 and NO_3-N in canal command waterlogged area of Indian desert. Sarvade *et al.*[18] opined that the vertical and horizontal root spreading of tree species is one important character for capturing and transpiration of excess water from waterlogged area and have the potential to reclaim waterlogged and saline soils efficiently and sustainably by improving soil health quality.

Experimental Site

The field experiment was carried out during the period from September 2016 to March 2017 at the Teaching Farm of Bidhan Chandra Krishi Viswavidyalaya, Mohanpur encompassing the lower Indo-Gangetic alluvial plains of West Bengal. The farm is located at 23.35^0 N latitude and 89^0 E longitude at an altitude of 9.35 m above mean sea level in a sub-humid tropical climate. The area is characterized by hot dry summer months (May-June) and cold winter (December-January). The mean monthly temperature ranges from 37.6 to 25.4 ^OC in summer and 23.7 to 10.5 ^OC in winter. January is the coldest month with a mean temperature ranging from 10.5 to 16.5 ^OC. Sporadic rain during April-May and November-February is the common feature of the region. Monsoon ceases in October and cool season sets in November. The average annual rainfall is about 1500 mm with more than 75% of it being received during the four monsoon months of June through September. The mean relative humidity remains high (82 to 95%) during June to October and reaches low (70%) in January. The wind speed velocity around the year varies from 0.2 to 2.3 kmph. The pan evaporation loss ranges from 0.9 to 1.5 mm day^{-1} in the month of January which reaches 3.9 to 5.2 mm day^{-1} during May. There is a flat patch of 4 ha area distributed in scatter in the farm has been suffering from drainage congestion and waterlogging condition and did not support any agricultural activities. This wasteland had been switched into agro-forestry system with different plant species for land reclamation. Important physical and hydro-physical properties of the experimental soil are furnished in Table 1. The soil had pH 6.83, EC 0.37 dS m^{-1} and organic C 5.6 g kg^{-1}. Available N, P and K contents of the soil were 153.7, 21.5 and 160.2 kg ha^{-1}, respectively.

The entire experimental site was sub-divided into four segments under four different vegetation species. The tree species *viz*., Kadamba (*Neolamarckia cadamba*), eucalyptus (*Eucalyptus* sp.) and Lamboo (*Dysoxylum* sp.) were planted 12 years back each with a spacing of 3 m x 3 m. Banana (*Musa* sp.) vegetation was planted at 2 m x 2 m spacing at every 2-year interval. An open non-vegetation area was taken as control for comprison.

The spatial distribution of soil moisture in vertical and lateral planes underneath each vegetation species and in control plot was monitored at weekly interval commencing from September 2016 to March 2017. Soil samples were drawn from a depth of 0-15, 15-30, 30-45 and 45-60 cm and at 0, 15, 30, 45 and 60 cm lateral distance away from plant base with the help of a soil auger. The moisture content of the soil samples was determined by the gravimetric method. To measure the depth of water table from local ground surface during the experimental period, four shallow observation wells were installed in the centre of each four plantation sites and another one in open non-vegetated control site up to a depth of 5 m. The observations were recorded twice in a month with a measuring tape.

The data on soil moisture collected at different standard week was averaged over the vertical and horizontal lines for better understanding and interpretation of the variability of soil moisture in different vegetation system in comparison with the non-vegetated control. Soil moisture data obtained were subjected to statistical investigation following the analysis of variance techniques by using software packages of MS Excel and SPSS 12.0 version. Statistical significance between means of individual treatments was assessed using Fisher's Least Significant Difference (LSD) at 5% level of probability[6].

RESULTS AND DISCUSSION

Soil moisture dynamics underneath vegetation

The results furnished in Table 3 indicated that the distribution of overall soil moisture contents, irrespective of horizontal distance, under Kadamba plantation consistently increased along the depth up to 30-45 cm layer, then decreased at 45-60 cm layer. Similarly, the overall soil moisture values regardless of soil depth increased substantially at 15 cm lateral distance, thereafter gradually decreased with advances in lateral distance from tree trunk. In comparison with the moisture contents in control (Table 2), there was an average depletion of soil moisture contents at 0, 15, 30, 45 cm lateral distances by 19.06, 12.42, 19.81, 16.43% for 0-15 cm depth; 16.08, 12.90, 8.69, 10.85% for 15-30 cm depth; 9.74, 6.21, 6.98, 5.02% for 30-45 cm depth; 10.44, 8.09, 9.58, 3.69% for 45-60 cm depth, respectively (Fig 1). It is conspicuous that maximum depletion of soil moisture was occurred in surface (0-15 cm) and sub-surface (15-30 cm) soil layers as compared with the third (30-45 cm) and fourth (45-60 cm) soil layers along the lateral distances.

