PLANT HEIGHT MODEL FOR EUCALYPTUS PLANTATIONS FOR BIODRAINAGE USE

S.K.Singh[1], Chhedi Lal Verma[2], D.K. Sharma[3]

[1]Ph.D. Scholar, Faculty of Engineering & Technology, Uttar Pradesh Technical University, Lucknow, U.P., India
[2]Senior Scientist and Ex. Professor, Central Soil Salinity Research Institute, RRS, Lucknow, U.P., India
[3]Director, Central Soil Salinity Research Institute, ICAR, Karnal, India

Abstract

Biodrainage is advocated for controlling seepage, water logging and salt accumulation in root zone due to its excessive ET demand. Eucalyptus is most suitable for establishing biodrainage belt. Farmers are also growing as a sole plantations crop for meeting timber. Eucalyptus wood has got different uses in different sector. Eucalyptus logs are most commonly used for preparing shuttering of building construction. Its plies in boxes are used for making fruits packing. It is also used in paper and pulp industry. Its chips are used making particles board. Many times, shelter belt of eucalyptus are also develop protect in area under varying topographic situation and climatic condition. It can be successfully grown on marginal, saline, sodic and waterlogged land. It is fast growing tree and its economic return depends on its height and girth. It's used for biodraining waterlogged land depend upon the plant height and canopy cover. Information on plant height relation to plantation age will be quite useful for optimizing net return from agricultural block. Use of eucalyptus plant for biodrainage waterlogged soil is based on the highest evapotranspirative demand. Which is again a function of plant height, thus plant height modeling with plantation age can provide a base for optimization economic return and water table and salinity management. Annual budgeting of ground water extraction is required for designing biodrainage belt. Eucalyptus plant's height keeps on increasing up to the age of 8 to 10 years. In the present study a best fitting correlation model was identified describing plant height response with age of eucalyptus using lysimetric data. The Weibull Model described tree height with age extremely well with r = 0.9998 and S = 0.0419. The Weibull Model predicted eucalyptus plant heights were found to be 3.35, 5.92, 9.39, 12.68, 15.07, 16.47, 17.12, 17.37, 17.45 and 17.47 m for every month of December over a period of 10 years. The Weibull Model predicted maximum plant height of 17.12 m in seven year matching well with reported plant height data in the literature. The present model could be used for estimating height of eucalyptus trees at different age in biodrainage belt.

***Keywords**: Biodrainage; Canal Seepage; Evapotranspiration; Sodic; Waterlogging*

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1. INTRODUCTION

Agriculture over the globe is confronted with the serious problem of waterlogging and salinity. Major reasons for waterlogging of agricultural lands are excessive seepage from canals, high rainfall, over irrigation, insufficient existing internal drainage and blockage of natural drainage systems. Salt accumulation is generally associated with waterlogging. More than 3.95 million hectare of (M ha) land is waterlogged and 8.6 M ha is salt affected in India [14]. Reclamation of waterlogged and waterlogged salt affected soil is possible only by lowering water table below a critical depth so that capillary rise can be minimized to reduce the salt accumulation in the root zone. Lowering water table below root zone is essentially required for successful crop management under water logged condition when salt accumulation is not an issue. Lowering of water table below critical depth is required for the area where secondary salinization is acute problem. In arid and semiarid areas where annual evaporation is much higher than the annual rainfall depth, there is a great risk of salt accumulation in the root zone due to secondary salinization. India is having a good network of unlined canals; consequently appreciable amount of water goes as waste due to excessive seepage. Seepage water slowly makes the adjoining area waterlogged if internal drainage of the area is not sufficient to cope up with the canal seepage rate. In India, the seepage losses are estimated to the tune of 45% of the water diverted into canal systems [15]. In the areas where gravity outlet is not available with sufficient fall and water quality is poor for recycling, biodrainage remains only left out option for controlling waterlogging and salinization [9]. Biodrainage is also suitable for difficult terrain and subsoil with poor fertility and water transmission characteristics. The biodrainage system involves growing certain categories of plants/trees/shrubs/grasses that habitually draw their main water supply directly from the ground water or the capillary fringe just above it [10]. The Eucalyptus and Popular are the most common tree species grown widely over the globe for controlling water table. Species suggested for plantation in the salt affected areas for reclamation purpose was Salvadora, Tamarix, Eucalyptus, Prosopis juliflora etc [17]. Biodrainage belt along the canal is recommended to intercept canal seepage. Biodrainage is a cheaper option and it does not involve highly skilled techniques and person to grow and maintain it. It may give in return timber, fuel and fodder besides improving environment. Systematic data, design criteria and performance of biodrainge under waterlogged situation with or without salinity are still missing and need to be studied. No study had been yet reported for arresting canal seepage for lowering water table using biodrainage for crop production. Biodrainge systems for seepage control, reclamation of waterlogged salt affected soils or for sewage disposal need to be studied in terms of ET demand of the trees. Water uptake by the growing trees is dependent on climatic factors, type of tree and species, age of the tree, height of tree, soil salinity/alkalinity status and water table depths. Evaporation from soil surface, plant surface and transpiration from plant stomata together is referred as ET of the plant. ET is also dependent upon plant height.

