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Formulation of Harvesting Regimes from Bulrush (*Scirpus grossus L. f.*) Growth Responses to MSW Leachate in Constructed Wetlands with Coir-Based Media

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ABSTRACT. *Experience is lacking in the tropics for establishing and operating constructed wetlands. Although it is becoming a popular technology, design criteria and management practices are not clearly defined. This manuscript describes the selection of a rapid media for plant establishment, growth responses of bulrush to MSW leachate and kinetic analysis of growth responses.*

Two concrete lysimeters were filled with crushed granite aggregate, forming a gravel bed. On top of that, in one, 30 cm of soil and in the other, layers of 15 cm of soil and coconut mattress coir fibre were compacted. Bulrush plants were established in them. The growth parameters of height, shoot emergence, tillers and girth were recorded. The results were analyzed with a new approach to determine the kinetics of these growth parameters.

All of the growth parameters follow classical logistical growth curves. The growth in the mixed media was less than that of the soil due to immobilization of nitrogen. However, the kinetic study indicates that there is greater potential for tiller formation if sufficient nutrients are available in the coir mixed media. Maximum transformation of shoot emergence was in 30 days after planting (DAP) and it is more rapid than the other indicative parameters. The enlargement of girth in the soil media had taken place in two phases and with higher biological oxygen demand (BOD) loading coir mixed media would be similar. Further increases in BOD loading can be expected, if bulrush is harvested at the maximum transformation rate of 40 DAP and trials on optimum time of staggered harvesting is to be undertaken.

INTRODUCTION

Application of constructed wetland technologies for treatment of wastewater has received increasing attention in recent years. Natural and constructed wetlands are relatively simple systems in terms of operation and maintenance (Hantzsche, 1985). They are extremely energy efficient when compared to mechanical systems. They are rich with a variety of wild life and enhance the aesthetic value of the area. Therefore, considerable attention has been directed towards the constructed wetlands to treat municipal and industrial wastewater.

Constructed wetlands can be defined as engineered systems designed to simulate natural wetlands to exploit water purification functional value for human uses and benefits. It occupies wetland flora and fauna for the primary purpose of removal of pollutants from wastewater or runoff (Hammer, 1992). The water is treated with physical, chemical and biological means. The media and the plants play major and important roles (Boyd, 1970; Gersberg, *et al.*, 1986) in determining the effective function of the wetland.

The growth of non-food crops in a constructed wetland system, could solve the wastewater problem in an ecologically acceptable way by utilizing the wastewater as a nutrient solution (Chan *et al.*, 1982). The selection of suitable media for growing plants in order to treat the wastewater is an important task in the management of constructed wetland.

The development of a rapid media for establishing wetland plants has been the focus of this research. Bulrush plant was selected for this study since it can be grown well in tropical conditions in inundated areas, but the growth performance of this plant in constructed wetland in Sri Lanka has not been studied yet. Incorporating coir into the constructed wetland system is an innovative idea for improving the hydraulic of wastewater flow in subsurface flow system of constructed wetlands. It is a renewable resource with no hazardous disposal problems. The lignin content of around 45 % ensures that the excellent water/air ratio may last over 5 years. Therefore coir can be incorporated as a media of the constructed wetland. However, the growth performances of the Bulrush plant in the coir incorporated soil media (refer to as coir mixed media) need to be studied.

This study has been conducted to examine the growth performances of the bulrush plant in soil and coir mixed media. Additionally an analytical approach has been developed using growth kinetics to formulate management practices of harvesting to rapidly stabilize the constructed wetland and to improve biological oxygen demand (BOD) removal efficiencies. The study also aims to investigate the problems and potential of coir as a media for constructed wetlands.

MATERIALS AND METHODS

Lysimeter experiment

Lysimeter experiment was conducted in Meewatura farm, Faculty of Agriculture, University of Peradeniya from January to October, 2004. Two waterproof lysimeters were constructed using Ferro-cement and chicken mesh. The width, length and depth of the lysimeters were 1, 20 and 0.6 m. The bottom had an inclination of 0.6 % (Wile *et al.*, 1985) from the inlet towards the outlet. The constructed lysimeters were filled with 3 cm of crushed granite aggregate 3 - 8 mm in diameter (Mavrogianopoulos *et al.*, 2001) forming a gravel bed. One of the lysimeters was filled with coir and soil each with 15 cm thickness. The coir was mattress coconut fiber obtained from Heyles Company Ltd. The other lysimeter was filled only by soil to the depth of 30 cm.