In Banana plantation, the overall soil moisture contents consistently decreased down the soil layer up to 30-45 cm depth and then increased at 45-60 cm layer (Table 4). Likewise, the overall soil moisture values increased substantially up to 15 cm lateral distance, and then decreased with increase in lateral distance up to 45 cm from the plant base. As compared with the soil moisture status in non-vegetated control plot, the depletion of soil moisture contents at 0, 15, 30, 45 cm lateral distances was 7.40, 15.63, 3.73, 6.57% for 0-15 cm depth; 4.73, 18.75, 13.36, 7.78% for 15-30 cm depth; 42.97, 49.18, 51.24, 34.11% for 30-45 cm depth; 34.75, 31.20, 33.07, 37.68% for 45-60 cm depth, respectively (Fig 2). The results revealed that maximum depletion was occurred at 30-45 cm and 45-60 cm soil layers as compared with 0-15 cm and 15-30 cm soil layers along the lateral distances.

Under Eucalyptus plantation, the soil moisture contents down the soil profile did not follow the systematic pattern of distribution; rather it showed the rhythmic pattern of decrease and increase up to 45-60 cm layer from 0-15 cm layer (Table 5). Likewise, the soil moisture values first decreased at 15 cm lateral distance, thereafter consistently increased up to 45 cm distance from the tree trunk. The depletion of soil moisture contents at 0, 15, 30, 45 cm lateral distances accounted to 16.59, 24.85, 4.90, 5.16% for 0-15 cm depth; 10.64, 26.81, 12.92, 9.20% for 15-30 cm depth; 36.42, 52.34, 52.78, 34.11% for 30-45 cm depth; 35.40, 39.97, 38.66, 35.31% for 45-60 cm depth, respectively over the corresponding values under control (Fig 3). Maximum depletion of soil moisture was experienced in 30-45 cm followed by 45-60 cm depth compared with 0-15 cm and 15-30 cm depths along the lateral distances.

In Lamboo plantation the soil moisture contents followed the rhythmic pattern of decrease and increase up to 45-60 cm layer from 0-15 cm layer (Table 6). On the contrary, the soil moisture values increased up to 30 cm lateral distance, then decreased considerably at 60 cm lateral distance from plant base. The soil moisture depletion at 0, 15, 30, 45 cm lateral distances were found to be 23.32, 30.66, 12.59, 21.13% for 0-15 cm depth; 16.55, 25.81, 28.06, 21.23% for 15-30 cm depth; 47.92, 58.94, 48.76, 43.65% for 30-45 cm depth; 38.66, 37.77, 51.28, 48.48% for 45-60 cm depth, respectively over their respective status recorded in control plot (Fig 4). It is evident that maximum soil moisture depletion was occurred in the 30-45 cm soil layer at 0 and 15 cm lateral distance and 45-60 cm soil layer at 30 and 45 cm lateral distance from the base of the plant. Similarly, in between the surface and sub-surface soil layers, maximum depletion was occurred in 0-15 cm soil layer at 0 and 15 cm lateral distance and 15-30 cm soil layer at 30 and 45 cm lateral distance from plant base.