Eucalyptus is the most favored plantation trees in Indian subcontinent due to its fast growth, suitability to all types of soils, adoptability to varying climatic conditions and tolerance to waterlogging, salinity and sodicity. Eucalyptus camaldulensis is being widely adapted for plantation in Pakistan and it is third largest farm grown hard wood after Dalbergia sisso and Acacia nilotica [1]. Eucalyptus can grow up to the soil pH of 11.0, 9.2 and 8.8 in sandy soil, clay and loamy soils respectively [8],[19]. The amount of water used by eucalyptus plantation is an ecological issue worldwide but a useful attribute for managing waterlogging and salinity [16]. In India and Pakistan eucalyptus plantation is established for about 5 to 6 years. High water use efficiency of a eucalyptus tree contribute significantly to its survival during dry years [12]. Water table under eucalyptus plantation has been observed to be deeper compared to the area without plantation [3]. Eucalyptus tereticornis plants can bio-drain 5.03, 5.14, 6.96 and 8.01 times the potential evaporation in the second, third, fourth and fifth year respectively [4]. Eucalyptus as a biodrainage belt has great potential to extract soil moisture for improving internal drainage of the soil. Extraction of soil moisture pattern is highly dependent on the seasons. A systematic record of plant ET over a long duration is needed for designing biodrainage belt for controlling waterlogging or canal seepage. Lysimeters are the most commonly used device for measuring daily plant ET. Modern instruments such as sap flow using thermal probes and infrared gas analyzers are being used to measure water extractions trees [5]. These instruments have their own limitations and many times readings may be quiet misleading with error more than 100% [7], depending on the type of instrument, methods, tree girth, size and number of trees used for estimation [18]. These methods require complex and very costly instrumental devices and are generally suitable only for specific research purposes. ET of any tree is a function of volume of canopy cover and volume of canopy cover is a function of plant height. Productivity of plantation is also a function of plant height and girth. Girth is a function of plant height again. Thus plant height modeling can provide relevant information for its economic maturity and ET demand. The present study was undertaken with sole objective to develop simple mathematical model for plant heights as a function of its age.

2. MATERIALS AND METHODS

2.1 Study Area

The study area is located in Sharada Sahayak Canal Command at Kashrawan village of Bachhrawan block in district Raibareli, U.P., India. The area represents a semi-arid-sub-tropical climate, characterized by hot summers and a cool winter with mean annual rainfall of 984 mm, most of which occur during June to September. Average ten year maximum and minimum temperature varies between 21.36 to 38.53 ^{0}C and 7.72 to 26.81 ^{0}C, respectively. Geographical coordinates lies between $26^0 30^/ 18.90^{//}$ N latitudes and 81^0 $6^/$ $40.18^{//}$ E longitudes at an elevation of 110 m above the mean sea level. The land is having flat topography with general slope of 1.5 percent in the direction of East. Sharda Sahayak Canal system is a large canal taking off water from the right bank of the lower Sharada Barrage suppling irrigation water to 2.0 M ha. Lower Sharda Barrage is built across the Mahakali River in district Nainital (Uttrakhand) in India. The Mahakali River is the natural boundary between India and Nepal. The command area of this canal extends over a vast area to the west and south of the Karnali river (known as the Ghaghra River in India). The total length of the branch, secondary and tertiary canal is 8704 km. The capacity of canal is 650 m^3/s. A vast area on either side of the canal is waterlogged coupled with sodicity. Water table depth fluctuates from 0.00 m to 1.5 m below ground surface throughout the year. The bottom width of canal at the site is 46 m and canal depth is 2.2 m with side slope of 1:2. Canal discharge at full supply level at this reach of canal is 170 m^3/s. The soil textural classes were observed as loam up to 30 cm, clay from 30 to 60 cm and sandy clay loam from 60 to 120 cm soil depth. Soil pH were observed to be 10.5, 10.3, 9.78, 9.43, 8.83 and 8.72; and EC were 2.60, 2.10, 1.02, 0.80, 0.54 and 0.55 dS/m for soil depths of 00 to 15, 15 to 30, 30 to 45, 45 to 60, 60 to 90 and 90 to 120, respectively. The soil p^H and EC is high toward soil surfaces and decreases with increase in soil depths.