The leachate from municipal solid waste was generated in a vertically constructed column lysimeters 500 m away from the experiment site. Leachate was loaded daily, to the overhead tank and diluted with tap water in such a ratio that electrical conductivity was kept to a value of 400 – 500 μS/m (Mavrogianopoulos *et al.*, 2001). The leachate was supplied to the lysimeters through the constant head tank continuously at the rate of 70 ml/min. The flow rate was increased to 150 ml/min in the later part of the experiment due to the high evapo-transpiration of the plants.

Establishment of plant in the lysimeters

Bulrush (*Scirpus grossus*) is an emergent macrophyte, growing along lakes, streams, drains and other inundated conditions. It is a robust perennial grass like herb (60-90) cm tall, growing in many stolons, spreading from horizontal rootstocks below the soil and often forming large colonies across the media. Individual stems are triangular in shape and solid from (0.9 - 9) cm circumference. Stems are unbranched or with feeble tillers from the rhizomes. Leaves emerge opposite in one plane have parallel veins and a shiny surface. It produce a tall, flower head at the upper end of stem like leaf, the flowers closely spaced in a purple–colored nuts like cluster borne 60-70 days after planting (http://www.fs.fed.us/database/feis/plants/graminoid/sciacu/all.html)

Tillers of bulrush, brought from Maha Illuppallma with 10 cm length were planted to a depth of 5cm in the topsoil with the spacing of xx 40 x 25 cm. Thirty three plants were planted in three rows in lysimeters. Twenty one individual plants were marked randomly in each lysimeters with those 33 plants to accomplish the destructive sampling once in two weeks.

Growth measurement

Growth of the plants was recorded weekly by measuring the plant height, girth size (stem circumference), number of leaves, number of tillers and shoot density (Tanaka *et al.*, 2002) in both soil and soil-coir media. Plant height was taken as the height from the soil surface to the tip of the leaf. A wooden quadrant with the size of xxx 50 x 50 cm was placed in the lysimeters and the number of tillers was counted weekly. Number of tillers of randomly selected individual plants also measured.

Kinetic analysis of plant growth

It has been assumed that all of the growth parameters follow the logistical growth curve (Allen *et al.*, 1983 and Paramsothy *et al.*, 2004) as shown in the equation below,

$$X_t = \frac{\alpha X_0 e^{\alpha t}}{\beta X_0 e^{\alpha t} + \alpha - \beta X_0} \text{ ------------ (1)}$$

Where, X_t = Biological transformation mass (plant growth) at time t,
X_0 = Initial value of (reactive) growth,
α = Transformation or growth coefficient, and
β = Retardation coefficient.

The first derivative

$$\frac{dX_t}{dt} = \alpha X_t - \beta X_t^2 \text{ ------------------- (2)}$$

A non-linear computer program based on Math Lab has been developed to obtain the above coefficients and X_0. The program parameters are:

β = Retardation coefficient.
a = α,

$$m = \frac{\alpha}{\beta} X_0 \text{, and}$$

c = X_0.

A on-linear regression analysis was done to obtain R^2. The program optimizes the value of a, m and c to give the optimum R^2 value.

When the first derivative $\frac{dX_t}{dt}$ equated to transformation rate, *Tr* and differentiated with respect to X_t;

$$\frac{dTr}{dX_t} = \alpha - 2\beta X_t \text{ ---------- (3)}$$

and at the maximum value of the transformation rate, the slope is equal to zero. Therefore, the maximum growth utilizing the substrate is;

$$X_t = \frac{\alpha}{2\beta} \text{ -------------------- (4)}$$

Substituting $\frac{\alpha}{2\beta}$ in equation (1), the time for maximum substrate utilization rate could be found.

$$\frac{\alpha}{2\beta} = \frac{\alpha X_0 e^{\alpha t}}{\beta X_0 e^{\alpha t} + \alpha - \beta X_0}$$

$$\therefore \alpha\beta X_0 e^{\alpha t} = \alpha^2 - \alpha\beta X_0$$

$$e^{\alpha t} = \frac{\alpha^2 - \alpha\beta X_0}{\alpha\beta X_0}$$

$$t_{\max} = \frac{1}{\alpha} \ln\left(\frac{\alpha}{\beta X_0} - 1\right) \text{ -------- (5)}$$

RESULTS AND DISCUSSION

Plant height

The increase in plant height follows a classical sigmoid curve as shown in Figure 1 for both soil and mixed media of soil/coir. There was a height difference between the plants of the two media since the coir seems to lag behind the soil and would only reach a peak of 161 cm as opposed to 170 cm for coir and soil respectively, see Table 1.