Groundwater dynamics underneath vegetation

The depth to groundwater table in different months under biodrainage plantations vis-à-vis non-vegetated control field is presented in Table 7. It is evident that there was positive impact of lowering groundwater table underneath bio-drainage vegetation. The rate of decline in groundwater table with different elapsed time was found maximum under Eucalyptus vegetation, followed by Lamboo, Banana and Kadamba vegetation when compared with that of non-vegetated control site. The results indicate that the efficiency of Eucalyptus vegetation in lowering down the depth of watertable were more pronounced than in Lamboo, Banana and Kadamba vegetation. The peculiar behaviour of different vegetation species by absorbing variable amounts of soil moisture from the deeper soil layers and consequent lowering of groundwater table may be due to their differential growth rate, canopy spread, deeper and extensive root system, larger sapwood area and evapotranspirative demand of the plants[5]. However, the high biodrainage species like Eucalyptus was emerged as the tree of choice in depression of rising groundwater table in waterlogged inland. The findings are in consonance with the observation of Jena *et al*.[10] who demonstrated that Eucalyptus plantation was superior in providing drainage relief in coastal waterlogged wasteland through interception water from deeper soil profile. The adoption of biodrainage vegetation is thus a feasible option to maintain the water table below root zone depth and may help the farmer to work out the land in time for rabi cultivation.

Table 1: Physical and hydro-physical properties of the experimental soil

Soil depth (cm)	Soil texture (%)			BD (Mg m^{-3})	Ks (cm hr^{-1})	Infiltration (cm hr^{-1})
	Sand	Silt	Clay			
0-15	50.07	25.75	24.18	1.49	1.95	1.17
15-30	52.31	26.24	21.45	1.53	1.53	1.03
30-45	58.82	22.27	28.91	1.56	1.28	0.92
45-60	54.46	24.01	21.46	1.45	1.14	0.85

BD: bulk density, Ks: hydraulic conductivity

Table 2: Soil moisture status (cm) in non-vegetation control field

Soil depth (D), cm	Lateral distance (L), cm				Mean
	0-15	16-30	31-45	46-60	
0-15	4.46	4.99	4.29	4.26	4.50
15-30	4.23	4.96	4.49	4.24	4.48
30-45	6.26	7.89	8.45	5.98	7.15
45-60	6.13	5.93	6.26	6.23	6.14
Mean	5.27	5.94	5.87	5.18	-
	D	L	D x L		
CD (*P*=0.05)	0.009	0.009	0.018		

Table 3: Soil moisture status (cm) in Kadamba vegetation field

Soil depth (D), cm	Lateral distance (L), cm				Mean
	0-15	16-30	31-45	46-60	
0-15	3.61	4.37	3.44	3.56	3.75
15-30	3.55	4.32	4.10	3.78	3.94
30-45	5.65	7.40	7.86	5.68	6.65
45-60	5.49	5.45	5.66	6.00	5.65
Mean	4.58	5.39	5.27	4.76	-
	D	L	D x L		
CD (*P*=0.05)	0.008	0.008	0.016		

Table 4: Soil moisture status (cm) in Banana vegetation field

Soil depth (D), cm	Lateral distance (L), cm				Mean
	0-15	16-30	31-45	46-60	
0-15	4.13	4.21	4.13	3.98	4.11
15-30	4.03	4.03	3.89	3.91	3.97
30-45	3.57	4.01	4.12	3.94	3.91
45-60	4.00	4.08	4.19	3.87	4.04
Mean	3.93	4.08	4.08	3.93	-
	D	L	D x L		
CD (*P*=0.05)	0.01	0.01	0.019		

Table 5: Soil moisture status (cm) in Lamboo vegetation field

Soil depth (D), cm	Lateral distance (L), cm				Mean
	0-15	16-30	31-45	46-60	
0-15	3.72	3.75	4.08	4.04	3.90
15-30	3.78	3.63	3.91	3.85	3.79
30-45	3.98	3.76	3.99	3.94	3.92
45-60	3.96	3.56	3.84	4.03	3.85
Mean	3.86	3.68	3.96	3.97	-
	D	L	D x L		
CD (*P*=0.05)	0.009	0.009	0.018		

Table 6: Soil moisture status (cm) in Eucalyptus vegetation field

Soil depth (D), cm	Lateral distance (L), cm				Mean
	0-15	16-30	31-45	46-60	
0-15	3.42	3.46	3.75	3.36	3.50
15-30	3.53	3.68	3.23	3.34	3.45
30-45	3.26	3.24	4.33	3.37	3.55
45-60	3.76	3.69	3.05	3.21	3.43
Mean	3.49	3.52	3.59	3.32	-
	D	L	D x L		
CD (*P*=0.05)	0.009	0.009	0.019		