2.2 Establishing Biodrainage Belt and Installation of Lysimeters

Auger hole plantation technique was used for plantation of eucalyptus. Tractor mounted auger was used for making a circular hole of 300 mm diameter in the soil to a depth of 600 mm from soil surface. An input mixture of 5 kg gypsum, 5 kg farm yard manure and 10 kg canal sand was filled in holes. After filling mixture holes 4 to 6 month old eucalyptus sapling were planted and manually irrigated. The biodrainage belt was established over a length of 400 m along with canal. The width of biodrainage belt was 30 m. Spacing between row and plants were 1.5 m x 1.5 m. Total 267 row formed in biodrainage belt. In each row, 20 eucalyptus plants were planted in biodrainage belt. Four non-weighing type metallic lysimeters of one meter diameter and 2 m depth were installed inside the biodrainage belt for measuring plant heights data at regular interval of time. Installation of lysimeters inside the biodrainage belt was done with the sole objectives to avoid boundary effect and damage or uprooting by animals and passerby. Constant water table depths inside the lysimeters were maintained as it was observed outside the lysimeters by applying water every morning. The amount of water required to maintain the desired water level inside the lysimeters was considered as the total ET demands of the eucalyptus plant. Plant height of eucalyptus was measured on monthly basis.

2.3 Modeling of Plant Height

Eucalyptus plants keeps on growing with time. Plant growth rate is dependent on plant species, soil type, fertility and moisture status of the soil, salt concentration and climatic conditions. At a specific plant species and specific site soil type, soil fertility level and soil moisture regime are fixed and growth rate of a plant becomes a function of age. Height of a plant species is genetic character and will confine to its permissible height range. Canopy volume is a function of plant height for a specific species. Integrated responses of plant physiological parameters are also a function of age. Thus there exists a relationship between plant height and age. Twenty two correlation models were used for fitting plant height (Table 1). Mathematical relationships between plant height and time (age, month) were established using correlation models (Table 2). Based on the best fit models, plant heights were back calculated for an age of 12, 36, 60, 84 and 120 months of plantation and the suitability of the model was tested (Table 3). Annual average percent deviations for suitable models were calculated for three years (Table 4). Tree heights were calculated for 10 years (Table 5) with the help of best fit correlation model was compared with the reported tree height data (Table 6).

Table 1: Correlation models

Model Number	Model name	Model Function	Model Number	Model name	Model Function
1	Bleasdale	$\mathrm{H} = (a + bT)^{-\frac{1}{c}}$	12	Power	$\mathrm{H} = a\mathrm{T}^{b}$
2	Exponential	$\mathrm{H} = ae^{bT}$	13	Quadratic	$\mathrm{H} = a + bT + c\mathrm{T}^2$
3	Gompertz relation	$\mathrm{H} = ae^{-e^{b-cT}}$	14	Reciprocal Log	$\mathrm{H} = \frac{1}{a + b\ln\mathrm{T}}$
4	Geometric	$\mathrm{H} = a\mathrm{T}^{bT}$	15	Reciprocal	$\mathrm{H} = \frac{1}{aT + b}$
5	Hoerl	$\mathrm{H} = ab^{\mathrm{T}}\mathrm{T}^{c}$	16	Reciprocal quadratic	$\mathrm{H} = \frac{1}{a + bT + c\mathrm{T}^2}$
6	Harris	$\mathrm{H} = \frac{1}{(a + b\mathrm{T}^{c})}$	17	Rational function	$\mathrm{H} = \frac{a + bT}{1 + cT + d\mathrm{T}^2}$
7	Linear	$\mathrm{H} = a + bT$	18	Richard	$\mathrm{H} = \frac{a}{(1 + e^{b-cT})^{\frac{1}{d}}}$
8	Logarithm	$\mathrm{H} = a + b\ln\mathrm{T}$	19	Shifted power	$\mathrm{H} = a(\mathrm{T} - b)^{c}$
9	Logistic	$\mathrm{H} = \frac{a}{1 - be^{-cT}}$	20	Sinusoidal	$\mathrm{H} = a + b\cos(cT + d)$
10	Modified exponential	$\mathrm{H} = ae^{b/\mathrm{T}}$	21	Vapor Pressure	$\mathrm{H} = e^{a + \frac{b}{\mathrm{T}} + c\ln\mathrm{T}}$
11	Modified power	$\mathrm{H} = ab^{\mathrm{T}}$	22	Weibull	$\mathrm{H} = a - be^{-c\mathrm{T}^{d}}$

3. RESULTS AND DISCUSSION

3.1 Measured Plant Heights

Measured monthly average plant heights of eucalyptus plants in lysimeters for a period of three years are shown in Fig. 1. The range of average monthly plant heights were observed to be 2.45 to 3.40 m, 3.51 to 5.80 m and 6.19 to 9.40 m for first, second and third year, respectively. Plant heights kept on increasing with time.