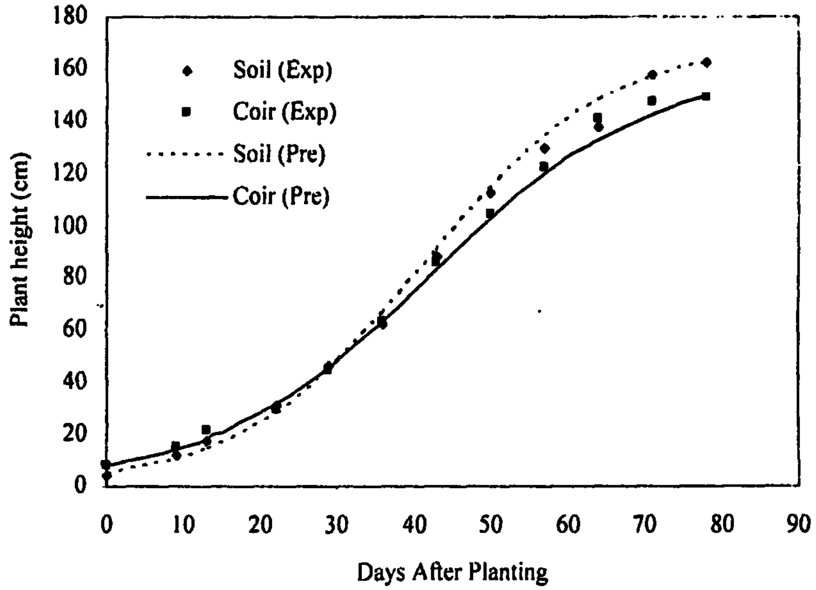

Fig. 1. Change in height of the plants (Exp) and predictions (Pre) in soil and soil-coir media

There was a notable difference in the plants grown near the inlet as compared to the neighborhood outlet of the lysimeter as shown in plate 1. Near the inlet higher growth was recorded compared to the growth of plants at the outlet in soil-coir media. This may be due to the fact that the microbial decomposition of organic compounds in wastewater and the nutrient uptake by plants are taking place in parallel along the lysimeter. Nitrate deficiency in plants at the outlets of lysismeter has shown that there may be a greater nitrate transformation into the plant and nitrate immobilization by coir.

The number of tillers with time has increased in both media. The average number of tillers per plant was around 9. Although tiller formations in the soil-coir medium was lower compared to soil media, similar number of tillers was observed at the later stage of growth (Figure 2). In fact, the kinetic study, as shown in Table 1 indicates that number of tillers would have increased by only one between the treatments. As reported by Vavrina (1996) and Handreck (1993), nitrogen immobilization might have had an effect on the tiller formation in soil-coir media. It must have been to the extent where the prediction of maximum rate of tiller transformations in the soil-coir media might have taken place after 60 days from the time of planting as given in Table 1.