Table 7: Groundwater table (m) fluctuations under different biodrainage vegetation during the experimental period

Vegetation	Depth of groundwater table (m)						
	Sept'16	Oct'16	Nov'16	Dec'16	Jan'17	Feb'17	Mar'17
Kadamba	1.56	1.68	1.95	2.21	2.55	2.96	3.21
Banana	1.61	1.75	2.05	2.27	2.74	3.13	3.34
Lamboo	1.67	1.82	2.13	2.39	2.88	3.18	3.47
Eucalyptus	1.78	1.91	2.32	2.62	3.06	3.54	3.82
Control	1.18	1.24	1.39	1.52	1.67	1.81	1.95

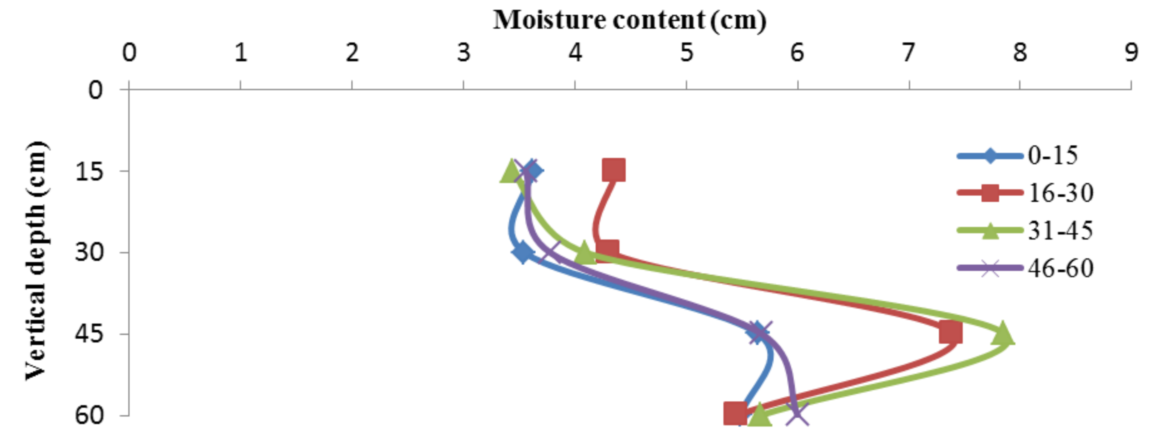

Fig 1: Soil moisture deplition pattern at Kadamba vegetation

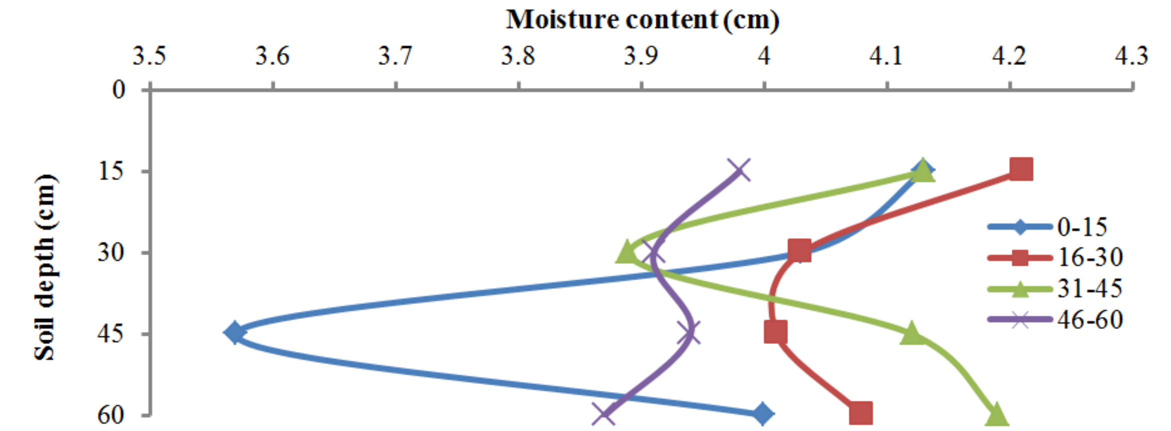

Fig 2: Soil moisture depletion pattern in Banana plantation

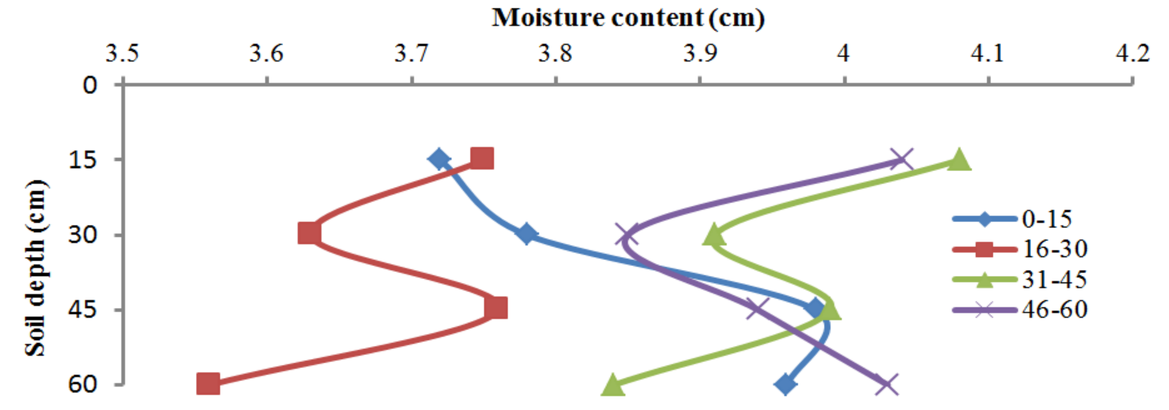

Fig 3: Soil moisture depletion pattern in Lamboo vegetation

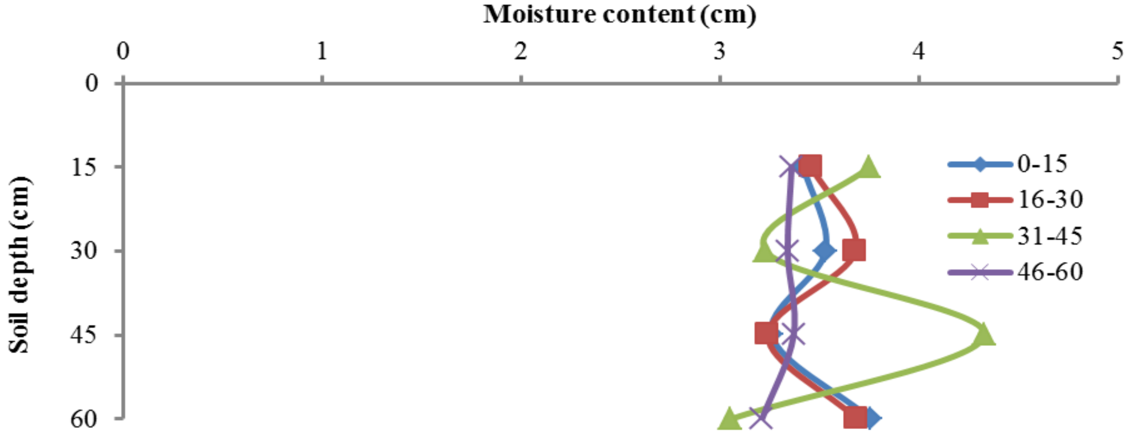

Fig 4: Soil moisture depletion pattern in Eucalyptus plantation

CONCLUSION

It may be inferred that all the four biodrainage species have differential potential to draw soil water from deeper soil layers and lower the groundwater table. However, in terms of the efficiency of soil water depletion and lowering the depth to groundwater table, the Eucalyptus vegetation has the highest potential followed by that of Lamboo, Banana and kadamba vegetation. The right choice of plant species with optimum plant population and suitable plant geometry will help to control the elevated groundwater table in waterlogged areas and thus maintain the desired soil moisture regime for timely rabi cultivation. However, the low-cost monoculture biodrainage potential species like Eucalyptus as partial substitution or complementary to and/ in conjunction with conventional subsurface drainage could be commissioned with suitable plant geometry to tackle the sustained waterlogging and environmental hazards and maintain the desired soil moisture regime as compared with other vegetation species studied.

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