Fig. 1: Measured monthly eucalyptus heights up to 3 years

3.2 Plant Height Model

For establishing relationship between plant heights and plant age (month), twenty two correlation models were fitted with plant heights and plant age data. The correlation parameters, correlation coefficient (r) and standards error (S) of different models are presented in Table 2. Out of 22 correlation models seven had values of r less than 0.99 and 15 correlation models have values of r greater than 0.99. The correlation models were further tested for their applicability by back calculating plant heights for growing period of 12, 36, 60, 84 and 120 months and presented in Table 3. Table 3 shows that the Bleasdale model (Model 1) and exponential model (Model 2) predicted tree height of eucalyptus as 410 m and 336.29 m at an age of 120 months which is too high and not the representative values.

Gompertz relation model (Model 3) predicted tree height as 47.64 m which is still high enough for eucalyptus. Geometric model (Model 4) calculated back an extreme height of eucalyptus as 1062.0 m and found unfit for explaining plant height with age. Hoerl Model (Model 5) again predicted a very high value of plant height as 376.0 m. The Harris model (Model 6) gave a wrong trend throughout and linear model (Model 7) predicted a marginally high plant height at the age of 120th month. Linear model was considered for further comparison with field data. Logarithmic model (Model 8) predicted growth rate shows an extremely low growth rate between 84th and 120th months hence not found suitable for describing plant height with age. Logisitc model (Model 9) calculated extremely high tree height at an age of 120th month while Modified exponential (Model 10) responded with a very slow growth between age of 84th and 120th months. Both the models are unacceptable for plant height response with age. Modified power (Model 11) predicted extremely high tree height at an age of 120th month and height predicted by Power Model (Model 12) seems to be reasonable. Model 12 is further subjected to comparison among the good models. Estimated tree height by quadratic model (Model 13) is extremely high and the overall trend calculated by reciprocal log model (Model 14), Reciprocal (Model 15), Reciprocal quadratic (Model 16) and Rational function (Model 17) are wrong and unacceptable. Richard model (Model 18) and shifted power model (Model 19) calculated similar tree heights initially but high at an age of 84th months and onward. Both the models were considered for further comparison for selecting best model.

Shifted power model (Model 19) once again predicted very high tree height values at an age of 120th months, hence treated as unsuitable models for describing plant height and age relationship. Sinusoidal (Model 20) gave wrong trend of predicted tree height and also theoretically it is not suitable for describing the plant height and age relationship. Vapour pressure model (Model 21) yielded with a marginally high tree height and Weibull model (Model 22) gave fairly close values of plant heights reported in the literature.

Model 21 and Model 22 were selected for comparing their performance with reported tree height data. Thus six models namely Model 7, Model 12, Model 18, Model 19, Model 21 and Model 22 were selected for further comparison for making a final selection of the most suitable model for describing tree height with age. It can be seen from Table 2 correlation coefficient for Model 22 was the highest (0.9998) with the lowest standard error (0.0419). The correlation coefficients for Model 7, Model 12, Model 18, Model 19 and Model 21 were observed to be 0.9793, 0.9553, 0.9984, 0.9890 and 0.9843 and standard errors were 0.4550, 0.6651, 0.1293, 0.3376 and 0.4031, respectively. The best model was selected as Weibull's Model which described eucalyptus tree height with age satisfactorily well throughout the growth period.

Table 2: Correlation models parameter with plant height and age data

Model Number	Parameter	r	S	Model Number	Parameter	r	S
1	a = 0.983461 b = -0.000901 c = 0.022133	0.9981	0.1387	12	a = 0.531600 b = 0.776690	0.9553	0.6651
2	a = 2.117941 b = 0.041974	0.9982	0.1344	13	a = 2.302427 b = 0.039390 c = 0.004500	0.9993	0.0841
3	a = 91.537199 b = 1.362128 c = 0.014902	0.9968	0.1812	14	a = 0.675613 b = 0.159224	0.9922	0.2802
4	a = 2.547400 b = 0.010500	0.9962	0.1938	15	a = -0.00721 b = 0.357721	0.9809	0.4375
5	a = 2.218500 b = 1.044900 c = -0.03055	0.9983	0.1322	16	a = 0.430500 b = -0.01380 c = 0.000132	0.9975	0.1602
6	a = 0.626314 b = -0.139725 c = 0.369221	0.9949	0.2282	17	a = 2.182573 b = -0.01063 c = -0.03901 d = 0.000460	0.9993	0.0805
7	a = 1.245650 b = 0.206256	0.9793	0.4550	18	a = 30.24780 b = 4.206202 c = 0.071615 d = 1.564513	0.9984	0.1293
8	a = 0.561613 b = 2.114813	0.8247	1.2729	19	a = 0.042190 b = 13.32279 c = 1.374800	0.9890	0.3376
9	a = -648.760812 b = -308.13312 c = 0.041902	0.9981	0.1377	20	a = 8.827817 b = 6.342431 c = 0.047223 d = 3.102132	0.9999	0.0427
10	a = 11.924013 b = -14.524212	0.8577	1.1574	21	a = -1.41360 b = 2.498200 c = 0.985406	0.9843	0.4031
11	a = 2.117900 b = 1.042800	0.9982	0.1340	22	a = 17.47305 b = 14.99729 c = 0.000300 d = 2.128915	0.9998	0.0419