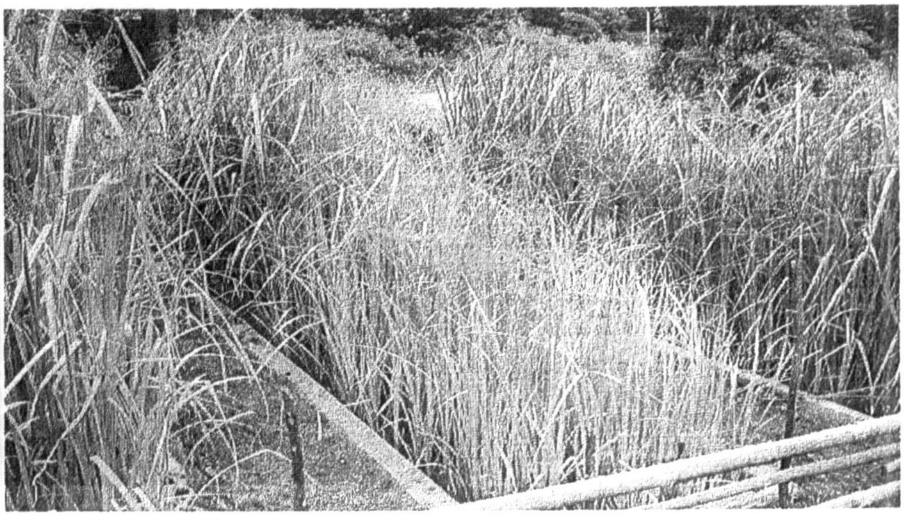

Table 1. Kinetic parameters for the logistical growth curves

Parameter	*A*	*B*	α/β	X_o	T_{rm}	t_{max}	R^2
Height							
Soil	0.083594	0.000492	170	5.2	3.552747	41	0.997
Coir	0.070314	0.000437	161	8	2.830121	42	0.9981
Tillers							
Soil	0.074328	0.007433	10	0.3	0.185819	47	0.9706
Coir	0.062828	0.005712	11	0.25	0.172777	60	0.9701
Shoot density Soil	0.091288	0.000787	116	7.5	2.647363	29	0.9903
Coir	0.081984	0.00082	100	6.2	2.049606	33	0.9901
Girth							
Soil-1st phase	0.086213	0.021553	4	0.88	0.086213	15	0.9843
Soil-2nd Phase	0.050704	0.006183	8.2	0.88	0.103942	56	0.9957
Coir	0.03475	0.003949	8.8	1.25	0.076451	52	0.9949

Shoot density

This reasoning becomes clearer in the shoot density measured in the 1m^2 wooden quadrant in both lysimeters (Figure 3). The shoot density at 60 days after planting was 119 and 96 in soil and soil-coir media, respectively. Shoot density is limited by water and nutrient supply (Haslam, 1970). The difference can be attributed to the deficit in nitrogen of coir media. On the other hand it is clear that the plants, which were grown in soil-coir media, needed additional nitrogen supply, thus the substrate loading rate, can be increased to coir base media than to soil media. This will no doubt increase the shoot density and the maximum number of shoot emergence would take place at the same time, towards 30 days after planting. It is an early occurrence vis-à-vis of all the other parameters. Thus, shoot emergence should be encouraged in establishing the required planting density.

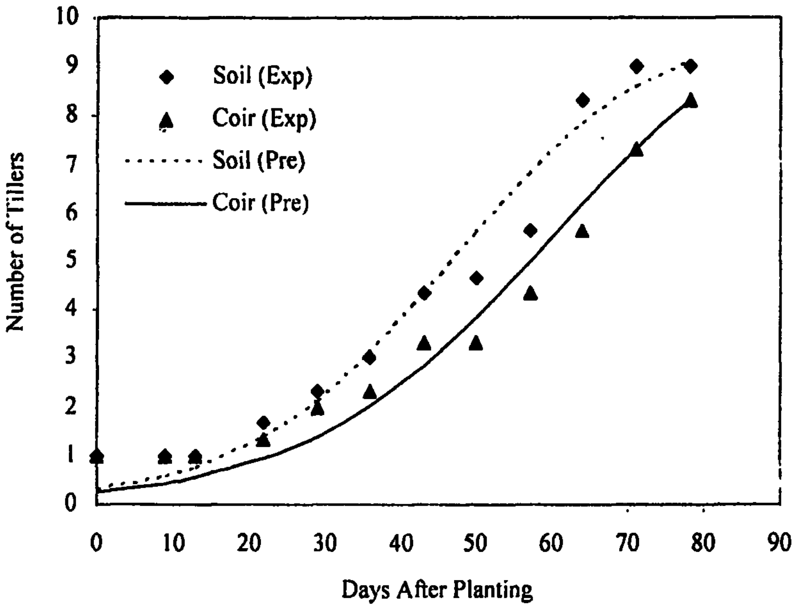

Fig. 2 Tiller formation in soil and soil-coir media (Exp) and their predictions (Pre)

Plant girth

The prediction on girth may not be accurate because once it reaches the peak value of α/β, it remains static and thereafter, the strength of the stem, increases. Interestingly, in the soil media, two distinct phases of stem growth can be identified as shown in Figure 4. The retardation would have been due to competitiveness between the parameters of girth with height, shoots and tillers. However, in the soil-coir media, this aspect of competitiveness had not been a critical factor, since the growth phases are not very distinguishable and the size of stem would have surpassed the plants in the soil media. This could be again attributed to the lack of nutrient availability at the beginning. If higher concentration of leachate is supplied, lower the growth of the stems would have two phases similar to that of soil media. It would enlarge in a regular manner rather than fluctuating during the active phase of stem growth as can be noticed in Figure 4, of increase in girth of plants in the soil-coir media.