Table 3: Back calculated eucalyptus plant heights by correlation models

Model Number	Plant height against month (m)					Remark
	12th	36th	60th	84th	120th	
	3.50	9.67	27.35	79.27	410	Very high height for 120th month
2	3.49	9.65	26.61	73.41	336.29	Height for 120th month too high
3	3.49	9.33	18.54	29.96	47.64	Height for 120th month high
4	3.48	9.87	33.62	126.97	1062	Extremely high height for 120th month
5	3.48	9.69	27.42	78.02	376	Very high height for 120th month
6	3.61	9.84	-136.17	-10.96	-5.20	Wrong trend
7	3.72	8.67	13.62	18.57	25.99	Height for 120th month high
8	4.69	7.01	8.09	8.80	9.56	Too low growth between last 60 month
9	3.50	9.66	27.15	80.09	641.68	Extremely high for 120th month
10	3.55	7.96	9.36	10.03	10.56	Low height at 60th and 120th month
11	3.49	9.65	26.61	73.41	336.29	Height for 120th month too high
12	3.66	8.59	12.78	16.60	21.90	Height for 120th month high
13	3.42	9.56	20.90	3743	71.96	Height for 120th month too high
14	3.57	9.54	42.65	-33.16	11.49	Wrong trend

15	3.69	10.31	-13.01	-3.98	-1.955	Wrong trend (negative growth)
16	3.53	9.70	13.19	4.96	1.47	Wrong trend
17	3.43	9.34	4.85	1.32	0.30	Wrong trend
18	3.48	9.53	19.99	27.45	30.01	Height for 120th month high
19	3.58	8.97	15.47	22.83	35.2	Height for 120th month too high
20	3.35	9.39	14.79	13.31	3.80	Wrong trend
21	3.46	8.90	14.33	19.73	27.76	Height for 120th month high
22	**3.34**	**9.38**	**15.07**	**17.12**	**17.46**	**Most appropriate heights**

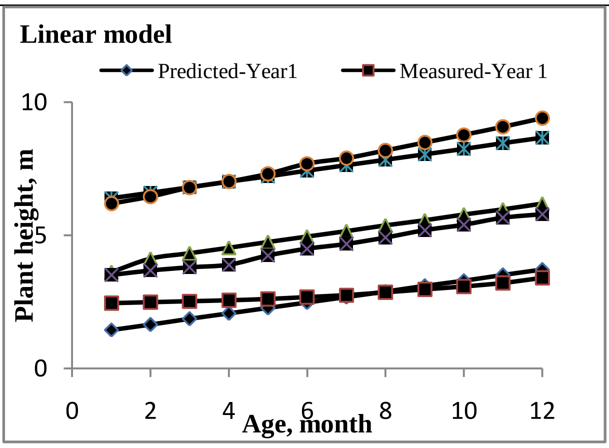
A comparison between measured and calculated plant heights by Linear, Power, Richard, Shifted Power, Vapour Pressure and Weibull Model for a period of three years are shown in Fig. 2. Percent deviations of calculated monthly tree heights from monthly measured heights were calculated as under.

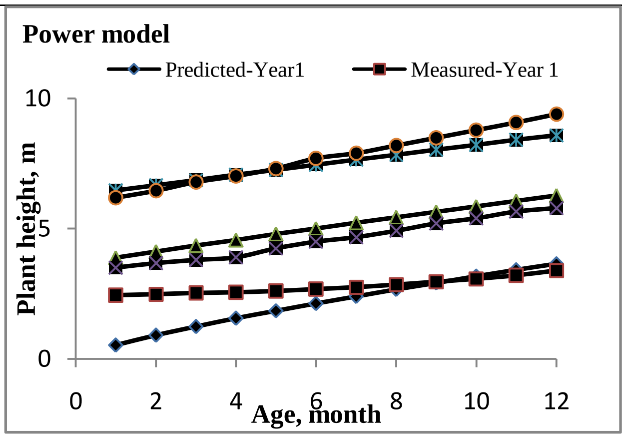
$$percent\ deviation = \frac{(measured\ monthly\ plant height - calculated\ monthly\ plant height)}{measured\ plant height} \times 100$$

Annual average percent deviations of calculated tree heights for different years are presented in Table 4. It may seen from Table 4 that the range of average annual deviations for Linear, Power, Richard, Shifted Power, Vapor Pressure and Weibull Model were 3.67-14.57, 4.06-26.67, 1.17-4.53, 2.29-11.88, 2.61-16.61 and 0.25-0.52 respectively. The Weibull Model calculated the closest values of monthly tree heights. The measured and calculated tree heights with Weibull Model overlapped each other (Fig. 2). The Weibull Model, therefore was selected as the best model for calculating tree heights with age.

Table 4: Average percent deviations of calculated plant heights with observed heights

Model Name	Average percent deviation, %		
	Year-1	Year-2	Year-3
Linear	14.57	9.45	3.67
Power	26.67	11.13	4.06
Richard	4.53	2.08	1.17
Shifted power	11.88	7.08	2.29
Vapor pressure	16.61	7.13	2.61
Weibull	0.43	0.82	0.25





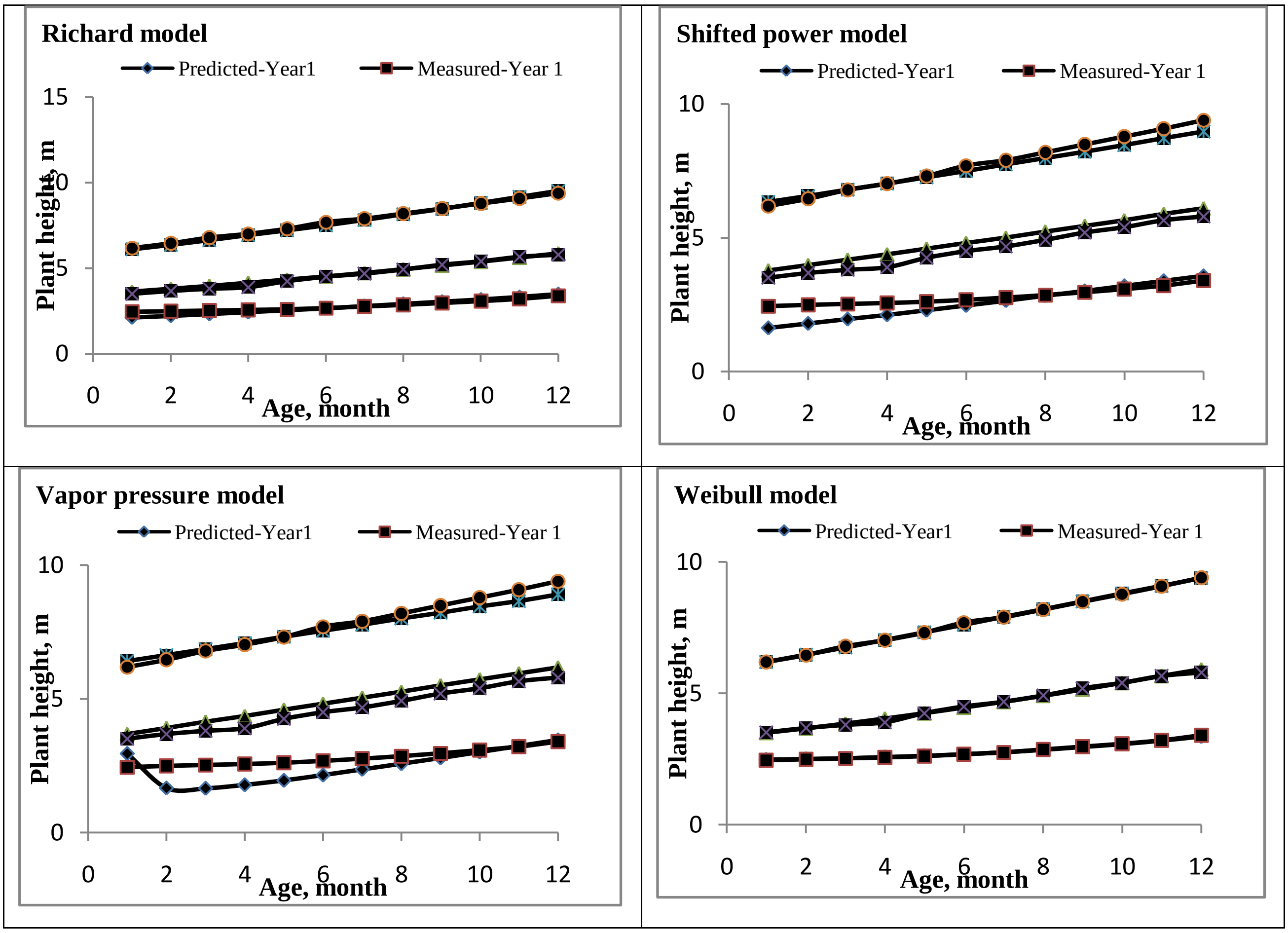


Fig. 2: Comprision of measured and predicted plant height

Limitations and validity of correlation models were observed by viewing the trend of growth pattern of the eucalyptus. The model with no limitations was selected as the best model for explaining plant height with plant age. The most fitting model was found to be Weibull model with corresponding r = 0.9998, S = 0.0419. The sinusoidal model was also close to the Weibull model in terms of r = 0.9999 and S = 0.0427 but theoretically the sinusoidal model does not seem logical and estimates a low value of plant height at the age of 120th month and hence rejected. The Weibull model performed well throughout the life span of 10 years, hence selected as the best model for describing plant height with age. The Weibull correlation model can be written as below.

$$H = 17.4730 - 14.9973\, e^{-0.0003T^{2.1289}} \qquad (1)$$

Where,
H = plant height, m
T = plant age, month

3.3 Comparison of Plant Height with Time

Eucalyptus plant heights were calculated using Eq. (1) up to the age of 10 years and shown in Fig. 3 and Table 5. Predicted eucalyptus plant heights were found to be 3.35, 5.92, 9.39, 12.68, 15.07, 16.47, 17.12, 17.37, 17.45 and 17.47 m for every month of December over a period of 10 years. It can be seen from Fig. 3 that plant heights increased steadily up to 6th year and reached a very low growth rate with decreasing incremental rates. The maximum height of 17.47 m was obtained at the end of 10th year. The attained plant height at the end of 6th year was found to be 16.47 m. There was a nominal increase of 1 m in last four years. After acquiring maximum heights of the eucalyptus trees the girth increases with the age. Since the model was developed using three years lysimetric plant height data yet need to be validated for its long term predicting ability. Eucalyptus tree heights at different locations reported in the literature were compared with the heights calculated by the best selected models.