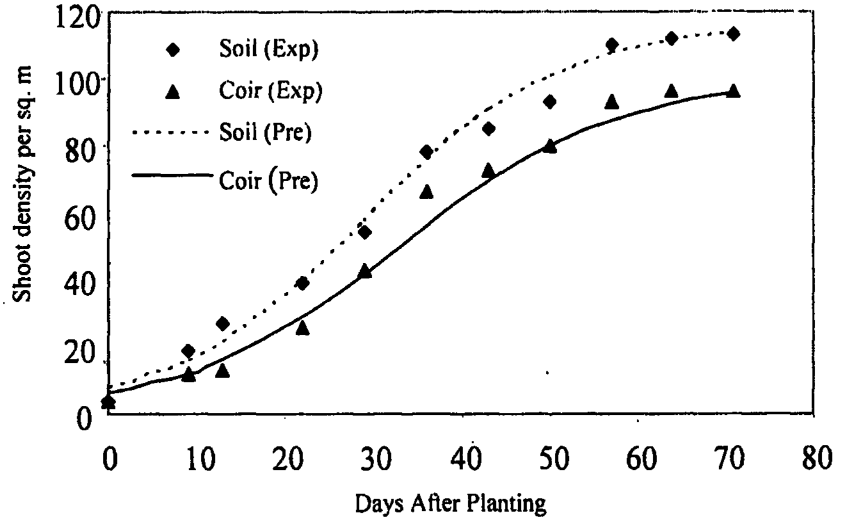

Fig. 3. Change in number of shoots (Exp) and predictions (Pre) for soil and coir mixed media with time

Discussion

The method of analysis of growth responses seems very accurate and the maximum transformation rates for different parts of the wetland plants are good indicators to determine the competitiveness and repartition of growth regulators among them, since maximum production had taken place of shoots at 29 DAP, height 41 DAP, tillers 47 DAP and girth having two peaks at 15 and 56 DAP. This parameter also provides the best choice for the optimum harvesting time rather than allowing the plant to mature with less reduction in the BOD of the leachate. Harvesting at the time when the growth rates are highest would promote greater number of shoots and increase in the number of tillers while greater reductions in BOD are achieved. In order to stabilize the wetland, it is best then to harvest one month after planting, coinciding with the maximum number of sprouting. Then subsequent harvesting times should be determined with growth responses of the ratooned plants and it would very likely to be 40 days after harvesting at the maximum rate of increase in height. The harvesting should be done in a staggered manner along the length of the constructed wetland; otherwise there would be fluctuations in the BOD reductions.

CONCLUSIONS

The comparative kinetic parameters of height, number of tillers, number of shoots and size of girth of the bulrush plant points towards greater potential for increasing the leachate loading on soil + coir mixed media as opposed to soil. Since the evaluation of the growth responses between the treatments is very conclusive indicating that at low loadings of leachate, nitrogen immobilization takes place in the soil + coir media due to greater microbial activity than in soil which has less porosity. Further increases on loading on soil + coir media could be expected if plants are initially harvested at maximum rate of emmergence of shoots thirty days after planting and then perhaps ratooned every forty days depending on the growth responses of the ratooned plants, particularly with reference to plant height.

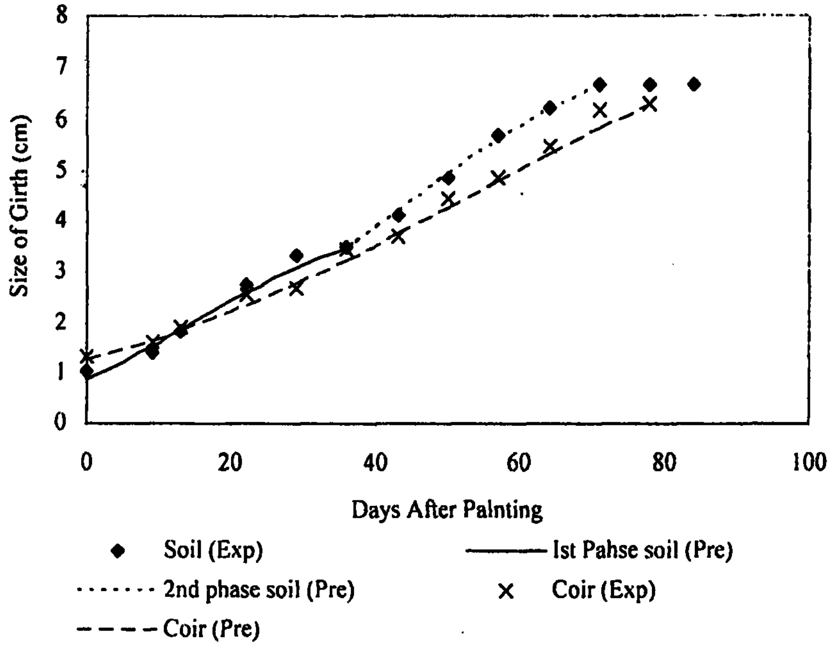

Fig. 4. **Increase in girth of stems for experimental (Exp) and predicted (Pre) values for soil/coir media and the predictions for the two distinct phases of growth in the soil media**

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