A comparison was further made between predicted plant heights and reported plant heights of eucalyptus with age in the literature as shown in Table 6. Siddique et al. (1979) reported eucalypts plant heights as 15.80 m after 10 years and Ayyoub et al. (2002) reported plant heights 13.02 to 14.63 m after 6 to 10 years of plantations. The model estimated plant heights to the tune of 17.47 m for the case of Siddique et al. (1979) and 17.12 to 17.47 m for the case of Ayyoub et al. (2002) which are quite close to each other. The plant height data reported by Myers et al. (1995) and Dean and Richard (1984) did not match with the predicted plant heights data of eucalyptus for Californian situations due to high rainfall, most of which occurs between November and March. The Weibull model, thus explained plant height variations with plant age satisfactorily well under Indian subcontinent climatic conditions

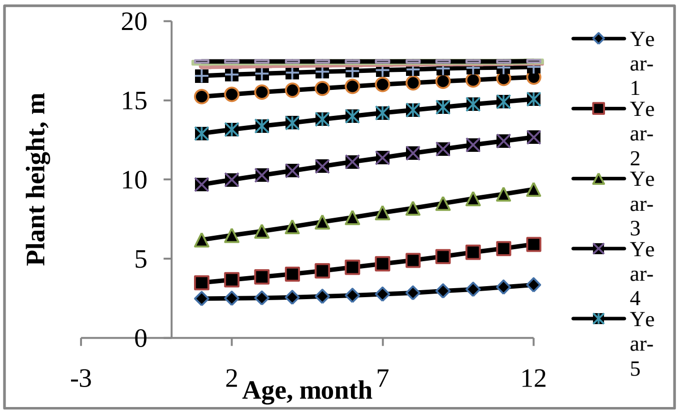


Fig. 3: Year wise predicted plant heights of eucalyptus plant

Table 5: Predicted plant height for 10 years

Month	Plant height in meter									
	Year									
	1	2	3	4	5	6	7	8	9	10
Jan	2.48	3.50	6.19	9.68	12.92	15.23	16.54	17.15	17.38	17.45
Feb	2.50	3.67	6.47	9.98	13.15	15.37	16.62	17.18	17.39	17.45
Mar	2.53	3.85	6.75	10.27	13.37	15.51	16.68	17.21	17.40	17.45
Apr	2.57	4.04	7.03	10.55	13.59	15.64	16.75	17.23	17.40	17.46
May	2.62	4.24	7.32	10.84	13.80	15.77	16.81	17.25	17.41	17.46
Jun	2.68	4.46	7.61	11.11	14.01	15.88	16.86	17.28	17.42	17.46
Jul	2.76	4.68	7.91	11.39	14.20	16.00	16.91	17.29	17.42	17.46
Aug	2.85	4.91	8.20	11.66	14.39	16.10	16.96	17.31	17.43	17.46
Sep	2.96	5.15	8.50	11.92	14.57	16.20	17.01	17.33	17.43	17.46
Oct	3.07	5.40	8.80	12.18	14.75	16.29	17.05	17.34	17.44	17.46
Nov	3.20	5.66	9.09	12.43	14.91	16.38	17.08	17.36	17.44	17.46
Dec	3.35	5.92	9.39	12.68	15.07	16.47	17.12	17.37	17.45	17.47

Table 6: Comparison of reported and predicted plant heights of eucalyptus (m)

Age (year)	Predicted	Reported	Location	Reference
1	3.35	2.0	Multan, Pakistan	[20] Zahid et al. (2010)
2	5.92	7.62	Faisalabad, Pakistan	[2] Ayyoub et al. (2002)
3	9.39	9.82	Faisalabad, Pakistan	Ayyoub et al. (2002)
	9.39	9.40	W. Hill ex-Maiden, Australia	[11] Myers et al. (1995)
4	12.68	11.92	Faisalabad, Pakistan	Ayyoub et al. (2002)
	12.68	4.90	Bale Lane, California	[6]Dean and Richard (1984)
	12.68	6.70	Grant Street, California	Dean and Richard (1984)
5	15.07	12.56	Faisalabad, Pakistan	Ayyoub et al. (2002)
6	16.47	9.90	Bala Lane, California	Dean and Richard (1984)
	16.47	10.00	Grant Street, California	Dean and Richard (1984)
	16.47	13.02	Faisalabad, Pakistan	Ayyoub et al. (2002)
7	17.12	13.57	Faisalabad, Pakistan	Ayyoub et al. (2002)
8	17.37	14.24	Faisalabad, Pakistan	Ayyoub et al. (2002)

9	17.45	14.39	Faisalabad, Pakistan	Ayyoub et al. (2002)
10	17.47	15.80	Peshawar, Pakistan	[13] Siddique et al. (1979)
	17.47	14.63	Faisalabad, Pakistan	Ayyoub et al. (2002)

4. SUMMARY AND CONCLUSIONS

Biodrainage is an ecofriendly cheaper option to reclaim and manage waterlogged, seepage prone and water logged salt affected areas. It does not involve high skilled techniques unlike interceptor drainage, subsurface horizontal or vertical drainage. It can be easily adopted in the areas where these measures become uneconomical or practically infeasible. Increasing environmental concerns and decreasing forest covers are adding pressure for adaption of biodrainage has land reclamation strategy. The most common tree species recommended for biodrainage in Indian subcontinent and other parts of the world is eucalyptus due to its high ET demand and adaptability to the varying soil, wet and salinity conditions. Tolerance to salinity and sodicity with and without waterlogging provides added advantage for its adaption in establishing biodrainage belt or sole plantation crop. The problem associated with biodrainage option is varying ET demand. It is very effective during summer season and almost ineffective during extreme winter and rainy seasons during initial years of establishment. Time series ET demand data of eucalyptus are essentially required for designing and planning of biodrainage belt at large scale. Eucalyptus plant keeps on growing in height up to the age of 7 to 10 years and hence ET demand also grows with the age of plantation. Measurement of long term ET at different locations may not be advisable due to cost constraints. Plant height based ET prediction model may be quite useful under these circumstances. Eucalyptus logs of 5 to 6 years fetch good market price in comparison to weight based price after a period of 10 to 15 years. Growth of eucalyptus is much faster during initial 5 years period. For optimization of net return from a block of agricultural lands plant height age model will be quite useful. Thus information about the plant height with age may be quite useful in optimizing productivity of the plantation, net return and maximization of ET for achieving the highest efficiency of biodrainage system. A model for describing tree height with age is essentially required for the development of ET model for maximizing the efficiency of biodrainage model or for maximizing the productivity of the plantation especially when the procurement rate is a function of tree height. A best model out of 22 correlation models was selected for describing tree height with age. Six models namely Linear, Power, Richard, Shifted power, Vapor pressure and Weibull explained eucalyptus tree heights with age accurately well. Annual average percent deviations of calculated tree heights of these models were found more than Weibull Model for three years. The Weibull Model calculated the closest values of monthly tree heights. Correlation coefficient (0.9998) of Weibull model was the highest and standard error (0.0419) was the lowest among six models. The Weibull model was further tested by predicting eucalyptus height for different age and comparing with the reported eucalyptus heights in the literature under Indian subcontinental climatic conditions. The Weibull Model predicted eucalyptus plant heights were found to be 3.35, 5.92, 9.39, 12.68, 15.07, 16.47, 17.12, 17.37, 17.45 and 17.47 m for every month of December over a period of 10 years. The developed model could be used satisfactorily for estimating plant height of eucalyptus plant/trees at different age. Model may be also linked with ET demand with age for the calculation of the areal extent of biodrainage belt.

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